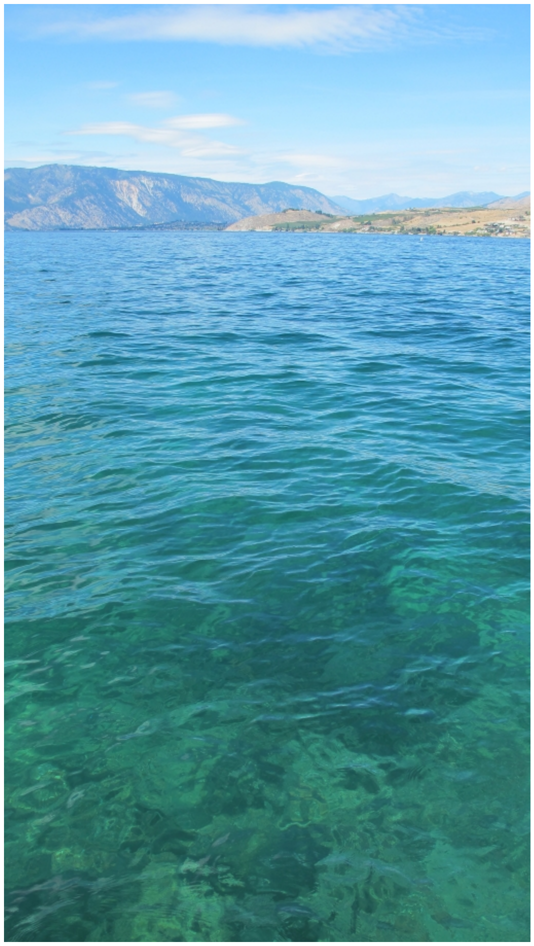

Lake Chelan Wapato Basin Total Phosphorus Total Maximum Daily Load

Water Quality Effectiveness Monitoring Report

DEPARTMENT OF ECOLOGY
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Cover photo: Lake Chelan (Wapato Basin) taken by Amy Cook (Department of Ecology)

Lake Chelan Wapato Basin
Total Phosphorus
Total Maximum Daily Load

Water Quality
Effectiveness Monitoring Report

by
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Abstract

This report succeeds the August 1997 report, *Water Quality in the Wapato Basin of Lake Chelan, Summer 1996,* by Sargeant.

Lake Chelan was sampled in 2007 to monitor nutrient levels in the lake's lower basin (Wapato Basin). This basin is the area most likely to be impacted from any possible increases in total phosphorus loading.

The Total Maximum Daily Load (TMDL) criterion for the Wapato Basin was met (not exceeded) in 2007, based on total phosphorus concentrations measured in these samples. This criterion is calculated as the summer mean total phosphorus concentration for the epilimnion (upper water layer). For 2007 this mean was less than 2.6 ug/L, with 95% confidence, which is lower than the TMDL criterion of 4.5 ug/L.

Weak decreasing trends in total phosphorus concentrations from 1987 to 2007 were found to be more than 95% significant at each station and depth monitored based on Kendall's tau test.

Confirmation of good water quality in Lake Chelan was provided by low chlorophyll-a concentrations and high water transparency. Phosphorus remains the limiting nutrient in the lake based on nitrogen-to-phosphorus ratios and the trophic state index (TSI).

Recommendations include (1) continued periodic monitoring and supporting efforts to protect the lake and (2) a slight design change to avoid the possibility of sample contamination by bottom sediments at one station.

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Background

What is a TMDL?

The federal Clean Water Act established a process to identify and clean up polluted waters. Under the Act, every state has its own water quality standards designed to protect, restore, and preserve water quality. Every two years, states are required to prepare a list of waterbodies – lakes, rivers, streams, or marine waters – that do not meet water quality standards. This list is called the 303(d) list or Water Quality Assessment. To develop the list, the Washington State Department of Ecology (Ecology) compiles its own water quality data along with data submitted by local, state, and federal governments, tribes, industries, and citizen monitoring groups. All data are reviewed to ensure that they were collected using appropriate scientific methods before the data are used to develop the 303(d) list.

The Clean Water Act requires that a Total Maximum Daily Load (TMDL) be developed for each of the waterbodies on the 303(d) list. A TMDL identifies how much pollution needs to be reduced or eliminated to achieve clean water. The local community then works with Ecology to develop a strategy to control the pollution and a monitoring plan to assess the effectiveness of the water quality improvement activities.

Lake Chelan does not currently appear on the 303(d) list for total phosphorus, because it is not considered to be water quality limited. The TMDL for total phosphorus in Lake Chelan is a preventive TMDL designed to protect water quality. The *Lake Chelan Total Phosphorus TMDL* (Pelletier, 1991) provides the Lake Chelan Water Quality Committee with a tool to use for planning for future growth while preventing degradation of the lake.

What Is Effectiveness Monitoring?

An effectiveness monitoring evaluation determines if the interim TMDL targets and water quality standards have been met. This is an essential component of any restoration or implementation activity since it measures to what extent the work performed or recommended has attained the watershed restoration objectives or goals.

In this case, water quality is not considered impaired, but is rather being protected by the TMDL. The goal is therefore to verify that water quality remains high in Lake Chelan.

Lake Chelan TMDL Summary

Lake Chelan, the largest and deepest natural lake in Washington State, contains near pristine water which helps establish it as a unique and extremely valuable water resource. This excellent water quality is due in large part to an exceptionally low concentration of total phosphorus. High phosphorus levels inhibit the growth and productivity of aquatic plants and algae.

Lake Chelan is classified as ultra-oligotrophic. The lake has extremely low nutrient levels and a high degree of clarity. In the 1980s increasing development pressures raised concerns about maintaining the lake's high water quality. In response to these concerns, a comprehensive limnological study was performed in 1986-87 and published as *The Lake Chelan Water Quality Assessment* (Patmont et al., 1989). In response to the assessment, five local agencies formed the Lake Chelan Water Quality Committee: the City of Chelan, Chelan County, Chelan County Public Utilities District, Lake Chelan Sewer District, and Lake Chelan Reclamation District. This committee completed the *Lake Chelan Water Quality Plan* in December 1991 (Lake Chelan Water Quality Committee, 1991).

The federal Clean Water Act requires that a TMDL process be initiated and an actual pollutant load be established where the beneficial uses of a waterbody are being threatened or impaired by that pollutant. The *Lake Chelan Water Quality Plan* included a TMDL for total phosphorus that was approved by the U.S. Environmental Protection Agency (EPA) in January 1993. The TMDL for total phosphorus is 51.0 kg/day (Pelletier, 1991). It is calculated that if the TMDL is met, the average water-column concentration of total phosphorus in the Wapato Basin will not exceed 4.5 ug/L (considered the upper threshold of ultra-oligotrophic conditions). The two source loads of total phosphorus listed in the TMDL are Chinook Net Pens and Tributaries/Groundwater.

In 1995, the Lake Chelan Water Quality Committee began long-term monitoring of the Wapato Basin of Lake Chelan. A Quality Assurance (QA) Project Plan was developed for the project (Congdon, 1995), and Ecology developed protocols for determining low-level phosphorus concentrations (Seiders et al., 1995)

In 1996, the Lake Chelan Water Quality Committee did not obtain money for monitoring. At the request of Ecology's Central Region Office, Ecology's Watershed Assessments Section conducted the monitoring of Lake Chelan, described in Ecology Report #97-323, "Water Quality in the Wapato Basin of Lake Chelan, Summer 1996" (Sargeant, 1997).

In 1999, Anchor Environmental prepared a water quality study in Lake Chelan for the Public Utility District No. 1 of Chelan County (Anchor, 2000). This study included a calculation of summer volume-weighted epilimnetic mean total phosphorus for the Wapato Basin. Phosphorus concentrations in the lake were reportedly found to agree with a constant watershed loading model over a 13-year period.

A study examining the presence and concentrations of PCBs and the pesticide DDT in the water column and in fish tissue in Lake Chelan was initiated in 2003 (Coots et al., 2005). This study resulted in a proposed TMDL for PCBs and DDT for Lake Chelan (Schneider and Coots, 2006; Anderson and Peterschmidt, 2008).

In 2006, again at the request of Ecology's Central Region Office, Ecology's Environmental Assessment Program (EAP) was asked to revisit the lake and assess whether any detectable changes in water-column phosphorus concentration had occurred since the 1996 monitoring project. In the summer of 2007, EAP made seven visits to Lake Chelan to sample for total phosphorus, total nitrogen, chlorophyll-*a,* and other parameters. This Effectiveness Monitoring Report presents the results of that monitoring.

Total Phosphorus Criterion

The average water-column concentration of total phosphorus in the Wapato Basin is calculated as a volume-weighted average, and the upper 95% confidence limit for this value is used to evaluate the condition of the lake relative to the 4.5 ug/L criterion for total phosphorus (Seiders et al., 1997).

To assess overall water quality, the Effectiveness Monitoring Study also measured the following parameters which have no associated criteria in the TMDL:

- Total nitrogen
- Nitrite/nitrate
- Chlorophyll-a
- Water transparency
- Dissolved oxygen
- Temperature
- Specific conductance
- pH

Study area

Lake Chelan is located in the north-central part of Washington State (Figure 1). The lake follows a long, steep sided, glacially carved valley for over 50 miles from its head in the Northern Cascades, southeast to its outlet near the city of Chelan. The city is perched above and just west of the Columbia River. Most of the agricultural, industrial, recreational, business development, and population are found along the shoreline of the lower half of the lake. The upper half of the lake is not connected by road to the lower portion and is accessible only by foot, boat, or floatplane. There are two small communities, Lucerne and Stehekin, located in the upper end of the lake.

Lake Chelan is relatively narrow for its length, averaging only a mile wide. It is the third deepest lake in North America, exceeded by Crater Lake (1932 ft) and Lake Tahoe (1645 ft). At its deepest spot, 1486 ft. (Kendra and Singleton, 1987), the lake bottom is 388 ft. below sea level. The watershed filling Lake Chelan is approximately 924 square miles, and the largest tributary is the Stehekin River entering the lake at its upper end.

The lake consists of two distinct basins: the Lucerne Basin in the upper 38 miles of the lake contains 92% of the lake volume, and the Wapato Basin in the lower 12 miles contains 8% of the volume (Kendra and Singleton, 1987). The two basins are separated by a sill rising to within 122 feet of the surface at a location known as the narrows, between Chelan State Park and Twenty-five Mile Creek.

The smaller Wapato Basin receives most of its water input from the Lucerne Basin and has a maximum depth of 400 feet (Patmont et al., 1989). Three small lakes, often referred to as Manson Lakes, are located about a mile east of the Lucerne and Wapato Basin divide and north of the city of Manson. These lakes drain by way of Stink Creek to Lake Chelan.

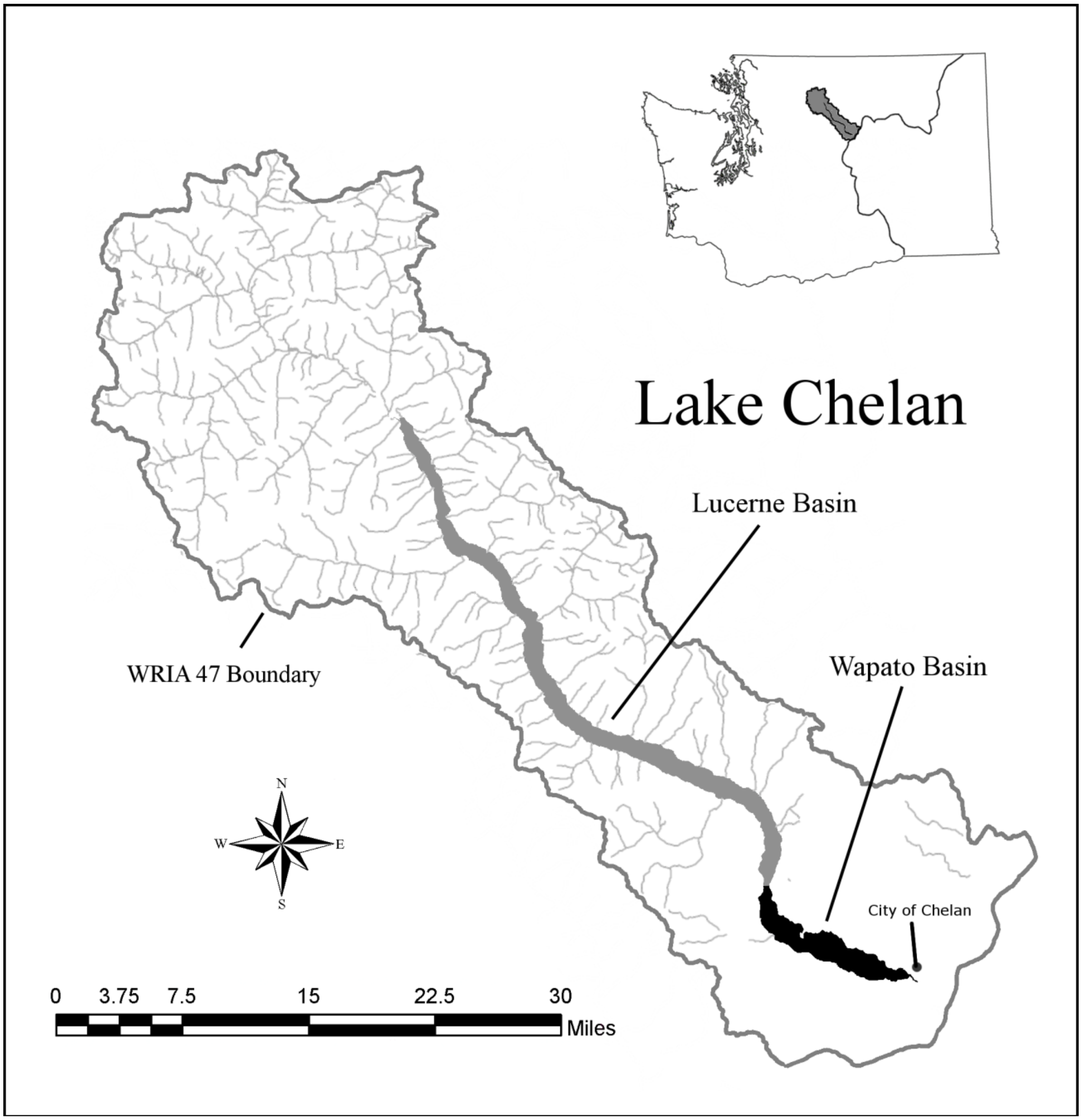

Figure 1. Location and Basin Division of Lake Chelan.

WRIA: Water Resource Inventory Area

Lake level and its discharge at the outlet are controlled by a dam that diverts much of the outflow through a penstock and turbines used to generate hydroelectric power. Because of the power diversion, the natural outlet to the lake, the Chelan River, is dry most of the year in its precipitous three-mile reach to the Columbia River.

The water in the lake has historically been low in nutrients and relatively free of nuisance plants, algae, and bacteria. The lake is classified as ultra-oligotrophic (ultra-low in nutrient inputs and low organic production) as described in Water Quality Standards for Surface Waters of the State of Washington, Chapter 173-201A-230 WAC. The standard for ambient total phosphorus in ultra-oligotrophic lakes is 4 ug/L or less.

Because most of the activities, population, development, and agriculture that may influence water quality occur in the lower portion of the lake, the focus of this study is on the Wapato Basin:

- Being at the lower end of the lake, the Wapato Basin is likely to show signs of degradation before the upper basin (Lucerne Basin).
- Most of the ongoing human influence to the lake occurs in and along the shoreline of the Wapato Basin. Boating activities and on-water recreation are much more prevalent in the lower end of the lake.
- The Wapato Basin is shallower and holds far less volume than the upper lake; is more heavily influenced by the surrounding population; is exposed to the influence of agriculture, on-site septic systems, and stormwater runoff from roads and developed land; and receives irrigation spill, runoff, and subsurface flow from lawns, golf courses, orchards.

Samples in the Wapato Basin were taken from within a layer of water called the epilimnion. This is a layer of warm water which forms near the surface during summer stratification. It is more or less uniformly warm, circulating, and fairly turbulent. Previous studies have found that the epilimnion develops to a depth of approximately 30 meters in the Wapato Basin.

Flow in the Wapato Basin is largely advective, analogous to “river-run” lake conditions (Patmont, 1989). In 1987, the average residence time of water in the epilimnion of this basin was reported as approximately 3 months (calculated by dividing the volume of the epilimnion by the average flow out of the lake during the April to September time period).

For a more complete description of Lake Chelan, consult Patmont (1989).

Sources of Phosphorus Entering the Lake

The following are believed to be sources of phosphorus to Lake Chelan. Changes in these sources have the potential to impact phosphorus levels in the lake.

Natural Sources within the Basin

Natural sources of phosphorus to Lake Chelan include undeveloped forested areas and direct precipitation. Patmont (1989) estimates these sources contribute 75-90% of the phosphorus to Lake Chelan. These sources may vary depending on precipitation.

Based on modeling, Anchor (2000) concluded that changes in phosphorus concentrations from 1987-1999 may simply be the result of different runoff and dilution characteristics from year to year, with a constant loading of phosphorus to the lake.

Increased precipitation and snow melt in 2007 had the potential to affect natural sources of phosphorus in the lake relative to previous studies. To estimate precipitation and snow melt, the average flow for April-June in the Stehekin River was graphed (Figure 2). Flow data was provided by the United States Geological Survey (USGS). In this figure, the lowest average flow was seen in 2005; the highest in 1997. Flows for 2007 are the fourth largest in this figure, and higher than the other study years.

