# Watson Lake Limno-corral Study: Phase II

# Final

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## Introduction and Methods

To address the issue of periphytic biomass being a contributor to processes within the limno-corrals and within the lake, we used Hester-Dendy (HD) samplers to quantify periphyton chlorophyll *a* levels from 8/16/12 – 10/10/12. City of Prescott Wastewater Operations personnel obtained all the data with the exception of the initial sampling on 8/16/12 which was performed by personnel from the UA/Walker Lab. Samples were collected for periphyton biomass, physico-chemistry (using a YSI multi-probe and sonde), nutrients (ammonia-N, nitrate+nitrite-N, TKN, ortho-P, total-P), aluminum (total and dissolved), total alkalinity, and Secchi disk depth. Physico-chemical samples were collected as a vertical profile from the surface to 0.5m above lake sediment. Samples were collected on 8/16, 8/29, 9/12, 9/26, and 10/10 2012. No periphyton samples were collected on 8/16/12 as the HD samplers needed to remain in the water for 2 weeks before the first sample could be obtained. Water chemistries were collected as a 2 m composite of the photic zone using a sampler provided by ADEQ. All water chemistries were sent to Accutest Analytical Laboratories in Tempe, AZ.

Hester-Dendy (HD) substrate samplers were hung at 0.5 and 3m below the water surface within both limno-corrals at site A and 0.5 and 2m below the water's surface at site B based upon secchi disk depth's taken at the beginning of the project and based upon overall water depth and length of each limno-corral. HD samplers were also hung at the same depths outside of the limnocorrals within the lake at each site. Each round HD plate has a surface area of 1277$cm^2$. The uppermost plate from each HD unit was placed into a wide-mouth plastic jar and preserved with a 4-5% total concentration of formaldehyde for overnight shipping to the UA Environmental Research Laboratory. The next lowest plate was then moved to become the upper-most plate during each sampling event.

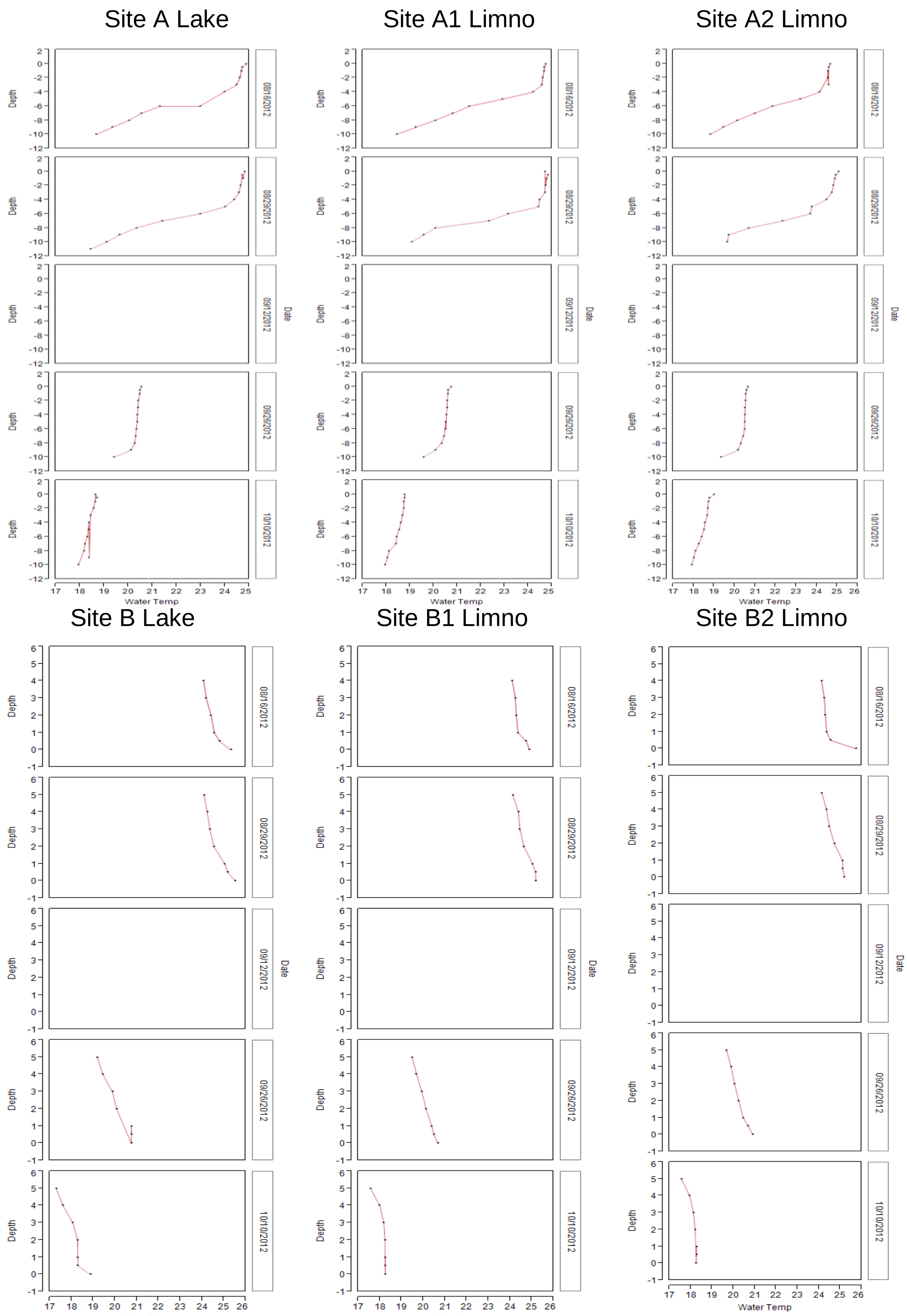
Granular aluminum sulfate was added on 8/15/2012 to the "2" limnocorral at each site (B2Limno and A2Limno) at a rate and initial dosage as the previous study. The "1" limnocorral had no aluminum sulfate added to it (B1Limno and A1Limno).

