Aquatic Ecosystem Sciences LLC

TECHNICAL MEMORANDUM

Upper Klamath Lake 2009 Data Summary Report

Prepared By:

Jacob Kann, Ph.D.
Aquatic Ecosystem Sciences LLC
295 East Main St., Suite 7
Ashland, OR 97520

Prepared For:

Klamath Tribes Natural Resources Department
PO Box 436
Chiloquin, OR 97624

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INTRODUCTION

The Klamath Tribes have been monitoring water quality parameters in Upper Klamath Lake (UKL) since 1990. These data have been described and summarized to varying degrees in a series of reports and manuscripts (e.g., Kann 1998; Kann and Smith 1999; Kann and Welch 2005; Kann 2007; 2008; 2009). The UKL water quality database was previously updated with 2009 data and appropriate quality assurance analyses (*see Excel spreadsheet: Klamath Tribes UKL Water Quality Data 1990-2009.xls*). This report serves as an annual update to the UKL water quality database, including a summary of 2009 data (basic summary statistics and graphical analysis), and limited comparison of inter- annual trends of UKL data collected for the 20 year period between 1990 and 2009. A recently completed report provides a more in-depth treatment of the entire 1990-2009 database (Jassby and Kann 2010).

METHODS

Methods followed the Klamath Tribes established procedures for field collection and laboratory analysis of water quality parameters (see Klamath Tribes 2003 and Klamath Tribes 2006 for a complete description of these methods). Beginning in 2008 for nutrient parameters and 2009 for Chlorophyll-a, a laboratory switch occurred from Aquatic Research, Inc in Seattle WA to the Sprague River Water Quality Laboratory in Chiloquin OR. During the 2009 sampling season limnological data (Table 1) were collected biweekly from the end of April through October at 10 standardized stations in UKL and Agency Lake.

Table 1. Limnological parameters colleted in Upper Klamath Lake, 2009.

Parameter	Abbreviation/ Unit	Profile [a]	Grab [b]
Temperature	T (°C)	X	
Dissolved Oxygen	D.O. (mg/L)	X	
pH	pH	X	
Specific Conductivity	(µSiemens/cm)	X	
Secchi Transparency	Secchi (m)		
Light (Photosynthetically Active Radiation)	PAR ($uEm^{-2}s^{-1}$)	X	
Total Phosphorus	TP (µg/L)		X
Soluble Reactive phosphorus	SRP (µg/L)		X
Total Nitrogen	TN (µg/L)		X
Ammonia Nitrogen	NH_4-N (µg/L)		X
Nitrate-Nitrite Nitrogen	NO_3+ NO_2-N (µg/L)		X
Chlorophyll *a*	CHL (µg/L)		X
Phytoplankton Species Composition and Biomass[c]	(mm^3/L)		X
Zooplankton Species Composition and Biomass[c]	(mg/L)		X

a Profile = collected with multi-parameter WQ probe at multiple depths in water column
b Grab = integrated water column sample collected with "tube sampler" except for zooplankton which was collected with a Schindler-Patalis Trap
c. Phytoplankton and zooplankton data for 2009 were only recently received from the laboratories and are thus not summarized herein

Site Code	Site Description	Coordinates	
AN	AGENCY NORTH	N 42° 33' 38.0	W 121° 56' 50.8
AS	AGENCY SOUTH	N 42° 31' 24.9	W121° 59' 03.4
CP	COON POINT	N 42° 26' 08.6	W 122° 01' 41.5
ER	EAGLE RIDGE	N 42° 25' 19.5	W 121° 56' 35.8
ML	MID LAKE	N 42° 22' 08.7	W 121° 50' 55.3
MN	MID NORTH	N 42° 26' 28.9	W 121° 59' 55.8
NB	NORTH BUCK IS.	N 42° 18' 30.2	W 121° 51' 22.4
PB	PELCIAN BAY	N42 27.593	W122 04.582
PM	PELICAN MARINA	N 42° 14' 16.892	W 121° 48' 37.341
SB	SHOALWATER BAY	N 42° 24' 26.1	W 121° 57' 47.1
WB	WOCUS BAY	N 42° 19' 35.0	W 121° 55' 11.9

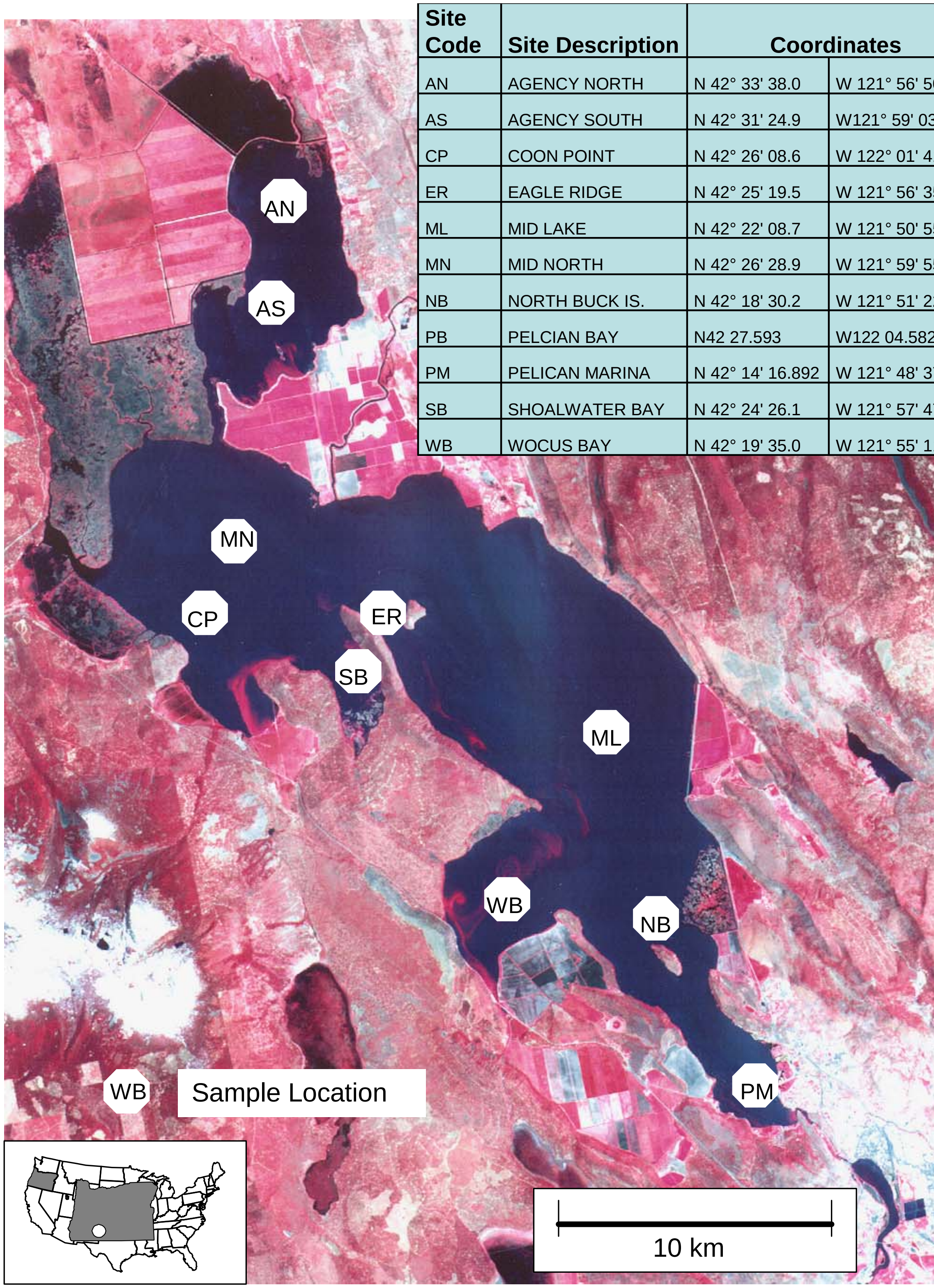

Figure 1. Location of Upper Klamath Lake 2009 sampling stations.

Data reduction consisted of computation of both lake-wide means on a given sample date and of growing season (June-September sample dates) means. Because of bloom timing differences between Upper Klamath and Agency Lake (e.g., see Kann 1998), lake-wide means and analyses are shown separately for Upper Klamath Lake only and Agency Lake only. Chlorophyll and nutrient data tended to be either normally or log-normally distributed both within a date and seasonally. Based on a comparison of both log transformed ($\log_{10}$ or $\log_{10}$ (x+1)) and non-transformed data with the normal distribution using Kolmogorov-Smirnov one-sample tests or the Shapiro-Wilk standard test for normality (*cf.* Systat® 2004), the geometric mean tended to provide the best estimate of lake-wide or seasonal central tendency.

RESULTS/DISCUSSION

Seasonal and Water Column Trends in Profile Water Quality Data (T, D.O., and pH)

Water column and seasonal trends in T, D.O., and pH are important aspects of water quality dynamics and fish habitat in UKL. Depth-time plots of isotherms and isopleths for these parameters allows both seasonal and depth distribution to be evaluated simultaneously. These are plotted below for two representative stations, ER located in the deep trench area, and MN located in an open-water area in the northern part of the lake (Figures 2 and 3). At both stations temperature ranged between 10-12 ^{o}C during late-April and early-May, with little warming occurring during that period. Substantial warming then occurred during the second half of May, and the lake continued to warm through June and July, peaking during the July 27th sample date (Figures 2 and 3). Maximum surface and water column temperature occurred during late-July to early-August, with seasonal cooling beginning in early-August when a temperature drop of 4-5 ^{o}C occurred (from ~24 to <20 ^{o}C).

At both ER and MN water column pH increased into late-June, but then decreased during July, showing a seasonal low in the latter part of July. pH then increased in early-August reaching a seasonal maximum during the late-August to early-September period (Figures 2 and 3). Unlike other years, pH maxima were not in sync with the period of maximum water column temperature.

Similarly, although dissolved oxygen (D.O.) decreased during the period of maximum water column temperature at both stations, ER showed lowest D.O. concentrations (<5 mg/L) throughout the water column during late-August and early-September, coinciding with the period of maximum pH (Figure 2). The reason for the lack of coincidence in pH and D.O. (low pH and low D.O. typically coincide) during that time is unclear and requires further exploration, including the possibility of wind-driven current effects (e.g., Wood et al. 2006 and 2008).

Similar depth-time plots were constructed for these stations for all years of data (1990-2009) and are included here as Figure 4 through Figure 9; however, due to file size considerations, only lower-resolution versions of the figures are included here. Full-resolution versions of these figures are also included in separate electronic files.

2009

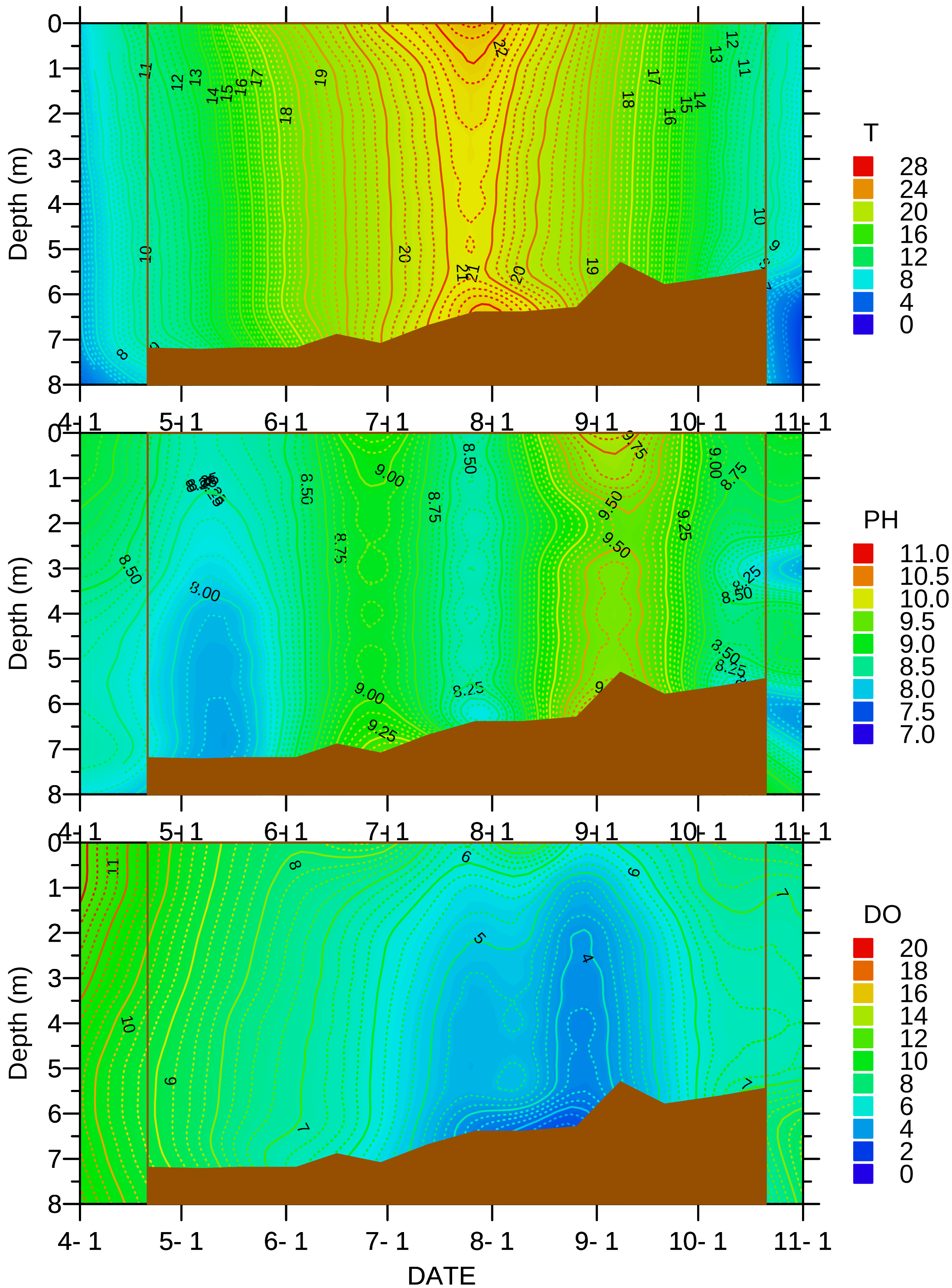

Figure 2. Depth-time distributions of isotherms of T (oC), and isopleths of D.O (mg/L) and pH at UKL station Eagle Ridge (ER), 2009. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).

2009

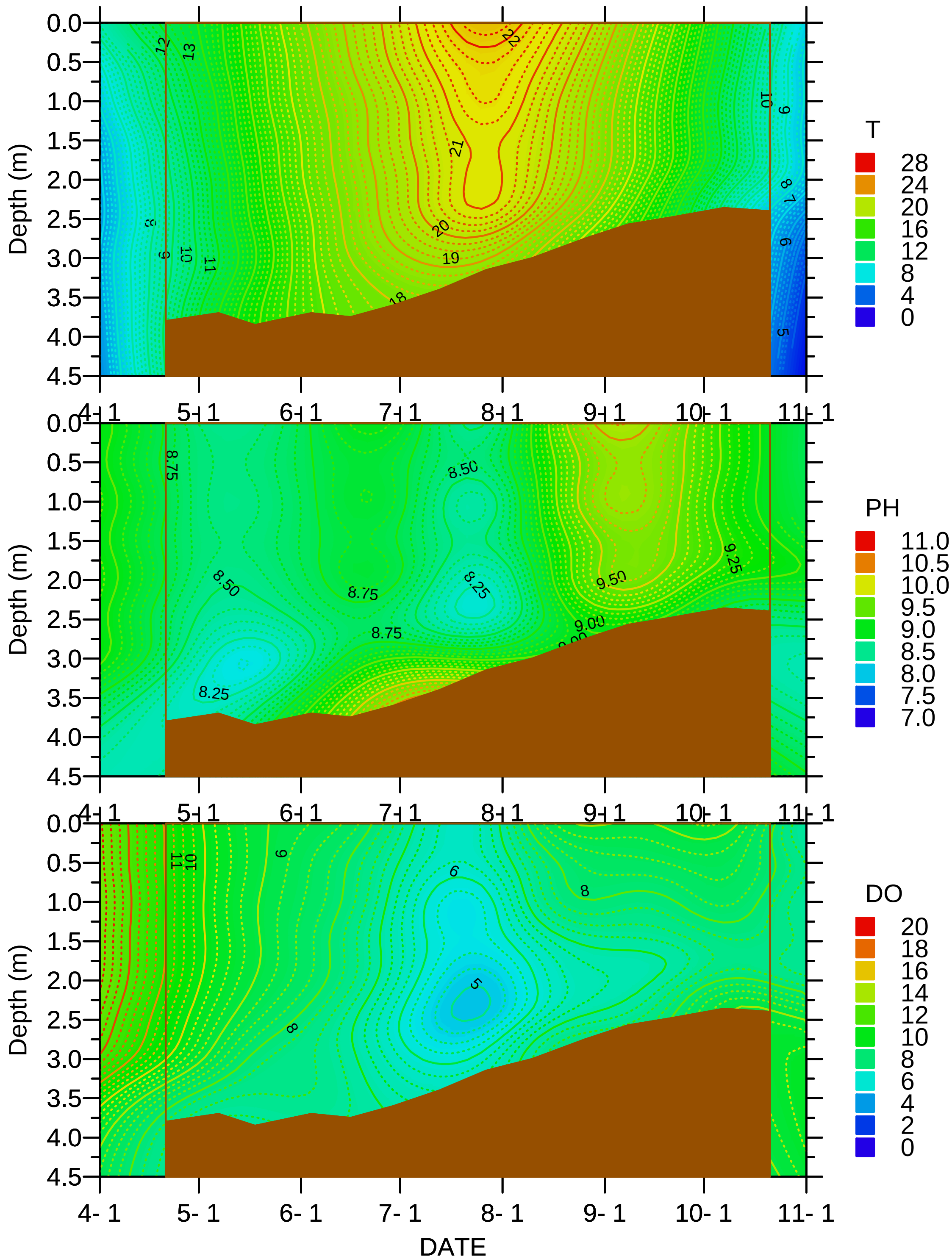

Figure 3. Depth-time distributions of isotherms of T (˚C), and isopleths of D.O (mg/L) and pH at UKL station Mid North (MN), 2009. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).

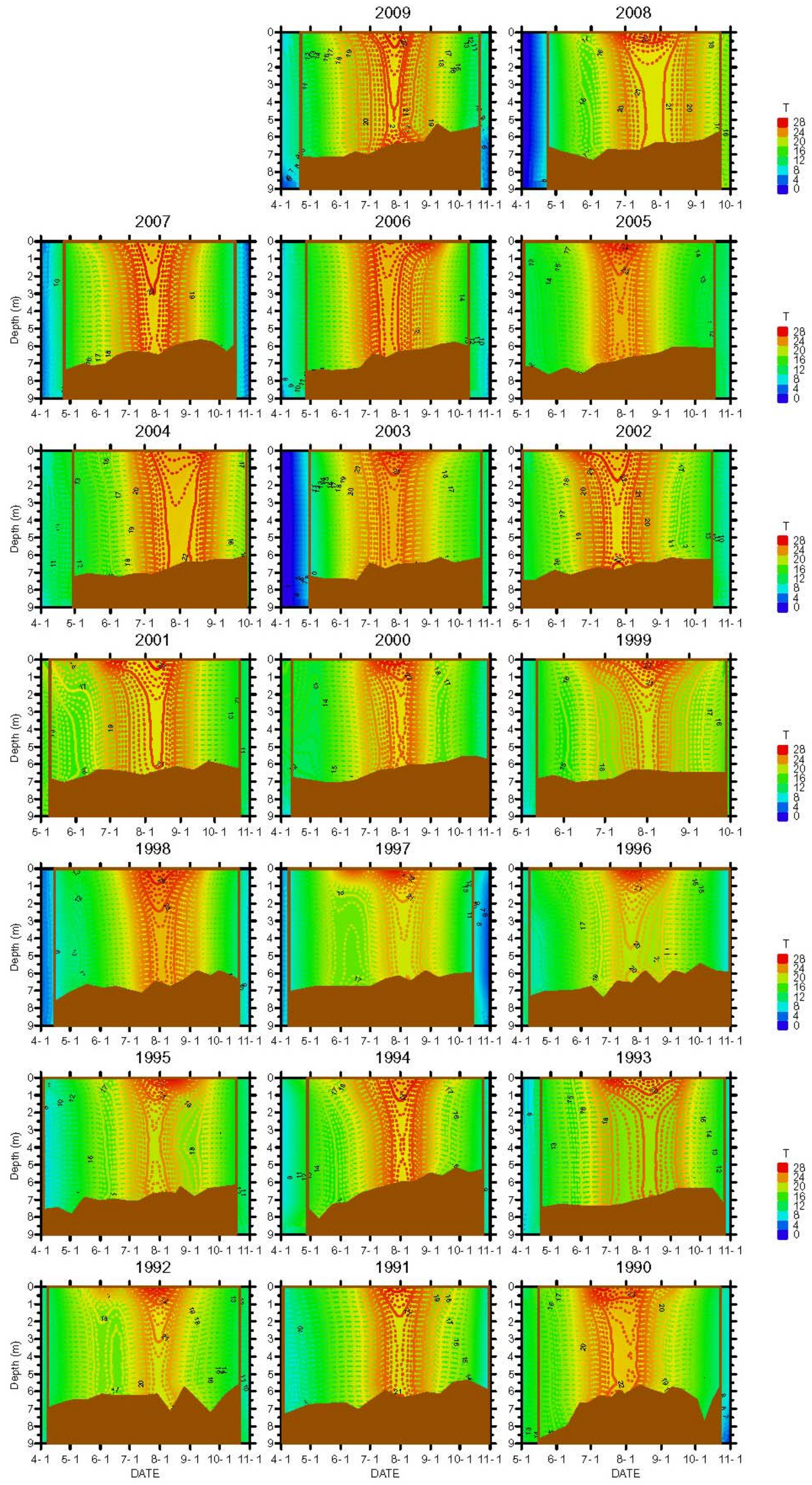

Figure 4. Depth-time distributions of isotherms of temperature (˚C) at UKL station Eagle Ridge (ER), 1990-2009. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).