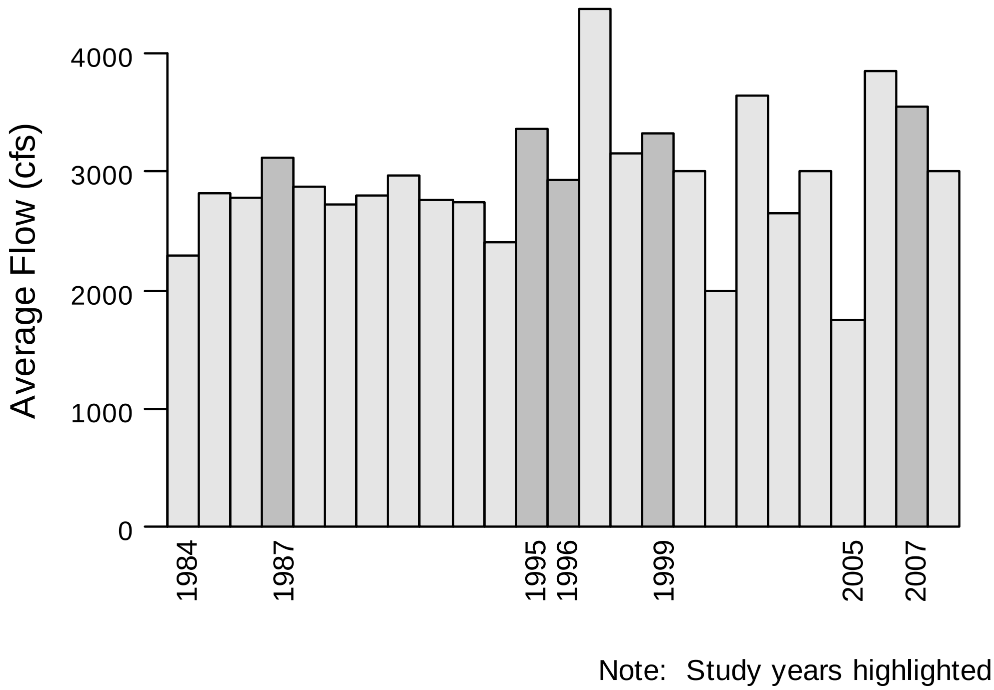

Figure 2. Average Flows (April-June) for the Stehekin River by Year, 1984-2007.

Contrary to flow in the Stehekin River, the average reported outflow rate at the Chelan Dam was lower in 2007 compared to previous study years (May-Sept averages are shown in Table 1). Residence time for the Wapato Basin epilimnion was reported as 3 months in 1987 (Patmont, 1989). Using the same method as that report, residence time for the Wapato Basin epilimnion was estimated by dividing the epilimnion volume (2.78×10^{10} cubic feet) by the combined average outflow rate (turbine + spillway). Outflow records for the dam were provided by the Chelan County Public Utility District; records prior to 1995 were not available.

Table 1. May-Sept Average Outflow from Chelan Dam and Estimated Residence Times, 1995-2007.

Year	Turbine (cfs)	Spillway (cfs)	Residence Time (months)
1995	2820	1030	2.8
1996	3090	1190	2.5
1999	2090	1130	3.3
2005	1360	30	7.7
2007	1830	1180	3.6

Stormwater Runoff

Increases in population near Lake Chelan could potentially increase the phosphorus load from urban stormwater runoff. Patmont (1989) estimates that stormwater runoff contributes 1-12% of the total phosphorus to the lake. Most of these inputs are reportedly particulates which settle near the outfall discharges.

Population has increased in both the City of Chelan and Manson during the previous decade. The population of the City of Chelan in 2009 is estimated by the census bureau at 4,107 people, up from 3,522 in the 2000 census. Manson (unincorporated) is not tallied separately by the census bureau. The zip code which includes Manson is 98831, which had a population of 3,178 in the 2000 census. No population estimates from the 2010 census are available for this zip code at the time of writing.

Septic Systems

It is not known whether septic systems have changed since the original study in 1987. Septic system inputs were estimated by Patmont (1989) to contribute 1-5 % of the total phosphorus to the lake. Although the source percentage is small, this source may affect near-shore algal accumulations in the Wapato Basin. Most of the input is reportedly attributable to drain fields installed in areas with relatively shallow groundwater.

Sewer Lines

Improvements to two sewer lines in recent years may have reduced the phosphorus load to the Wapato Basin, although the extent, if any, is unknown.

Along the north side of the Lake Chelan, numerous breaks have been reported from a sewer line, some resulting in spills of sewage into the lake (Ecology, 2009). The sewer is a 7-mile line constructed in 1976. Approximately 1,000 feet of the more problematic section of force main was replaced in the summer of 1995, and another 2,000 feet was replaced in 1999. In approximately 2003, the existing sewer was replaced with high-density polypropylene lines.

Another sewer along the south shore of the lake had problems with infiltration, until replacement in 1999 (Ecology, 2009). The line originally consisted of more than three miles of asbestos-cement line buried along the south shore of the lake. In 1999 this line was replaced with high-density polypropylene. Infiltration to the system was reduced by an estimated 160,000 gal/day during the maximum month.

Agricultural Sources

A decrease in the number of farm operations near the Wapato Basin may have reduced agricultural sources of phosphorus to the lake. Patmont lists agricultural sources as primarily orchard, contributing 4-12% of the total phosphorus to the lake. Most of this load would enter the Wapato Basin. Table 2 shows the number of farms operating in two representative zip codes[1] near Lake Chelan between the years 1997 and 2007 (Table 2). Data were obtained from the Census of Agriculture provided by the National Agriculture Statistics Service. For zip codes, the census reports only the number of farms, not total acreage or crop type, and records from this census are not available prior to 1997.

Table 2. Number of Farms, 1997 versus 2007 (zip codes 98816 and 98831).

Farm size (acres)	Zip Code 98816 City of Chelan		Zip Code 98831 Manson	
	1997	2007	1997	2007
1-49	110	94	92	76
50-999	59	52	37	28
>999	6	5	2	0

Fish Net Pens

Removal of fish net pens from the Wapato Basin in the early 1990s may have reduced phosphorus loading. These pens are listed on the TMDL as a source of phosphorus. Net pens were operated for several years in Lake Chelan during the early 1990s, but have been moved out of the lake (Penny, 2011). They were used for acclimating Chinook salmon in Lake Chelan near Wapato Point. Currently, four fish pens are operated in Chelan River downstream of the Lake Chelan Dam; two fish pens are owned by Washington Department of Fish and Wildlife and two are owned by Chelan Public Utility District. A hatchery is planned to replace these pens in the near future (Yates, 2011).

Beneficial Uses

The water in Lake Chelan is used for domestic and irrigation supply, fisheries, power production, transportation, and extensive water recreation, especially during the summer. A hydroelectric dam was constructed in 1927 and raised the water level of the lake by 21 feet.

Lake Chelan supports a number of fisheries, including mackinaw/lake trout, rainbow trout, cutthroat trout, burbot/freshwater lingcod, kokanee (landlocked sockeye salmon), and smallmouth bass. The fish in Lake Chelan are landlocked. Manson Lakes are stocked with rainbow trout, largemouth bass, bluegill, perch, and crappie (Lake Chelan Chamber of Commerce, 2008).

[1] Zip codes were chosen since county-wide statistics would include large areas which do not impact the lake, such as the Wenatchee Valley.

Goals and Objectives

Project Goals

The goal of the 2007 study is to determine whether concentrations of phosphorus in the epilimnion of the Wapato Basin of Lake Chelan remain below (meet) the TMDL criterion. The study will also examine whether any changes in chemical nutrient concentrations or physical water characteristics have occurred as compared to previous studies. Sampling in 2007 monitored water distant from the shoreline; local variations in phosphorus which may impact near-shore waters were not addressed.

Study Objectives

The objectives of this study are as follows:

- Following standard operating procedures, collect water samples and other key water quality parameters in the Wapato Basin (total phosphorus, chlorophyll-a, total nitrogen, nitrite/nitrate, dissolved oxygen, temperature, pH, conductivity, and water transparency) for laboratory analysis and comparison to previous years.
- As described by Seiders et al. (1995), determine the 95% upper confidence limit for the volume-weighted epilimnetic mean concentration of total phosphorus in the Wapato Basin and compare it to the 4.5 ug/L TMDL criterion.

Methods

Sampling and Measurement Procedures

The QA Project Plan (Sargeant, 2007) describes study design, sampling, and measurement procedures. These procedures duplicate those used in the previous studies (Congdon, 1996; Sargeant, 1997). The primary change from the Sargeant (1997) study is that improved laboratory analyses for total phosphorus resulted in a lower detection limit for the current 2007 study as compared to 1996.

Water samples were collected from four stations in the Wapato Basin using the same locations as the 1995 and 1996 studies (Figure 3). The stations were located using the coordinates (North American Datum, 1927) presented in Table 3.

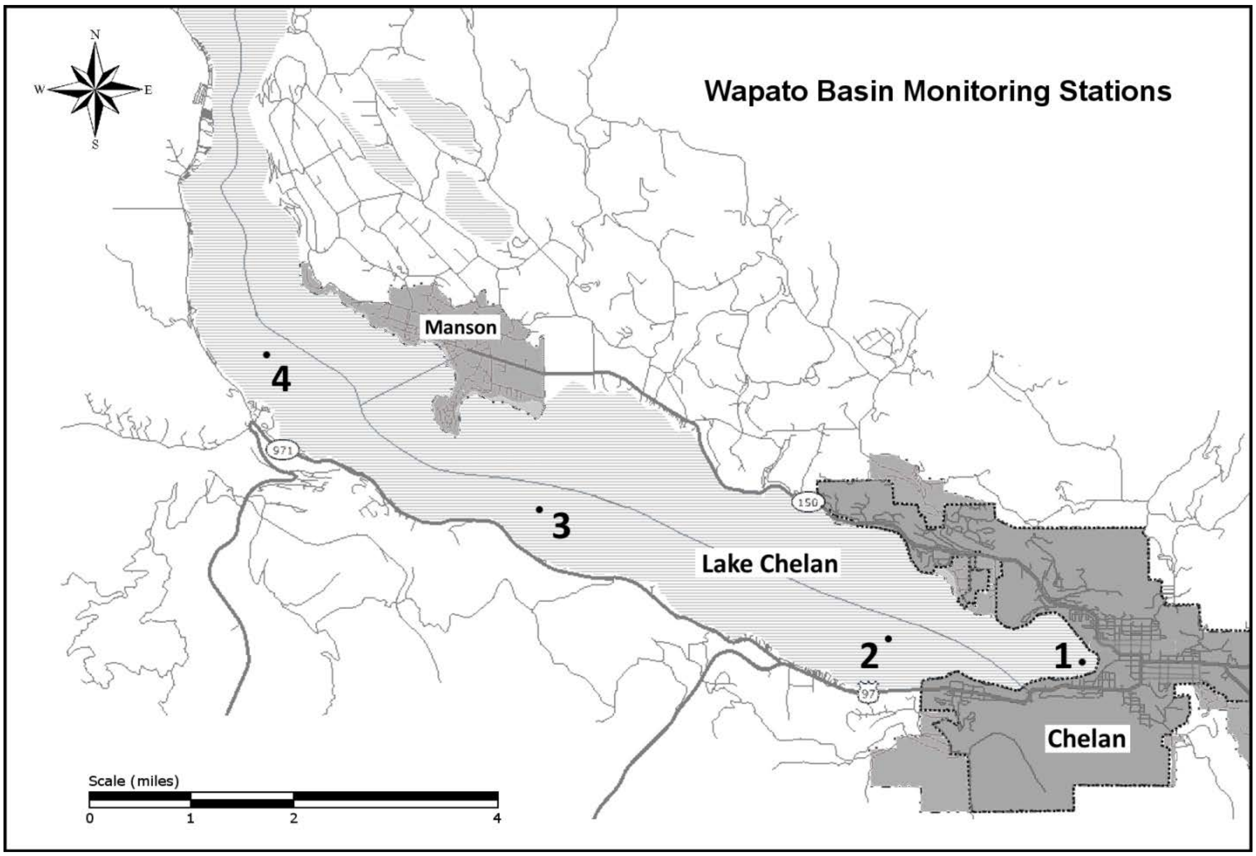

Figure 3. Wapato Basin Monitoring Stations.

Table 3. Coordinates for Sampling Stations.

Station Number	Latitude	Longitude
1	47.84138	-120.02425
2	47.84342	-120.06658
3	47.86205	-120.13990
4	47.88404	-120.19724

A hand-held global positioning system (GPS) device was used to help locate the sampling stations, along with the use of shoreline landmarks. At stations 2, 3 and 4, samples were obtained from three depths: 0.3, 10 and 20 meters. At station 1, the shallow lake bottom allowed only a single sample at 0.3 meters depth. The lake was sampled during seven surveys on the following dates in 2007: May 30, June 21, July 18 and 31, August 21 and 29, and September 18.

Ecology's Manchester Environmental Laboratory analyzed water samples for the following nutrients: total phosphorus, total nitrogen, nitrite-nitrate, and chlorophyll-a. Field staff collected QA samples in accordance with the QA Project Plan. The samples were collected using a clear acrylic Kemmerer sampler and transferred into pre-cleaned containers supplied by Manchester Lab. The samples were immediately placed into a dark, iced cooler and returned to Ecology's Central Regional Office, where the chlorophyll-a samples were filtered the same day as collected. These filters were placed in acetone tubes and stored in the freezer. Acetone tubes and other laboratory samples were then shipped to Manchester Lab within 24 hours after sample collection. Samples were analyzed in accordance with the QA Project Plan.

Field staff collected measurements for water temperature, pH, conductivity, dissolved oxygen, and visibility at each station to a depth of 50 meters when possible. Measurements were made using a Hydrolab Minisonde® multi-parameter meter. Dissolved oxygen was additionally measured at discrete intervals by collecting water samples for Winkler modified-azide titration, in accordance with standard operating procedures. Winkler titration was performed within 30 hours of sample collection, and the results were used to verify the accuracy of the multi-meter.

Water transparency was measured at stations 2, 3, and 4 using a 20-cm diameter limnological style Secchi disk.

Quality Assurance

Appendix B compares QA samples to data quality objectives (DQOs) as set forth in the QA Project Plan (Sargeant 2007).

All nutrient analyses and field measurements are deemed usable for this study, apart from the following rejections and qualifications. Chlorophyll-a data did not fully meet the DQO and should be used with caution. Laboratory analyses for all chlorophyll-a samples collected on

8/21/07 are rejected as unreliable due to improper wrapping which may have exposed the samples to light, potentially degrading them. These samples were all reported as below the detection limit, in contrast to the detected levels of chlorophyll-a in all other samples. Additionally, one chlorophyll-a sample leaked during transit and is qualified as an estimate. Transparency measurements on 5/30/07 were performed without a viewing tube and were qualified as estimates.

One unusually high concentration of total phosphorus in 2007 came from the same location and depth as a rejected sample in 1995 (station #2 at 20 meters). The 1995 sample was rejected due to sand in the sample. No sand was observed in the 2007 sample; however this sample was collected near the lake bottom (measured between 20.1 to 22.5 meters). The datum is not rejected, but a recommendation is made to collect future samples at this station from a slightly shallower depth.

Changes in detection limits for phosphorus present difficulties for comparing concentrations between years, as discussed in the "Results and Discussion" section below. Total phosphorus concentrations are a primary concern for this study. Laboratory analysis established a 1 ug/L detection limit for this nutrient in 2007, which is lower than the detection limit of 3 ug/L reported for much of the 1996 study. Other studies did not report non-detect samples for phosphorus.

Analysis of Data

Using standard graphical and statistical techniques, the 2007 data were compared to data collected in 1987, 1995, and 1996.

Volume-Weighted Epilimnetic Mean Calculation

A stratum is a depth-defined section of water column across a section of the lake. For the Wapato Basin of Lake Chelan, there are a total of ten strata, one associated with each station/depth pair.

- The volume-weighted mean ($\overline{\mathrm{X}}_{\mathrm{n}}$) across n strata is:

$$\overline{\mathrm{X}}_{\mathrm{n}} = \sum_{h=1}^{n} \mathrm{W_h} * \overline{\mathrm{X}}_{\mathrm{h}}$$

$\mathrm{W_h}$ = (volume of stratum h) / (total volume of all strata)
$\overline{\mathrm{X}}_{\mathrm{h}}$ = mean value of stratum h across all sample events

- The volume-weighted standard error ($\mathrm{S_n}$) is:

$$S_n = \sqrt{\sum_{h=1}^{n} \frac{\mathrm{W_h^2 * S_h^2}}{\mathrm{n_h}}}$$

$\mathrm{S_h}^2$ = variance in stratum h
$\mathrm{n_h}$ = number of observations in stratum h

To compare the mean volume-weighted epilimnetic concentration of total phosphorus to the TMDL threshold of 4.5 ug/L, the 95% upper confidence limit of the mean volume-weighted epilimnetic concentration of total phosphorus is determined by the following equation:

$$\mathrm{UCL}_{95} = \overline{\mathrm{X}}_{\mathrm{n}} + \mathrm{t}_{0.05,\mathrm{N-n}} * \mathrm{S}_{\mathrm{n}}$$

N = total number of observations across all n strata
n = number of strata
$t_{0.05,N-n}$ = critical value of the one-sided Student's t-distribution, at level 0.05 with N-n degrees of freedom. The number of degrees of freedom was set to this level because all n_h are equal. If this had not been the case, then Satterwaite's approximate degrees of freedom would have been used.

The calculated upper confidence limit (UCL_{95}) is then compared to the TMDL threshold limit.

To provide the most cautious estimate possible for the UCL_{95}, the reporting limit was substituted for non-detect samples. This method biases the mean and UCL_{95} high.

Other Analysis Methods

Plots were created using the software package R (version 2.12.2) and Microsoft Excel 2007.