Data gaps are known. On 9/12/12, the YSI multiprobe sonde owned by City of Prescott was not working so no physico-chemical data was collected on this date. On 8/29/12, the DO probe on the same YSI multiprobe sonde was not working. Some HD samplers were either vandalized or lost to natural causes. On 9/12/12, the HD sampler from 2m in the lake at site B was missing, on 9/26 the HD sampler from 0.5m from within the B2 limnocorral was missing, and on 10/10/12, the HD sampler from within the limnocorral at 2m from site B2 and the HD sampler from 3m with the lake at site A were both missing.

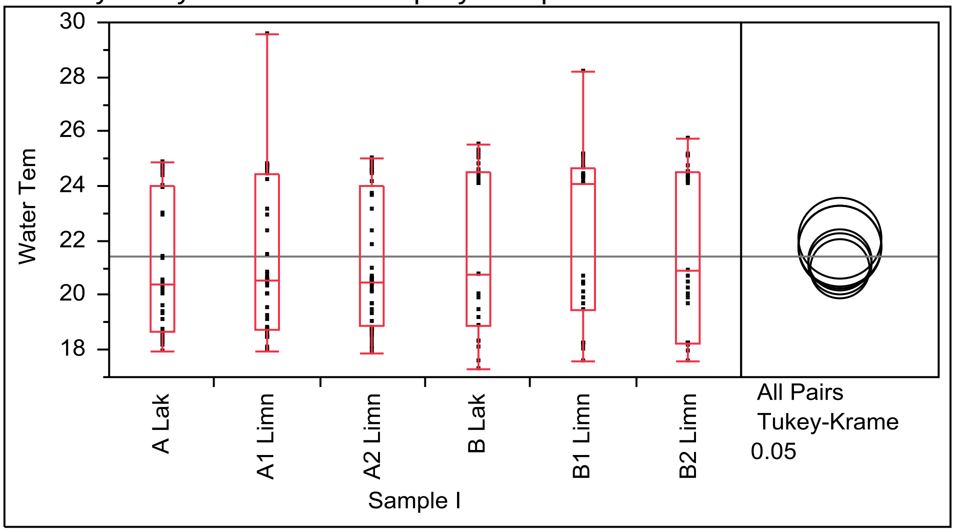
## Results

<u>Physico-Chemical</u>

### Water Temperature X Depth and Date.



Oneway Analysis of Water Temp By Sample ID




**Oneway Anova**
**Summary of Fit**

| | |
|---|---|
| Rsquare | 0.020232 |
| Adj Rsquare | -0.00204 |
| Root Mean Square Error | 2.700477 |
| Mean of Response | 21.41863 |
| Observations (or Sum Wgts) | 226 |

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Sample ID | 5 | 33.1303 | 6.62607 | 0.9086 | 0.4762 |
| Error | 220 | 1604.3671 | 7.29258 | | |
| C. Total | 225 | 1637.4975 | | | |