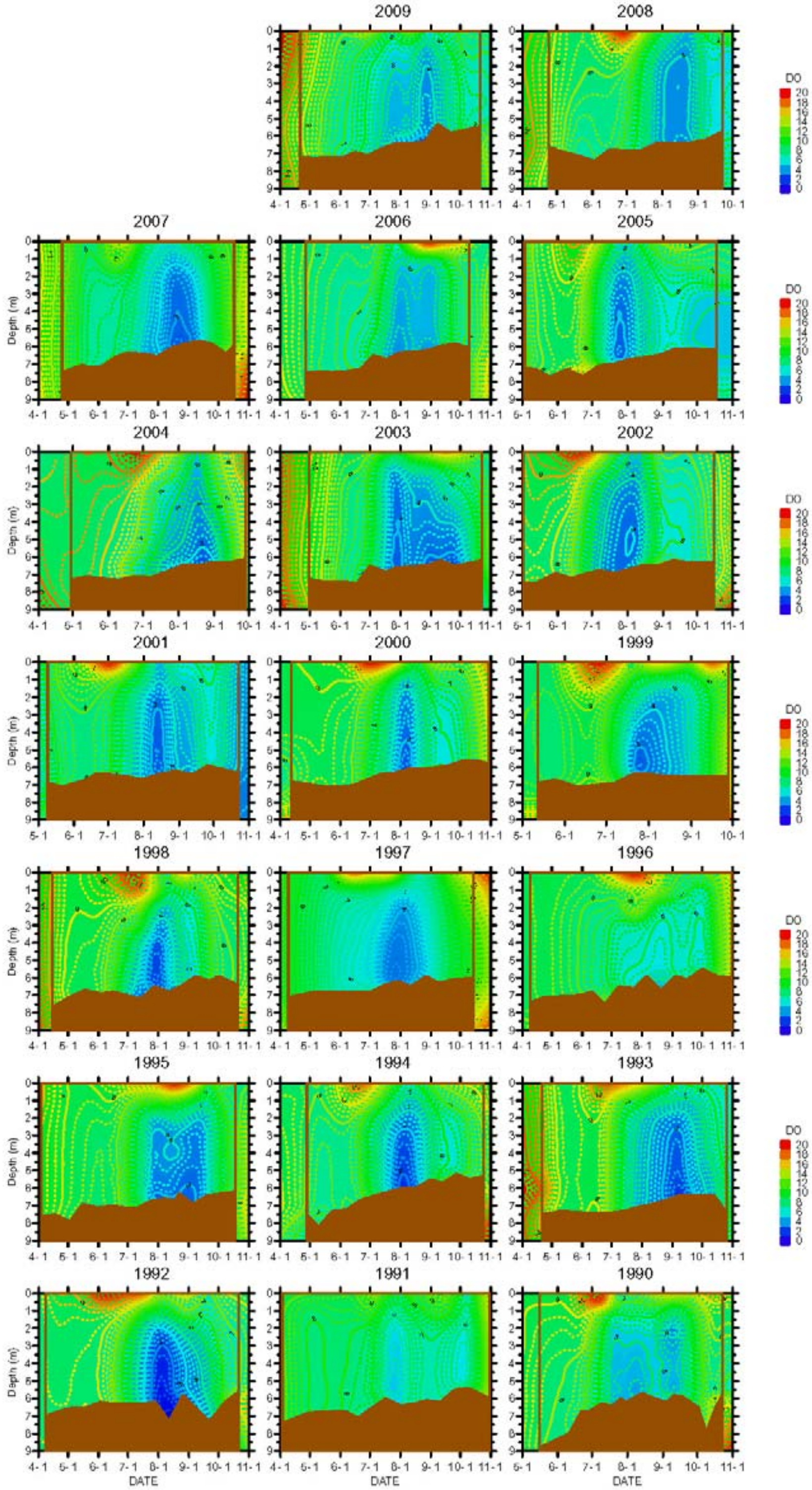

Figure 5. Depth-time distributions of isopleths of dissolved oxygen (mg/L) at UKL station Eagle Ridge (ER), 1990-2009. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).

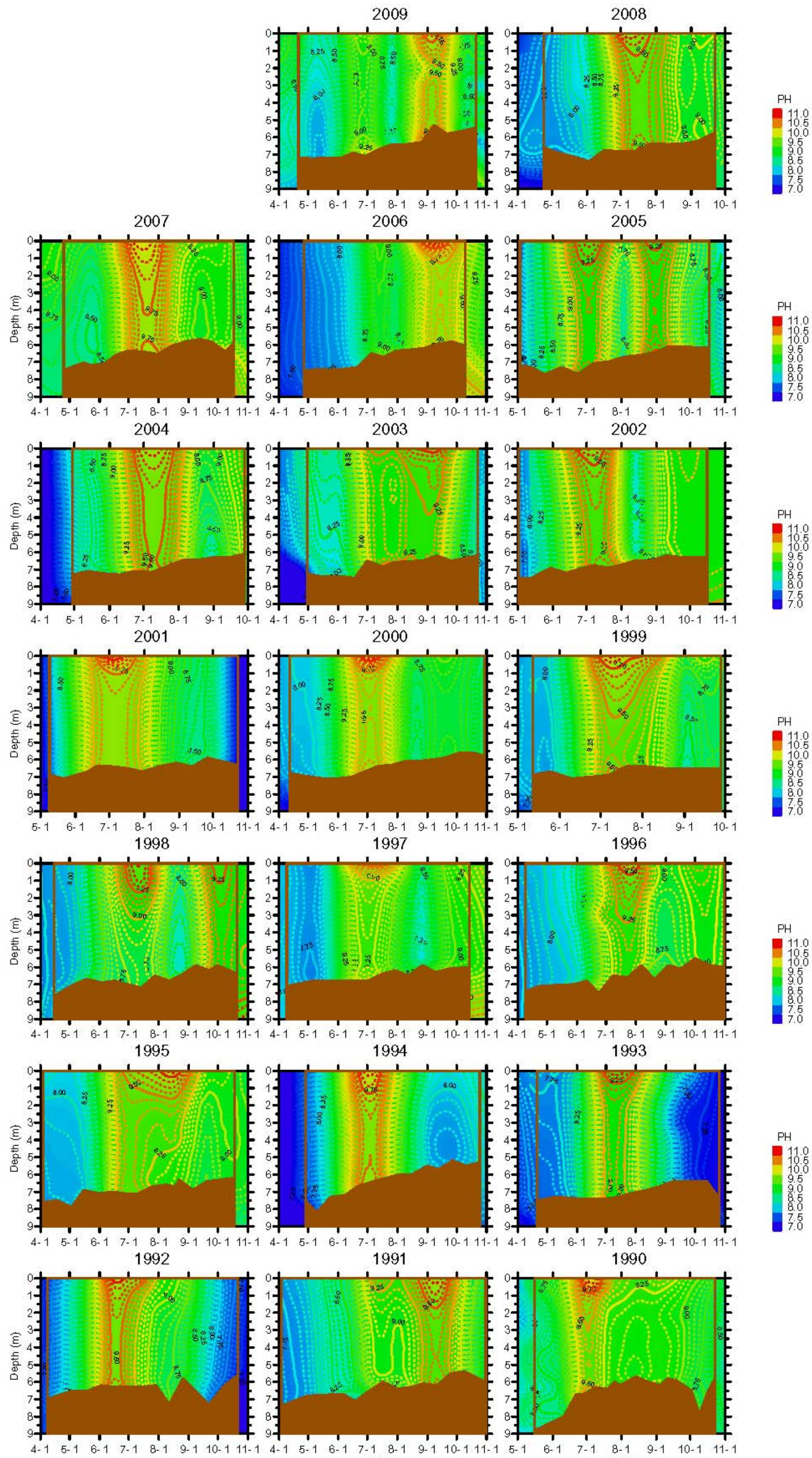

Figure 6. Depth-time distributions of isopleths of pH at UKL station Eagle Ridge (ER), 1990-2009. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).

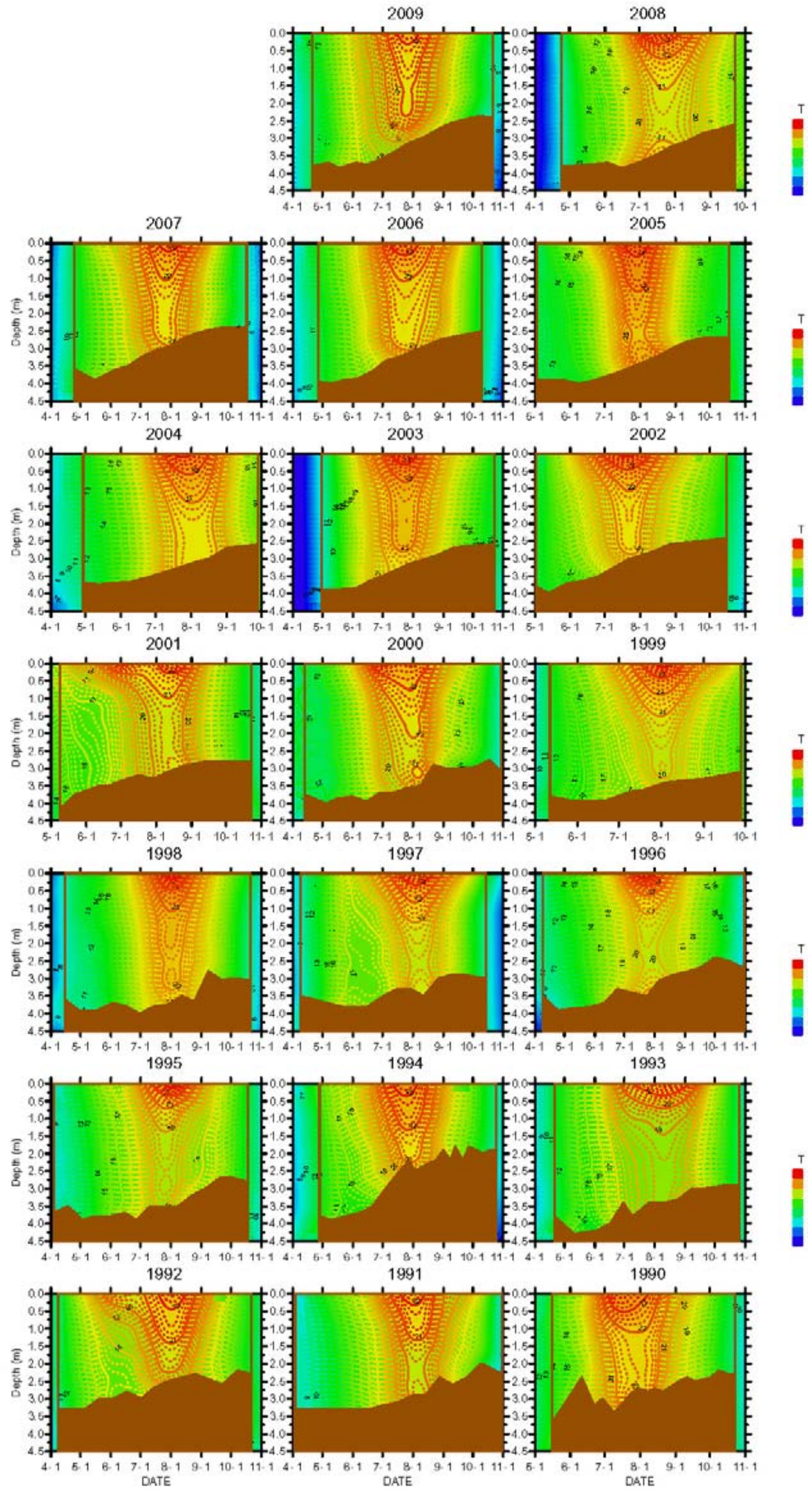

Figure 7. Depth-time distributions of isotherms of temperature (˚C) at UKL station Mid-North (MN), 1990-2009. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling)

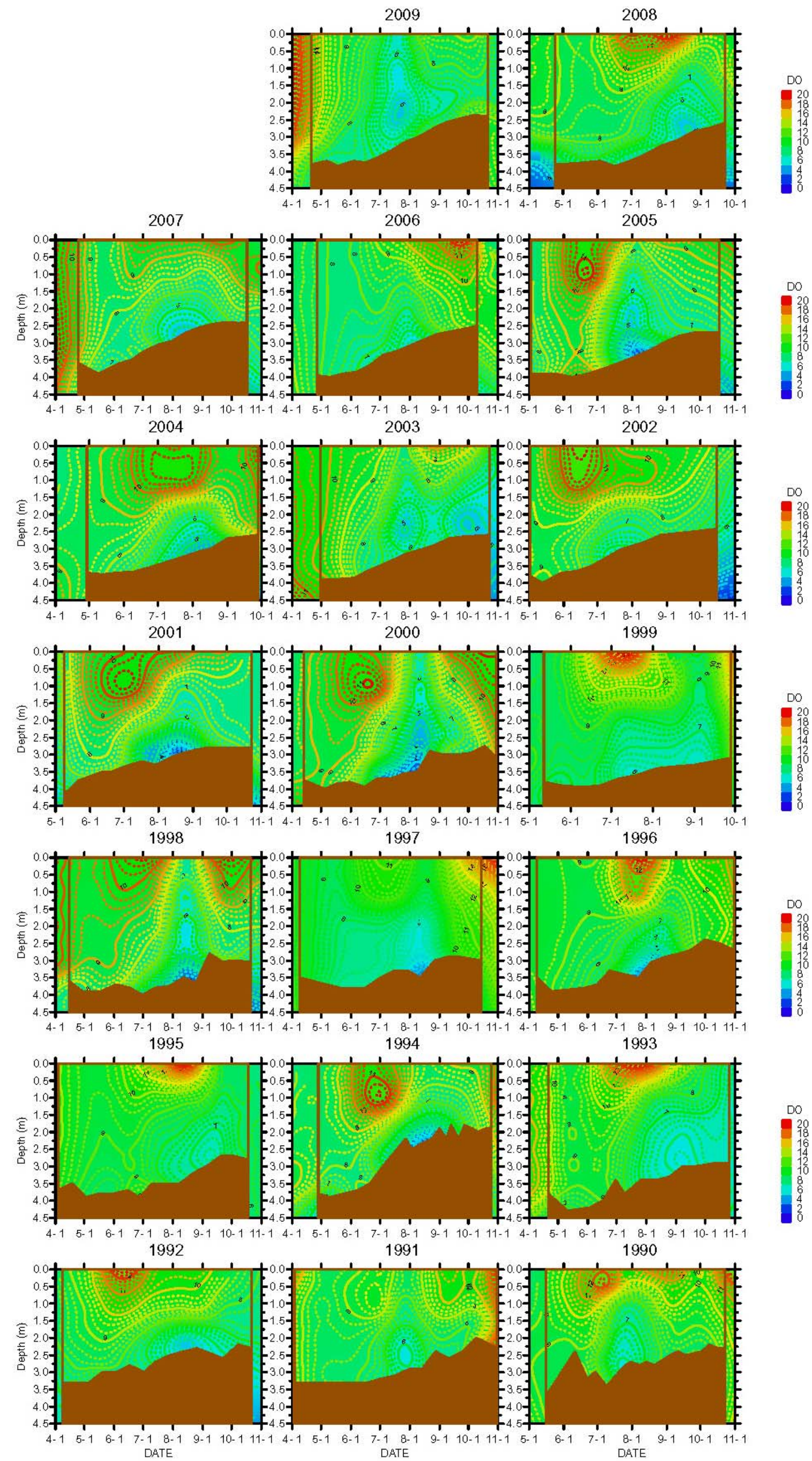

Figure 8. Depth-time distributions of isopleths of dissolved oxygen (mg/L) at UKL station Mid-North (MN), 1990-2009. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).

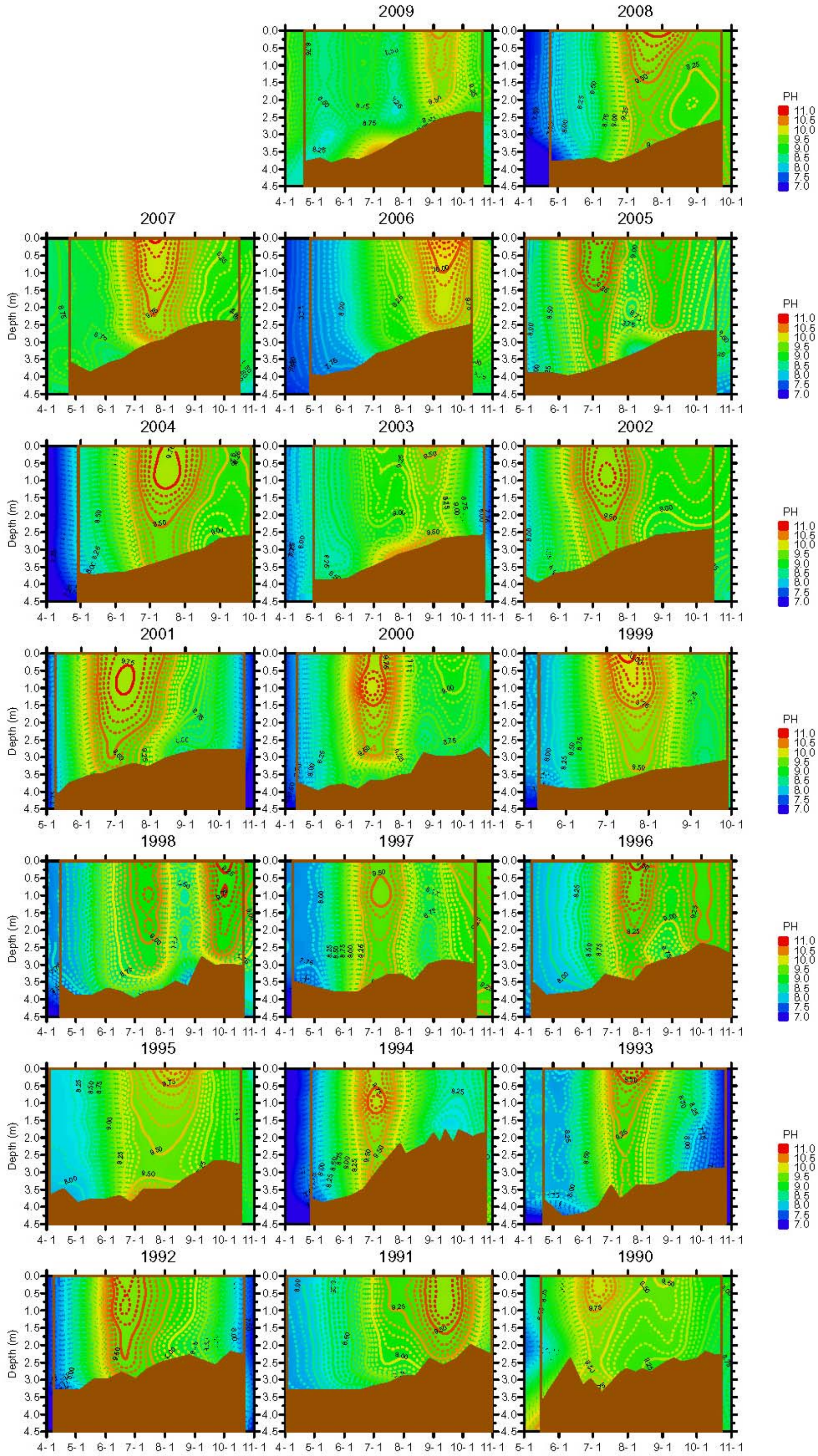

Figure 9. Depth-time distributions of isopleths of pH at UKL station Mid-North (MN), 1990-2009. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).