Boxplots

Standard boxplots as described in Helsel and Hirsch (2002) are used in this report to graphically summarize the distribution of measured data. Boxes show the 25th, 50th, and 75th percentiles, with whiskers extending up to 1.5 times the box height. Data beyond the whiskers are plotted individually as circles.

Notches in the box give an indication of whether the medians are significantly different. When notches between boxplots do not overlap, this is strong evidence that the two medians differ. This is based on asymptotic normality of the median and roughly equal sample sizes for the two medians being compared. The idea is to give roughly a 95% confidence interval for the difference in two medians.

Boxplots were created using the software package R (version 2.12.2.)

Non-detect data were included in the boxplots by substituting a value below the reporting limit. The boxplots were then truncated at the reporting limit, as recommended by Helsel (2005).

Kendall's Tau

Tau is a non-parametric measure of correlation which does not assume a statistical distribution. It can be stated most generally as a test for whether Y values tend to increase or decrease with time (monotonic change). The test assumes no serial correlation between data for the resulting p-values to be correct. Since it is rank based, it is resistant to the effect of a small number of unusual values. The value for tau lies between -1 and 1, to indicate positive or negative correlations. The statistical significance of the correlation is given as a p-value, indicating the likelihood that the observed correlation would occur by random chance.

Kendall's tau was calculated using the cenken function from the Non-Detects and Data Analysis (NADA- version 1.5-3) package for R. This function correctly includes non-detects at different reporting limits in the calculations (see Helsel, 2005).

Akritas-Theil Sen (ATS) Line

We used the ATS line as a visual aid for identifying increasing or decreasing trends, but do not interpret the line to imply the existence of any linear relationship in the data. The ATS line is a non-parametric regression line which allows the inclusion of non-detect samples. It is considered a "linear median" and is not strongly influenced by the presence of outliers.

Seasonal Kendall

This test accounts for seasonality by computing Kendall's Tau for each season separately, and then combining the results. This test is calculated using software provided by USGS ("Program for the Kendall Family of Trend Tests").

Trophic State Index (TSI)

TSI is a numerical scale which incorporates most lakes between values of 0 and 100. Low values represent small algal biomass, and each major division (10, 20, 30) represents a doubling of algal biomass (Carlson, 1977). It was calculated using the following formulas:

For Secchi disk depth readings (SD):

$$TSI_{SD} = 10\left(6 - \frac{\ln(SD)}{\ln(2)}\right)$$

For chlorophyll-a concentrations (Chl):

$$TSI_{Chl} = 10\left(6 - \frac{2.04 - 0.68\ln(Chl)}{\ln(2)}\right)$$

For total phosphorus concentrations (TP):

$$TSI_{TP} = 10\left(6 - \frac{\ln(48/TP)}{\ln(2)}\right)$$

Results and Discussion

Total Phosphorus TMDL Criterion

As discussed above, the average water-column concentration of total phosphorus in the Wapato Basin is calculated as a volume-weighted average, and the upper 95% confidence limit (95% UCL) for this value is used to evaluate the condition of the lake relative to the 4.5 ug/L criterion for the total phosphorus TMDL (Seiders et al., 1997).

The 2007 volume-weighted summer epilimnetic mean and 95% UCL were less than 2.0 and 2.6 ug/L, respectively (Figure 4). Calculations are shown in Appendix C. The 2007 95% UCL is well below the 4.5 ug/L TMDL criterion for total phosphorus. Values from previous years are also shown in this figure. For samples reported as non-detect, the reporting limit was substituted into the calculation, to provide the most conservative estimate possible.

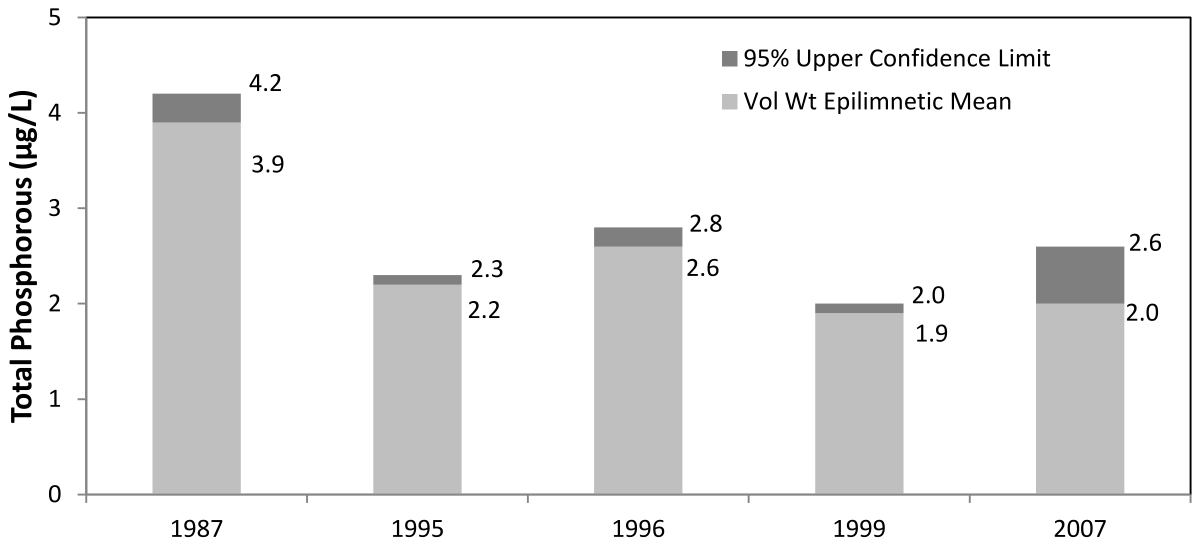

Figure 4. Volume-Weighted Total Phosphorus Summer Epilimnetic Means and 95% UCLs, 1987-2007.

The 1999 mean of 1.9 ug/L shown above differs from the mean of 1.8 ug/L reported by Anchor (2000). The reason for this difference is uncertain[2]. The reason for recalculating the mean is that no value for the 95% UCL was provided in their report. The mean and 95% UCL were therefore recalculated based on all their reported data, to provide a consistent comparison to the TMDL criterion for all years.

[2] The mean total phosphorus from Table 5 in their report (Anchor, 2000) is 1.8 ug/L, but calculating the mean as described in the analysis section above yields 1.88 ug/L. One possible way Anchor could have reached 1.8 is to average the individual total phosphorus concentrations in their Table 5, which yields 1.83. However, this introduces additional round-off error, since their table values are already rounded.

Trend is addressed in the section "Total Phosphorus" below. It should not be inferred from the above figure for two reasons:

1. The reporting limit was substituted for non-detect samples, biasing the mean and 95% UCL high (the reporting limit of 1 ug/L was substituted for 25 out 70 water samples in 2007, while in 1996 the reporting limit of 3 ug/L was substituted for 38 out of 70 water samples.)
2. The mean and 95% UCL are sensitive to outliers which may not reflect the overall condition of the lake. In 2007 two such high-concentration total phosphorus samples occurred which might bias the mean and 95% UCL high. These are discussed in the section on total phosphorus below.

Water Quality Comparison to Previous Years

Water quality parameters from previous years are compared to the 2007 data to evaluate possible trends in Lake Chelan. A summary of the 2007 field and laboratory monitoring data is presented in Appendix D. Descriptive (not volume-weighted) summary statistics are presented in Appendix E.

Total Phosphorus

The possibility of a decreasing trend in total phosphorus concentrations over time is indicated by the notched boxplots in Figure 5.

No boxplot is shown for 1996 because of the increased reporting limit of 3 ug/L for part of that year. If the 1996 boxplot were shown in the figure, all boxplots would need to be truncated at the higher reporting limit, removing most of the information shown in the current figure.

The two highest recorded total phosphorus concentrations (28.8 ug/L on 5/22/95 and 20.0 ug/L on 6/21/07) were both collected near the lake bottom at station #2 and could possibly be affected by bottom sediment. The 1995 datum was rejected by Congdon based on sand in the sampler (Congdon, 1996). Congdon also rejected the next sequential sample after observing sand in the sampler, noted in the figure above. These rejected samples were not included in the boxplot calculation and do not affect the median or other percentiles of the boxplot.

It is possible that bottom sediments affected the 2007 total phosphorus result of 20.0 ug/L, although no sand was observed in the sampler. The bottom depth in 2007 was reported to vary between 20.0 and 21.8 meters, and boat drift due to wind could have potentially brought the sampler near the bottom. However, we accepted this concentration as a valid result since contamination is not clearly documented, and including it is protective of the lake. To avoid the possibility of contamination at this site, we recommend that future studies collect samples at station #2 from a depth of 19 meters instead of 20 meters. This should ensure that samples are collected at least 1 meter above the lake bottom.

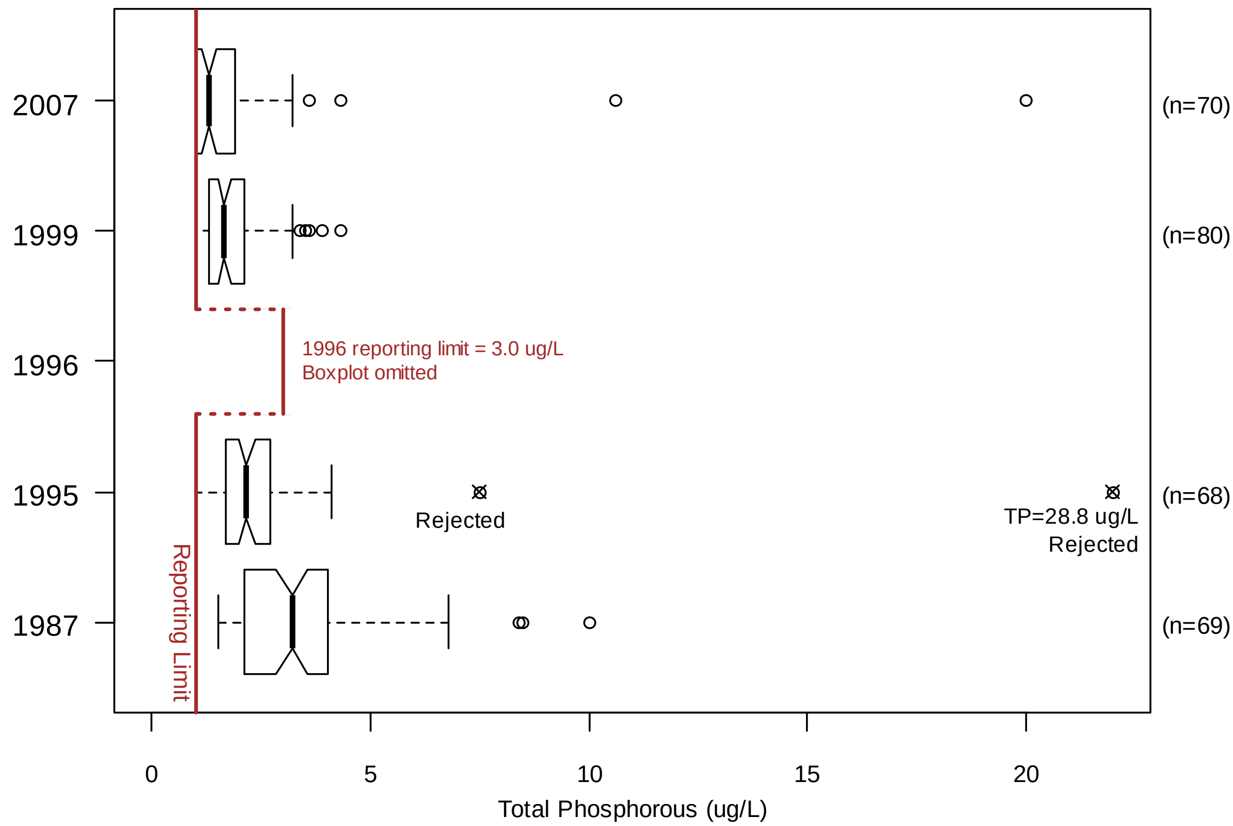

Figure 5. Notched Boxplots of Total Phosphorus Concentrations 1987-2007.

The other high-concentration total phosphorus sample in 2007 was collected on 8/29/07 from station #4 at 10 meters depth (10.6 ug/L total phosphorus). Samples from every other station on this date were non-detect (<1 ug/L) for total phosphorus.

Weak seasonality in total phosphorus concentrations was observed for 1999 and 2007 (Figure 6), but the pattern does not appear consistent across all years. Concentrations for these two years appear lowest in late August and early September. As recommended by Helsel (2005), non-detects were shown on this plot as a vertical line from zero to the reporting limit. The true concentration of each non-detect sample lies at an unknown location along this line. The raised detection limits for 1996 are easily seen in this figure. In 2007, most samples from late August are non-detect (<1 ug/L) for total phosphorus.

Because seasonality in the data appears weak and inconsistent across the years, data were combined from all seasons at each station/depth combination and tested for trend using Kendall's tau.

Trend was inferred when a statistically significant correlation was found at the 95% confidence level (p-value < 0.05) between total phosphorus concentrations and time using Kendall's tau.

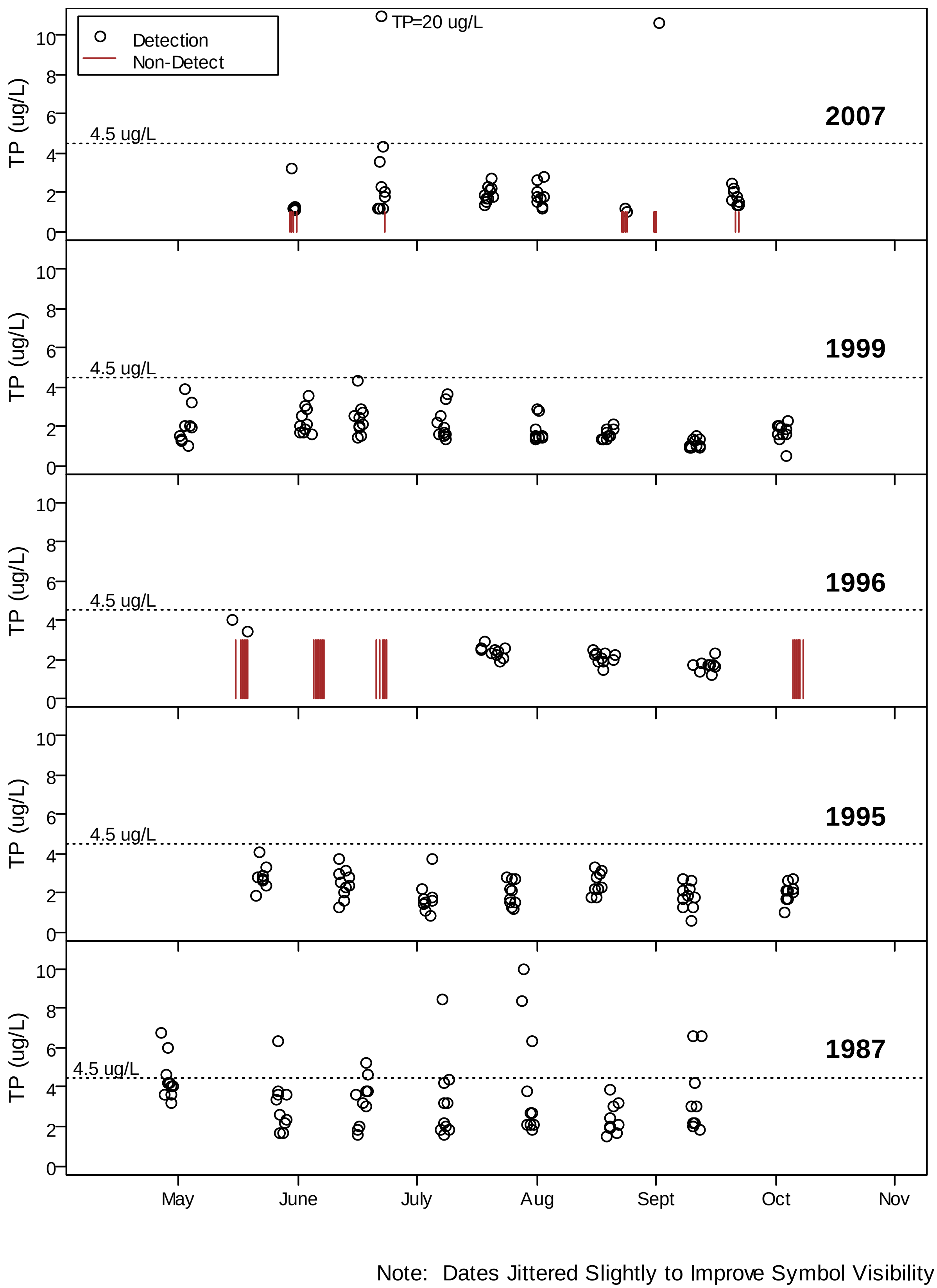

Figure 6. Seasonal Total Phosphorus (TP) Concentrations by Year, 1987-2007.

The changing reporting limits were addressed by testing for trend using a specialized function designed for this situation. The function (cenken) is part of the Non-Detects and Data Analysis package for the software program R. Since the Kendall test is rank based, non-detects can only be compared to detections higher than the reporting limit. The cenken function takes all detection limits fully into account, and non-detects are compared correctly against appropriate detections.

Based on this test, a weak trend was found in total phosphorus at each station/depth combination between 1987 and 2007 (Figure 7). In all cases, the trend is decreasing. Among the different stations and depths, tau ranged from -0.25 to -0.56 with a confidence level of 95% or better. Similar to the previous figure, non-detects are shown as lines extending from zero to the reporting limit. The dotted lines are non-parametric Akritas-Theil-Sen (ATS) lines, offered as a visual guide. No linear relationship in the data is implied by these lines.