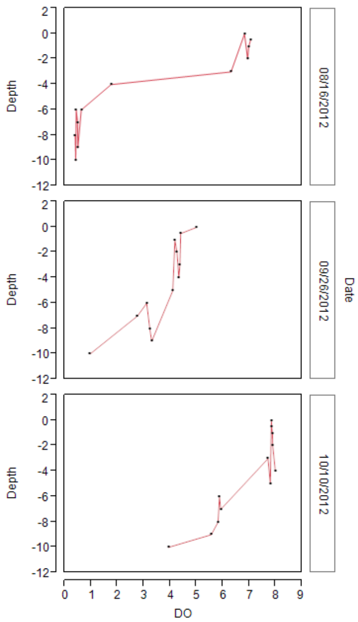
**Means for Oneway Anova**

| Level | Number | Mean | Std Error | Lower 95% | Upper 95% |
|---|---|---|---|---|---|
| A Lake | 49 | 20.9753 | 0.38578 | 20.215 | 21.736 |
| A1 Limno | 48 | 21.3315 | 0.38978 | 20.563 | 22.100 |
| A2 Limno | 48 | 21.1610 | 0.38978 | 20.393 | 21.929 |
| B Lake | 27 | 21.7630 | 0.51971 | 20.739 | 22.787 |
| B1 Limno | 27 | 22.1044 | 0.51971 | 21.080 | 23.129 |
| B2 Limno | 27 | 21.8059 | 0.51971 | 20.782 | 22.830 |

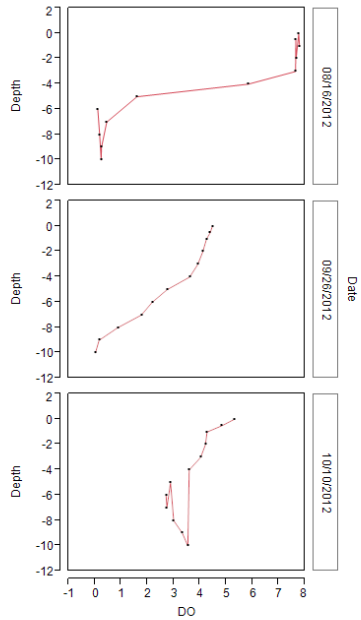
Both the limno-corrals and the lake were thermally stratified at the beginning of the project through 8/29/12. Following this, the lake at this site became mixed. Site B, being much shallower, did not show signs of thermal stratification. There was no significant difference in temperature between any lake site or limno-corral.