Although a comprehensive inter-annual analysis will not be performed here, 2009 water column temperatures showed a fairly typical seasonal pattern; however, the extent of stratification appeared to be lower than many of the other years during the period of peak surface temperature (Figures 4 and 7). The lack of coincidence in the timing of the 2009 annual minimum D.O and maximum pH period at ER was not observed in other years of record (Figures 5 and 6). As shown below and as shown in Kann (2008), 2006-2009 differences in pH and dissolved oxygen can be explained partly by both temperature and bloom dynamics.

2009 Station Distributions

The data distribution for each station for the June-September period (chosen here to encompass the major algal growing season in UKL) is shown in Figures 10 and 11. Although the seasonal timing of water quality has been shown to vary among stations, the season-wide distributions as indicated by the interquartile range (25^{th} -75^{th} percentiles or box hinges in the plots below) tend to overlap. Although the timing of sample collection can also effect the distribution of these variables (Jassby and Kann 2010), the below plots reflect water column means which are less sensitive to the effect of sample timing than are surface values.

Nonetheless, certain stations tended to stand out from other stations on a seasonal basis. For example, the temperature distribution (as indicated by the upper or lower quartile) was skewed higher for AS and AN, and skewed lower for WB (Figure 10). The distribution for pH was skewed lower for SB and CP, while ER and CP showed the lowest overall D.O. distribution (Figure 10). Secchi depth (transparency) was also notably higher at both ER and AS, which also tended to show a smaller lower quartile for CHL (Figure 11). These among-station comparisons were not necessarily consistent with 2008 patterns (see Kann 2009).

Embayment stations SB and WB, along with southern station PM were among the highest with respect to the overall CHL distribution (Figure 11). ER also showed a relatively high upper quartile, but as noted above, the lower quartile was also among the lowest along with AS. The AN station stands out with respect to both TP and SRP, with a relatively narrow but elevated inter-quartile range (Figure 11). SRP at AS was also higher than other stations.

Conversely, as in 2008, Agency Lake stations were among the lowest for nitrogen, particularly for NH_4-N (Figure 11; Table 2). SB and WB were among the highest for TN, while WB, ML, ER, SB, MN, and CP were among the highest for ammonia (NH_4-N; Figure 11; Table 2). The AN and AS stations also showed somewhat higher nitrate concentrations than other stations (NO_3-N; Figure 11).

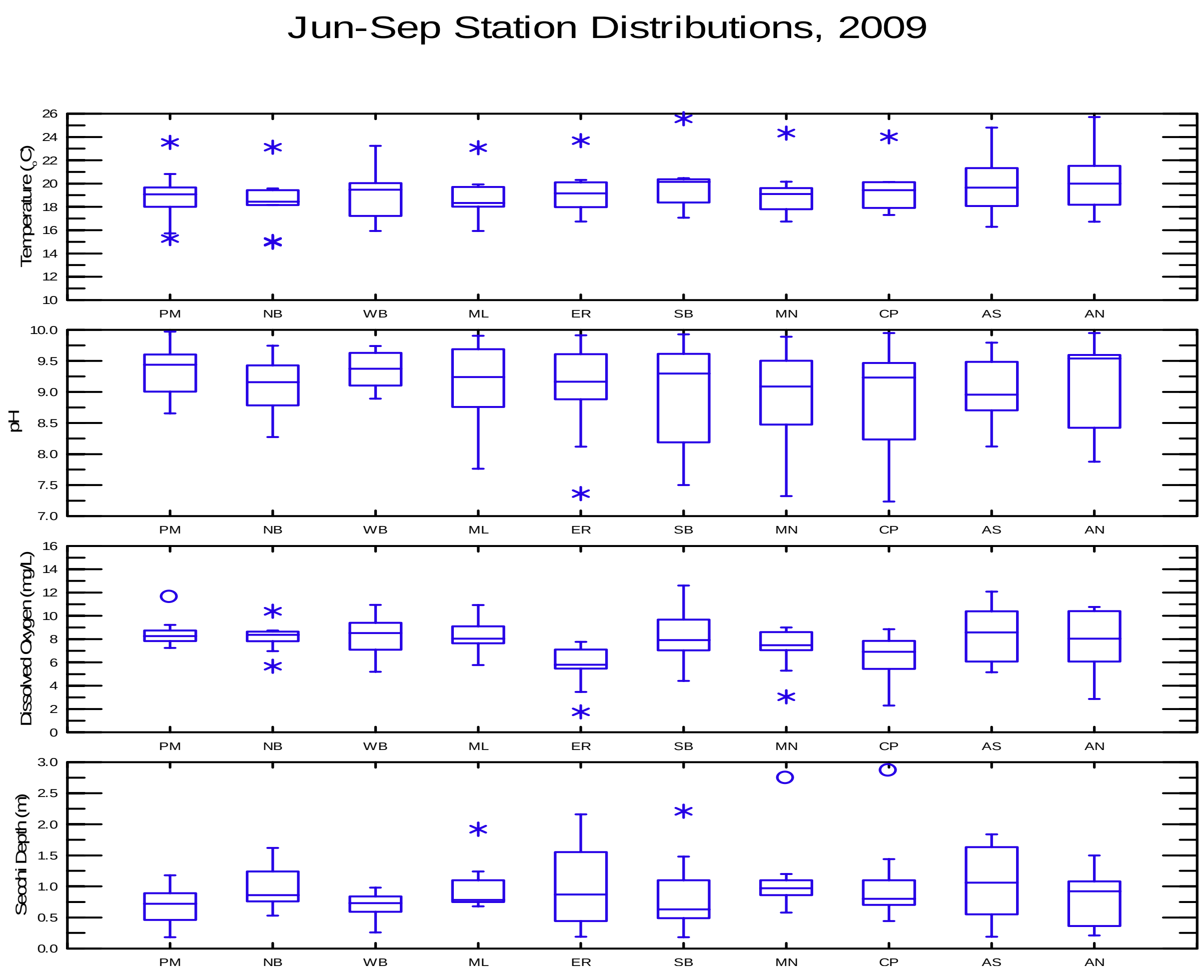

Figure 10. Station distributions of T (˚C), pH, D.O (mg/L), and Secchi depth, June-September, 2009.

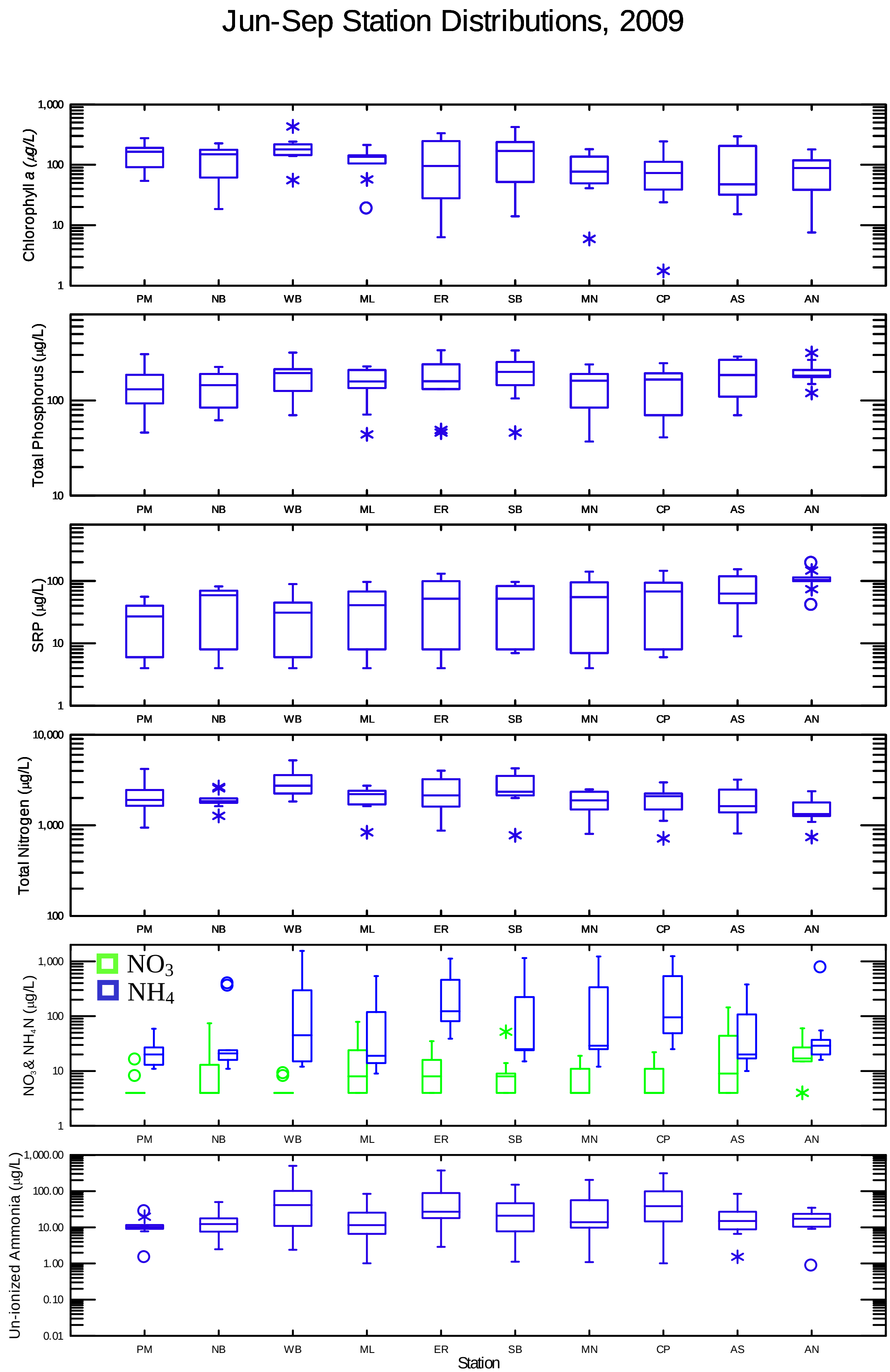

Figure 11. Station distributions of CHL, TP, SRP, TN, NO_3+ NO_2-N, NH_4-N, and un-ionized ammonia, June-September, 2009.

Seasonal differences in algal biomass (CHL) among stations in 2009 show that, similar to 2008, but unlike 2006 and 2007 when AS and AN increased earlier and declined earlier in the season relative to UKL stations (Figure 12); early- season CHL in Agency Lake remained lower and then increased to levels similar to UKL (Figure 12). Although not as early as previous years, AS and AN still declined earlier than UKL stations in 2009. Unlike 2006, 2007, and 2008, CHL distribution at the more southerly stations WB and PM did not tend to show relatively higher CHL in August and September.

As noted in Kann (2008; 2009), water temperature partially explained the early season CHL patterns among the years. For example, low temperatures coincided with a depressed early-June bloom in 2006, and in 2008 much cooler lake-wide water temperature (median value <7 ^{o}C) in late April and early-May coincided with low CHL levels. However, it was clear that factors other than temperature were affecting bloom dynamics in those years (Figure 12).

In 2009, late-April and early-May CHL was higher than the previous three years (generally >10 µg/L), but despite a large mid-May temperature increase, CHL declined slightly until early-June, when a sharp increase occurred (Figure 12). Levels then continued to increase, showing a bimodal peak, with the first in late-June and the second in August. The July CHL decline tended to be of greater magnitude than the previous three years, and although temperature first decreased slightly, and then increased sharply in July, the bloom continued to decline at UKL stations through July (Figure 12). The southern three stations (PM, NB, and WB) did not decline to the same extent as remaining stations in late-July.

Because water temperature in the above plots is measured biweekly, it is also instructive to evaluate daily air temperatures as another indicator of water column warming. Data obtained from the USBR AgriMet station located near Agency Lake indicate some tracking of May air temperature and CHL levels (Figure 13a).

For example, temperature declines in mid-May of 2006 and 2008 that remained near or below 15 ^{o}C through mid-June were associated with suppressed CHL levels in early-June (Figure 12). Whereas in 2007 and 2009, air temperatures warmed between mid- and late-May and were associated with more elevated CHL levels in early June. Previous analyses indicating a threshold temperature of ~15 ^{o}C for *Aphanizomenon* bloom development in Upper Klamath Lake (Kann 1998), continue to be supported.

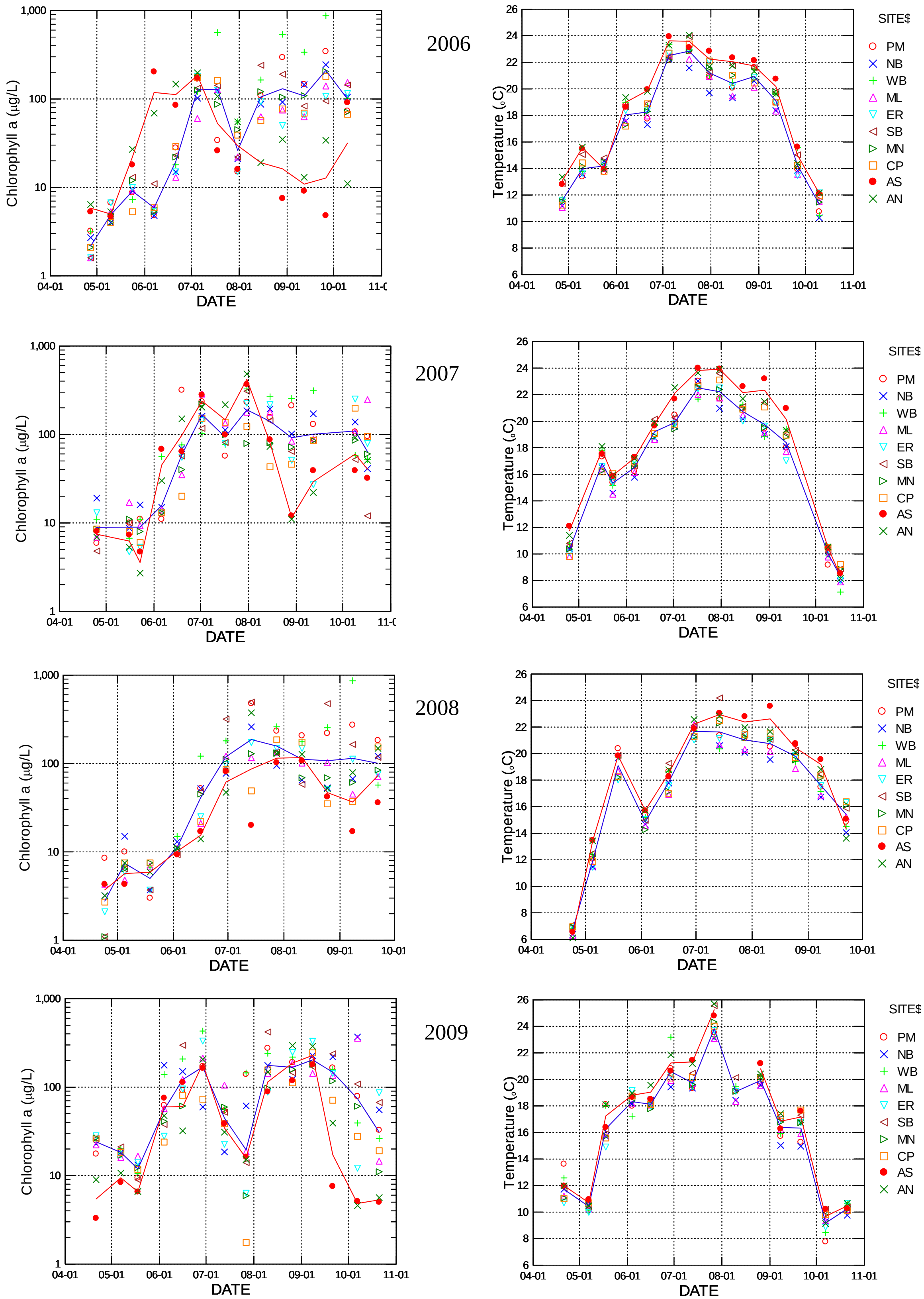

Figure 12. Seasonal CHL and temperature trends for UKL stations, 2006-2008 (blue line shows the median value for UKL-only, red line shows the median value for Agency Lake-only).

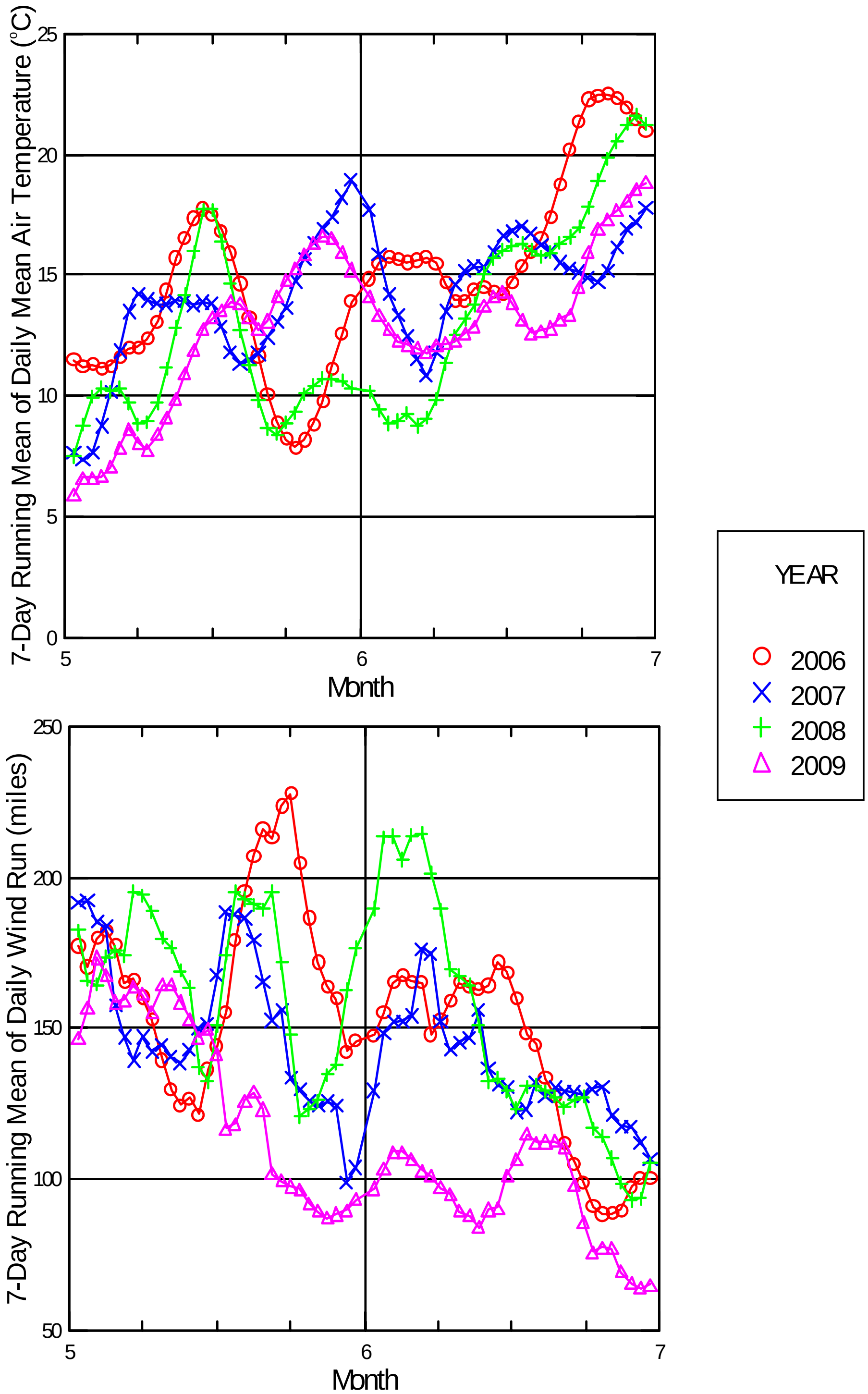

Figure 13. Time series of the 7-day running mean of daily air temperature (a) and 7-day running mean of the daily wind run in miles (b), May-June, 2006-2009. Data are from the Bureau of Reclamation AgriMet station located at Agency Lake (AGKO).