Also note on this figure that phosphorus levels from the near surface at station #1 are roughly similar to near-surface concentrations from the other three stations for all years. Since station #1 is located near the lake outlet, it is expected to represent a mixture of the water flowing through the basin towards the lake outlet. If elevated levels had been noted at station #1, it might indicate near-shore contributions of phosphorus arriving at the lake outlet.

For comparison, trend testing was repeated after excluding the entire 1996 data set. This was done because data from 1996 bias the detections towards the mid-summer months. Since 1996 is near the center of the datasets, omitting it may not strongly affect the results. Omitting it leaves only four years of data, however, which is not considered sufficient to test trend.

Repeating the trend test after omitting all 1996 data gave a slightly improved indication of trend than above. In all cases, trend remained decreasing. Among the different stations and depths, tau ranged from -0.33 to -0.67 with a slightly higher confidence level of 98% or better.

Trend testing provides some encouragement for decreasing phosphorus in the lake, but it does not indicate whether this is due to decreased phosphorus loading or whether the lower concentrations could be attributed to constant loading with different dilution and runoff characteristics.

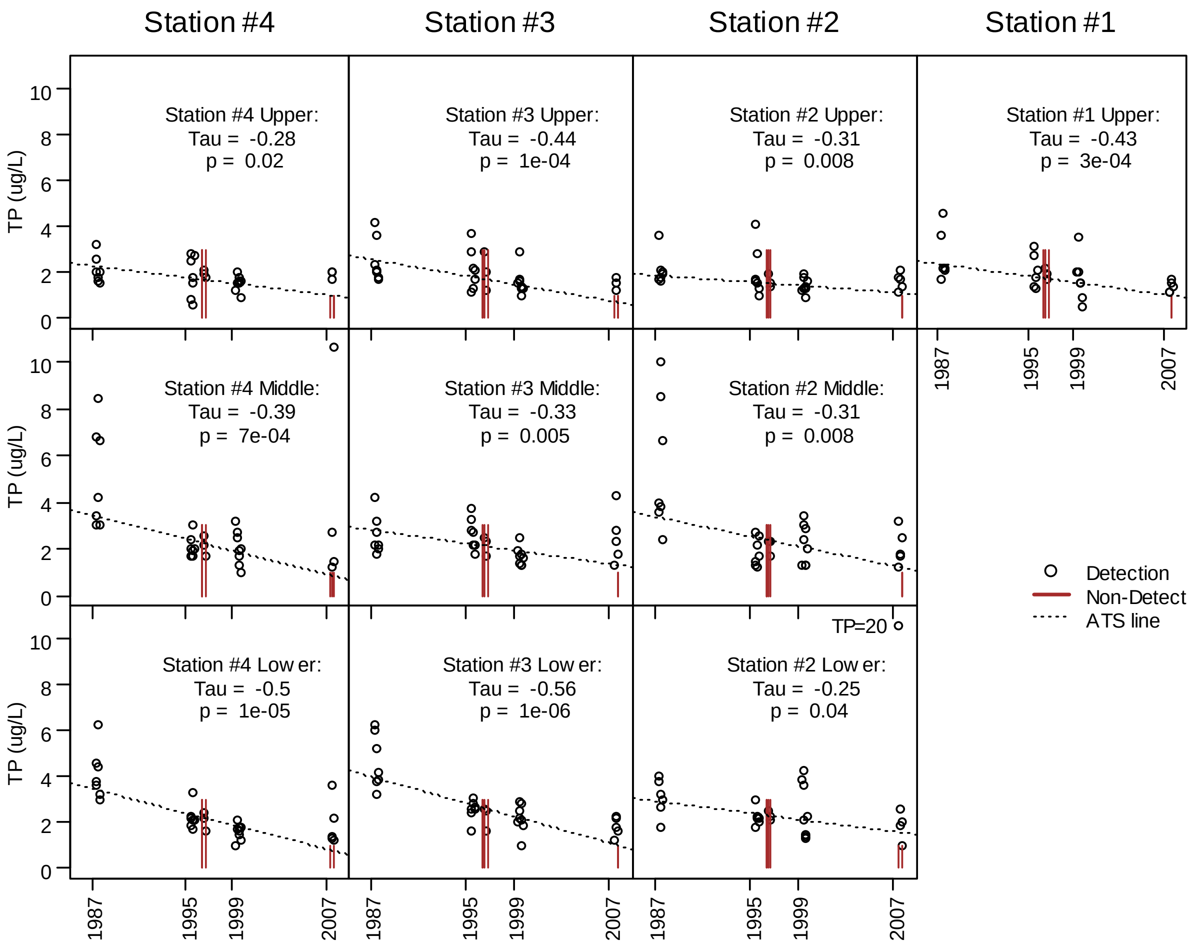

Figure 7. Trends in Total Phosphorus (TP) from Kendall's Tau, 1987-2007 (1996 included).

Nitrogen

Notched boxplots of nitrite-nitrate and total nitrogen do not show clear trends over time (Figures 8 and 9). Concentrations of nitrite-nitrate in 1995 appear significantly lower than concentrations from other years, and similarly for total nitrogen in 1996, but the reason is unknown. Concentrations of nitrite-nitrate exceeding 80 ug/L have not been observed since 1987. (The high concentrations from 1987 were plotted at a lower concentration and labeled with actual measured concentrations in the figure.) Similar to findings in previous reports, concentrations of nitrite-nitrate declined over the course of the sampling season in 2007.

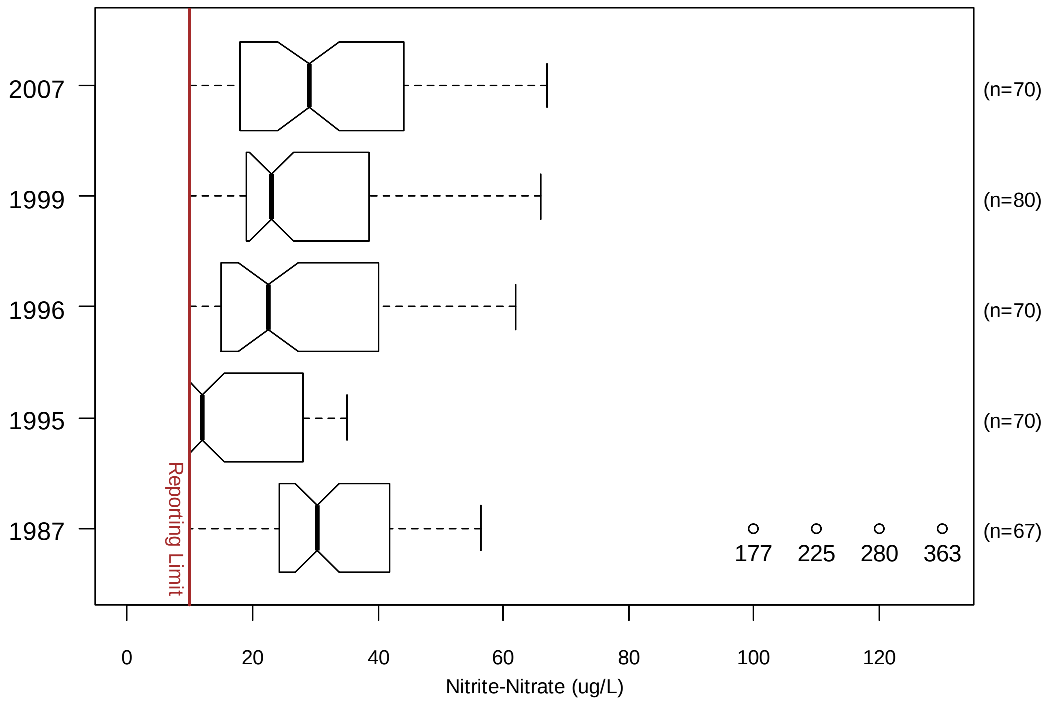

Figure 8. Notched Boxplots of Nitrite-Nitrate Concentrations, 1987-2007.

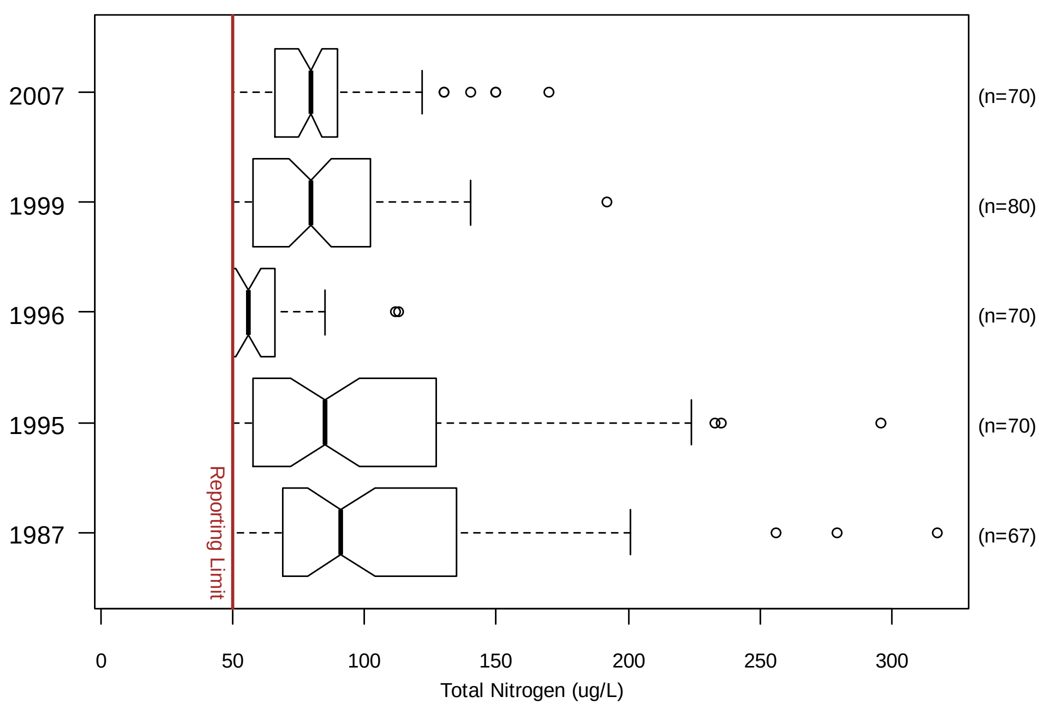

Figure 9. Notched Boxplots of Total Nitrogen Concentrations, 1987-2007.

Nitrogen-to-Phosphorus Ratios

According to Congdon (1996), nitrogen-to-phosphorus ratios exceeding roughly 7:1 to 15:1 (by weight) indicate that phosphorus may be the more limiting nutrient. Calculating this ratio for 2007 resulted in 68 out of 70 (97%) values having ratios of 20:1 or higher; the only two ratios below 20:1 were from the two high concentrations of total phosphorus discussed above. These two measurements had nitrogen-to-phosphorus ratios of 4:1 and 7:1.

The mean 2007 nitrogen-to-phosphorus ratios is at least 59:1, which indicates that phosphorus remains the limiting nutrient controlling algal biomass in Lake Chelan. For this calculation, the reporting limit was substituted for non-detect total phosphorus concentrations. Previous studies reported mean ratios of 44:1, 20:1, 46:1 and 30:1 for 1999, 1996, 1995, and 1987, respectively (Anchor, 2000; Sargeant, 1997; Congdon, 1996). The decreased mean in 1996 was partly due to the raised detection limits for total phosphorus.

Chlorophyll-a

Notched boxplots for chlorophyll-a (Figure 10) do not show a clear trend over time. Chlorophyll-a samples in 2007 did not fully meet DQOs, since half of the replicate pairs exceeded 20% relative standard deviation (RSD). In addition, the reporting limit improved in 2007 to 0.05 ug/L, ten times lower than the 0.50 ug/L reporting limit for 1996 which was used to censor the boxplot figure below.

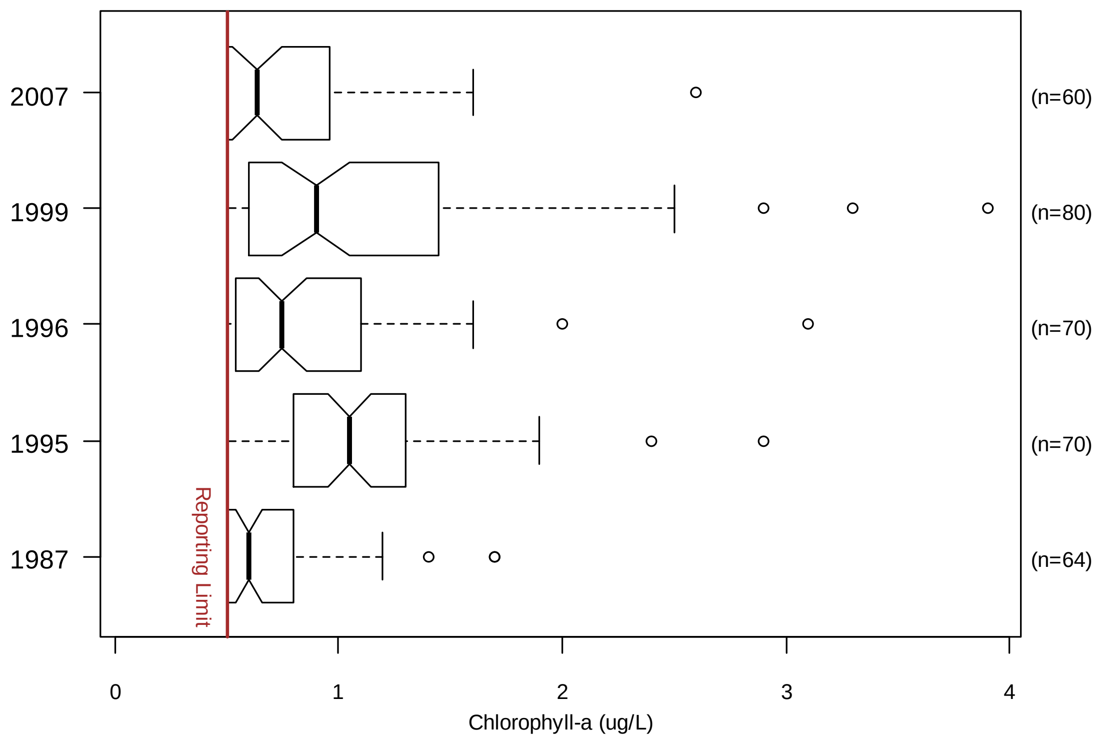

Figure 10. Boxplots of Chlorophyll-a Concentrations, 1987-2007.

Chlorophyll-a samples collected on 8/21/07 were rejected as degraded due to likely light exposure and were the only samples reported below the 0.05 ug/L detection limit. These samples were not used in the boxplot calculation.

Over 75% of the chlorophyll-a concentrations in 2007 satisfy the ultra-oligotrophic threshold of 1 ug/L reported by Patmont et al. (1989). This threshold is not a criterion for the current TMDL, but this is a positive indication of relatively low phytoplankton biomass.

Water Transparency (Secchi disk)

Secchi disk measurements of water transparency over time are shown in Figure 11. Seasonal variation is apparent, with improvement later in the season, possibly associated with settling of glacial silt. Therefore, changes in the early season may be independent of organic production. The dotted lines mark the ultra-oligotrophic threshold of 14 m for Secchi disk readings (Patmont et al., 1989).

Testing average monthly transparency from May-Sept for trend provided a weak indication of improving transparency, but at less than 95% confidence. This is based on the Seasonal Kendall test for trend, tau=0.39, p=.05 (less than 95% confidence). Repeating this test after limiting data to July-Sept gave a similar result but with decreased confidence: tau=0.40, p=.12 (less than 90% confidence).

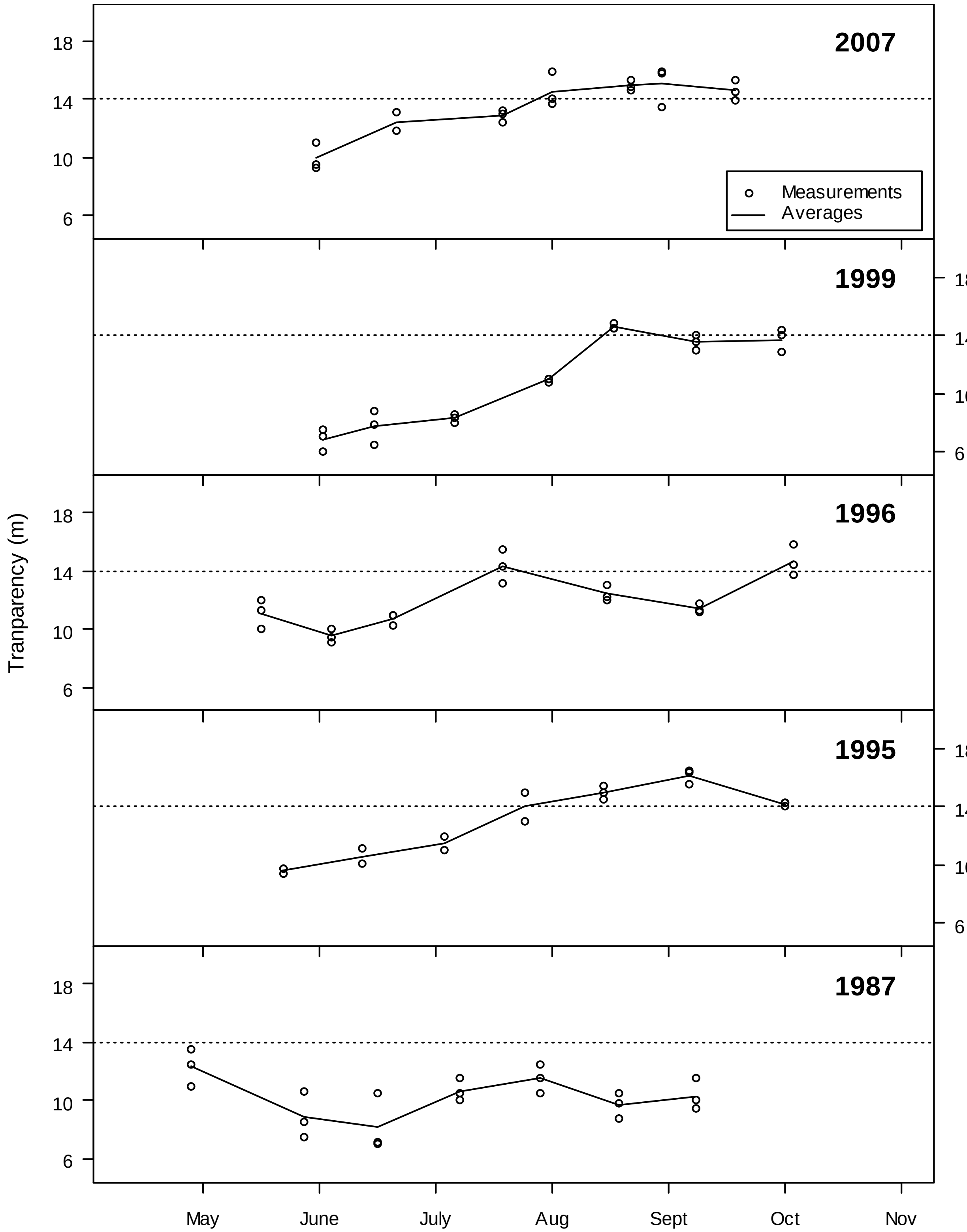

Figure 11. Secchi Depth Transparency versus Time, 1987-2007.