Dissolved Oxygen (mg/L) by Depth and Date

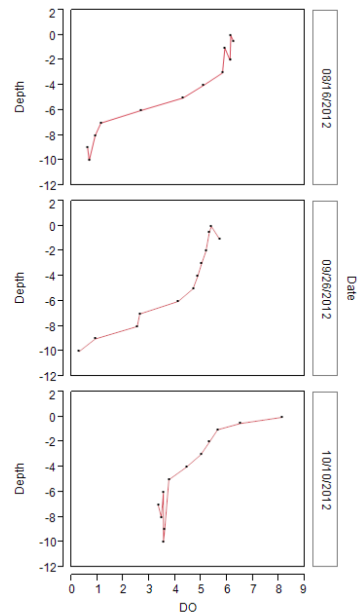
Site A Lake



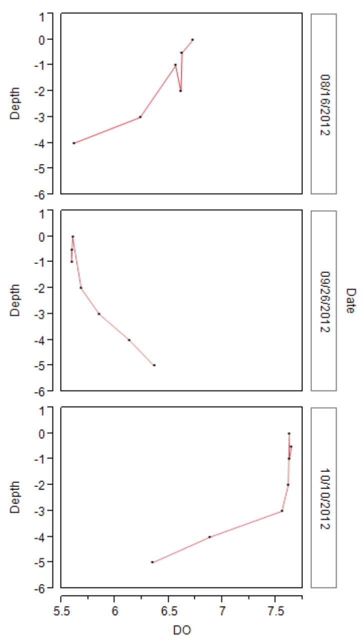

Site A1 Limno



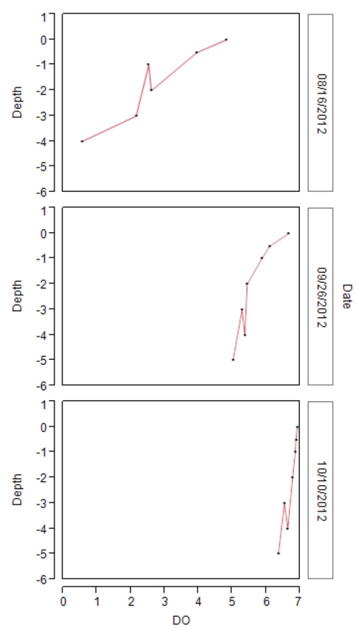

Site A2 Limno



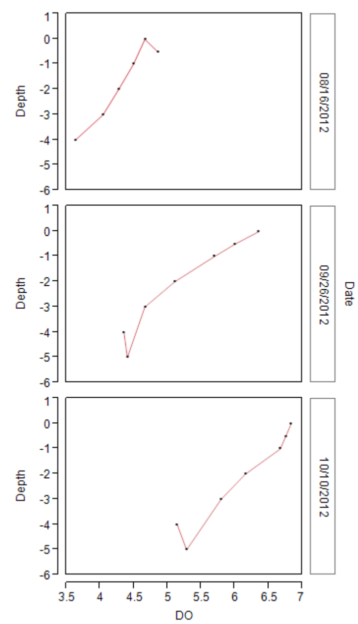

Site B Lake



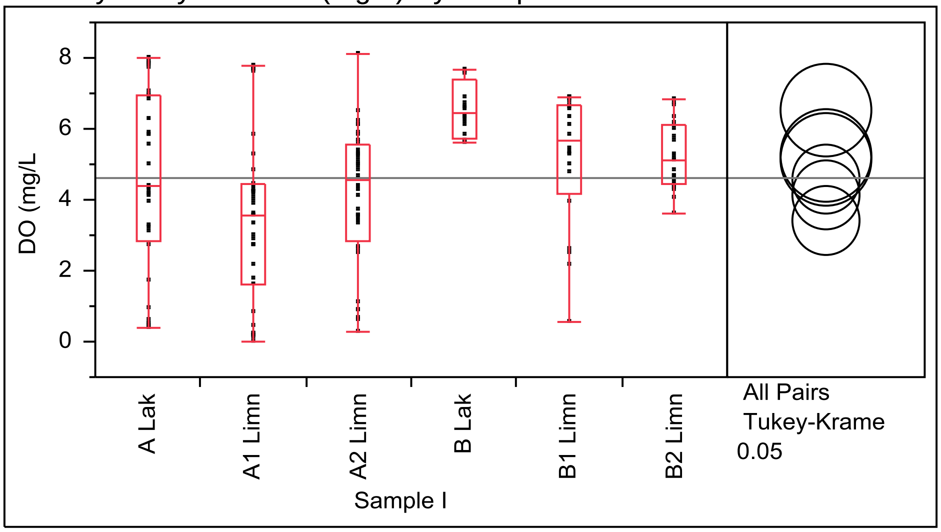

Site B1 Limno




Site B2 Limno



Oneway Analysis of DO (mg/L) By Sample ID




**Oneway Anova**
**Summary of Fit**

| | |
|---|---|
| Rsquare | 0.180542 |
| Adj Rsquare | 0.155251 |
| Root Mean Square Error | 2.020997 |
| Mean of Response | 4.6125 |
| Observations (or Sum Wgts) | 168 |

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Sample ID | 5 | 145.78041 | 29.1561 | 7.1383 | <.0001* |
| Error | 162 | 661.67754 | 4.0844 | | |
| C. Total | 167 | 807.45795 | | | |

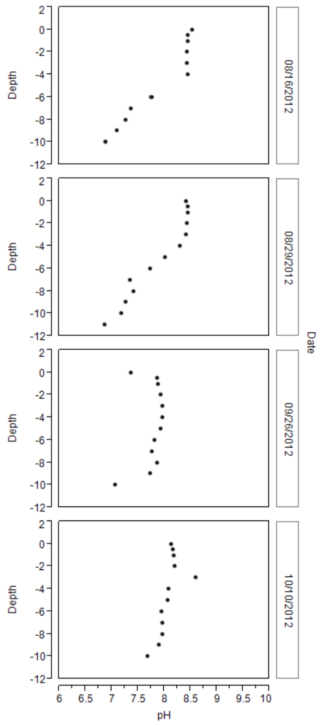
**Means for Oneway Anova**

| Level | Number | Mean | Std Error | Lower 95% | Upper 95% |
|---|---|---|---|---|---|
| A Lake | 36 | 4.56778 | 0.33683 | 3.9026 | 5.2329 |
| A1 Limno | 36 | 3.43750 | 0.33683 | 2.7724 | 4.1026 |
| A2 Limno | 36 | 4.11250 | 0.33683 | 3.4474 | 4.7776 |
| B Lake | 20 | 6.52050 | 0.45191 | 5.6281 | 7.4129 |
| B1 Limno | 20 | 5.15750 | 0.45191 | 4.2651 | 6.0499 |
| B2 Limno | 20 | 5.25500 | 0.45191 | 4.3626 | 6.1474 |