As noted previously (Kann 2009), analysis of wind speed as an indicator of the extent of water column mixing, showed that the periods directly preceding and during the typical period of June bloom development in 2006 and 2008 were characterized by generally higher wind speed relative to 2007 (Figure 13b). Likewise, with the addition of 2009 data a similar pattern was observed with low wind preceding and during development of the early June bloom, which was more similar in terms of algal biomass to 2007 than either 2006 or 2008, which were suppressed. Similar to previous 2006-2008 analysis of air temperature and wind speed data that showed wind and temperature to be related such that warm/calm conditions co-occur and that cool/windy conditions co-occur (Kann 2009), these parameters also tended to co-occur in 2009 (Figure 14). Moreover, confidence ellipses computed for the period encompassing 10 days prior to and subsequent to June 1st show that both 2006 and 2008 (red and green ellipses in Figure 14) tended to be cooler and windier than during the same periods in 2007 and 2009 (blue and pink ellipses). Furthermore, 2009 showed the lowest wind speed of the four years (Figures 13b and 14) and was associated with higher early- and mid-June CHL than the other years (Figure 12). These climate data as well as water temperatures shown above indicate that cooler and well mixed conditions during the usual early season bloom development period (e.g., Kann and Welch 2005) help explain year-to-year bloom development.

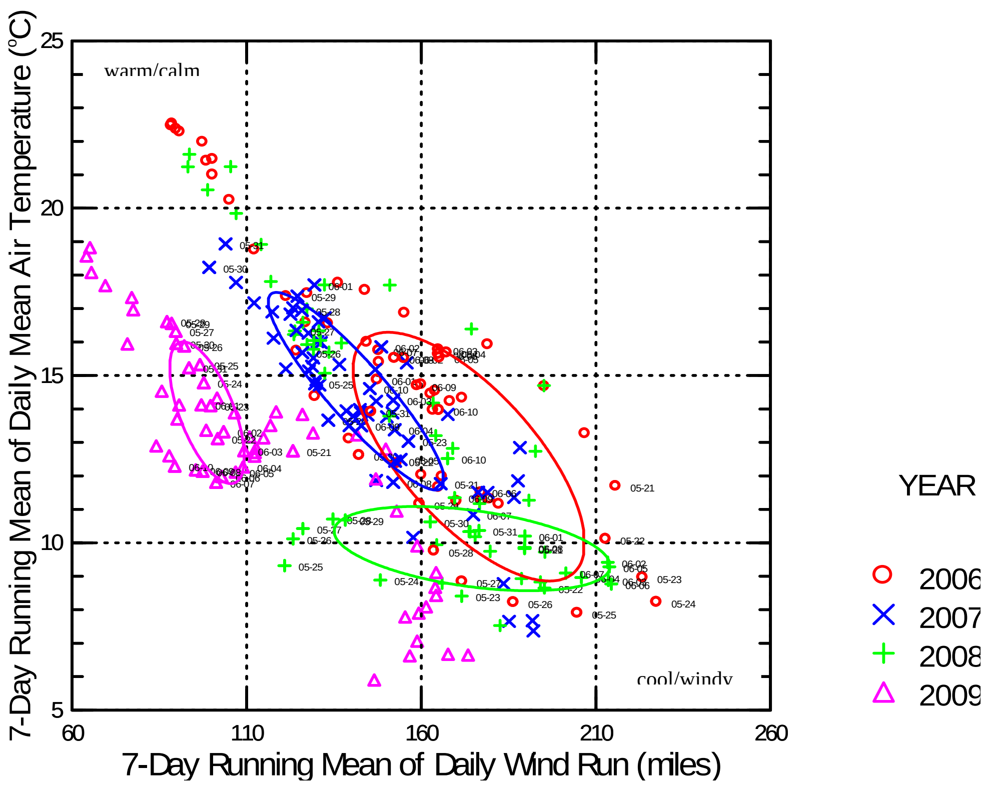

Figure 14. Scatter plot of the 7-day running mean of the daily wind run (miles) vs. 7-day running mean of daily air temperature (°C) during May and Jun. Data are from the Bureau of Reclamation AgriMet station located at Agency Lake (AGKO). Data labels are day of the month. Confidence ellipses are drawn for dates occurring during the last 10 days of May and first 10days of June; confidence ellipses are centered on the sample means of the x and y variables where the unbiased sample standard deviations of x and y determine its major axes and the sample covariance between x and y, its orientation (Systat 2004).

Table 2. Summary statistics for each UKL station for the June-September period, 2009 (LQ= Lower Quartile; UQ=Upper Quartile).

Year	Station	Parameter	Temp-erature (°C)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2009	AS	n	8	8	8	9	9	9	9	9	9	9	8
2009	AS	Median	19.7	9.35	8.6	1.06	47	185	63	1620	9	20	15
2009	AS	Mean	19.9	9.31	8.4	1.03	123	184	80	1860	32	81	24
2009	AS	LQ	18.1	8.70	6.1	0.53	32	107	39	1287	4	16	9
2009	AS	UQ	21.3	9.97	10.4	1.64	227	270	126	2645	49	111	29
2009	ER	n	9	9	9	9	9	9	9	9	9	9	9
2009	ER	Median	19.2	9.17	5.8	0.87	95	159	52	2140	8	123	27
2009	ER	Mean	19.3	9.01	5.6	1.00	143	171	60	2360	12	311	96
2009	ER	LQ	17.7	8.69	5.0	0.40	27	111	8	1518	4	76	17
2009	ER	UQ	20.2	9.63	7.2	1.60	268	249	101	3295	18	487	131
2009	ML	n	9	9	9	9	9	9	9	9	9	9	9
2009	ML	Median	18.3	9.42	8.0	0.78	136	158	41	2200	8	19	11
2009	ML	Mean	18.8	9.26	8.2	0.99	125	155	44	2007	19	102	22
2009	ML	LQ	17.6	8.86	7.5	0.75	93	119	7	1680	4	14	6
2009	ML	UQ	19.8	9.83	9.2	1.14	153	211	74	2423	27	127	29
2009	MN	n	9	9	9	9	8	9	9	9	9	9	9
2009	MN	Median	19.1	9.19	7.5	0.97	79	161	55	1880	4	29	14
2009	MN	Mean	19.1	9.07	7.2	1.12	90	142	56	1835	8	255	43
2009	MN	LQ	17.5	8.49	6.6	0.82	50	74	7	1375	4	24	9
2009	MN	UQ	19.7	9.75	8.7	1.13	138	198	97	2348	11	383	59
2009	NB	n	9	9	9	9	9	9	9	9	9	9	9
2009	NB	Median	18.4	9.41	8.4	0.86	150	145	59	1840	4	21	12
2009	NB	Mean	18.5	9.31	8.1	0.98	135	142	43	1932	17	97	17
2009	NB	LQ	17.4	8.86	7.6	0.71	61	79	7	1733	4	16	7
2009	NB	UQ	19.5	9.81	8.7	1.32	188	195	71	2125	20	107	22
2009	PM	n	9	9	9	9	9	9	9	9	9	9	9
2009	PM	Median	19.1	9.52	8.3	0.72	165	131	27	1910	4	20	10
2009	PM	Mean	18.8	9.45	8.6	0.70	150	155	27	2279	6	26	12
2009	PM	LQ	17.4	9.18	7.8	0.44	84	84	6	1593	4	13	9
2009	PM	UQ	20.0	9.72	8.9	0.95	193	214	43	2778	5	34	14
2009	SB	n	9	9	9	9	9	9	9	9	9	9	9
2009	SB	Median	20.1	9.32	7.9	0.63	170	199	52	2340	8	25	21
2009	SB	Mean	19.8	9.09	8.3	0.89	172	192	48	2643	12	257	42
2009	SB	LQ	18.1	8.22	6.6	0.49	48	135	8	2105	4	22	8
2009	SB	UQ	20.4	9.84	9.8	1.20	253	261	86	3575	10	339	63
2009	WB	n	9	9	9	9	9	9	9	9	9	9	9
2009	WB	Median	19.5	9.44	8.5	0.73	180	194	31	2740	4	45	41
2009	WB	Mean	19.2	9.48	8.3	0.70	198	185	34	2988	5	290	115
2009	WB	LQ	16.9	9.16	7.0	0.55	143	123	6	2180	4	15	10
2009	WB	UQ	20.8	9.73	9.4	0.87	224	220	52	3640	5	328	141
2009	AN	n	8	8	8	9	9	9	9	9	9	9	8
2009	AN	Median	20.0	9.55	8.0	0.92	89	182	104	1330	17	29	18
2009	AN	Mean	20.2	9.18	7.8	0.80	89	198	109	1537	25	111	17
2009	AN	LQ	18.2	8.42	6.1	0.35	33	169	93	1225	12	20	11
2009	AN	UQ	21.5	9.79	10.4	1.12	130	224	122	1890	35	42	23
2009	CP	n	8	8	8	9	9	9	9	9	9	9	8
2009	CP	Median	19.4	9.27	6.9	0.80	73	166	68	2090	4	95	44
2009	CP	Mean	19.5	8.99	6.4	1.07	89	150	62	1981	9	316	80
2009	CP	LQ	17.9	8.23	5.5	0.69	35	66	8	1398	4	44	15
2009	CP	UQ	20.1	9.78	7.9	1.19	123	206	98	2420	13	568	105

2009 Monthly Trends

Basic statistics for monthly distributions for all sampling years are shown in Appendix 1. Unlike other years when monthly distributions for pH showed a progressive seasonal increase with seasonal maxima generally occurring in July that coincided with the lowest Secchi depth (indicating reduced transparency) and highest CHL distributions; in 2009 high pH values occurred in June and coincided with maximum CHL but not lowest Secchi values (Figures 15 and 16). pH levels then rebounded in August with maximum pH occurring in September of 2009. Lowest lake-wide D.O. occurred during July in 2009 when CHL declined lake-wide (Figures 12 and 16). CHL then exhibited a second peak with lake-wide values generally >100 µg/L during August and September (Figure 16). The July CHL decline in 2009 tended to be among the earliest of the 20 year period of record, with bloom declines typically observed in late-July and early-August.

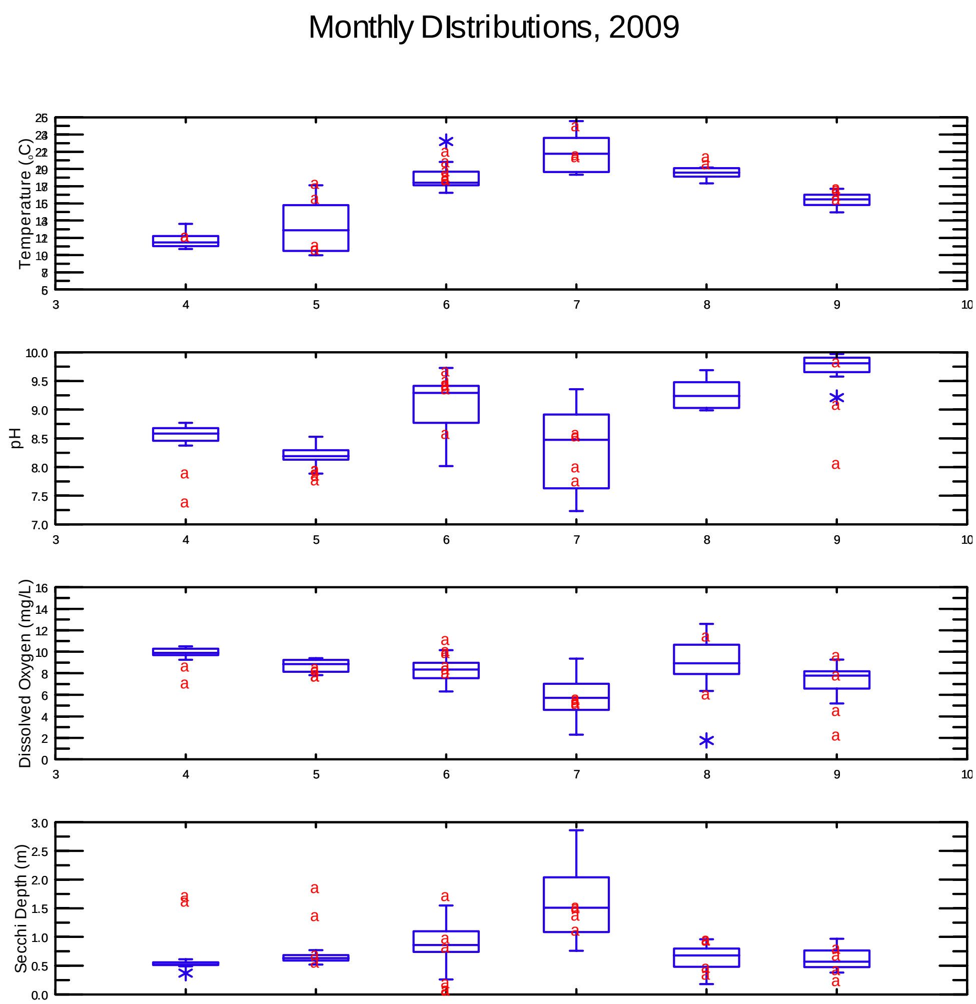

Figure 15. Monthly distributions of T (˚C), pH, D.O (mg/L), and Secchi depth, 2009 (symbol "a" denotes values for Agency Lake plotted separately from the box plot distribution).

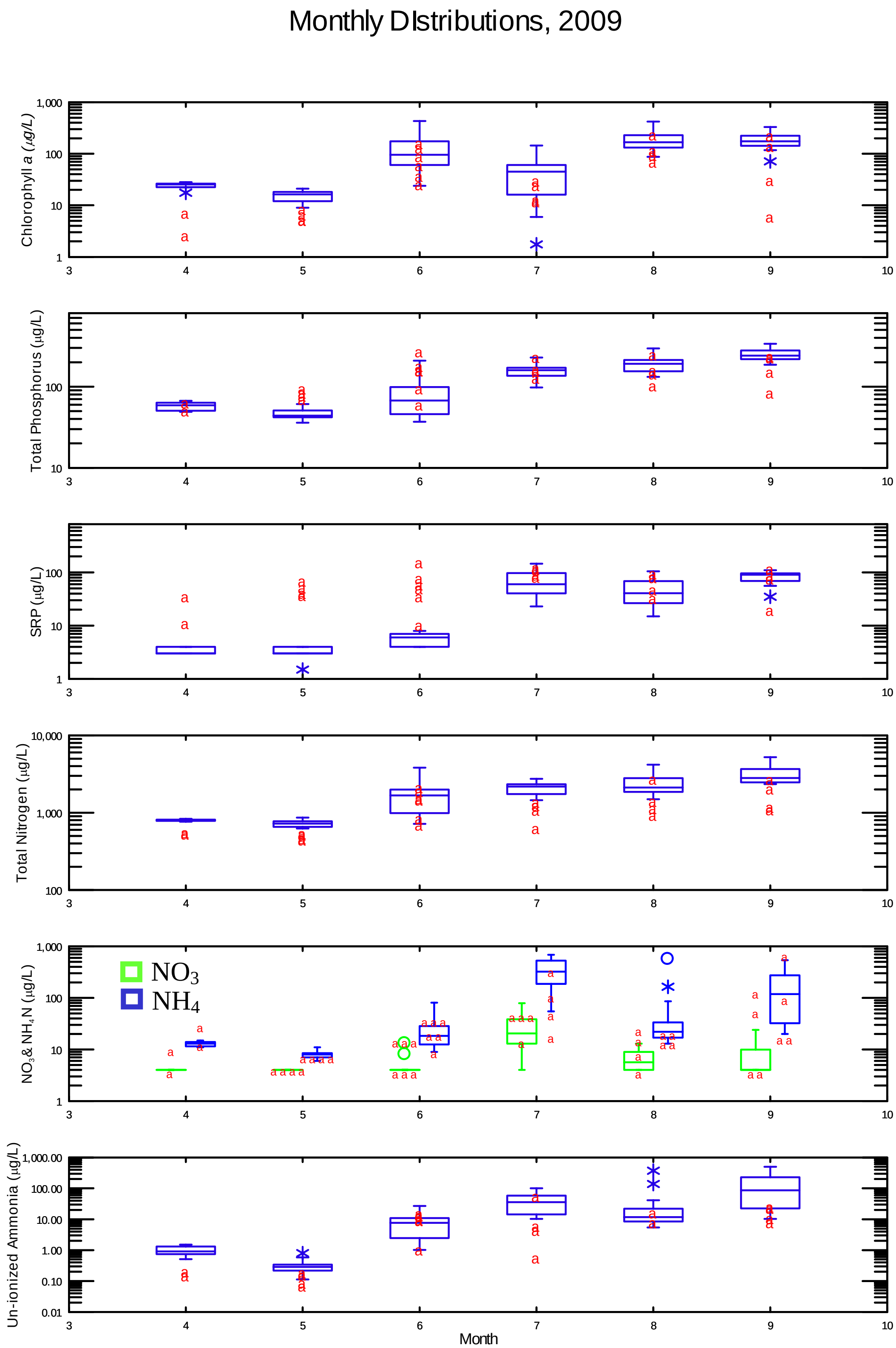

Figure 16. Monthly distributions of CHL, TP, SRP, TN, NO3+ NO2-N, NH4-N, and un-ionized ammonia, 2009 (symbol "a" denotes values for Agency Lake plotted separately from the box plot distribution).

TP, SRP, TN, and TIN (NO_3 and NH_4) all decreased between April and May before showing a progressive increase into July (Figure 16). TP and TN then remained elevated through September, but SRP and TIN declined in August before increasing again in September (Figure 16). A further look at the 2009 time-series with respect to CHL and dissolved nutrients shows that at the UKL stations SRP remained low through the June period (prior to July bloom decline) even while CHL increased substantially (Figure 17). This trend did not apply to the Agency Lake stations which showed elevated SRP in April and May, which then remained high at AN as CHL increased, and declined as CHL increased at AS (Figure 17).

TIN generally decreased between April and May before increasing in June with an abrupt peak in July during the bloom decline (Figure 17). Both SRP and TIN tend to decline as CHL undergoes a second peak in August, although not to the same extent as the early season concentrations. There is an indication that SRP may be limiting the early season bloom, especially since internal sources of phosphorus are also increasing during that time period.

As noted by Lindenberg et al. (2008) potential phosphorus-limitation can be characterized by chlorophyll a to phosphorus ratios greater than 1, and they observed such conditions to occur during the initial bloom in late June and early July of 2006 but to a lesser degree during late-season blooms. In 2009, chlorophyll to TP ratios greater than 1 were observed at a high frequency in June during the initial bloom (Figure 18). Ratios then declined in July to values less than 1, with an increase in frequency occurring during August-October when the bloom rebounded (Figure 18). In August ~35% of stations and dates showed chlorophyll to TP ratios greater than 1.

The underwater light environment is another factor that can influence both bloom dynamics and other water quality parameters, especially those that are photosynthetically driven. Although not discussed in detail here, a plot of photic zone depth (defined as the depth where 99% of incident light is absorbed and computed from extinction coefficients) relative to the maximum depth at UKL and Agency Lake stations shows that despite the shallow nature of the system that the photic zone depth was often shallower than maximum depth in 2009 (Figure 19; occurring when the blue line is higher in the water column than the red line). A plot showing the percent of the water column in the photic zone indicates that, at times, a substantial portion of the water column does not have sufficient light for photosynthesis (Figure 20). The deeper ER station consistently shows greater than 50% of the water column to be light limited.

To the extent that underwater light is influenced by seasonal algal dynamics (in concert with ambient light and the interaction with lake depth), decreases in available light during the early spring of 2009 were likely influenced by diatom blooms, followed by a “clear water” phase in May as the diatoms declined, and another greater decline in available light as the June *Aphanizomenon* bloom increased (Figure 20). Greater transparency was then observed during the July bloom decline with a subsequent decrease in August as the bloom rebounded.