Other Parameters

Appendix E presents descriptive statistics for physical parameters and Appendix F presents 2007 depth profiles for temperature, dissolved oxygen, and pH for all sample events and stations.

Temperature

Temperature profiles were similar to previous study years (Figure 12). Past reports list the thermocline depth as 30-40 meters; however this figure shows a thermocline between <10 m to 40 m. The thermocline is remarkably diffuse (Hallock, 2011). Sharp thermoclines are caused by wind mixing the upper layer, creating the epilimnion. For most months there is not a strong vertical profile, even near the surface, although the reason for this is unclear. Temperatures taper slowly rather than drop sharply, as in many lakes in Central Washington. Depth profiles of temperature for all stations and sampling events in 2007 are presented in Appendix F.

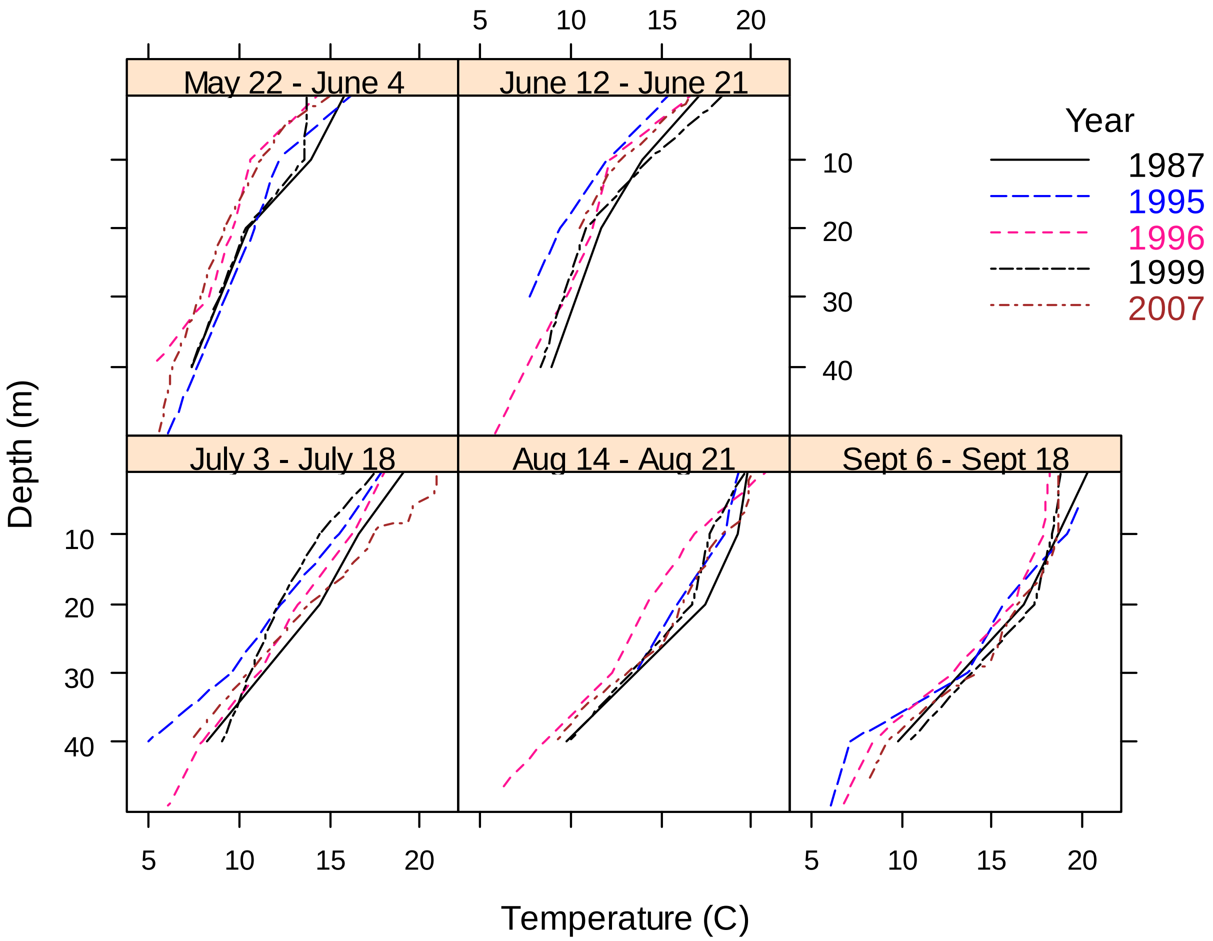

Figure 12. Temperature Profiles at Station #3 by Month, 1987-2007.

Dissolved Oxygen

Dissolved oxygen levels in 2007 are roughly similar to previous studies (Figure 13). Dissolved oxygen levels from 1995 and 1999 are omitted from this figure due to accuracy concerns. Data from these years showed excessive scatter when compared to solubility limits.

As shallow waters warm during the summer, oxygen levels drop due to decreased solubility limits. Deeper waters remained fairly constant in both temperature and oxygen level. This relationship is illustrated in Appendix F, along with depth profiles of dissolved oxygen in 2007 for each station/sampling event.

Mid-summer oxygen profiles are generally orthograde, which is typical of oligotrophic lakes. Concentrations increased in the cooler water below the epilimnion. The cool, oxygenated, deeper water is a remnant of spring conditions prior to stratification. However, there are indications of oxygen consumption near the bottom, especially in July, where the oxygen concentration declines below 35-40 m. This is not typical of ultra-oligotrophic lakes, which may show a constant oxygen concentration throughout the hypolimnion (Hallock, 2011).

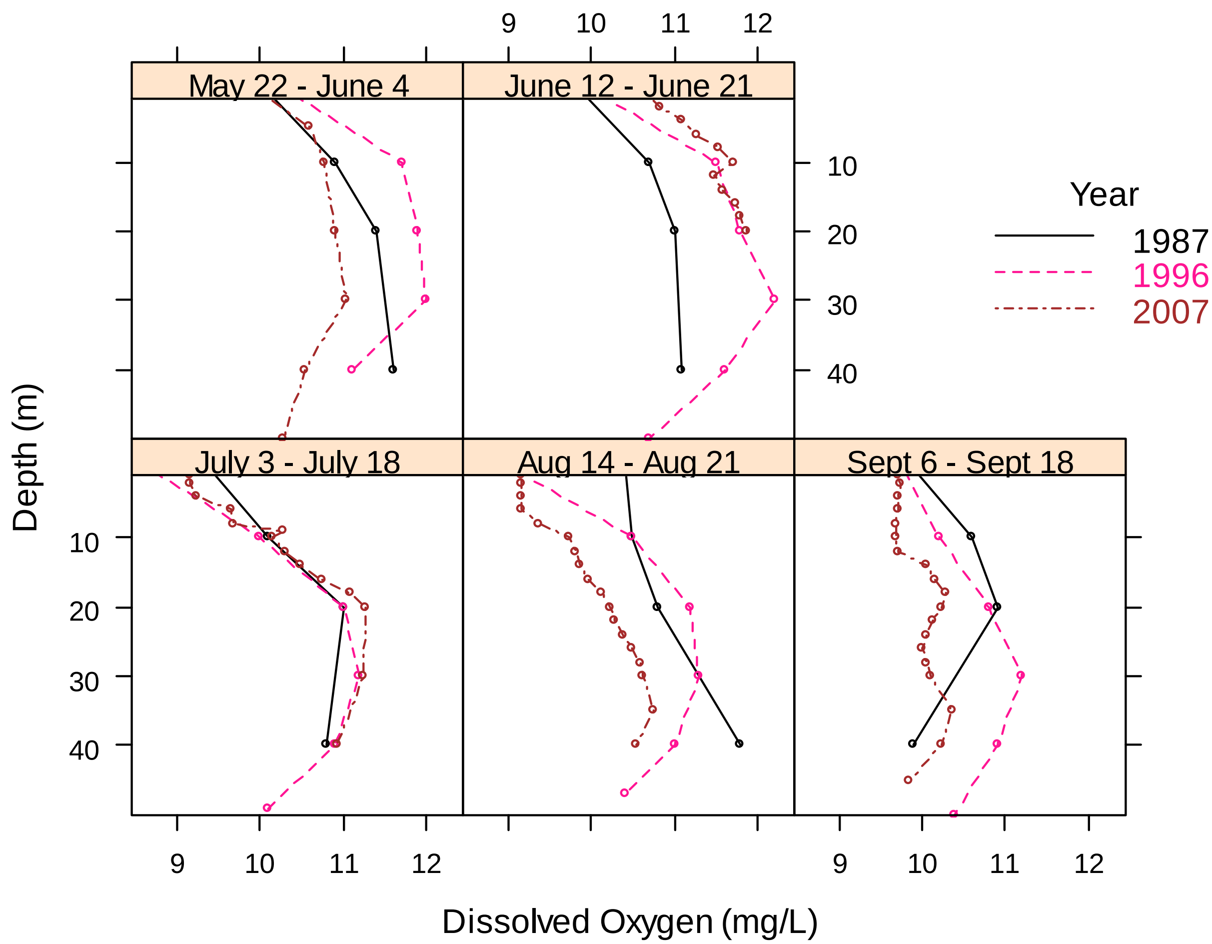

Figure 13. Dissolved Oxygen Profiles at Station #3 by Month, 1987-2007.

pH

pH levels in 2007 are roughly similar to previous studies (Figure 14). Similar to dissolved oxygen, readings from 1995 and 1999 are omitted from this figure. Depth profiles of pH in 2007 for each station/sampling event are shown in Appendix F.

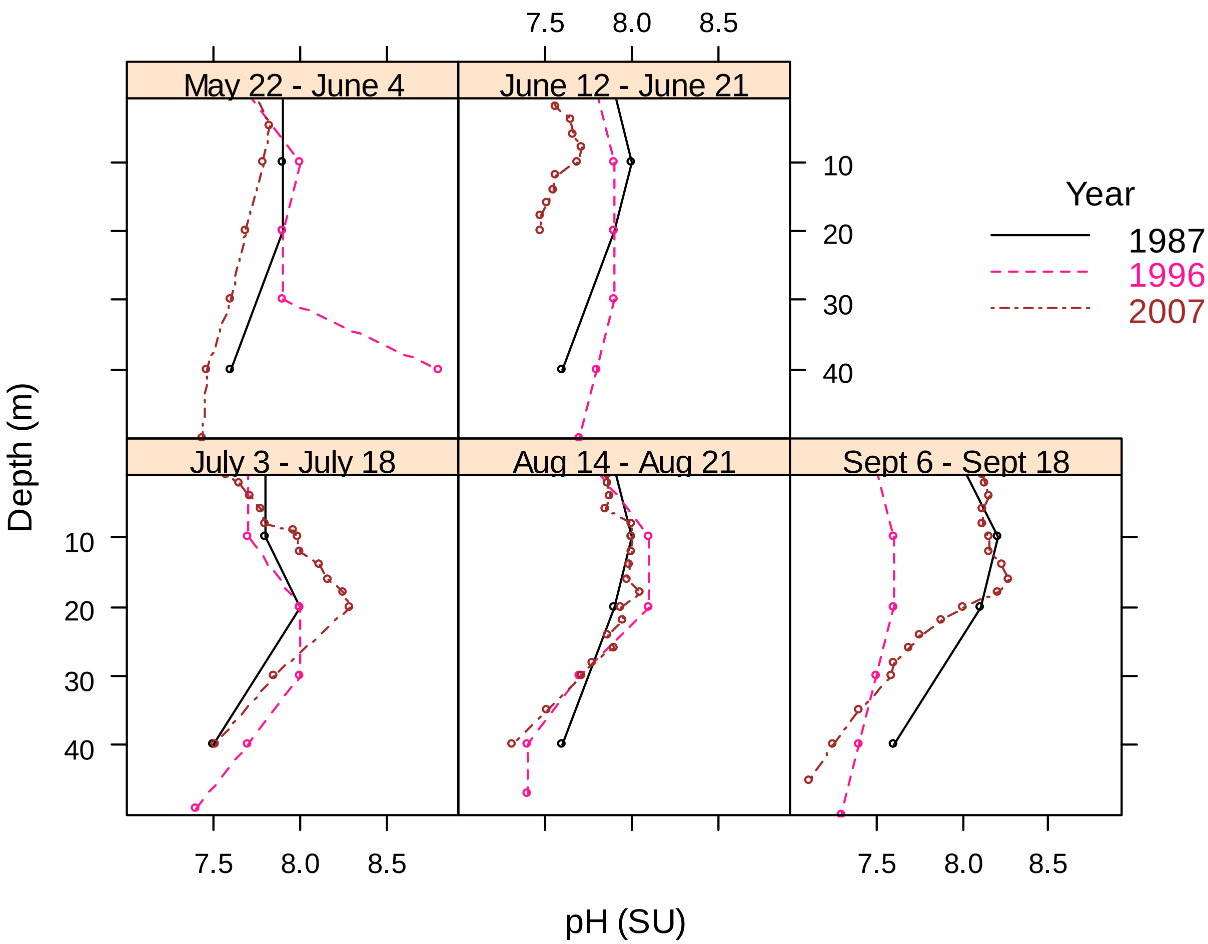

Figure 14. pH Profiles at Station #3 by Month, 1987-2007.

Trophic State Index (TSI)

Further evidence that Lake Chelan was phosphorus limited in 2007 is provided by the TSI boxplots in Figure 15. According to Carlson (1983), lakes in which ($TSI_{SD} = TSI_{Chl}$) > TSI_{TP} are phosphorus limited, which is the case in this figure.

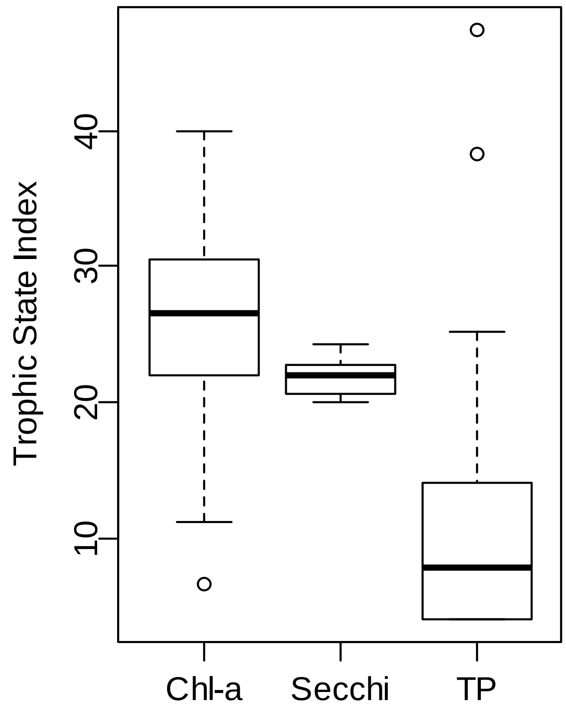

Figure 15. Boxplots of 2007 Trophic State Index for Chlorophyll-a, Transparency, and Total Phosphorus.

Conclusions and Recommendations

As a result of this 2007 study, the following conclusions and recommendations are made:

Conclusions

- The 2007 volume-weighted mean epilimnetic concentration of total phosphorus in the Wapato Basin was less than 2.6 ug/L with 95% confidence, which satisfies the TMDL criterion of 4.5 ug/L.
- Continued ultra-oligotrophic status (ultra-low nutrient input and organic production) for the lake is supported by low chlorophyll-a concentrations and high water transparency.
- Weakly decreasing trends for total phosphorus since 1987 were found at each station/depth pair based on Kendall's tau, significant at the 95% confidence level.
- A weakly improving trend since 1987 was in average water transparency based on the Seasonal Kendall test, but at less than the 95% confidence level.
- Evidence that total phosphorus continues to limit algal biomass in Lake Chelan is provided by high nitrogen-to-phosphorus ratios and low trophic state index values for total phosphorus.
- Water quality in Lake Chelan remains excellent and should continue to be protected.