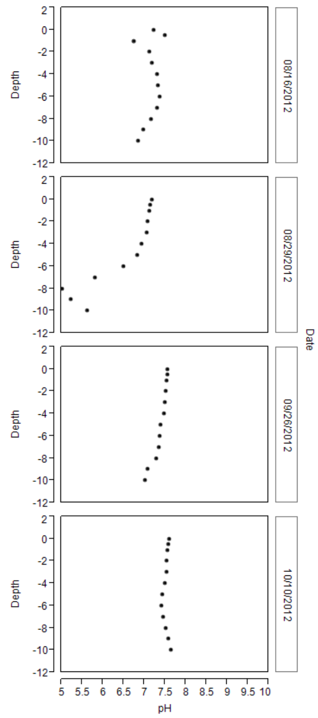
The limno-corrals at Site A mirrored DO losses at depth within the lake after ~ 3-4 meters. The lake and limno-corrals at Site A were both anoxic under the thermocline at the beginning of the project becoming more mixed as time went by. Site B did not have the same loss of DO with depth as did site A. Site B1 had the most DO loss with depth. It is unclear as to why but it could have been due to decomposing vegetation trapped in the bottom of this limno-corral and subsequent decomposition.

pH (SU) by Date and Depth

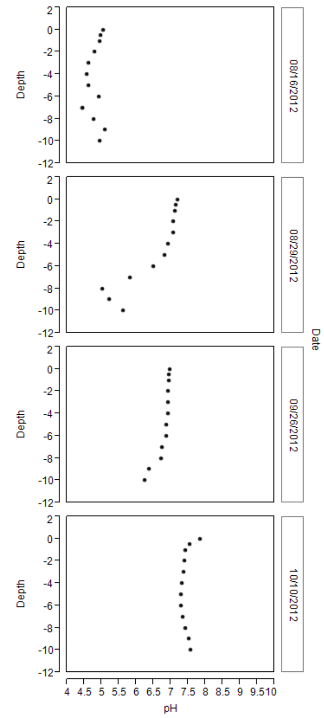
Site A Lake



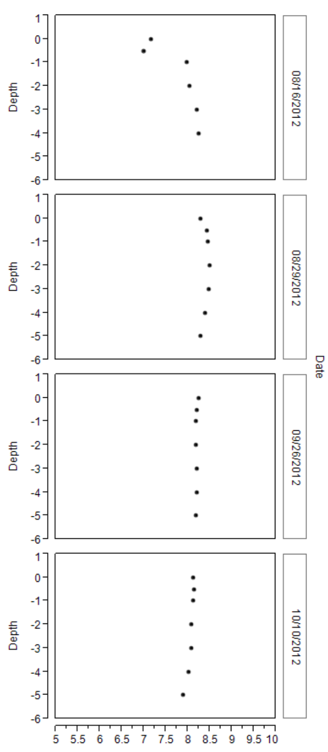

Site A1 Limno



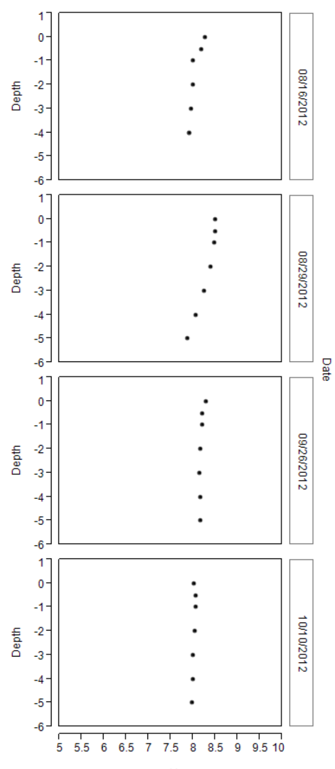

Site A2 Limno



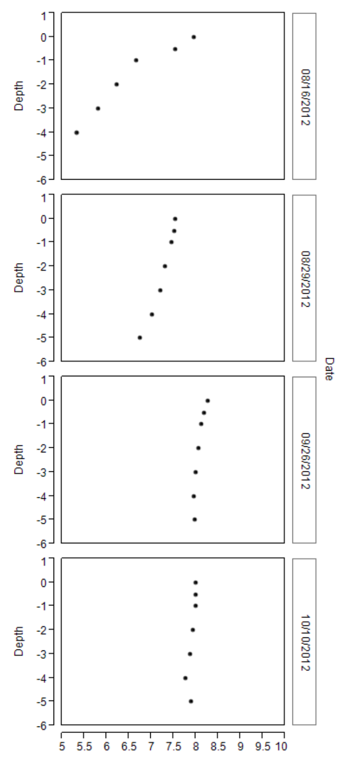

Site B Lake



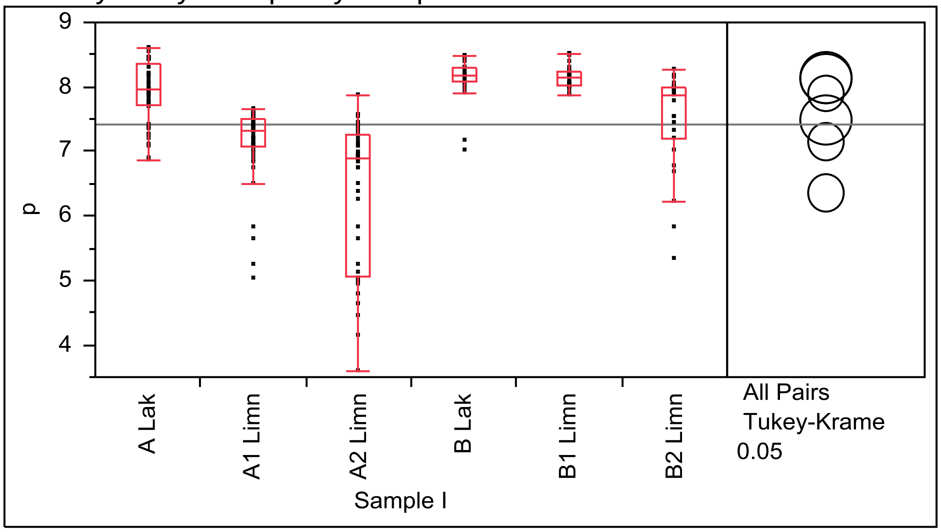

Site B1 Limno




Site B2 Limno



Oneway Analysis of pH By Sample ID