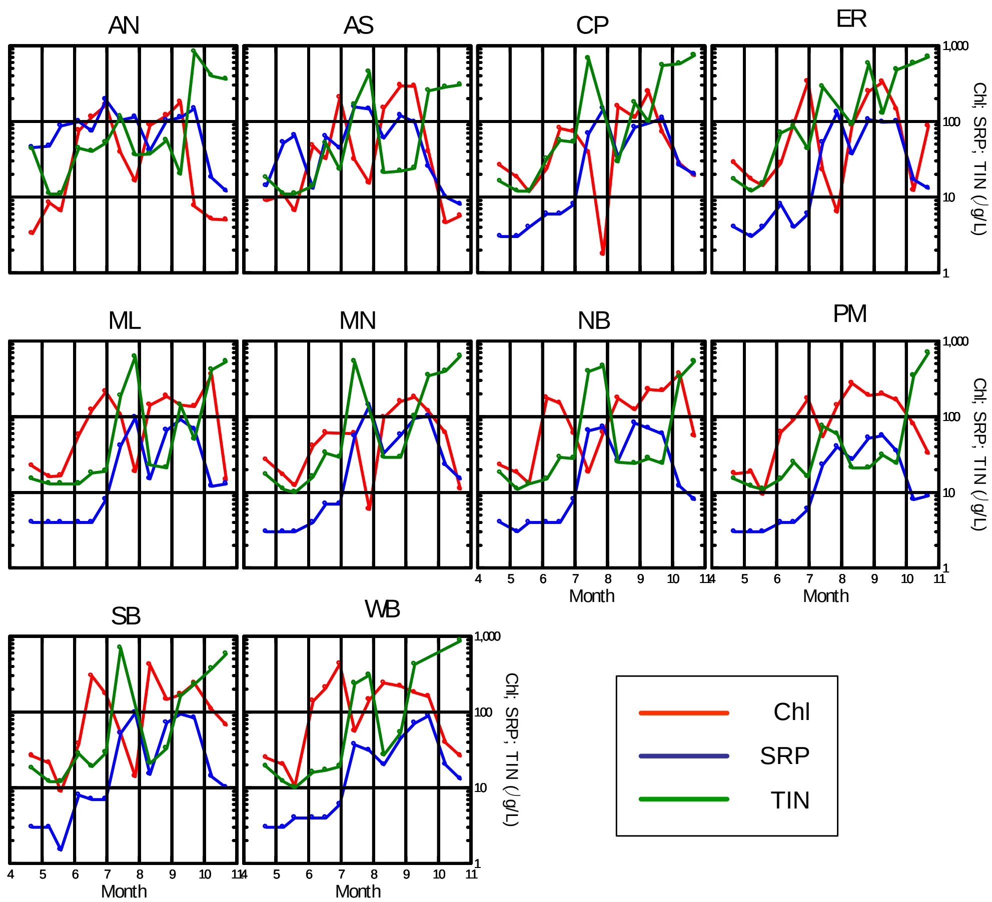

Figure 17. Chlorophyll, SRP, and TIN time-series for UKL and Agency Lake Stations, 2009.

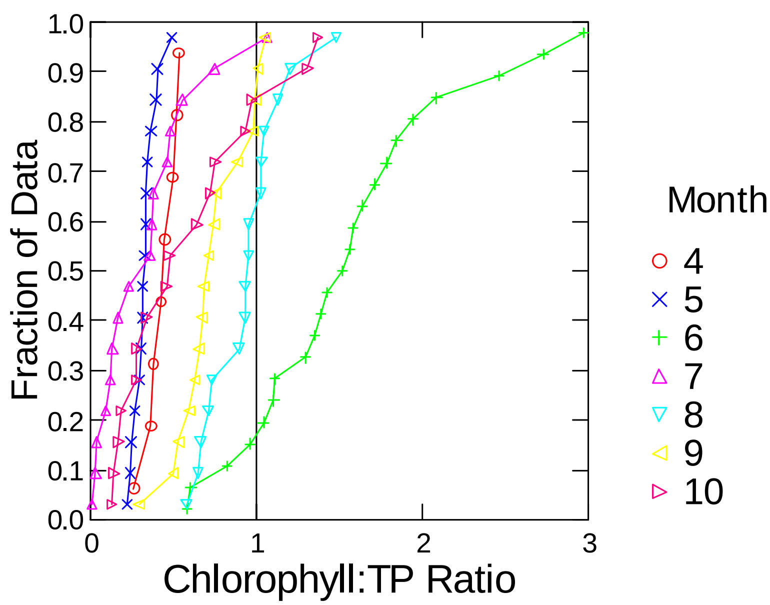

Figure 18. Quantile plot (cumulative frequency) of April-October chlorophyll to TP ratios in Upper Klamath Lake, 2009.

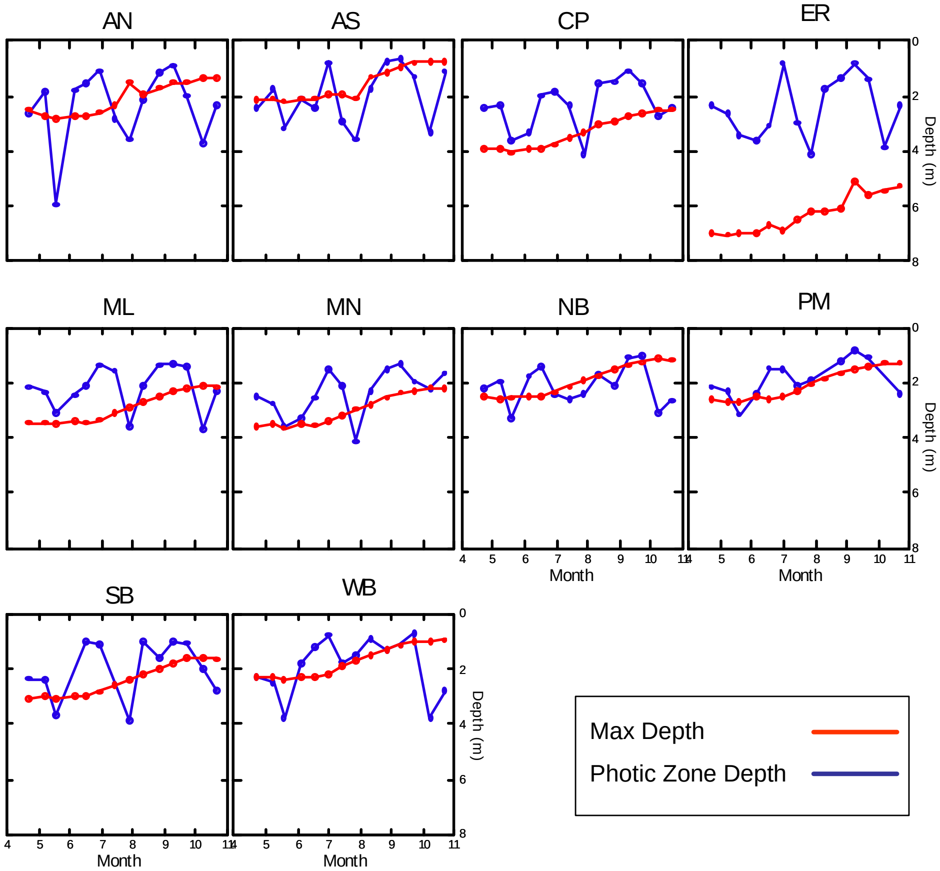

Figure 19. Photic zone depth and maximum depth at UKL and Agency Lake stations in 2009.

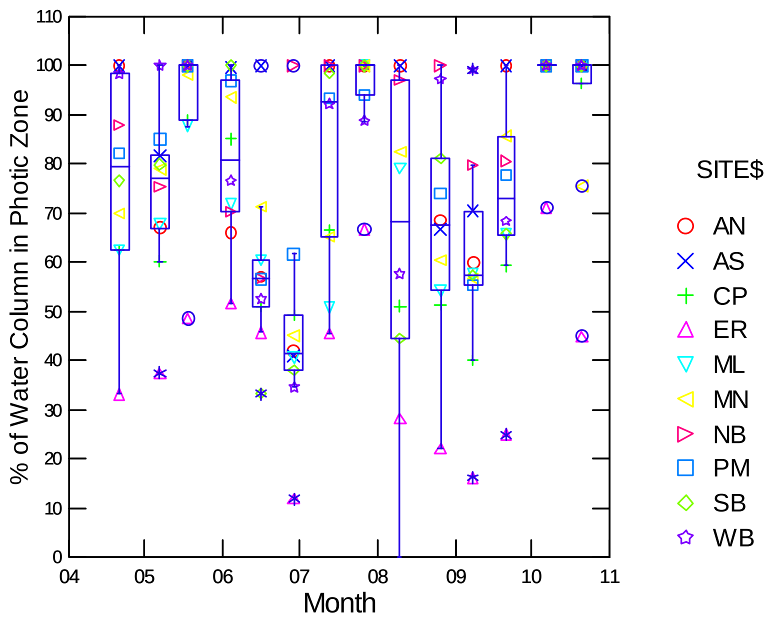

Figure 20. Percent of the water column in the photic zone for UKL and Agency Lake Stations, 2009.

Comparison of 2009 to Previous 1990-2008 Data

To facilitate inter-annual comparisons of the major water quality variables, lake-wide means were computed for UKL-only and Agency Lake-only. The distributions for the June-September period are shown in Figures 21-24 and summary statistics in Tables 3 and 4. The June-Sep UKL-only distribution for 2009 was somewhat lower than other years for temperature while pH was not notably different (Figure 21). However, similar to 2008, the upper and lower distributions (upper and lower quartile values) for D.O. in 2009 did not show the same extent of extreme values as many of the other years (Figure 21; Table 3).

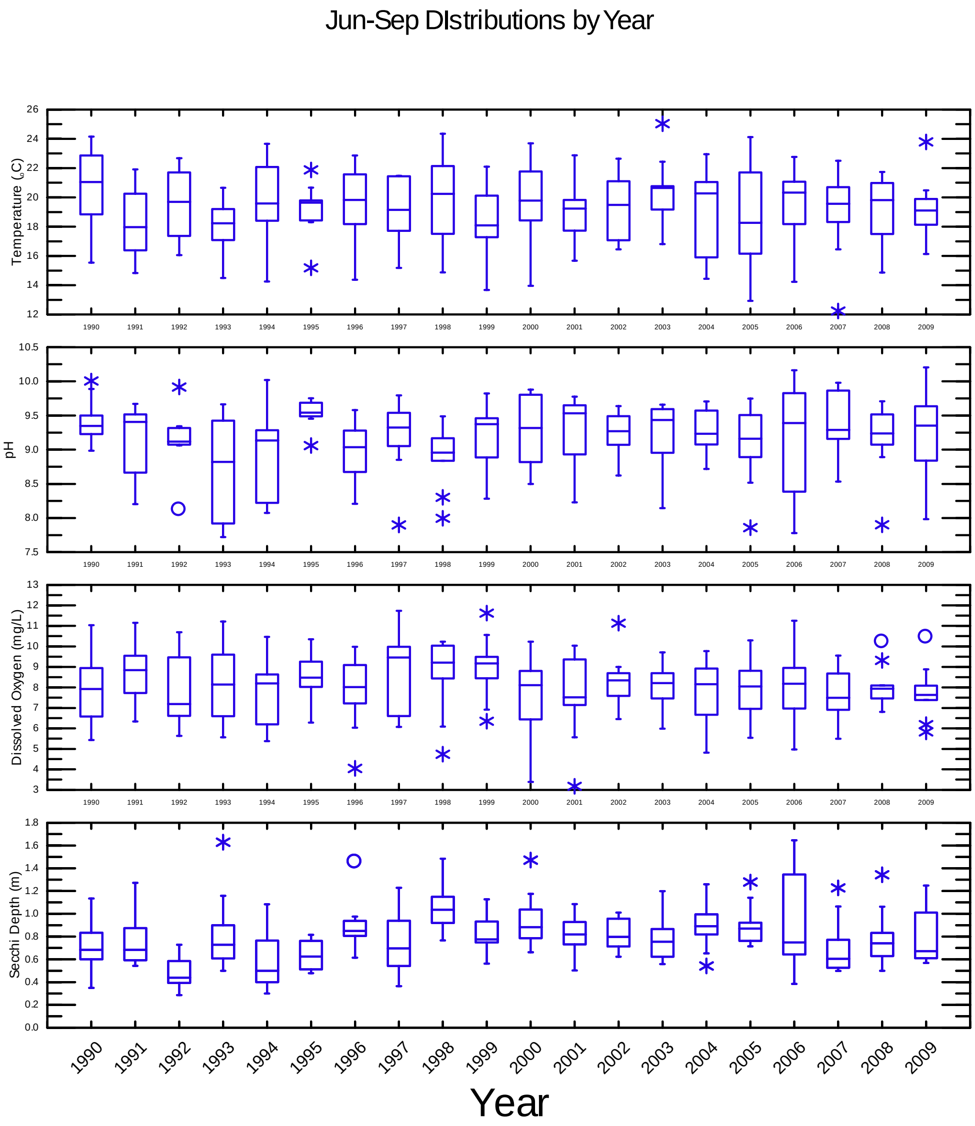

Figure 21. June-September distribution of UKL-only lake-wide means for T (˚C), pH, D.O (mg/L), and Secchi depth, 1990-2009.

Jun-Sep Distributions by Year

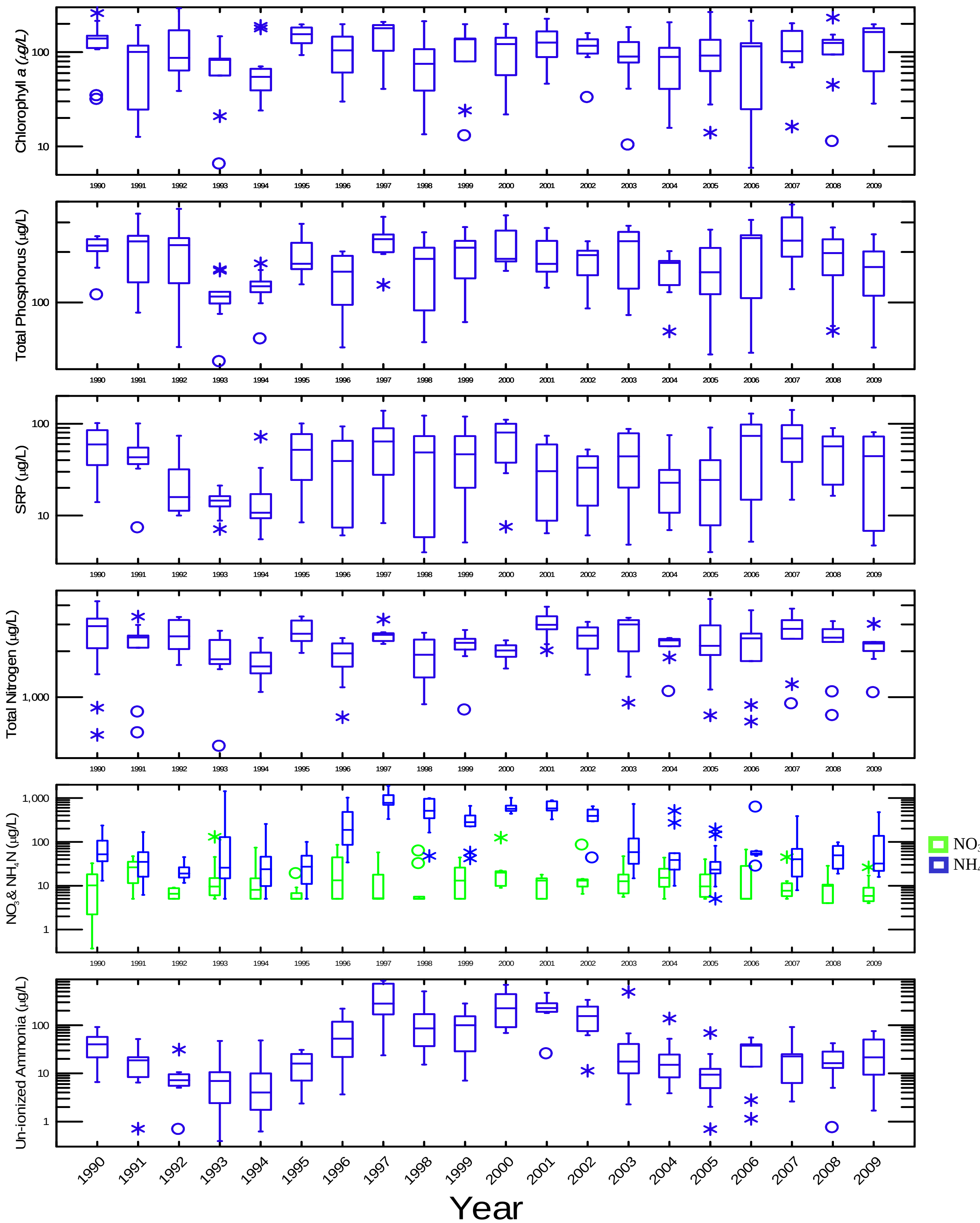

Figure 22. June-September distribution of UKL-only lake-wide means for CHL, TP, SRP, TN, NO_3+ NO_2-N and NH_4-N, 1990- 2009.

Table 3. Summary statistics for June-September UKL-only lake-wide means, 1990-2009 (LQ= Lower Quartile; UQ=Upper Quartile).

Year	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll *a* (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1990	n	14	14	14	14	13	13	13	13	10	11	11
1990	Median	21.0	9.35	7.9	0.68	140	219	59	2916	9	52	50
1990	Mean	20.7	9.41	8.0	0.72	137	208	61	2643	11	85	54
1990	LQ	18.8	9.23	6.6	0.60	109	193	34	1923	2	34	37
1990	UQ	22.9	9.50	8.9	0.83	156	239	87	3379	18	124	73
1991	n	9	9	9	9	9	9	9	9	3	7	7
1991	Median	18.0	9.41	8.8	0.68	101	232	43	2459	26	35	29
1991	Mean	18.1	9.17	8.7	0.77	96	202	47	2172	26	52	35
1991	LQ	16.4	8.66	7.7	0.59	25	122	35	1780	10	14	13
1991	UQ	20.4	9.54	9.6	0.91	135	256	58	2643	42	73	57
1992	n	8	8	8	8	8	8	8	8	8	8	8
1992	Median	19.7	9.12	7.2	0.44	87	220	16	2531	7	19	10
1992	Mean	19.5	9.13	7.9	0.48	123	200	25	2571	7	22	13
1992	LQ	17.4	9.07	6.6	0.39	65	130	11	2066	5	15	7
1992	UQ	21.7	9.32	9.5	0.59	174	242	32	3202	9	26	20
1993	n	10	10	10	10	9	9	9	9	9	9	9
1993	Median	18.2	8.82	8.1	0.73	83	109	15	1772	10	26	15
1993	Mean	17.9	8.77	8.2	0.83	75	110	14	1841	26	235	38
1993	LQ	17.1	7.92	6.6	0.61	48	95	12	1620	6	13	2
1993	UQ	19.2	9.43	9.6	0.90	96	126	17	2375	23	211	20
1994	n	10	10	10	9	14	15	15	15	15	16	10
1994	Median	19.6	9.13	8.2	0.50	55	125	11	1590	8	24	5
1994	Mean	19.6	8.96	7.8	0.59	69	124	18	1705	15	49	11
1994	LQ	18.4	8.22	6.2	0.40	39	115	9	1421	5	10	2
1994	UQ	22.1	9.28	8.6	0.77	67	134	20	1984	15	46	10
1995	n	9	9	9	8	8	8	8	8	8	8	8
1995	Median	19.6	9.54	8.5	0.62	155	170	53	2608	5	28	30
1995	Mean	19.2	9.53	8.6	0.64	152	192	53	2698	7	35	31
1995	LQ	18.4	9.48	8.0	0.51	125	158	26	2336	5	11	17
1995	UQ	20.0	9.69	9.3	0.76	182	229	78	3183	7	49	47
1996	n	10	10	10	7	10	10	10	10	10	10	10
1996	Median	19.8	9.04	8.0	0.85	104	154	40	1936	14	196	54
1996	Mean	19.6	8.96	7.8	0.92	106	143	41	1819	27	331	84
1996	LQ	18.2	8.67	7.2	0.79	61	97	7	1584	5	85	23
1996	UQ	21.6	9.28	9.1	0.96	146	190	65	2252	44	483	130
1997	n	8	8	8	8	8	8	8	8	8	8	8
1997	Median	19.1	9.32	9.5	0.70	179	239	64	2563	5	778	327
1997	Mean	19.2	9.19	8.7	0.74	151	230	65	2562	17	941	500
1997	LQ	17.7	9.05	6.6	0.54	106	200	33	2332	5	699	238
1997	UQ	21.4	9.54	10.0	0.94	194	255	89	2624	25	1172	876
1998	n	9	9	9	9	9	9	9	9	9	9	9
1998	Median	20.2	8.96	9.2	1.04	75	182	49	1897	5	510	186
1998	Mean	19.9	8.89	8.6	1.09	87	163	47	1821	14	588	200
1998	LQ	17.0	8.70	7.9	0.91	39	85	6	1237	5	299	59
1998	UQ	22.4	9.22	10.1	1.23	120	218	76	2391	12	963	265
1999	n	9	9	9	9	9	9	9	9	9	9	9
1999	Median	18.1	9.37	9.2	0.77	137	212	46	2267	13	283	129
1999	Mean	18.2	9.15	8.9	0.83	111	193	52	2149	18	307	160
1999	LQ	16.5	8.74	8.1	0.73	66	139	17	2002	5	183	29
1999	UQ	20.2	9.54	9.8	0.97	151	240	76	2471	29	426	245
2000	n	8	8	8	8	8	8	8	8	8	8	8
2000	Median	19.8	9.32	8.1	0.88	122	182	80	2025	20	567	268
2000	Mean	19.7	9.28	7.5	0.94	111	217	69	2001	29	619	344
2000	LQ	18.4	8.82	6.4	0.79	71	176	39	1841	10	508	109
2000	UQ	21.8	9.80	8.8	1.04	143	268	100	2192	21	672	580
2001	n	9	9	9	9	9	9	9	9	9	9	9
2001	Median	19.2	9.53	7.5	0.82	126	170	30	2978	13	580	274
2001	Mean	18.8	9.26	7.5	0.81	133	194	33	2978	11	632	281
2001	LQ	17.3	8.91	6.7	0.71	85	152	8	2645	5	478	241
2001	UQ	19.9	9.66	9.4	0.93	179	243	60	3434	15	845	321
2002	n	8	8	7	8	8	8	8	8	8	8	8
2002	Median	19.5	9.27	8.3	0.80	117	192	34	2535	13	400	175
2002	Mean	19.3	9.24	8.4	0.82	112	176	31	2437	20	398	184