Recommendations

- Monitoring should continue to ensure that the TMDL water quality criterion is met, and that pollution control efforts be supported to protect water quality.
- To avoid contamination from the lake bottom in future studies, samples at station #2 should be collected at a slightly shallower depth.

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Appendices

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Appendix A. Glossary and Acronyms

Glossary

Ambient monitoring: Background or away from point sources of contamination.

Clean Water Act: Federal Act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Act establishes the TMDL program.

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.

Data quality objectives (DQOs): Qualitative and quantitative statements derived from systematic planning processes that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.

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

Effectiveness monitoring: Monitoring to determine whether the recommended *Detailed Implementation Plan*, after a significant portion of the recommendations or prescriptions have been implemented, is adequate in meeting (1) the goals and objectives for the TMDL project or (2) other desired outcomes over long temporal scales.

Epilimnion: The upper layer of more or less uniformly warm, circulating, and fairly turbulent water developed during the period of summer stratification. For this study, epilimnion refers to the upper 30 m of water.

Hypolimnion: The cold and relatively undisturbed water underlying the epilimnion during summer stratification; the two layers are separated by the thermocline.

Limnological: A scientific study of the physical and biological processes occurring in a lake's waters.

Loading capacity: The greatest amount of a substance that a waterbody can receive and still meet water quality standards.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities. This includes, but is not limited to, atmospheric deposition, surface water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System Program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Nutrient: Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

Outlier: A number (or observation) that deviates markedly from other numbers in a sample population (group of observations).

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.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

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 is 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.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Thermocline: A layer in a large body of water, such as a lake, that sharply separates regions differing in temperature, so that the temperature gradient across the layer is abrupt.

Total Maximum Daily Load (TMDL): A distribution of a substance in a waterbody designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a margin of safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Ultra-oligotrophic: A lake ultra-low in nutrient inputs and low organic production, where oxygen concentration with depth is regulated largely by physical means as summer stratification occurs. The TMDL threshold criterion for Lake Chelan requires maintaining the summer epilimnetic total phosphorus concentration mean below 4.5 ug/L.

Volume-weighted mean: An estimate of the mean calculated by assigning weights within an average. These weights determine the relative importance of each volume on the average.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

303(d) List: Section 303(d) of the federal Clean Water Act requires Washington State periodically to prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited waterbodies (ocean waters, estuaries, lakes, and streams) that fall short of state surface water quality standards, and are not expected to improve within the next two years.

95% upper confidence limit: A maximum value calculated from a given set of data which places an upper limit on an unknown population parameter (such as the mean), bounding the true parameter 95% of the time.

Acronyms and Abbreviations

DQO	(See Glossary above)
EAP	Environmental Assessment Program
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
LPQL	Lower practical quantitative limits
QA	Quality assurance
RPD	Relative percent difference
RSD	Relative standard deviation
SD	Standard deviation
TMDL	(See Glossary above)
TPN	Total persulfate nitrogen
UCL	Upper Confidence Limit
USGS	United States Geological Survey
WAC	Washington Administrative Code

Units of measurements

°C	degrees Centigrade
cfs	cubic feet per second
cm	centimeter
m	meter
mg/L	milligrams per liter
su	standard unit
ug/L	micrograms per liter
umho	micromhos

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Appendix B. Quality Assurance

This appendix compares the quality of data collected for this study against the data quality objectives (DQOs) described in the QA Project Plan (Sargeant, 2007). DQOs are statements of the precision, bias, completeness, representativeness, and comparability necessary for the data to address project objectives which together express data accuracy.

Analytical laboratory QA was evaluated by Manchester Laboratory in accordance with their policies (MEL, 2006) prior to reporting the data. Their reported data meets DQOs.

To maintain data quality, standard operating procedures were followed for all field measurements, sample collection, laboratory analysis, and data reduction. Field instruments were calibrated and used in accordance with user manuals.

Precision

Precision for the total phosphorus sampling is fully described in Seiders et al. (1997). Precision of laboratory analyses and field measurements are estimated below using field replicate samples and also through comparing instrument readings to sample measurements.

Measures of variability used below include:

- SD: standard deviation.
- RSD (relative standard deviation): the standard deviation between two or more samples divided by their mean, multiplied by 100, and expressed as a percentage.
- RPD (relative percent difference): the difference of two samples divided by their mean, multiplied by 100, and expressed as a percentage.
- Pooled standard deviations are also calculated as required by Seiders et al. (1997) using the equation $\sqrt{\frac{\left(\sum_{i=1}^{n}(x_{i1} - x_{i2})^2\right)}{2n}}$ for n replicate sample pairs x_{i1} and x_{i2}.
- NC: not calculated.

In cases where both duplicates were below the detection limit, no calculation of variability was performed, nor were such pairs used in the pooled standard deviation. No cases occurred in which only one sample of the replicate pair fell below detection limits.

Table B-1 presents DQOs described in the QA Project Plan (Sargeant, 2007) and Mathieu (2006), as well as the lower practical quantitative limits (LPQL) of laboratory data reported by Manchester Laboratory. Tables B-2 through B-7 present the variability in field replicates for total phosphorus, chlorophyll-a, nitrite-nitrate, total persulfate nitrogen (TPN), dissolved oxygen, and conductivity. There are a maximum of seven replicate pairs per compound; this does not meet the criterion of 10 pairs needed to compare mean RSD to the measurement quality objective tables given in Mathieu (2006). Therefore usability of the data will be based upon review by the project manager in combination with the QA Project Plan.

Because analytical variability increases as low concentrations approach the method detection limits, the DQOs do not strictly apply to concentrations of less than five times the detection limit. In these circumstances, data usability is determined based on the judgment of the project manager, as described in the QA Project Plan.

Because greater variability is expected for samples approaching the reporting limit (LPQL), Table B-1 specifies that samples with a mean of less than or equal to five times the reporting limit will be evaluated separately, which is the case for all replicate pairs for total phosphorus, nitrite-nitrate and TPN.

Table B-1. Data Quality Objectives (DQOs) and Lower Practical Quantitation Limits (LPQLs).

Laboratory Analyte	Method	DQOs	LPQLs (ug/L)
Ammonia	SM 4500 NH_3H	10% RSD[1]	10
Chlorophyll-a	SM 10200 H3	20% RSD[1]	0.05
Nitrite-Nitrate	SM 4500 NO_3I	10% RSD[1]	10
Ortho-Phosphate	SM 4500 PG	10% RSD[1]	3
Total Persulfate Nitrogen	SM 4500 NB	10% RSD[1]	25
Total Phosphorus	EPA 200.8	10% RSD[1]	1
Dissolved Oxygen	Winkler modified azide (EPA 360.2)	±0.1 mg/L	------
	Hydrolab Minisonde®	5% RSD	------
Specific Conductivity	Hydrolab Minisonde®	±0.5 % RPD	------
pH	Hydrolab Minisonde®	0.05 SU	------
Temperature, Water	Hydrolab Minisonde®	±0.1°C	------

SM: Standard Methods for the Examination of Water and Wastewater, 21st Edition (APHA, AWWA and WEF, 2005).
EPA: U.S. Environmental Protection Agency method code.
[1]replicate results with a mean of less than or equal to 5X the reporting limit will be evaluated separately.

Table B-2 presents the seven replicate pairs analyzed for total phosphorus. None of these pairs have an average concentration greater than five times the LPQL, hence their variability is not guaranteed to meet the DQO due to low concentrations approaching the reporting limit (Mathieu, 2006). Of these seven pairs, two are below the detection limit, and two meet the DQO of ≤10% RSD. The remaining three pairs (RSD = 18%, 18%, and 26%) exceed the DQO (RSD=10%).

Table B-2. Variability in Field Replicates Analyzed for Total Phosphorus.

Total Phosphorus (ug/L) (5 X LPQL = 5 ug/L)										
Station	Depth (m)	Date	Sample		Replicate		SD	RSD	> 5X LPQL?
1	0.3	5/30/07	1.0		1.3		0.21	18%	no
1	0.3	6/21/07	1.2		1.1		0.07	6%	no
2	10	8/21/07	1	UJ	1	UJ	NC	NC	no
3	20	7/31/07	1.9		1.7		0.14	8%	no
3	20	9/18/07	1.8		1.4		0.28	18%	no
4	10	7/18/07	2.2		3.2		0.71	26%	no
4	0.3	8/29/07	1	U	1	U	NC	NC	no

Total number of replicate pairs:	7
Number of replicate pairs > 5 X LPQL:	0
Pooled Standard Deviation:	0.36

The largest variability among these seven replicate pairs (RSD = 26%) occurs from a pair obtained at station #4 at 10 m on 7/18/07. Replicate pairs for other compounds collected at the same location and time show greater variability for chlorophyll-a (RSD=44%), nitrite-nitrate (RSD=18%), and TPN (RSD = 56%). Because all these replicate pairs have significant differences from this particular site and date, the likelihood is strong that the variability between pairs is due to heterogeneity in the sampled media, as opposed to analytical error or problems with field techniques.

The pooled standard deviation is 0.36 ug/L, which is similar in size to the standard deviation for the lab duplicates pair (0.26 ug/L). This variability is an acceptable component for an analytical method whose LPQL is 1 ug/L, and only three of the seven replicate pairs exceed the DQO. Hence these data are sufficiently precise for use in this study.

Six replicate pairs are shown in Table B-3. Omitted from Table B-3 is one replicate pair rejected due to improper sample sealing which could have exposed the samples to light, degrading chlorophyll; both measured concentrations in the rejected pair were non-detect for chlorophyll-a at 0.05 ug/L. Additionally, one sample above is J-qualified as an estimate, due to leaking during transportation.

Average concentrations for all six pairs exceed the standard of five times the LPQL, satisfying one of the conditions of Mathieu (2006). However that paper also stipulates that 10 replicate pairs are needed to compare the average RSD to the given DQO, hence there are insufficient replicate pairs to validly perform that test, and the project manager will decide upon the usability of the chlorophyll-a data.

Table B-3. Variability in Field Replicates Analyzed for Chlorophyll-a.

Chlorophyll-a (ug/L)									(5 X LPQL = 0.25 ug/L)
Station	Depth (m)	Date	Sample		Replicate		SD	RSD	> 5X LPQL?
1	0.3	5/30/07	0.43		0.073		0.25	100%	yes
1	0.3	6/21/07	0.61		0.60		0.01	1%	yes
3	20	7/31/07	0.99		0.88		0.08	8%	yes
3	20	9/18/07	1.50		1.10		0.28	22%	yes
4	10	7/18/07	0.86	J	0.45		0.29	44%	yes
4	0.3	8/29/07	0.37		0.47		0.07	17%	yes

Total number of replicate pairs:	6
Number of pairs > 5X LPQL:	6
Pooled Standard Deviation:	0.2

Pooled standard deviation is 0.2 ug/L.

Of the pairs shown above, half meet the DQO of 20% RSD, and the remainder fail:

- one pair only slightly (22%).
- one pair due to a J-qualified sample which leaked during shipment (44%) which is also associated with increased variability for total phosphorus, nitrite-nitrate, and TPN replicate pairs collected at the same location and time (station #4 @ 10 m on 7/18/07).
- one pair (RSD = 100%) reports a notable difference between the sample and replicate.

We know that the increased variability in one of the pairs is likely due to heterogeneity in the sampled media because variability increases for all compounds at station #4 @ 10 m on 7/18/07. This pattern is not repeated for station 1 at 0.3 m depth, where RSD=100%, so we cannot conclude that this difference is due to media heterogeneity, neither can we rule it out, since chlorophyll-a is independent of the other three compounds.

Variation between samples and replicates represent the combined effects of sampling and analysis. Laboratory variation was estimated through three lab duplicate pairs, shown below:

Sample (ug/L)	Duplicate (ug/L)	SD	RSD
0.61	0.57	0.28	5%
0.24	0.28	0.28	11%
1.60	1.60	0	0%

Since the RSD for the lab samples remain low, it is possible that the high RSD seen in field replicate pairs may represent heterogeneity in the sampled media or possibly an unknown fault in the field method.

Sargeant (1997) reports that of seven field duplicates, only one did not meet the 20% RSD criterion, but this was likely due to one sample being close to the detection limit and the other below the detection limit, and substituting one-half the detection limit for calculations.

Due to the presence of one replicate pair reporting RSD = 100%, chlorophyll-a data do not meet our DQOs and this will be noted in this report.

Seven replicate pairs are shown in Table B-4, none of which qualify as greater than five times the LPQL. However, all but one of these replicate pairs meets the DQO of 10% RSD. The sample that did not meet the DQO was collected at station #4 @ 10 m on 7/18/07, and other pairs collected at this location and date for total phosphorus, chlorophyll-a, and TPN also did not meet the DQO, increasing the likelihood of heterogeneity in the sampled media, as opposed to analytical error or problems with field technique. The pooled standard deviation is 2.7 ug/L. Field data quality is good.

Table B-4. Variability in Field Replicates Analyzed for Nitrite-Nitrate.

Nitrite-Nitrate (ug/L)							(5 X LPQL = 50 ug/L)
Station	Depth (m)	Date	Sample	Replicate	SD	%RSD	> 5X LPQL?
1	0.3	5/30/07	46	46	0.00	0%	no
1	0.3	6/21/07	43	43	0.00	0%	no
2	10	8/21/07	20	20	0.00	0%	no
3	20	7/31/07	30	30	0.00	0%	no
3	20	9/18/07	18	18	0.00	0%	no
4	0.3	8/29/07	15	13	1.41	10%	no
4	10	7/18/07	35	45	7.07	18%	no

Number of replicate pairs:	7
Number of pairs > 5X LPQL:	0
Pooled Standard Deviation:	2.7

Seven replicate pairs are shown in Table B-5, none of which qualify as greater than five times the LPQL. Five of the seven pairs meet the DQO of 10% RSD, one barely fails (11%) and one sample has an RSD of 56%. Again, the sample with 56% RSD was collected from station #4 @ 10 m on 7/18/07, and is associated with replicate pairs which did not meet the DQO for total phosphorus, chlorophyll-a, and nitrite-nitrate. It is likely that these replicate pairs differ due to heterogeneity in the sampled media, as opposed to field or analytical error.

Dissolved oxygen concentrations measured by Hydrolab® and modified-azide Winkler titration are displayed in Table B-6. The Hydrolab data meet the DQO of 5% RSD, and the difference between Winkler/replicate pairs is within the required ±0.1 mg/L, indicating that these data are sufficiently precise for use in this study.

Table B-5. Variability in Field Replicates Analyzed for Total Persulfate Nitrogen.

Total Persulfate Nitrogen (ug/L)									
									(5 X LPQL = 125 ug/L)
Station	Depth (m)	Date	Sample		Replicate		SD	%RSD	> 5X LPQL?
1	0.3	5/30/07	83		81		1.41	2%	no
1	0.3	6/21/07	77		79		1.41	2%	no
2	10	8/21/07	63		55		5.66	10%	no
3	20	7/31/07	91		79		8.49	10%	no
3	20	9/18/07	50		51		0.71	1%	no
4	0.3	8/29/07	62		53		6.36	11%	no
4	10	7/18/07	74		170		67.88	56%	no

Number of replicate pairs:	7
Number of pairs > 5X LPQL:	0
Pooled Standard Deviation:	26

Table B-6. Variability Between Dissolved Oxygen Measured by Hydrolab, Winkler Titration, and Winkler Replicates.

Station	Depth (m)	Date	Dissolved Oxygen (mg/L)			Hydrolab RSD	Winkler/Replicate Difference (mg/L)
			meter	Winkler			
1	0.3	5/30/07	9.8	10.3	10.5	4%	0.2
1	0.3	6/21/07	10.5	10.0	10.0	3%	0
1	0.3	7/18/07	9.0	8.9		1%	
1	0.3	7/31/07	8.6	8.7		0%	
1	0.3	8/21/07	9.1	9.1		0%	
1	0.3	8/29/07	9.3	9.3		0%	
1	0.3	9/18/07	9.4	9.2		2%	
2	0.3	5/30/07	9.8	10.3		4%	
2	0.3	6/21/07	10.5	10.1		3%	
2	10	9/18/07	9.6	9.4		2%	
3	0.3	5/30/07	10.0	10.3		2%	
3	0.3	6/21/07	10.6	10.2		3%	
3	20	6/21/07	11.9	11.5		2%	
3	0.3	7/18/07	9.1	9.0		1%	
3	0.3	7/31/07	9.0	9.4		3%	
3	10	8/21/07	9.7	9.7		0%	
3	20	8/29/07	10.5	10.3		1%	
3	10	9/18/07	9.7	9.5		1%	
4	0.3	5/30/07	10.1	10.5		3%	
4	0.3	6/21/07	10.6	10.3		2%	
4	20	7/18/07	10.9	11.3		3%	
4	20	7/31/07	10.4	10.4		0%	
4	0.3	8/21/07	9.1	9.2		0%	
4	10	8/29/07	9.6	9.4		1%	
4	0.3	9/18/07	9.7	9.4		2%	
Luc2	0.3	8/29/07	10.4	10.4		0%	

The QA Project Plan lists the DQO for Hydrolab conductivity data as ±0.5% of the reading; however, this may be a typographical error, since given the readings of 50 umho/cm encountered at Lake Chelan, this DQO would require an accuracy of ±0.25 umho/cm, while the laboratory only provides data to the nearest umho/cm, making this an unverifiable target. However, the DQO given in Mathieu (2006) requires a 5% RSD in conductivity values, which is met by these data; hence they are sufficiently precise for use in this report.

Table B-7. Variability Between Conductivity Measured by Hydrolab and Manchester Laboratory.