**Oneway Anova**
**Summary of Fit**

| | |
|---|---|
| Rsquare | 0.480736 |
| Adj Rsquare | 0.468935 |
| Root Mean Square Error | 0.695703 |
| Mean of Response | 7.416903 |
| Observations (or Sum Wgts) | 226 |

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Sample ID | 5 | 98.58000 | 19.7160 | 40.7354 | <.0001* |
| Error | 220 | 106.48044 | 0.4840 | | |
| C. Total | 225 | 205.06043 | | | |

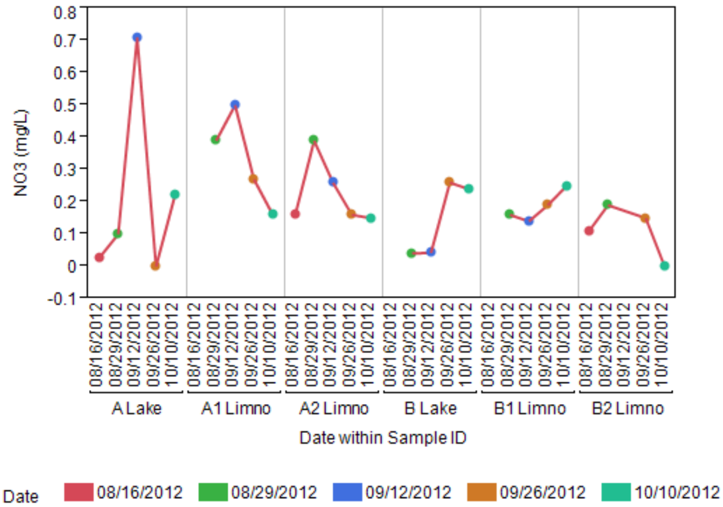
**Means for Oneway Anova**

| Level | Number | Mean | Std Error | Lower 95% | Upper 95% |
|---|---|---|---|---|---|
| A Lake | 49 | 7.90265 | 0.09939 | 7.7068 | 8.0985 |
| A1 Limno | 48 | 7.14146 | 0.10042 | 6.9436 | 7.3394 |
| A2 Limno | 48 | 6.34354 | 0.10042 | 6.1456 | 6.5414 |
| B Lake | 27 | 8.12593 | 0.13389 | 7.8621 | 8.3898 |
| B1 Limno | 27 | 8.14556 | 0.13389 | 7.8817 | 8.4094 |
| B2 Limno | 27 | 7.49556 | 0.13389 | 7.2317 | 7.7594 |