2002	LQ	17.1	9.07	7.4	0.71	97	148	16	2088	10	297	111
2002	UQ	21.1	9.49	8.8	0.96	137	204	45	2867	14	550	267
2003	n	9	9	9	9	9	9	9	9	9	9	9
2003	Median	20.6	9.43	8.2	0.76	90	232	44	2996	13	58	25
2003	Mean	20.3	9.20	8.0	0.80	94	206	47	2510	16	136	97
2003	LQ	18.6	8.89	7.3	0.61	68	119	18	1838	6	28	12
2003	UQ	21.2	9.61	8.7	0.92	131	268	79	3214	18	123	81
2004	n	9	9	9	9	9	9	9	9	9	9	9
2004	Median	20.3	9.23	8.2	0.89	89	172	23	2352	15	39	20
2004	Mean	19.3	9.24	7.8	0.88	88	152	28	2152	18	111	37
2004	LQ	15.9	9.03	6.6	0.78	38	124	10	2075	9	22	10
2004	UQ	21.4	9.58	8.9	1.00	117	178	37	2405	25	109	42
2005	n	18	18	18	9	16	18	18	18	18	18	18
2005	Median	18.3	9.16	8.0	0.87	92	152	24	2170	10	23	10
2005	Mean	18.8	9.13	8.0	0.90	101	159	29	2356	13	43	15
2005	LQ	16.1	8.89	7.0	0.76	63	112	8	1890	6	19	5
2005	UQ	21.7	9.51	8.8	0.98	136	212	40	2949	18	35	18
2006	n	9	9	9	9	9	9	9	9	9	9	9
2006	Median	20.3	9.39	8.2	0.75	115	242	74	2428	5	54	50
2006	Mean	19.7	9.20	8.1	0.93	98	201	61	2269	19	114	52
2006	LQ	18.2	8.34	7.0	0.62	23	101	15	1516	5	50	24
2006	UQ	21.4	9.90	9.1	1.38	129	258	98	2883	30	62	83
2007	n	9	9	9	9	8	9	9	9	9	9	9
2007	Median	19.6	9.29	7.5	0.60	102	234	69	2804	8	40	35
2007	Mean	19.0	9.41	7.7	0.71	115	242	71	2568	12	77	36
2007	LQ	17.8	9.14	6.8	0.52	79	172	35	2114	6	14	7
2007	UQ	21.1	9.89	8.8	0.84	168	323	100	3196	12	71	47
2008	n	9	9	9	9	9	9	9	9	9	9	9
2008	Median	19.8	9.24	7.9	0.74	125	197	57	2452	10	49	23
2008	Mean	18.9	9.16	8.1	0.80	114	185	52	2292	10	51	29
2008	LQ	16.9	9.03	7.4	0.63	82	127	21	1994	4	24	11
2008	UQ	21.1	9.53	8.4	0.89	140	240	76	2831	11	81	50
2009	n	9	9	9	9	9	9	9	9	9	9	9
2009	Median	19.1	9.35	7.6	0.68	164	163	44	2245	6	32	29
2009	Mean	19.1	9.24	7.8	0.91	131	158	42	2194	9	120	50
2009	LQ	17.7	8.76	7.1	0.63	59	101	6	1950	4	21	11
2009	UQ	20.0	9.70	8.3	1.09	183	211	74	2477	11	166	75

Median CHL in 2009 was higher than values for the previous decade, while median TP was among the lowest for the period of record (Figure 22). For the 20 years of record, the ammonia distribution was similar from 1990-1995, was elevated from 1996-2002, and then decreased to pre 1996 levels during the past 7 years (2003-2009). However, 2009 showed somewhat higher ammonia concentrations than the previous 5 years (Figure 22).

As opposed to 2008 when upper quartile pH and CHL in Agency Lake were among the lowest for the period of record, values in 2009 were not notable different (Figures 23 and 24; Table 4). The Agency Lake distribution for ammonia- and nitrate-nitrogen in 2009 was not considerably different from previous years (the overall 20 year pattern described above notwithstanding). Agency Lake continued to show several periods of apparent cyclical increase and decrease for both TP and SRP over the period of record (Figure 24).

SUMMARY

With the addition of 2009 data, the UKL water quality/limnological database now includes 20 years of data and includes the years 1990-2009. Given the dynamic and variable nature of shallow, high productivity lakes such as UKL, a long-term monitoring program is essential for assessing change relative to management programs, as well as for understanding lake dynamics.

For example, vast areas of wetlands are in the process of being restored on the periphery of UKL, riparian and nutrient management plans (e.g., Oregon 1010 and TMDL plans) have been developed, and water use plans have been implemented (e.g., KBRT Wood River Valley programs).

Continued monitoring is recommended to accommodate the restoration time-frame for Klamath Basin activities and to increase statistical power (sample size) for multi-variable analyses. Such a long-term database allows for statistical time series or trend analysis, as well as multi-variable assessment of the relationship between controlling variables (e.g., climate) and important water quality parameters (e.g., see Jassby and Kann 2010).

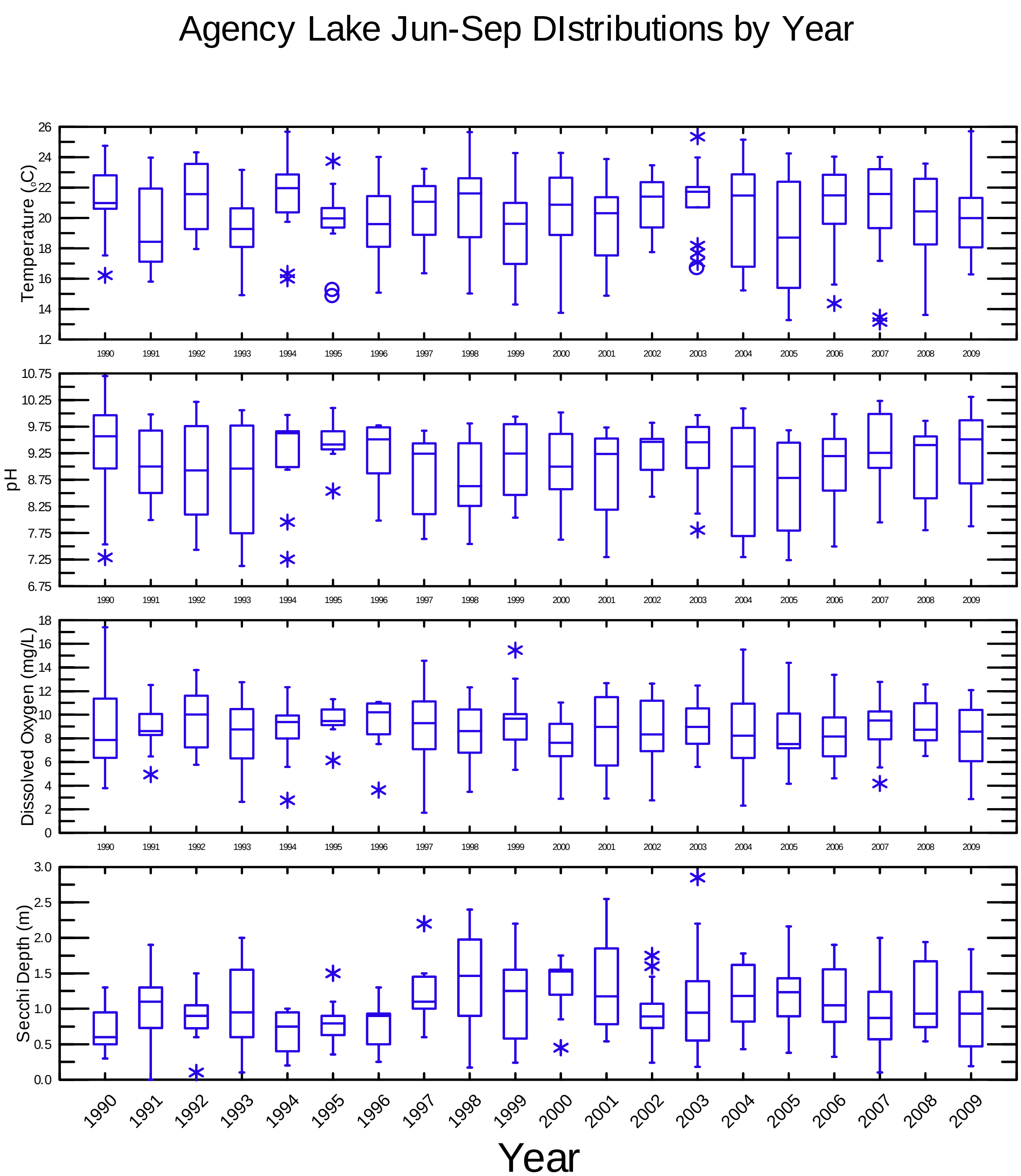

Figure 23. June-September distribution of Agency Lake means for T (˚C), pH, D.O (mg/L), and Secchi depth, 1990-2009.

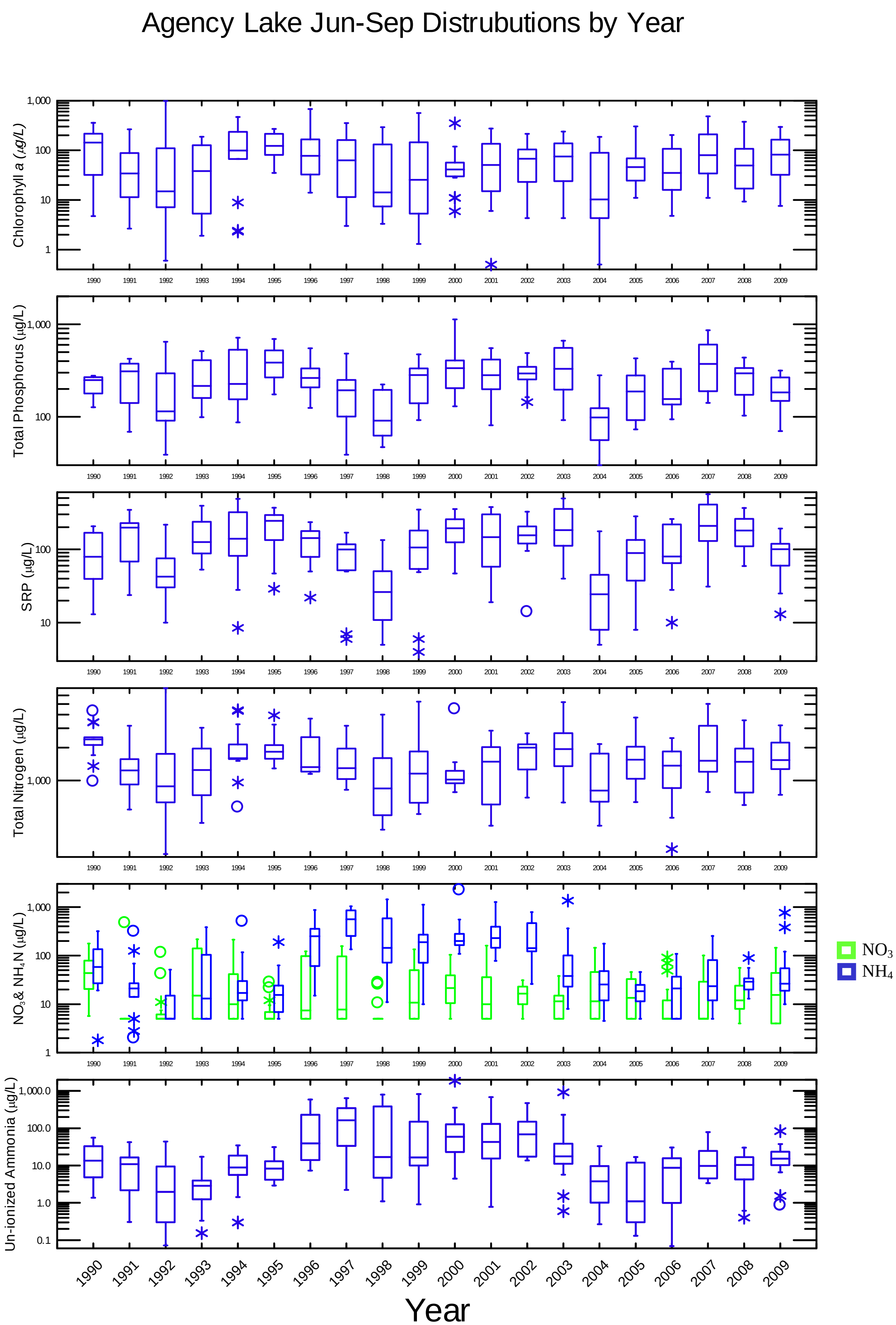

Figure 24. June-September distribution of Agency Lake means for CHL, TP, SRP, TN, NO3+ NO2-N, and NH4-N, 1990- 2009.

Table 4. Summary statistics for June-September Agency Lake means, 1990-2009 (LQ= Lower Quartile; UQ=Upper Quartile).

Year	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1990	n	14	14	14	11	13	13	13	13	9	11	11
1990	Median	21.0	9.57	7.9	0.60	143	249	79	2374	21	58	14
1990	Mean	21.1	9.31	9.0	0.75	151	223	99	2411	41	95	20
1990	LQ	20.6	8.97	6.4	0.50	32	178	35	2009	0	26	5
1990	UQ	22.8	9.97	11.4	0.98	224	270	172	2706	55	136	34
1991	n	18	16	18	18	18	18	18	18	6	13	11
1991	Median	18.4	9.00	8.6	1.10	34	310	198	1234	5	21	11
1991	Mean	19.2	9.07	8.9	1.04	71	275	179	1395	82	51	13
1991	LQ	17.1	8.50	8.3	0.73	11	141	68	919	5	12	2
1991	UQ	21.9	9.68	10.1	1.30	88	375	228	1566	5	38	18
1992	n	16	16	16	16	16	14	16	14	16	16	16
1992	Median	21.6	8.93	10.0	0.90	15	115	43	889	5	5	2
1992	Mean	21.4	8.87	9.5	0.87	107	187	65	1533	15	12	7
1992	LQ	19.3	8.10	7.2	0.73	7	91	31	631	5	5	0
1992	UQ	23.6	9.76	11.6	1.05	111	295	76	1750	6	15	10
1993	n	20	20	20	20	18	18	18	18	18	18	18
1993	Median	19.3	8.96	8.8	0.95	45	216	126	1275	15	14	3
1993	Mean	19.2	8.78	8.3	1.05	68	261	165	1459	62	73	4
1993	LQ	18.1	7.75	6.3	0.60	5	160	88	733	5	5	1
1993	UQ	20.6	9.77	10.5	1.55	126	409	238	1960	141	104	4
1994	n	14	13	14	12	13	13	13	13	13	13	12
1994	Median	22.0	9.63	9.4	0.75	99	227	139	1600	10	17	9
1994	Mean	21.3	9.22	8.6	0.68	156	334	188	2080	33	62	12
1994	LQ	20.4	8.98	8.0	0.40	52	146	81	1555	5	11	6
1994	UQ	22.9	9.71	9.9	0.95	253	537	331	2416	42	32	18
1995	n	16	16	16	16	16	16	16	16	16	16	16
1995	Median	20.0	9.41	9.5	0.80	124	386	245	1835	5	16	8
1995	Mean	19.8	9.47	9.6	0.78	139	392	214	2057	8	29	10
1995	LQ	19.4	9.32	9.1	0.63	81	267	140	1580	5	7	4
1995	UQ	20.6	9.66	10.4	0.90	214	523	293	2110	7	24	13
1996	n	8	8	8	6	8	8	8	8	8	8	8
1996	Median	19.6	9.51	10.2	0.90	78	265	143	1325	8	255	39
1996	Mean	19.7	9.25	9.2	0.80	159	286	134	1872	44	280	146
1996	LQ	18.1	8.87	8.3	0.50	37	208	87	1203	5	61	14
1996	UQ	21.4	9.74	11.0	0.93	176	334	177	2545	99	360	233
1997	n	12	12	12	10	12	12	12	12	12	12	12
1997	Median	21.1	9.24	9.3	1.28	63	194	99	1305	9	565	165
1997	Mean	20.4	8.90	8.8	1.46	104	200	87	1560	49	582	210
1997	LQ	18.9	8.11	7.1	1.00	12	107	52	1030	5	257	34
1997	UQ	22.1	9.44	11.1	1.50	165	252	118	1960	100	854	346
1998	n	16	16	16	16	16	16	16	16	16	16	16
1998	Median	21.7	8.63	8.6	1.47	14	90	26	845	5	144	17
1998	Mean	21.1	8.78	8.4	1.43	66	113	39	1187	8	355	183
1998	LQ	18.7	8.26	6.8	0.90	7	58	12	482	5	72	5
1998	UQ	23.3	9.44	10.4	1.98	131	196	50	1605	5	596	389
1999	n	18	18	18	18	18	18	18	18	18	18	18
1999	Median	19.6	9.25	9.7	1.25	27	283	107	1155	11	189	17
1999	Mean	19.1	9.11	9.5	1.21	103	259	127	1561	31	220	118
1999	LQ	17.0	8.47	7.9	0.58	5	140	54	626	5	71	10
1999	UQ	21.0	9.80	10.1	1.55	144	333	181	1840	50	271	151
2000	n	16	16	16	14	16	16	16	15	16	16	16
2000	Median	20.9	9.00	7.6	1.53	41	336	195	1020	22	200	59
2000	Mean	20.3	9.03	7.5	1.36	61	358	199	1293	32	360	192
2000	LQ	18.9	8.57	6.5	1.20	20	204	125	939	11	165	23
2000	UQ	22.7	9.61	9.2	1.55	58	407	257	1243	40	285	128
2001	n	18	18	18	18	18	18	18	18	18	18	18
2001	Median	20.3	9.24	9.0	1.18	52	282	147	1485	10	230	43
2001	Mean	19.7	8.81	8.1	1.34	77	297	175	1435	26	357	141
2001	LQ	17.5	8.19	5.7	0.78	15	199	58	603	5	145	15
2001	UQ	21.4	9.53	11.5	1.85	135	416	300	2020	36	393	131

Year	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2002	n	14	14	14	14	14	14	14	14	14	14	14
2002	Median	21.4	9.47	8.3	0.89	70	294	156	1998	17	143	69
2002	Mean	20.9	9.26	8.7	0.93	77	300	162	1773	17	264	132
2002	LQ	19.4	8.94	6.9	0.73	23	254	120	1260	10	122	17
2002	UQ	22.4	9.52	11.2	1.07	104	347	205	2140	23	468	151
2003	n	18	18	18	18	18	18	18	18	18	18	18
2003	Median	21.8	9.46	9.0	0.95	76	331	183	1935	12	40	18
2003	Mean	21.4	9.28	9.1	1.08	87	368	230	2112	15	149	84
2003	LQ	20.7	8.97	7.5	0.55	24	197	112	1350	5	23	11
2003	UQ	22.9	9.74	10.5	1.39	138	556	355	2710	15	101	39
2004	n	18	18	18	18	18	18	18	18	18	18	18
2004	Median	21.5	9.00	8.2	1.18	11	99	25	808	12	26	4
2004	Mean	20.4	8.79	8.4	1.21	51	108	41	1119	31	40	8
2004	LQ	16.8	7.69	6.3	0.82	4	56	8	639	5	12	1
2004	UQ	22.9	9.73	10.9	1.62	89	124	45	1760	46	48	10
2005	n	16	16	16	16	16	16	16	16	16	16	16
2005	Median	18.7	8.78	7.5	1.24	46	189	89	1555	14	19	1
2005	Mean	18.8	8.62	8.4	1.19	69	200	100	1741	19	19	5
2005	LQ	15.4	7.80	7.2	0.90	25	92	38	1035	5	12	0
2005	UQ	22.4	9.45	10.1	1.43	69	281	135	2045	33	25	12
2006	n	18	18	18	16	18	18	18	18	18	18	18
2006	Median	21.5	9.20	8.2	1.05	35	156	80	1365	5	21	9
2006	Mean	20.8	9.00	8.2	1.13	67	207	118	1354	18	28	10
2006	LQ	19.6	8.55	6.5	0.82	13	136	65	852	5	5	1
2006	UQ	22.8	9.52	9.8	1.56	107	331	219	1840	12	37	16
2007	n	18	18	18	18	16	18	18	18	18	18	18
2007	Median	21.6	9.26	9.5	0.87	80	375	209	1520	5	24	10
2007	Mean	20.5	9.38	8.9	0.90	138	406	261	2171	20	58	17
2007	LQ	19.3	8.97	7.9	0.57	35	189	130	1200	5	12	5
2007	UQ	23.2	9.99	10.3	1.24	210	603	407	3170	29	81	25
2008	n	18	18	18	18	18	18	18	18	18	18	18
2008	Median	20.4	9.40	8.7	0.93	50	295	182	1480	12	29	10
2008	Mean	19.8	9.07	9.2	1.12	78	266	184	1483	17	32	11
2008	LQ	18.3	8.40	7.8	0.74	17	173	110	774	8	20	4
2008	UQ	22.6	9.57	11.0	1.67	107	337	260	1960	24	34	17
2009	n	16	16	16	18	18	18	18	18	18	18	16
2009	Median	20.0	9.51	8.6	0.93	82	184	101	1540	16	27	15
2009	Mean	20.1	9.25	8.1	0.91	106	191	95	1698	29	96	21
2009	LQ	18.1	8.68	6.1	0.47	32	149	60	1270	4	19	10
2009	UQ	21.3	9.87	10.4	1.24	164	267	119	2220	44	55	23

LITERATURE CITED

Jassby, A., and J. Kann. 2010. Upper Klamath Lake Monitoring Program: preliminary analysis of status and trends for 1990-2009. Technical Memorandum prepared by Aquatic Ecosystem Sciences LLC for the Klamath Tribes Natural Resources Department, Chiloquin, OR. 55 p.