Station	Depth (m)	Date	Conductivity (umho/cm)		RPD	RSD
			meter	lab		
1	0.3	5/30/07	50.8	53	4%	3%
2	20	8/29/07	48.2	50	4%	3%
3	20	7/31/07	48.8	51	4%	3%
4	0.3	7/18/07	50.5	52	3%	2%
4	10	8/21/07	51.0	51	0%	0%
4	10	9/18/07	49.6	51	3%	2%

RPD: Relative percent difference
RSD: relative standard deviation

Bias

As described in the QA Project Plan (Sargeant, 2007), bias is estimated through the use of equipment blank samples. The results are presented in Table B-8, and no contamination was measured in any of the blanks. Once again, data were rejected for inadequately wrapped chlorophyll-a samples collected on 8/21. The absence of blank contamination indicates that field equipment and techniques did not introduce a bias to the data.

Table B-8. Equipment Blanks (concentrations in ug/L).

Station	Date	Total Phosphorus	Nitrite-Nitrate		Total Nitrogen		Chlorophyll-a	
Blank	5/30/07	1 U	10 U		25 U		0.05 U	
Blank	6/21/07	-----	10 U		25 U		0.05 U	
Blank	7/18/07	1 U	10 U		-----		0.05 U	
Blank	7/31/07	1 U	-----		-----		0.05 U	
Blank	8/21/07	1 U	10 U		25 U		0.05 REJ	
Blank	8/29/07	1 UJ	10 U	10 U	25 U	25 U	0.05 U	
Blank	9/18/07	1 U	10 U		25 U		0.05 U	

REJ: Data unusable for any purpose. Chlorophyll-a samples were loosely wrapped on 8/21/07, allowing potential exposure to light which can degrade chlorophyll.

Completeness and Representativeness

A complete set of data was collected, analyzed, and deemed usable to meet the report objectives. These data are representative of the water quality in Lake Chelan during the study period in 2007.

Comparability

As noted in the QA Project Plan (Sargeant, 2007), changes in laboratory techniques and method biases need to be taken into consideration when comparing 2007 data to previous years. Of particular concern are changing detection limits for total phosphorus and chlorophyll-a.

Appendix C. 2007 Volume-Weighted Mean Calculation

Volume-Weighted Mean Epilimnetic Concentration for Total Phosphorus for Wapato Basin of Lake Chelan in 2007

Volume-weighted mean is:

W_h = volume of stratum h / total volume of all n strata

= mean value of stratum h across all sample events

Station	Depth (m)	Volume (million m^3)	W_h	X_h (ug/L)	W_h*X_h (ug/L)
1	0.3	9.5	1.21%	1.27	0.0153
2	0.3	48.8	6.20%	1.44	0.0895
2	10	94.2	11.97%	1.77	0.2121
2	20	74.9	9.53%	4.21	0.4015
3	0.3	37.5	4.77%	1.21	0.0579
3	10	75.0	9.53%	2.07	0.1975
3	20	112.5	14.30%	1.59	0.2268
4	0.3	55.7	7.08%	1.39	0.0981
4	10	111.4	14.16%	2.71	0.3844
4	20	167.1	21.24%	1.67	0.3551

Volume-weighted mean: 2.04 ug/L

Volume-Weighted Standard error is:

Station	Depth (m)	W_h^2	S_h^2	n_h	$W_h^2*s_h^2/n_h$
1	0.3	0.000145	0.072	7	1.48E-06
2	0.3	0.003846	0.19	7	1.04E-04
2	10	0.014331	0.68	7	1.40E-03
2	20	0.009076	48.84	7	6.33E-02
3	0.3	0.002272	0.10	7	3.29E-05
3	10	0.009089	1.42	7	1.84E-03
3	20	0.020451	0.29	7	8.61E-04
4	0.3	0.005016	0.24	7	1.73E-04
4	10	0.020063	12.46	7	3.57E-02
4	20	0.045142	0.89	7	5.73E-03

S_n^2 = 0.1092

Volume-weighted standard error: S_n = 0.3304

<u>95% upper confidence level for the mean:</u>

α = 0.05

N-n = degrees of freedom =

(total # samples measured over all strata – number of strata) = 60

one-sided t-stat for (0.05, 60) = 1.671

UCL_{95} = Mean + t(α, v)*(standard error) = 2.04 + 1.671*0.3304

95% upper confidence level: UCL_{95} = 2.59 ug/L

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Appendix D. Data Summary

Table D-1. 2007 Field Data. (Additional field data are available online through Ecology's Environmental Information Management site: www.ecy.wa.gov/eim/.)

Station	Depth (m)	Date	Temp (°C)	Dissolved Oxygen (mg/L)			pH	Specific Conductivity (µS/cm)		Visibility (m)
				meter	Winkler			meter	lab	
1	0.3	5/30/07	16.4	9.8	10.3	10.5	7.8	51	53	
1	0.3	6/21/07	17.9	10.5	10	10	7.7	50		
1	0.3	7/18/07	21.2	9.0	8.9		7.6	51		
1	0.3	7/31/07	22.5	8.6	8.67		7.7	51		
1	0.3	8/21/07	20.5	9.1	9.07		7.6	51		
1	0.3	8/29/07	21.2	9.3	9.3		7.7	50		
1	0.3	9/18/07	18.9	9.4	9.2		7.9	50		
2	0.3	5/30/07	16.7	9.8	10.3		7.8	51		9.3 J
2	10	5/30/07	11.1	10.9			8.0	49		
2	20	5/30/07	9.2	11.6			8.4	49		
2	0.3	6/21/07	17.5	10.5	10.1		7.6	50		13.1
2	10	6/21/07	12.8	11.7			7.8	49		
2	20	6/21/07	10.8	12.1			7.8	48		
2	0.3	7/18/07	21.0	9.1			7.6	51		13.2
2	10	7/18/07	18.2	10.2			8.0	50		
2	20	7/18/07	13.7	11.5			8.4	49		
2	0.3	7/31/07	22.2	8.8			7.7	51		13.8
2	10	7/31/07	19.4	9.6			7.9	49		
2	20	7/31/07	16.1	10.8			8.2	49		
2	0.3	8/21/07	20.5	9.1			7.8	50		14.9
2	10	8/21/07	18.1	9.9			8.0	49		
2	20	8/21/07	15.9	10.4			7.8	48		
2	0.3	8/29/07	21.2	9.4			7.8	50		13.5
2	10	8/29/07	18.9	9.9			7.9	49		
2	20	8/29/07	16.6	10.7			7.8	48	50	
2	0.3	9/18/07	19.0	9.7			8.0	51		14.5
2	10	9/18/07	18.9	9.6	9.4		8.1	50		
2	20	9/18/07	16.0	10.0			7.7	48		
3	0.3	5/30/07	15.5	10.0	10.3		7.7	51		9.5 J
3	10	5/30/07	11.2	10.8			7.8	50		
3	20	5/30/07	9.2	10.9			7.7	49		
3	0.3	6/21/07	16.9	10.6	10.2		7.5	50		
3	10	6/21/07	12.7	11.7			7.7	49		
3	20	6/21/07	10.5	11.9	11.5		7.5	48		
3	0.3	7/18/07	20.8	9.1	9		7.5	51		12.4
3	10	7/18/07	17.5	10.1			8.0	49		
3	20	7/18/07	13.8	11.3			8.3	49		
3	0.3	7/31/07	21.1	9.0	9.38		7.7	51		14.0
3	10	7/31/07	18.5	9.7			7.8	49		
3	20	7/31/07	16.9	10.2			8.0	49	51	
3	0.3	8/21/07	20.0	9.2			7.9	50		14.6
3	10	8/21/07	18.4	9.7	9.69		8.0	49		
3	20	8/21/07	16.1	10.2			7.9	48		
3	0.3	8/29/07	21.0	9.4			7.7	50		15.8
3	10	8/29/07	18.6	9.8			7.8	49		
3	20	8/29/07	16.1	10.5	10.3		7.7	48		
3	0.3	9/18/07	18.6	9.7			8.1	50		15.3
3	10	9/18/07	18.6	9.7	9.5		8.2	50		
3	20	9/18/07	16.4	10.2			8.0	48		

Table D-1 continued.

Station	Depth (m)	Date	Temp (°C)	Dissolved Oxygen (mg/L)			pH	Sp. Cond (µS/cm)		Visibility (m)
				meter	Winkler			meter	lab	
4	0.3	5/30/07	15.6	10.1	10.5		7.5	48		11 J
4	10	5/30/07	10.9	10.8			7.7	47		
4	20	5/30/07	9.6	11.0			7.6	46		
4	0.3	6/21/07	16.3	10.6	10.3		7.7	50		11.8
4	10	6/21/07	13.1	11.3			7.9	49		
4	20	6/21/07	10.9	11.4			7.5	48		
4	0.3	7/18/07	20.5	9.2			7.6	51	52	13.0
4	10	7/18/07	17.6	10.0			7.9	49		
4	20	7/18/07	14.5	10.9	11.3		8.2	49		
4	0.3	7/31/07	20.6	9.0			7.4	50		15.9
4	10	7/31/07	18.4	9.5			7.8	49		
4	20	7/31/07	16.5	10.4	10.4		8.0	49		
4	0.3	8/21/07	19.7	9.1	9.2		7.2	50		15.4
4	10	8/21/07	18.3	9.4			7.9	51	51	
4	20	8/21/07	16.6	9.7			7.8	48		
4	0.3	8/29/07	20.8	9.4			7.8	50		15.9
4	10	8/29/07	18.9	9.6	9.4		7.7	49		
4	20	8/29/07	16.7	9.9			7.6	48		
4	0.3	9/18/07	18.0	9.7	9.4		8.0	50		14.0
4	10	9/18/07	18.0	9.7			8.1	50	51	
4	20	9/18/07	16.5	10.2			8.0	48		

J: Secchi disk measurements on 5/30 were made without the viewing tube; qualified as estimates.

Table D-2. 2007 Laboratory Data.
(Paired data represent field replicates.)

Station	Depth (m)	Date	Total Phosphorus (ug/L)		Chlorophyll-a (ug/L)		Nitrite-Nitrate (ug/L)		Total Persulfate Nitrogen (ug/L)	
1	0.3	5/30/07	1.0	1.3	0.43	0.073	46	46	83	81
1	0.3	6/21/07	1.2	1.1	0.61	0.6	43	43	77	79
1	0.3	7/18/07	1.5		0.16		35		150	
1	0.3	7/31/07	1.7		0.29		30		72	
1	0.3	8/21/07	1.0 UJ		0.05 REJ		16		81	
1	0.3	8/29/07	1.0 U		0.4		10 U		67	
1	0.3	9/18/07	1.4		0.25		10 U		64	
2	0.3	5/30/07	1.1		0.27		48		83	
2	0.3	6/21/07	1.8		0.63		44		76	
2	0.3	7/18/07	2.1		0.17		35		66	
2	0.3	7/31/07	1.7		0.29		31		82	
2	0.3	8/21/07	1.0 UJ		0.05 REJ		17		68	
2	0.3	8/29/07	1.0 U		0.45		13		51	
2	0.3	9/18/07	1.4		0.41		10 U		59	
2	10	5/30/07	3.2		0.69		51		89	
2	10	6/21/07	1.2		1.3		44		83	
2	10	7/18/07	1.7		0.087		31		61	
2	10	7/31/07	1.8		0.49		28		73	
2	10	8/21/07	1.0 UJ	1.0 UJ	0.05 REJ	0.05 REJ	20	20	63	55
2	10	8/29/07	1.0 U		1		14		71	
2	10	9/18/07	2.5		0.63		10 U		110	
2	20	5/30/07	1.0 U		1		48		83	
2	20	6/21/07	20.0		2.6		41		83	
2	20	7/18/07	1.9		1.2		29		70	
2	20	7/31/07	2.6		1		22		120	
2	20	8/21/07	1.0 J		0.05 REJ		23		61	
2	20	8/29/07	1.0 U		1.2		20		100	
2	20	9/18/07	2.0		0.77		20		130	
3	0.3	5/30/07	1.0 U		0.14		50		85	
3	0.3	6/21/07	1.2		0.67		44		77	
3	0.3	7/18/07	1.8		0.28		37		95	
3	0.3	7/31/07	1.5		0.24		29		70	
3	0.3	8/21/07	1.0 UJ		0.05 REJ		18		57	
3	0.3	8/29/07	1.0 U		0.45		13		48	
3	0.3	9/18/07	1.0 U		0.41		10 U		61	
3	10	5/30/07	1.3		0.43		54		87	
3	10	6/21/07	4.3		1.6		52		86	
3	10	7/18/07	2.3		0.47		35		110	
3	10	7/31/07	2.8		0.64		28		71	
3	10	8/21/07	1.0 UJ		0.13 REJ		19		73	
3	10	8/29/07	1.0 U		0.86		13		53	
3	10	9/18/07	1.8		0.64		10 U		66	

Table D-2 continued.

Station	Depth (m)	Date	Total Phosphorus (ug/L)		Chlorophyll-a (ug/L)		Nitrite-Nitrate (ug/L)		Total Persulfate Nitrogen (ug/L)	
3	20	5/30/07	1.2		0.77		64		90	
3	20	6/21/07	2.3		1.6		57		84	
3	20	7/18/07	2.2		0.72		35		150	
3	20	7/31/07	1.9	1.7	0.99	0.88	30	30	91	79
3	20	8/21/07	1.0 UJ		0.05 REJ		25		61	
3	20	8/29/07	1.0 U		1.2		25		77	
3	20	9/18/07	1.8	1.4	1.5	1.1	18	18	50	51
4	0.3	5/30/07	1.0 U		0.17		50		86	
4	0.3	6/21/07	2.0		0.57		47		82	
4	0.3	7/18/07	1.7		0.36		36		110	
4	0.3	7/31/07	2.0		0.24		32		120	
4	0.3	8/21/07	1.0 UJ		0.05 REJ		18		89	
4	0.3	8/29/07	1.0 U	1.0 U	0.37	0.47	15	13	62	53
4	0.3	9/18/07	1.0 U		0.51		10 U		63	
4	10	5/30/07	1.0 U		0.7		60		91	
4	10	6/21/07	1.0 U		1.1		55		88	
4	10	7/18/07	2.2	3.2	0.86 J	0.45	35	45	74	170
4	10	7/31/07	1.2		0.58		28		70	
4	10	8/21/07	1.0 UJ		0.05 REJ		19		65	
4	10	8/29/07	10.6		0.78		13		69	
4	10	9/18/07	1.5		0.41		10 U		74	
4	20	5/30/07	1.0 U		0.75		63		98	
4	20	6/21/07	3.6		1.2		67		100	
4	20	7/18/07	1.4		0.82		33		69	
4	20	7/31/07	1.3		1.1		32		140	
4	20	8/21/07	1.2 J		0.05 REJ		27		130	
4	20	8/29/07	1.0 U		0.98		20		66	
4	20	9/18/07	2.2		0.83		17		170	

U: The analyte was not detected at or above the reported result.
UJ: The analyte was not detected at or above the reported estimated result.
J: The analyte was positively identified. The associated numerical result is an estimate.
REJ: The data are unusable for all purposes. Chlorophyll samples collected on 8/21 were inadequately protected against sunlight and appear to be biased low.

Table D-3. 2007 Additional Laboratory Data.

(Paired data represent field replicates.)

Station	Depth (m)	Date	Ortho-Phosphate (ug/L)		Ammonia (ug/L)	
1	0.3	8/29/07	3.0 U		10 U	
2	0.3	8/29/07			10 U	
2	10	8/29/07			10 U	
2	20	8/29/07			10 U	
3	0.3	8/29/07			10 U	
3	10	8/29/07			10 U	
3	20	8/29/07			10 U	
4	0.3	8/29/07	3.3	7.4	10 U	10 U
4	10	8/29/07	4.8		10 U	
4	20	8/29/07	3.0 U		10 U	
4	20	9/18/07				

U: The analyte was not detected at or above the reported result.

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Appendix E. Descriptive Statistics.

Table E-1. Descriptive Statistics for Measured Parameters, 1987-2007.

		Valid N	Mean	Median	Min.	Max.	Range	Std Dev	Std Error
Total Phosphorus (ug/L)	2007	70	1.9	1.3	< 1	20.0	19.0	2.5	0.30
	1999	80	1.8	1.6	.5	4.3	3.8	0.7	0.08
	1996	70	2.6	< 3.0	1.2	4.0	2.8	0.6	0.07
	1995	68	2.2	2.2	0.6	4.1	3.5	0.7	0.09
	1987	69	3.5	3.2	1.5	10.0	8.5	1.8	0.29
Nitrite-nitrate (ug/L)	2007	70	31	29	< 10	67	57	16	1.9
	1999	80	29	23	< 10	66	56	15	1.7
	1996	70	27	23	< 10	62	52	15	1.8
	1995	70	18	12	10	35	25	9	1.1
	1987	67	44	30	9	363	354	59	7.2
Total persulfate nitrogen (ug/L)	2007	70	84	80	48	170	122	25	3.0
	1999	80	81	79	< 50	140	90	25	2.8
	1996	70	53	56	< 10	113	103	23	2.8
	1995	70	103	85	< 50	296	246	58	7.0
	1987	67	105	91	23	317	294	60	7.3
Chlorophyll-a (ug/L)	2007	60	0.69	0.64	0.09	2.60	2.51	0.45	0.06
	1999	80	1.09	0.85	0.10	3.90	3.80	0.69	0.08
	1996	70	0.86	0.75	< 0.50	3.10	2.60	0.43	0.05
	1995	70	1.08	1.10	0.10	2.90	2.80	0.47	0.06
	1987	64	0.66	0.62	0.13	1.66	1.53	0.32	0.04
Phaeopigments-a (ug/L)	2007	---	---	---	---	---	---	---	---
	1999	---	---	---	---	---	---	---	---
	1996	70	0.56	< 0.50	< 0.50	1.60	1.10	0.20	0.02
	1995	70	0.30	0.30	0.10	1.60	1.50	0.24	0.03
	1987	64	0.28	0.27	-0.31	1.20	1.51	0.19	0.02

Table E-1 continued.