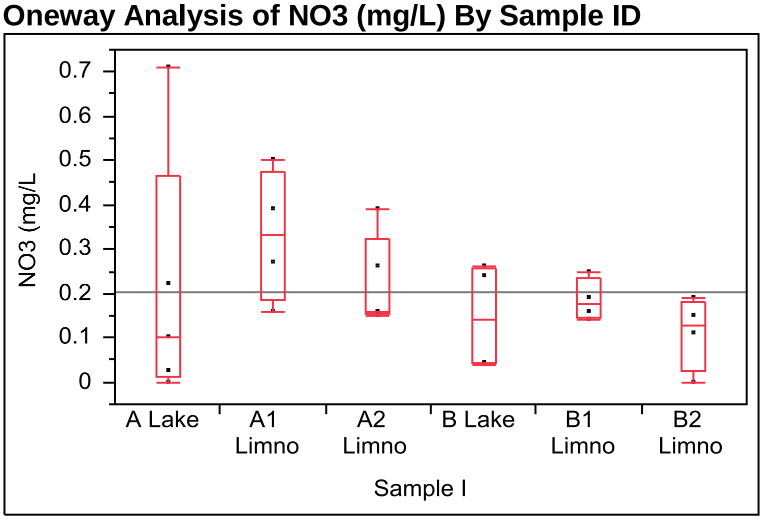
Levels of pH were significantly lower in the limno-corrals that received alum treatments. This was to be expected as we did not use buffered alum (sodium aluminate + aluminum sulfate) rather straight aluminum sulfate which dissociates in water with a hydrogen sulfide by-product. The alum dosing effect on pH levels was short-lived, only occurring during the very beginning of the experiment. Subsequent pH readings showed no difference between the limno-corrals at either site

## Nutrients

### Nitrate-N




### Oneway Analysis of NO3 (mg/L) By Sample ID




| | |
|---|---|
| Rsquare | 0.180704 |
| Adj Rsquare | -0.02412 |
| Root Mean Square Error | 0.160927 |
| Mean of Response | 0.202692 |
| Observations (or Sum Wgts) | 26 |

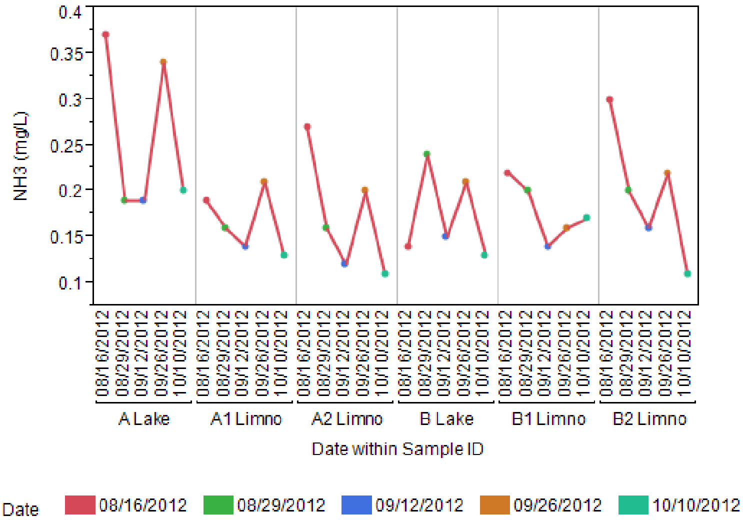
**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Sample ID | 5 | 0.11423859 | 0.022848 | 0.8822 | 0.5109 |
| Error | 20 | 0.51794695 | 0.025897 | | |
| C. Total | 25 | 0.63218554 | | | |

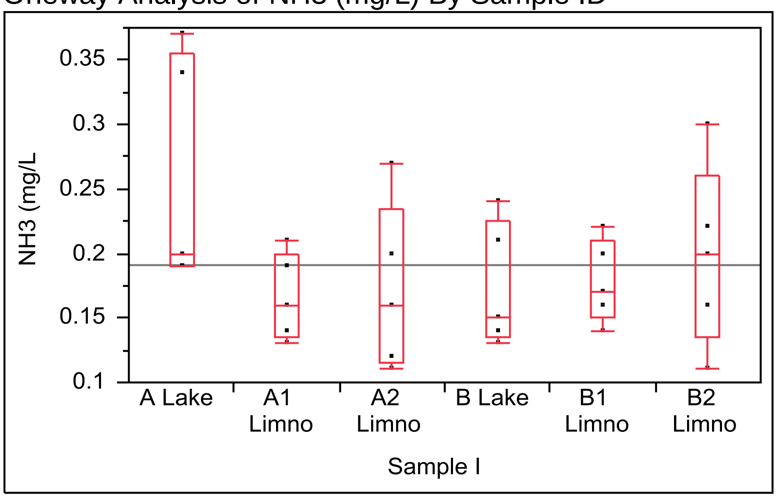
**Means for Oneway Anova**

| Level | Number | Mean | Std Error | Lower 95% | Upper 95% |
|---|---|---|---|---|---|
| A Lake | 5 | 0.211400 | 0.07197 | 0.0613 | 0.36152 |
| A1 Limno | 4 | 0.330000 | 0.08046 | 0.1622 | 0.49784 |
| A2 Limno | 5 | 0.224000 | 0.07197 | 0.0739 | 0.37412 |
| B Lake | 4 | 0.145750 | 0.08046 | -0.0221 | 0.31359 |
| B1 Limno | 4 | 0.185000 | 0.08046 | 0.0172 | 0.35284 |
| B2 Limno | 4 | 0.112500 | 0.08046 | -0.0553 | 0.28034 |