Kann, J. 1998. Ecology and water quality dynamics of a shallow hypertrophic lake dominated by Cyanobacteria (*Aphanizomenon flos-aquae*). Doctoral Dissertation. University of North Carolina. Curriculum in Ecology. Chapel Hill, North Carolina.

Kann, J., and V. H. Smith. 1999. Chlorophyll as a predictor of elevated pH in a hypereutrophic lake: estimating the probability of exceeding critical values for fish success using parametric and nonparametric models. Can. J. Fish Aquat. Sci 56: 2262-2270

Kann, J. and E. B. Welch. 2005. Wind control on water quality in shallow, hypereutrophic Upper Klamath Lake, Oregon. Lake Reserv. Manage. 21(2):149-158

Kann, J. 2007. Upper Klamath Lake 2006 Data Summary Report. Technical Memorandum Prepared for the Klamath Tribes Natural Resources Department, Chiloquin Oregon. April 2007.

Kann, J. 2008. Upper Klamath Lake 2007 Data Summary Report. Technical Memorandum Prepared for the Klamath Tribes Natural Resources Department, Chiloquin Oregon. June 2008.

Klamath Tribes 2003. Quality Assurance Project Plan (QAPP), Project: Baseline Water Quality Monitoring Project. Revision: 1.1, December 11, 2003. Klamath Tribes Natural Resources Department, Chiloquin, OR

Klamath Tribes 2006. Standard Operating Procedures (SOP) for Upper Klamath Lake Water Quality Field Sampling. Revision: 1.2, April 3, 2006. Klamath Tribes Natural Resources Department, Chiloquin, OR.

Lindenberg, M.K., Hoilman, Gene, and Wood, T.M., 2009, Water quality conditions in Upper Klamath and Agency Lakes, Oregon, 2006: U.S. Geological Survey Scientific Investigations Report 2008-5201, 54 p.

Wood, T.M., Hoilman, G.R., and Lindenberg, M.K., 2006, Water-quality conditions in Upper Klamath Lake, Oregon, 2002–04: U.S. Geological Survey Scientific Investigations Report 2006-5209, 52 p.

Wood, T.M., Cheng, R.T., Gartner, J.W., Hoilman, G.R., Lindenberg, M.K., and Wellman, R.E., 2008, Modeling hydrodynamics and heat transport in Upper Klamath Lake, Oregon, and implications for water quality: U.S. Geological Survey Scientific Investigations Report 2008–5076, 48 p.

Appendix 1

Summary statistics of monthly distributions for the June-September period, Upper Klamath Lake Stations; 1990-2009 (LQ= Lower Quartile; UQ=Upper Quartile).

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1990	6	n	13	13	13	12	11	11	12	11	2	2	2
1990	6	Median	16.1	9.18	8.9	1.00	60	119	17	795	25	62	50
1990	6	Mean	17.9	9.34	9.2	0.93	97	131	20	1111	25	62	50
1990	6	LQ	15.6	8.94	8.1	0.75	31	108	15	679	22	48	40
1990	6	UQ	20.8	9.64	9.8	1.20	117	141	20	1649	28	76	61
1990	7	n	17	17	17	15	15	15	15	15	8	15	15
1990	7	Median	22.2	9.42	7.1	0.50	138	215	67	2347	14	47	33
1990	7	Mean	22.4	9.48	7.3	0.61	170	222	66	2661	13	95	49
1990	7	LQ	21.7	9.27	6.3	0.40	95	194	53	2173	3	31	21
1990	7	UQ	23.1	9.65	8.9	0.86	278	247	81	3373	19	129	62
1990	8	n	9	9	9	9	9	9	9	9	9	9	9
1990	8	Median	23.3	9.28	7.8	0.50	191	241	95	3428	21	100	48
1990	8	Mean	22.1	9.24	7.4	0.73	201	243	94	3897	17	96	38
1990	8	LQ	19.1	9.04	5.3	0.35	82	171	87	2533	0	14	6
1990	8	UQ	23.5	9.37	9.1	1.00	276	307	104	4317	29	159	69
1990	9	n	15	15	15	15	13	13	13	13	13	13	13
1990	9	Median	18.2	9.37	9.6	0.60	147	228	59	3428	0	86	45
1990	9	Mean	18.5	9.41	8.9	0.71	164	236	68	3478	6	175	66
1990	9	LQ	17.7	9.24	6.8	0.43	76	201	52	2819	0	36	21
1990	9	UQ	19.1	9.60	10.9	0.98	235	251	73	3594	9	269	105
1991	6	n	16	16	16	16	14	14	14	14	14	7	7
1991	6	Median	15.9	8.43	8.1	0.85	17	89	19	681	47	5	1
1991	6	Mean	15.6	8.42	8.1	0.79	19	90	22	691	50	7	1
1991	6	LQ	14.9	8.17	7.4	0.35	12	83	7	593	16	5	0
1991	6	UQ	16.3	8.62	8.9	1.20	24	95	39	802	74	5	1
1991	7	n	12	12	12	12	10	10	10	10	3	10	10
1991	7	Median	19.9	9.43	8.9	0.68	107	155	40	2271	5	61	40
1991	7	Mean	19.5	9.49	8.8	0.70	118	162	37	2476	5	140	72
1991	7	LQ	18.4	9.37	7.6	0.50	77	141	24	2136	5	31	21
1991	7	UQ	20.3	9.67	10.5	0.80	139	176	49	2446	5	208	125
1991	8	n	22	18	22	24	21	21	21	21	0	21	18
1991	8	Median	20.3	9.28	9.2	0.66	126	241	55	2638		29	10
1991	8	Mean	20.0	9.14	8.6	0.71	140	257	65	2934		81	22
1991	8	LQ	18.3	8.71	6.7	0.46	39	212	41	2005		16	8
1991	8	UQ	21.8	9.59	10.1	1.05	196	297	99	3387		154	38
1991	9	n	15	15	15	15	14	14	13	14	0	7	7
1991	9	Median	16.3	9.59	9.0	0.72	134	272	57	2385		18	13
1991	9	Mean	16.6	9.57	8.8	0.75	187	312	63	2894		112	29

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1991	9	LQ	15.9	9.47	7.7	0.51	88	219	47	2068		13	9
1991	9	UQ	17.5	9.77	9.9	1.00	173	334	79	3939		52	31
1992	6	n	14	14	14	14	14	14	14	14	14	14	14
1992	6	Median	18.2	9.61	10.1	0.40	248	162	15	2625	5	34	22
1992	6	Mean	18.2	9.63	10.1	0.51	258	195	14	2874	5	33	21
1992	6	LQ	16.0	9.34	9.2	0.30	96	121	10	1960	5	15	8
1992	6	UQ	20.3	9.94	10.9	0.60	378	271	18	3600	5	49	31
1992	7	n	21	21	21	21	21	18	21	18	21	21	21
1992	7	Median	21.0	9.30	7.3	0.60	126	246	42	2835	5	12	6
1992	7	Mean	20.3	9.15	6.8	0.57	160	299	50	3096	9	147	17
1992	7	LQ	18.0	9.06	5.7	0.30	68	217	25	2420	5	5	2
1992	7	UQ	21.7	9.35	8.8	0.80	220	379	60	3635	8	50	18
1992	8	n	14	14	14	14	14	14	14	14	14	14	14
1992	8	Median	20.6	9.15	8.7	0.30	72	121	11	2363	6	19	6
1992	8	Mean	20.8	9.12	8.2	0.36	76	138	12	2444	8	21	7
1992	8	LQ	19.4	9.01	6.9	0.30	49	54	9	1980	5	5	2
1992	8	UQ	22.7	9.22	9.9	0.40	100	212	14	2880	11	23	11
1992	9	n	7	7	7	7	6	7	7	7	7	7	7
1992	9	Median	17.4	7.97	5.1	0.40	41	136	13	1620	5	13	0
1992	9	Mean	17.2	8.12	5.6	0.39	43	135	14	1639	16	13	1
1992	9	LQ	16.8	7.75	4.9	0.30	34	114	12	1483	5	7	0
1992	9	UQ	17.6	8.57	6.3	0.48	58	154	18	1811	16	17	1
1993	6	n	21	21	21	21	21	21	21	21	21	21	21
1993	6	Median	17.3	8.68	9.6	0.90	65	89	9	1660	5	5	1
1993	6	Mean	16.8	8.62	9.7	1.05	67	81	11	1498	6	13	1
1993	6	LQ	14.7	7.77	8.5	0.64	7	47	7	518	5	5	1
1993	6	UQ	18.4	9.35	10.9	1.40	114	102	12	2253	5	16	2
1993	7	n	15	15	15	15	14	14	14	14	14	14	14
1993	7	Median	18.2	9.31	8.4	0.80	109	121	14	1870	5	13	7
1993	7	Mean	18.3	9.38	8.4	0.65	140	139	13	2351	10	55	19
1993	7	LQ	17.8	9.16	7.8	0.50	71	97	11	1590	5	5	2
1993	7	UQ	18.8	9.65	9.4	0.80	150	175	15	2330	15	45	14
1993	8	n	14	14	14	14	14	14	14	14	14	14	14
1993	8	Median	18.9	8.93	7.6	0.73	85	137	19	1790	14	32	8
1993	8	Mean	18.9	8.80	7.0	0.67	100	141	19	1786	15	174	17
1993	8	LQ	17.4	8.55	5.1	0.50	72	100	14	1490	10	5	2
1993	8	UQ	20.7	9.12	8.7	0.80	125	159	22	2250	16	332	25
1993	9	n	14	14	14	14	14	14	14	14	14	14	14
1993	9	Median	18.1	7.99	6.2	1.05	34	105	18	1785	127	662	17
1993	9	Mean	17.7	7.92	5.9	0.99	63	114	18	2482	127	1254	131
1993	9	LQ	14.9	7.29	4.2	0.80	18	79	14	1595	35	473	6
1993	9	UQ	20.6	8.45	8.0	1.20	58	122	19	2740	178	1013	42
1994	6	n	14	14	14	14	14	14	14	14	14	14	14
1994	6	Median	16.9	9.55	9.8	0.73	103	86	5	1525	5	8	4

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1994	6	Mean	17.0	9.55	10.0	0.71	134	81	6	1846	5	10	4
1994	6	LQ	15.7	9.25	9.5	0.60	69	60	5	1020	5	5	3
1994	6	UQ	18.1	9.92	10.9	0.80	187	94	7	2330	5	12	5
1994	7	n	11	11	11	10	11	11	11	11	11	11	11
1994	7	Median	20.8	9.93	8.4	1.03	109	159	33	2010	11	13	9
1994	7	Mean	21.1	9.71	7.7	0.86	149	150	44	2239	16	54	20
1994	7	LQ	19.2	9.29	6.7	0.50	68	117	26	1698	8	5	4
1994	7	UQ	23.3	10.04	8.6	1.10	212	181	68	2693	14	46	24
1994	8	n	15	15	15	14	15	15	15	15	15	15	14
1994	8	Median	21.4	8.72	6.2	0.40	56	143	12	1940	5	20	6
1994	8	Mean	21.3	8.82	5.9	0.44	61	152	14	1957	19	45	12
1994	8	LQ	21.1	8.60	5.3	0.40	52	133	10	1740	5	10	2
1994	8	UQ	22.1	9.14	6.5	0.50	68	176	16	2185	22	45	9
1994	9	n	15	15	15	15	19	20	20	20	20	21	15
1994	9	Median	18.7	8.15	7.8	0.40	40	119	10	1435	5	19	1
1994	9	Mean	17.8	8.12	7.9	0.38	39	119	10	1471	9	44	1
1994	9	LQ	15.6	7.97	7.2	0.33	30	114	9	1370	5	15	1
1994	9	UQ	19.3	8.30	8.5	0.40	48	125	11	1580	8	44	2
1995	6	n	14	14	14	14	14	14	14	14	14	14	14
1995	6	Median	17.0	9.59	10.2	0.64	200	126	12	2110	10	9	6
1995	6	Mean	17.4	9.60	9.8	0.60	274	178	13	2870	12	27	16
1995	6	LQ	15.2	9.52	9.5	0.49	179	111	8	1850	5	5	2
1995	6	UQ	19.3	9.69	10.7	0.80	249	158	16	3020	17	25	17
1995	7	n	14	14	14	14	14	14	14	14	14	14	14
1995	7	Median	21.0	9.66	8.8	0.58	150	165	48	2300	5	5	4
1995	7	Mean	20.8	9.65	8.5	0.59	165	167	47	2404	21	43	21
1995	7	LQ	19.7	9.43	8.4	0.46	114	139	30	2005	5	5	3
1995	7	UQ	21.8	9.85	9.2	0.79	205	184	64	2580	5	14	7
1995	8	n	17	17	17	14	14	14	14	14	14	14	14
1995	8	Median	20.2	9.59	8.8	0.69	144	175	66	2623	5	29	17
1995	8	Mean	19.9	9.54	8.3	0.70	142	197	66	2716	5	84	41
1995	8	LQ	19.0	9.35	7.7	0.41	79	145	59	2200	5	11	8
1995	8	UQ	20.8	9.74	9.7	1.02	187	186	76	3115	5	146	66
1995	9	n	14	14	14	14	14	14	14	14	14	14	14
1995	9	Median	18.5	9.33	8.1	0.59	155	287	92	3393	5	42	19
1995	9	Mean	18.7	9.27	7.4	0.65	152	288	98	3337	5	189	47
1995	9	LQ	18.4	9.01	5.2	0.46	120	206	75	2555	5	18	9
1995	9	UQ	18.9	9.53	9.3	0.84	198	341	127	4220	5	330	75
1996	6	n	10	10	10	5	10	10	10	10	10	10	10
1996	6	Median	17.6	8.60	8.2	0.80	54	59	8	870	5	233	36
1996	6	Mean	17.9	8.63	8.4	0.83	61	63	8	972	8	274	67
1996	6	LQ	16.6	8.21	7.8	0.73	30	52	7	750	5	63	4
1996	6	UQ	19.3	9.09	9.1	0.94	95	66	8	1170	5	489	113
1996	7	n	10	10	10	8	10	10	10	10	10	10	10

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1996	7	Median	21.7	9.42	9.0	0.84	139	115	6	1740	5	194	97
1996	7	Mean	22.2	9.43	9.2	0.80	155	118	7	1850	5	266	123
1996	7	LQ	21.0	9.31	8.5	0.57	100	102	6	1580	5	31	20
1996	7	UQ	23.5	9.50	9.7	1.05	199	124	7	1870	5	482	227
1996	8	n	10	10	10	7	10	10	10	10	10	10	10
1996	8	Median	20.3	8.94	7.0	0.76	94	189	59	2165	26	243	74
1996	8	Mean	20.2	9.00	7.2	0.83	107	181	66	2129	43	451	94
1996	8	LQ	19.5	8.70	6.0	0.64	60	166	50	1910	22	122	54
1996	8	UQ	20.5	9.37	8.8	1.09	154	202	89	2440	51	791	129
1996	9	n	10	10	10	8	10	10	10	10	10	10	10
1996	9	Median	15.8	8.80	7.9	1.13	84	183	71	2010	21	181	27
1996	9	Mean	16.3	8.81	8.1	1.15	116	190	74	2142	36	211	28
1996	9	LQ	14.8	8.65	7.1	0.80	69	165	61	1780	5	47	14
1996	9	UQ	18.7	9.05	9.2	1.34	119	214	78	2350	48	324	41
1997	6	n	7	7	7	6	7	7	7	7	7	7	7
1997	6	Median	18.9	9.55	9.6	0.50	197	123	9	2190	5	298	164
1997	6	Mean	18.7	9.50	9.5	0.52	219	134	9	2312	5	395	219
1997	6	LQ	18.5	9.37	8.5	0.40	182	101	7	1984	5	272	154
1997	6	UQ	19.0	9.63	10.5	0.70	211	151	11	2463	5	518	240
1997	7	n	23	23	23	21	23	23	23	23	23	23	23
1997	7	Median	21.1	9.54	9.1	0.51	190	225	56	2240	5	1680	665
1997	7	Mean	20.0	9.53	8.5	0.54	267	271	57	2782	7	1666	912
1997	7	LQ	17.1	9.30	6.3	0.32	130	184	27	1895	5	774	401
1997	7	UQ	21.8	9.76	10.2	0.80	291	319	82	3248	5	1938	1452
1997	8	n	16	16	16	16	16	16	16	16	16	16	16
1997	8	Median	20.3	8.55	6.6	1.15	64	243	113	2650	47	854	73
1997	8	Mean	20.4	8.40	6.8	1.08	131	270	117	3277	55	836	144
1997	8	LQ	19.4	7.80	5.2	0.88	34	202	83	2355	23	619	20
1997	8	UQ	21.2	8.82	7.7	1.30	115	281	147	3170	85	980	139
1997	9	n	16	16	16	16	16	16	16	16	16	16	16
1997	9	Median	17.5	9.29	10.4	0.85	155	206	69	2065	5	597	233
1997	9	Mean	17.2	9.28	10.5	0.90	173	220	68	2337	6	758	302
1997	9	LQ	15.1	9.20	9.4	0.68	59	165	58	1665	5	472	151
1997	9	UQ	19.2	9.40	11.9	1.18	227	277	82	2945	5	902	396
1998	6	n	24	24	24	24	24	24	24	24	24	24	24
1998	6	Median	17.4	8.86	9.7	1.18	45	62	6	907	5	303	55
1998	6	Mean	17.3	8.87	9.6	1.13	63	83	8	1124	5	360	94
1998	6	LQ	15.6	8.71	9.2	0.93	35	50	5	828	5	187	30
1998	6	UQ	19.3	9.01	10.1	1.25	78	101	9	1323	5	454	103
1998	7	n	15	15	15	15	15	15	15	15	15	15	15
1998	7	Median	23.9	9.39	8.1	0.75	172	194	49	2330	5	963	451
1998	7	Mean	23.3	9.34	8.0	0.82	192	207	41	2501	5	957	499
1998	7	LQ	22.2	9.13	6.2	0.55	125	159	4	2071	5	648	353
1998	7	UQ	24.5	9.49	10.1	0.94	243	258	73	2663	5	1174	647