		Valid N	Mean	Median	Min	Max	Range	Std Dev	Std Error
Temperature (°C)	2007	70	17.0	17.5	9.2	22.5	13.3	3.4	0.40
	1999	80	15.5	16.2	7.1	22.1	15.0	3.6	0.40
	1996	69	14.8	15.4	7.8	21.8	14.0	3.5	0.42
	1995	69	16.2	16.4	9.2	21.8	12.6	3.0	0.36
	1987	70	15.9	16.5	7.8	21.0	13.2	3.7	0.44
Specific Conductance (umho/cm)	2007	70	50	49	46	53	7	1.2	0.15
	1999	80	56	57	53	59	7	1	0.15
	1996	99	56	59	43	66	23	7	0.7
	1995	70	61	62	53	67	14	3	0.4
	1987	68	59	59	56	62	6	1	0.2
Dissolved Oxygen (mg/L)	2007	70	10.1	10.0	8.7	12.1	3.5	0.8	0.10
	1999	80	11.3	10.9	9.0	14.1	5.2	1.4	0.15
	1996	63	10.4	10.2	8.7	12.2	3.5	0.9	0.12
	1995	59	10.7	10.7	8.4	12.4	4.0	0.9	0.12
	1987	67	10.4	10.5	9.2	11.9	2.7	0.6	0.08
Dissolved Oxygen (%)	2007	70	108	108	99	116	17	3.7	0.44
	1999	80	112	111	99	128	29	7	0.8
	1996	63	106	107	89	116	27	5	0.6
	1995	59	114	113	90	139	49	11	1.4
	1987	67	110	110	96	122	26	5	0.6
pH (std units)	2007	70	7.8	7.8	7.2	8.4	1.2	0.2	0.03
	1999	79	7.4	7.5	6.3	8.1	1.7	0.4	0.04
	1996	99	7.7	7.8	7.0	8.8	1.8	0.3	0.03
	1995	70	7.2	7.2	6.0	8.4	2.4	0.6	0.07
	1987	67	7.8	7.9	7.4	8.2	0.8	0.2	0.02
Transparency (m)	2007	20	13.5	13.9	9.3	15.9	6.6	2.0	0.44
	1999	21	10.8	11.0	6.0	14.8	8.8	3.1	0.68
	1996	21	12.0	11.7	9.1	15.8	6.7	1.9	0.42
	1995	18	13.2	14.2	9.4	16.5	7.1	2.4	0.57
	1987	21	10.2	10.5	7.2	13.5	6.3	1.7	0.37

Appendix F. 2007 Depth Profiles

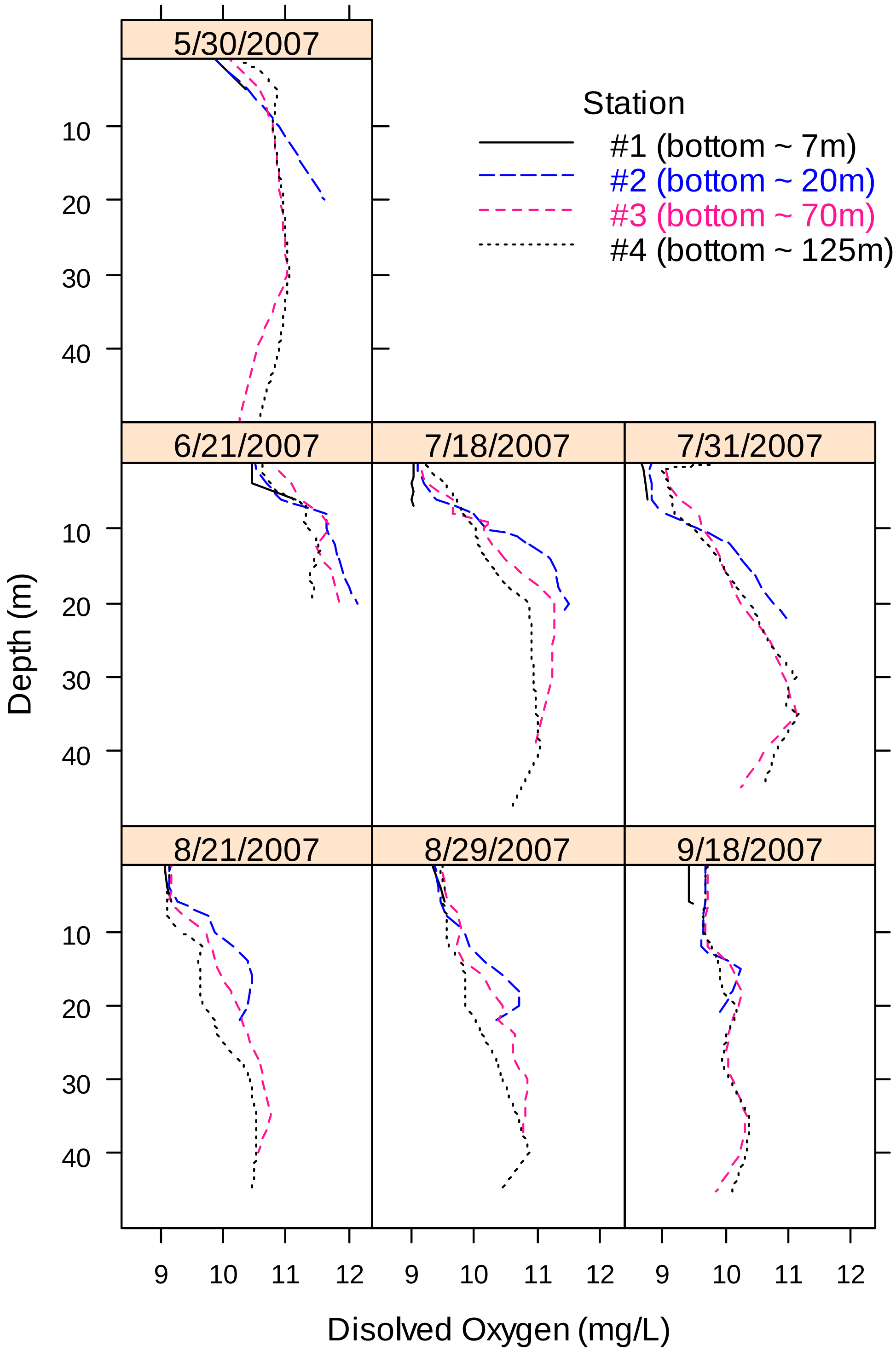

Figure F-1. Dissolved Oxygen versus Depth for 2007 Sampling Dates.

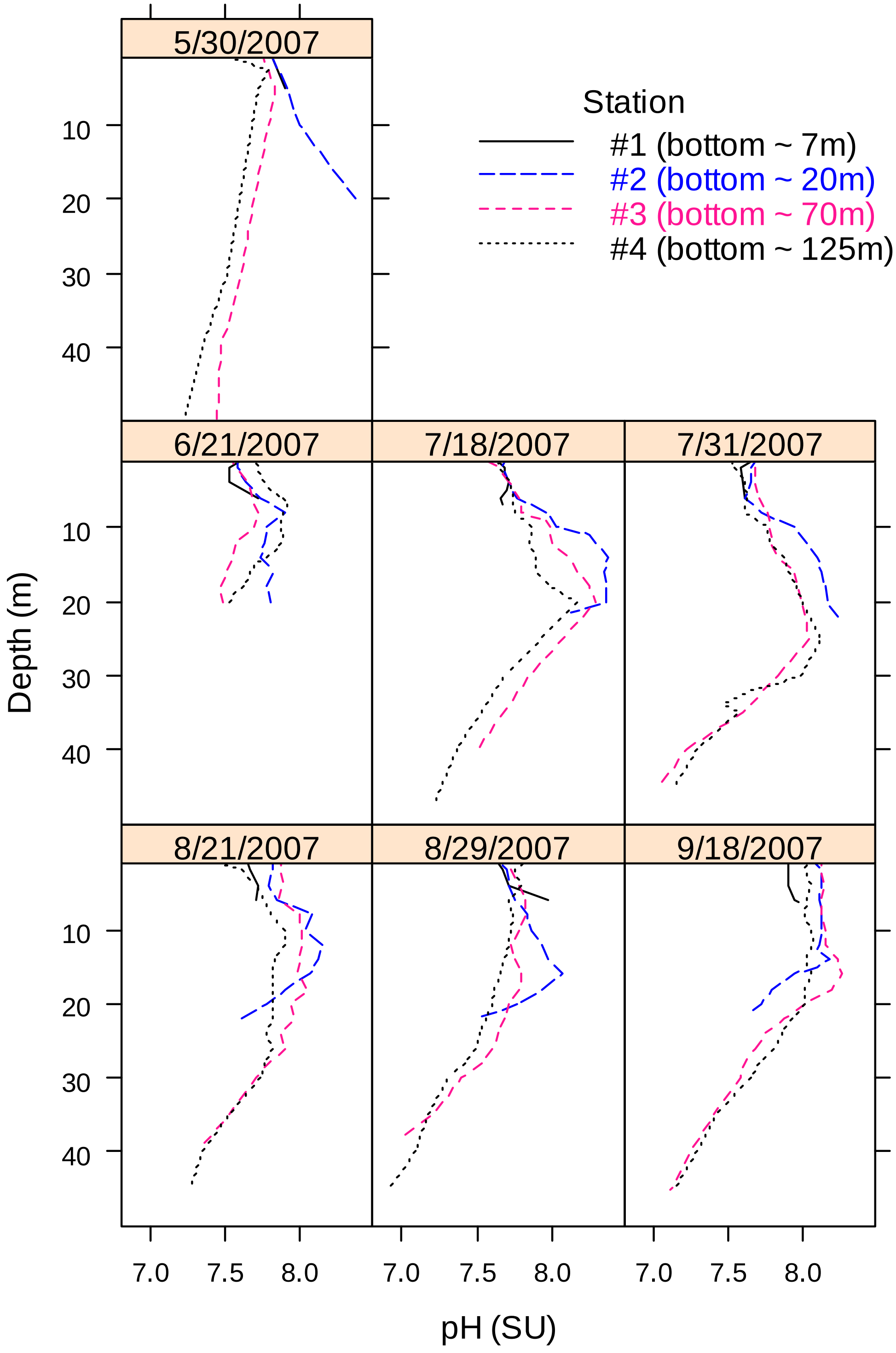

Figure F-2. pH versus Depth for 2007 Sampling Dates.

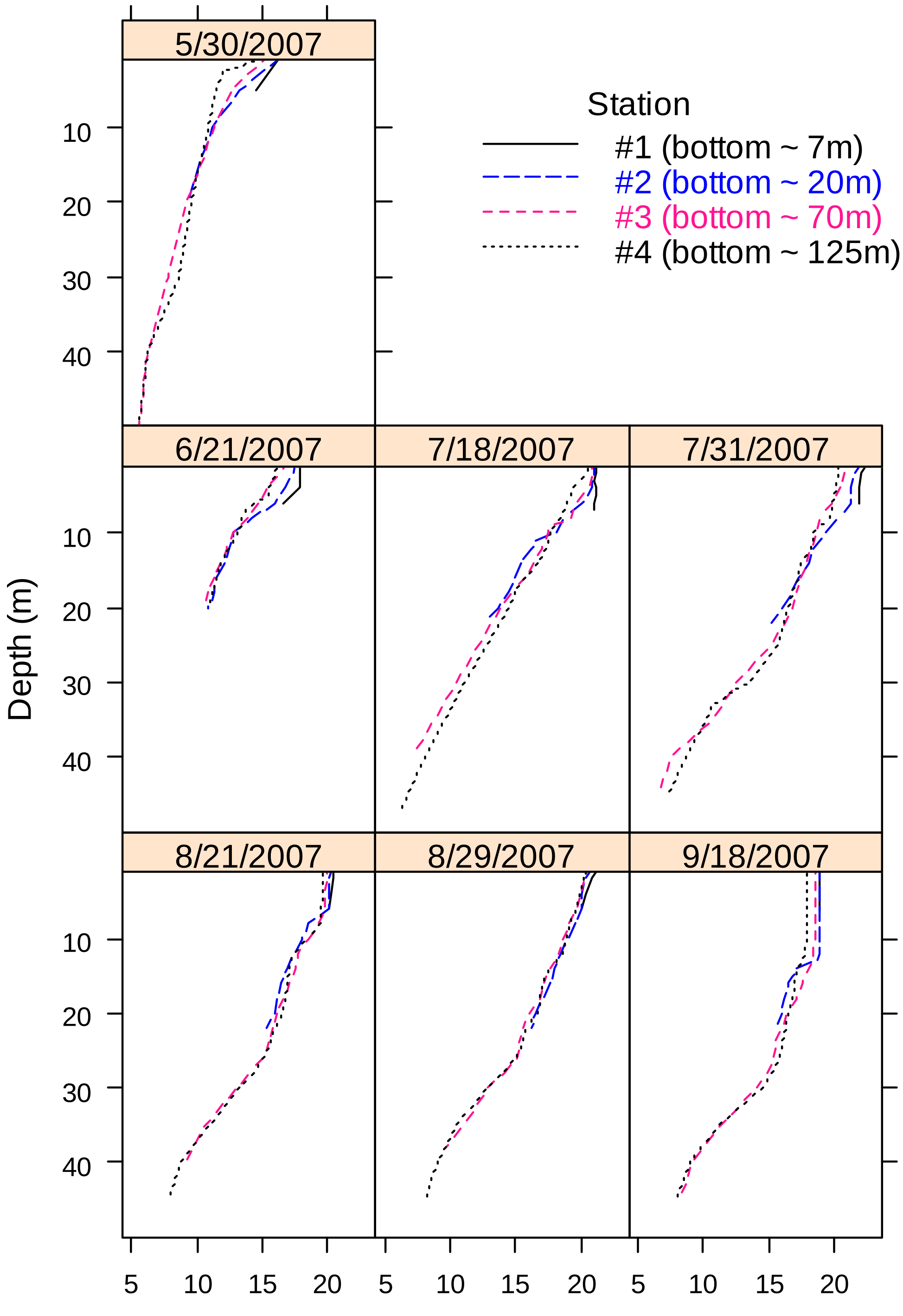

Figure F-3. Temperature versus Depth for 2007 Sampling Dates.

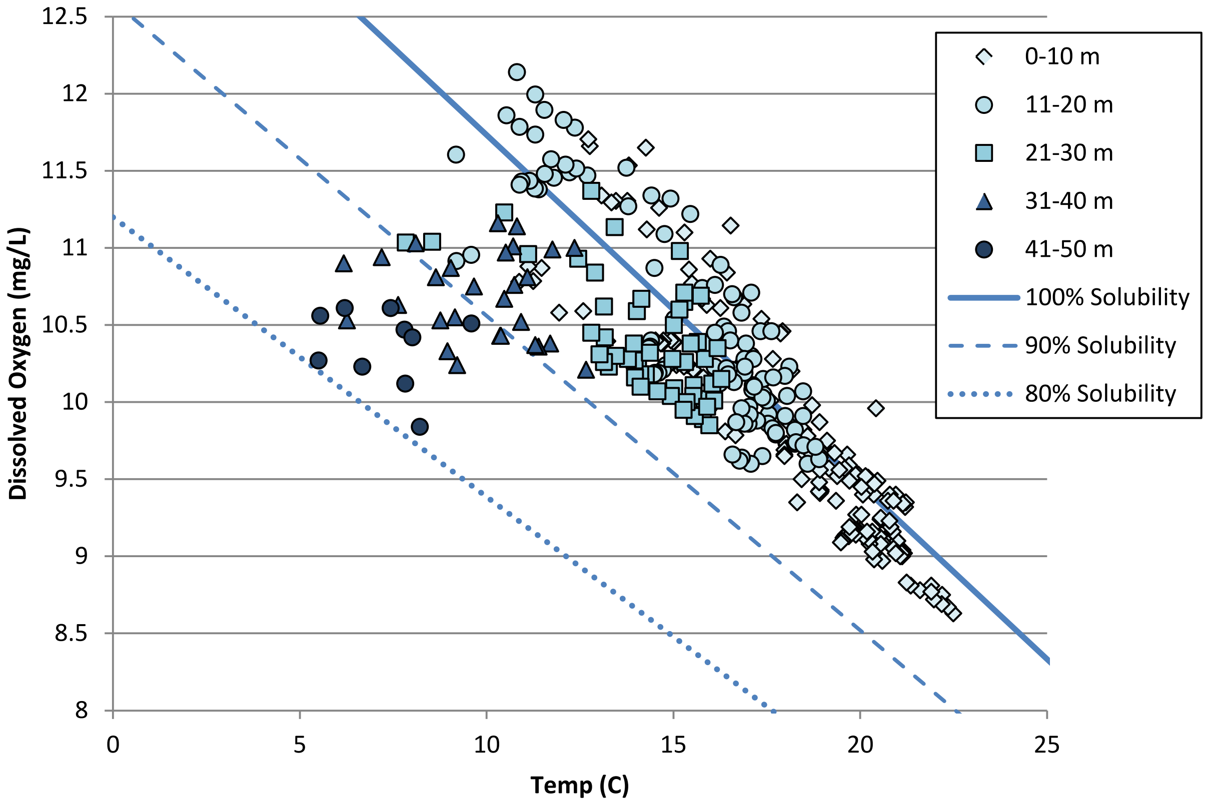

Figure F-4. Dissolved Oxygen vs. Temperature for 2007.