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1998	8	n	16	16	16	16	16	16	16	16	16	16	16
1998	8	Median	21.7	8.15	6.8	1.82	13	225	112	2220	55	1005	59
1998	8	Mean	21.7	8.12	6.6	1.55	82	247	113	2556	62	1122	128
1998	8	LQ	20.4	7.79	3.5	1.14	6	191	80	2065	16	826	22
1998	8	UQ	23.2	8.23	8.5	2.00	50	249	147	2475	80	1090	71
1998	9	n	16	16	16	16	16	16	16	16	16	16	16
1998	9	Median	18.9	9.28	10.0	1.01	93	182	56	1848	5	288	89
1998	9	Mean	18.7	9.20	9.5	0.91	115	198	63	1884	6	280	107
1998	9	LQ	15.3	9.04	8.7	0.73	72	162	49	1490	5	24	8
1998	9	UQ	21.8	9.38	10.5	1.13	156	222	71	2230	5	501	183
1999	6	n	16	16	16	16	16	16	16	16	16	16	16
1999	6	Median	16.8	8.76	10.1	1.05	46	88	12	1113	5	239	33
1999	6	Mean	16.9	8.83	10.5	0.93	95	112	14	1361	5	275	89
1999	6	LQ	14.3	8.26	9.1	0.70	23	74	7	751	5	153	9
1999	6	UQ	19.4	9.39	11.4	1.09	127	119	21	1930	5	310	132
1999	7	n	15	15	15	15	15	15	15	15	15	15	15
1999	7	Median	20.1	9.82	9.1	0.57	223	178	29	2310	5	233	162
1999	7	Mean	19.5	9.80	9.1	0.63	224	194	28	2719	10	393	280
1999	7	LQ	18.3	9.65	8.7	0.32	125	138	5	1913	5	151	108
1999	7	UQ	20.8	9.90	10.3	0.87	299	223	49	3378	15	549	372
1999	8	n	16	16	16	16	16	16	16	16	16	16	16
1999	8	Median	21.1	9.42	7.6	0.74	143	235	81	2405	11	165	68
1999	8	Mean	21.1	9.43	7.6	0.74	183	285	80	2626	13	432	246
1999	8	LQ	20.1	9.30	6.1	0.53	76	187	75	1855	5	61	27
1999	8	UQ	22.3	9.58	8.9	1.02	233	358	85	3040	14	641	359
1999	9	n	24	24	24	24	24	24	24	24	24	24	24
1999	9	Median	17.1	8.74	8.6	1.15	47	191	67	2020	43	364	33
1999	9	Mean	16.4	8.70	8.5	0.99	74	209	79	2244	46	405	58
1999	9	LQ	14.7	8.42	6.9	0.65	24	152	52	1805	16	92	13
1999	9	UQ	18.0	9.00	10.4	1.30	98	216	114	2400	61	741	58
2000	6	n	16	16	16	16	16	16	16	16	16	16	16
2000	6	Median	20.5	9.81	9.4	0.61	183	173	9	2275	14	734	541
2000	6	Mean	20.1	9.77	9.1	0.66	203	185	22	2323	18	930	618
2000	6	LQ	17.6	9.60	8.0	0.43	106	124	7	1603	5	607	436
2000	6	UQ	21.9	9.98	10.2	0.88	271	227	33	2948	22	1355	718
2000	7	n	16	16	16	16	16	16	16	16	16	16	16
2000	7	Median	21.1	9.64	7.5	0.99	97	228	92	1605	10	521	315
2000	7	Mean	20.9	9.64	7.5	0.90	165	369	91	2012	10	707	477
2000	7	LQ	20.2	9.45	6.9	0.55	70	206	88	1390	10	368	229
2000	7	UQ	21.6	9.82	8.2	1.22	189	321	97	2295	10	927	481
2000	8	n	16	16	16	10	16	16	16	16	16	16	16
2000	8	Median	21.5	8.49	4.5	1.35	21	226	141	2278	67	870	79
2000	8	Mean	21.3	8.52	4.6	1.44	34	225	129	2240	76	778	92
2000	8	LQ	18.5	8.34	2.9	1.20	17	184	118	1920	19	570	58

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2000	8	UQ	23.5	8.68	6.1	1.75	37	263	158	2460	134	971	125
2000	9	n	16	16	16	16	16	16	16	16	16	16	16
2000	9	Median	16.7	9.10	8.6	0.80	116	189	67	1680	18	484	116
2000	9	Mean	16.5	9.08	8.4	0.87	135	182	65	1900	24	496	150
2000	9	LQ	14.3	8.92	7.4	0.69	69	164	51	1445	13	358	80
2000	9	UQ	18.7	9.29	9.8	1.14	171	201	76	2160	29	605	188
2001	6	n	16	16	16	16	16	16	16	16	16	16	16
2001	6	Median	16.6	9.62	9.3	0.57	160	132	7	2490	5	502	258
2001	6	Mean	16.9	9.59	9.4	0.60	187	145	7	2566	5	499	270
2001	6	LQ	15.9	9.49	8.8	0.54	134	102	6	1900	5	254	161
2001	6	UQ	17.6	9.71	9.6	0.73	234	163	7	2943	5	645	333
2001	7	n	24	24	24	24	24	24	24	24	24	24	24
2001	7	Median	19.7	9.68	7.9	0.73	194	248	59	3340	13	623	356
2001	7	Mean	19.6	9.68	8.2	0.74	201	234	45	3330	13	614	384
2001	7	LQ	19.2	9.55	7.3	0.55	135	179	12	2545	12	348	268
2001	7	UQ	19.9	9.83	9.4	0.93	241	280	66	3890	15	716	482
2001	8	n	16	16	16	16	16	16	16	16	16	16	16
2001	8	Median	22.2	8.94	5.5	0.85	75	227	71	3120	8	861	231
2001	8	Mean	21.5	8.91	5.4	0.95	85	239	67	3388	11	934	253
2001	8	LQ	19.8	8.75	3.6	0.61	41	175	32	2863	5	677	138
2001	8	UQ	22.9	9.14	8.1	1.31	120	303	99	3820	15	1115	363
2001	9	n	16	16	16	16	16	16	16	16	16	16	16
2001	9	Median	16.7	8.74	6.7	1.09	83	165	31	2765	13	970	94
2001	9	Mean	16.8	8.49	6.1	1.03	103	168	36	2894	18	879	142
2001	9	LQ	16.0	7.91	3.7	0.75	60	132	17	2285	12	420	20
2001	9	UQ	17.8	8.99	8.0	1.33	140	196	58	3690	25	1165	103
2002	6	n	16	16	16	16	16	16	16	16	16	16	16
2002	6	Median	19.5	9.25	9.2	0.72	142	101	7	1848	6	249	125
2002	6	Mean	19.4	9.23	9.7	0.76	168	122	7	1786	8	382	192
2002	6	LQ	17.5	9.08	8.5	0.56	90	74	6	1383	5	44	9
2002	6	UQ	20.7	9.43	11.2	1.04	209	128	9	2155	10	660	350
2002	7	n	16	16	16	16	16	16	16	16	16	16	16
2002	7	Median	21.8	9.61	7.3	0.75	148	178	41	2435	11	399	266
2002	7	Mean	21.7	9.58	7.2	0.78	139	190	42	2345	18	417	261
2002	7	LQ	21.0	9.50	6.0	0.59	82	160	30	2130	10	322	189
2002	7	UQ	22.7	9.69	8.4	0.97	186	208	55	2600	13	511	333
2002	8	n	16	16	16	16	16	16	16	16	16	16	16
2002	8	Median	19.6	8.96	8.4	0.85	77	174	39	2745	55	585	112
2002	8	Mean	19.8	8.85	8.0	0.96	90	206	47	2830	71	591	153
2002	8	LQ	18.6	8.59	6.7	0.69	40	158	31	2285	11	439	58
2002	8	UQ	20.8	9.21	9.7	1.21	135	250	62	2963	88	701	218
2002	9	n	16	16	8	16	16	16	16	16	16	16	16
2002	9	Median	16.5	9.27	8.9	0.89	98	190	46	2653	12	310	87
2002	9	Mean	16.5	9.24	8.1	0.93	111	214	45	2923	13	337	121

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2002	9	LQ	15.9	9.12	6.9	0.69	78	151	32	2270	11	206	64
2002	9	UQ	17.1	9.43	9.0	1.10	136	267	58	3600	13	449	166
2003	6	n	16	16	16	16	16	16	16	16	16	16	16
2003	6	Median	20.1	8.40	8.0	1.24	16	91	19	1000	15	70	5
2003	6	Mean	20.0	8.40	8.2	1.16	29	102	17	1187	36	62	8
2003	6	LQ	19.1	8.15	7.7	0.99	12	69	12	794	12	54	2
2003	6	UQ	20.6	8.59	8.2	1.28	34	113	21	1508	63	76	10
2003	7	n	24	24	24	24	24	24	24	24	24	24	24
2003	7	Median	22.5	9.50	8.4	0.69	83	212	45	2785	9	380	73
2003	7	Mean	22.7	9.34	7.4	0.80	108	213	54	2844	9	449	218
2003	7	LQ	20.9	9.37	6.2	0.56	50	142	5	2235	5	24	14
2003	7	UQ	24.5	9.57	9.5	0.99	148	280	86	3325	12	720	285
2003	8	n	16	16	16	16	16	16	16	16	16	16	16
2003	8	Median	20.5	9.51	8.5	0.58	176	262	74	3045	14	16	8
2003	8	Mean	20.4	9.51	8.3	0.60	168	275	75	3124	14	43	17
2003	8	LQ	20.1	9.44	7.9	0.48	140	235	69	2870	5	11	7
2003	8	UQ	20.7	9.62	8.9	0.67	201	307	80	3505	19	23	13
2003	9	n	16	16	16	16	16	16	16	16	16	16	16
2003	9	Median	17.1	9.40	7.2	0.69	94	217	64	2480	17	151	30
2003	9	Mean	17.0	9.34	7.6	0.69	139	272	59	3065	29	178	70
2003	9	LQ	16.4	9.11	5.9	0.42	75	181	32	2048	12	34	15
2003	9	UQ	17.6	9.58	9.0	0.87	118	290	74	3060	42	241	109
2004	6	n	16	16	16	16	16	16	16	16	16	16	16
2004	6	Median	17.4	9.31	9.0	0.96	66	70	8	1325	5	22	4
2004	6	Mean	17.4	9.25	9.3	0.83	90	95	8	1448	7	27	11
2004	6	LQ	14.6	8.85	8.7	0.71	40	61	7	1035	5	13	3
2004	6	UQ	20.0	9.60	9.8	1.00	109	101	10	1570	10	36	8
2004	7	n	16	16	16	16	16	16	16	16	16	16	16
2004	7	Median	21.7	9.63	7.4	0.66	132	173	31	2120	16	22	13
2004	7	Mean	21.7	9.63	7.1	0.72	188	188	29	2457	26	33	20
2004	7	LQ	21.0	9.54	6.4	0.49	104	132	14	1745	10	12	9
2004	7	UQ	22.7	9.72	8.1	0.76	211	195	41	2525	41	38	24
2004	8	n	16	16	16	16	16	16	16	16	16	16	16
2004	8	Median	21.9	9.03	5.9	0.95	81	178	56	2450	30	159	37
2004	8	Mean	22.0	9.03	5.7	1.02	77	191	66	2410	35	206	49
2004	8	LQ	21.2	8.86	4.2	0.76	29	170	48	2130	20	43	19
2004	8	UQ	23.0	9.35	6.8	1.26	108	195	89	2660	42	342	82
2004	9	n	24	24	24	24	24	24	24	24	24	24	24
2004	9	Median	16.2	9.14	8.5	1.04	51	141	25	2030	15	105	25
2004	9	Mean	17.2	9.11	8.5	0.96	82	155	27	2447	17	227	59
2004	9	LQ	15.6	8.99	7.8	0.84	16	122	11	1860	9	23	9
2004	9	UQ	19.4	9.26	9.2	1.13	74	178	33	2575	20	418	107
2005	6	n	19	19	19	16	19	19	19	19	19	19	19
2005	6	Median	15.9	9.07	9.7	0.97	61	84	6	1410	5	27	4

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2005	6	Mean	15.7	8.96	9.7	0.87	59	93	7	1404	9	25	6
2005	6	LQ	14.5	8.73	9.5	0.75	29	63	5	990	5	15	2
2005	6	UQ	16.7	9.22	10.2	1.11	72	114	7	1815	11	33	11
2005	7	n	18	18	18	16	17	18	18	18	18	18	18
2005	7	Median	22.0	9.45	7.2	1.02	59	176	36	2090	8	69	37
2005	7	Mean	22.4	9.41	6.8	1.04	76	184	37	2432	10	111	49
2005	7	LQ	21.1	9.23	5.8	0.58	20	124	8	1890	5	15	10
2005	7	UQ	23.7	9.60	8.1	1.40	102	260	53	3150	14	137	74
2005	8	n	25	25	25	23	24	25	25	25	25	25	25
2005	8	Median	21.1	9.33	7.6	0.88	108	195	52	2470	13	19	9
2005	8	Mean	20.9	9.16	7.3	0.94	131	205	56	2836	18	128	21
2005	8	LQ	19.2	9.06	6.6	0.64	55	151	33	2048	5	9	5
2005	8	UQ	22.4	9.48	8.6	1.22	172	228	71	3418	26	133	31
2005	9	n	18	18	18	16	18	18	18	18	18	18	18
2005	9	Median	14.1	8.90	8.1	0.72	140	194	41	2870	10	58	8
2005	9	Mean	14.2	8.92	8.1	0.79	137	198	40	2978	11	92	14
2005	9	LQ	13.2	8.79	7.3	0.67	89	162	27	2510	5	23	5
2005	9	UQ	15.1	9.07	8.8	0.97	169	237	52	3290	14	113	19
2006	6	n	16	16	16	16	16	16	16	16	16	16	16
2006	6	Median	18.3	7.99	7.2	1.61	12	54	15	715	23	53	2
2006	6	Mean	18.1	7.99	7.3	1.59	13	74	15	793	23	58	2
2006	6	LQ	17.5	7.75	7.0	1.46	6	50	13	674	19	47	1
2006	6	UQ	18.7	8.22	7.8	1.73	20	59	18	919	27	73	3
2006	7	n	24	24	24	24	24	24	24	24	24	24	24
2006	7	Median	22.2	9.33	7.4	0.88	112	188	48	2065	20	102	32
2006	7	Mean	22.2	9.11	7.1	0.94	111	212	60	2192	41	289	56
2006	7	LQ	21.6	8.81	5.3	0.73	37	135	7	1825	5	41	25
2006	7	UQ	22.8	9.53	9.2	1.21	137	243	116	2340	62	534	66
2006	8	n	16	16	16	16	16	16	16	16	16	16	16
2006	8	Median	20.7	9.71	8.3	0.71	99	246	95	3160	5	30	18
2006	8	Mean	20.7	9.75	8.5	0.66	147	269	90	3386	5	119	71
2006	8	LQ	20.1	9.37	7.7	0.40	76	198	69	1975	5	14	9
2006	8	UQ	21.2	10.17	9.7	0.91	177	293	105	4565	5	79	55
2006	9	n	16	16	16	12	16	16	16	16	16	16	16
2006	9	Median	16.9	9.98	10.0	0.60	143	255	94	2500	5	62	37
2006	9	Mean	16.7	9.99	9.8	0.58	200	287	94	3389	5	95	71
2006	9	LQ	14.1	9.80	8.3	0.32	89	231	77	2385	5	27	17
2006	9	UQ	19.0	10.16	11.3	0.84	224	300	100	3515	5	147	100
2007	6	n	16	16	16	16	16	16	16	16	16	16	16
2007	6	Median	17.8	8.93	8.6	1.19	28	116	36	899	5	20	3
2007	6	Mean	17.9	8.81	8.4	1.18	51	127	33	1101	30	28	4
2007	6	LQ	16.6	8.58	7.4	1.01	13	92	16	800	5	9	2
2007	6	UQ	19.0	9.04	9.6	1.46	57	123	48	1070	63	45	5
2007	7	n	24	24	24	24	24	24	24	24	24	24	24

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2007	7	Median	21.8	9.92	7.3	0.62	141	303	111	3065	5	23	18
2007	7	Mean	21.5	9.92	7.3	0.60	160	312	94	3013	8	52	40
2007	7	LQ	20.1	9.88	5.9	0.40	101	255	28	2355	5	5	4
2007	7	UQ	22.6	10.01	8.7	0.75	223	361	134	3660	13	69	51
2007	8	n	16	16	16	16	16	16	16	16	16	16	16
2007	8	Median	20.3	9.39	7.3	0.61	122	256	106	2660	5	32	20
2007	8	Mean	20.2	9.41	6.5	0.62	135	293	101	3244	9	100	43
2007	8	LQ	19.5	9.26	5.0	0.44	68	236	88	2415	5	20	12
2007	8	UQ	21.0	9.57	7.7	0.84	203	304	116	3935	12	198	77
2007	9	n	16	16	16	16	8	16	16	16	16	16	16
2007	9	Median	15.0	9.23	9.2	0.66	88	199	50	2666	13	295	74
2007	9	Mean	15.4	9.18	8.4	0.63	123	209	63	2873	16	343	75
2007	9	LQ	12.5	9.04	7.4	0.51	85	178	39	2414	5	77	33
2007	9	UQ	18.5	9.34	9.5	0.74	151	245	84	3172	20	482	116
2008	6	n	23	23	23	23	23	23	23	23	23	23	23
2008	6	Median	17.8	8.95	9.2	1.03	48	77	18	1120	4	25	5
2008	6	Mean	18.3	8.82	9.2	1.00	67	102	19	1488	13	30	8
2008	6	LQ	15.2	8.05	8.2	0.71	14	59	17	737	4	20	1
2008	6	UQ	21.3	9.51	10.2	1.34	94	121	22	1903	18	36	14
2008	7	n	16	16	16	16	16	16	16	16	16	16	16
2008	7	Median	21.2	9.61	8.0	0.73	160	200	54	2600	7	20	14
2008	7	Mean	21.3	9.60	8.0	0.66	261	200	58	2604	7	93	43
2008	7	LQ	20.6	9.43	6.8	0.50	131	164	42	1855	4	17	12
2008	7	UQ	21.4	9.79	9.2	0.89	260	231	69	3035	10	77	49
2008	8	n	16	16	16	16	16	16	16	16	16	16	16
2008	8	Median	20.2	9.27	7.2	0.80	102	230	94	2870	9	153	68
2008	8	Mean	20.3	9.26	7.2	0.78	141	268	93	2892	10	190	61
2008	8	LQ	19.6	9.15	6.6	0.70	62	210	82	2070	4	25	12
2008	8	UQ	21.0	9.44	8.4	0.94	191	298	109	3405	13	287	100
2008	9	n	16	16	16	16	16	16	16	16	16	16	16
2008	9	Median	16.6	9.31	8.4	0.70	98	198	66	2475	10	35	12
2008	9	Mean	16.5	9.16	7.4	0.71	155	253	72	3116	11	314	30
2008	9	LQ	15.6	9.04	6.0	0.62	64	181	54	2055	9	23	10
2008	9	UQ	17.5	9.48	9.1	0.89	159	267	85	3255	12	152	32
2009	6	n	24	24	24	24	23	24	24	24	24	24	24
2009	6	Median	18.4	9.29	8.4	0.86	95	68	6	1670	4	19	8
2009	6	Mean	19.0	9.09	8.3	0.90	136	82	6	1735	5	26	9
2009	6	LQ	18.1	8.77	7.5	0.74	60	46	4	987	4	13	2
2009	6	UQ	19.7	9.42	9.0	1.10	176	99	7	1990	4	29	11
2009	7	n	16	16	16	16	16	16	16	16	16	16	16
2009	7	Median	21.8	8.47	5.7	1.51	45	160	60	2175	21	456	36
2009	7	Mean	21.8	8.34	5.7	1.61	50	157	72	2081	29	559	41
2009	7	LQ	19.7	7.63	4.6	1.09	16	136	41	1740	13	248	14
2009	7	UQ	23.6	8.92	7.0	2.04	60	171	97	2330	39	903	58

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2009	8	n	15	15	15	16	16	16	16	16	16	16	15
2009	8	Median	19.6	9.69	8.9	0.68	167	192	41	2115	6	22	12
2009	8	Mean	19.5	9.74	8.9	0.62	186	195	48	2353	7	68	47
2009	8	LQ	19.1	9.20	7.9	0.48	132	155	27	1855	4	17	8
2009	8	UQ	20.1	10.25	10.8	0.80	230	213	69	2800	9	35	23
2009	9	n	16	16	16	16	16	16	16	16	16	16	16
2009	9	Median	16.5	9.81	7.8	0.57	175	241	91	2810	4	121	86
2009	9	Mean	16.4	9.77	7.4	0.62	183	251	82	3103	8	266	137
2009	9	LQ	15.8	9.66	6.6	0.48	143	218	69	2470	4	33	23
2009	9	UQ	17.0	9.92	8.2	0.77	223	280	96	3670	10	380	231