Ammonia-N




Oneway Analysis of NH3 (mg/L) By Sample ID




| | |
|---|---|
| Rsquare | 0.255925 |
| Adj Rsquare | 0.10091 |
| Root Mean Square Error | 0.060194 |
| Mean of Response | 0.191 |
| Observations (or Sum Wgts) | 30 |

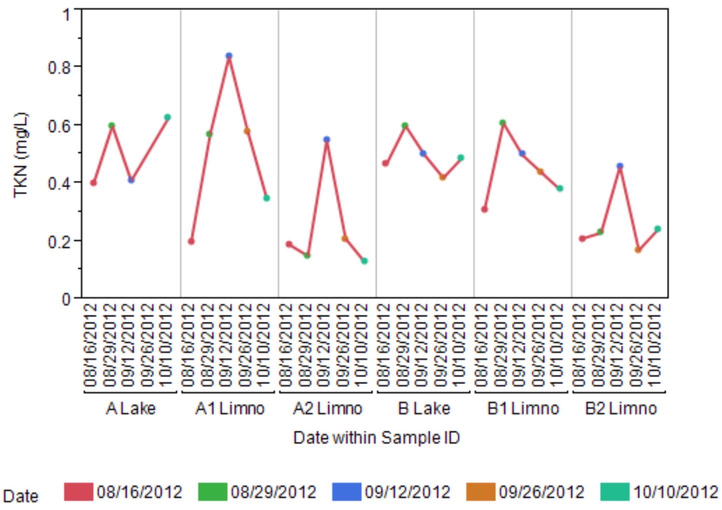
**Analysis of Variance**

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Ratio** | **Prob > F** |
|---|---|---|---|---|---|
| Sample ID | 5 | 0.02991000 | 0.005982 | 1.6510 | 0.1849 |
| Error | 24 | 0.08696000 | 0.003623 | | |
| C. Total | 29 | 0.11687000 | | | |

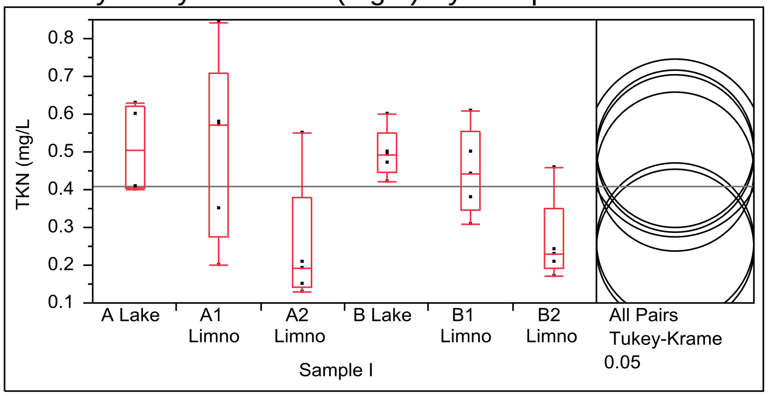
**Means for Oneway Anova**

| **Level** | **Number** | **Mean** | **Std Error** | **Lower 95%** | **Upper 95%** |
|---|---|---|---|---|---|
| A Lake | 5 | 0.258000 | 0.02692 | 0.20244 | 0.31356 |
| A1 Limno | 5 | 0.166000 | 0.02692 | 0.11044 | 0.22156 |
| A2 Limno | 5 | 0.172000 | 0.02692 | 0.11644 | 0.22756 |
| B Lake | 5 | 0.174000 | 0.02692 | 0.11844 | 0.22956 |
| B1 Limno | 5 | 0.178000 | 0.02692 | 0.12244 | 0.23356 |
| B2 Limno | 5 | 0.198000 | 0.02692 | 0.14244 | 0.25356 |

## Total Kjeldahl Nitrogen by Site and Date




## Oneway Analysis of TKN (mg/L) By Sample ID




| | |
|---|---|
| Rsquare | 0.417364 |
| Adj Rsquare | 0.290703 |
| Root Mean Square Error | 0.151095 |
| Mean of Response | 0.408276 |
| Observations (or Sum Wgts) | 29 |

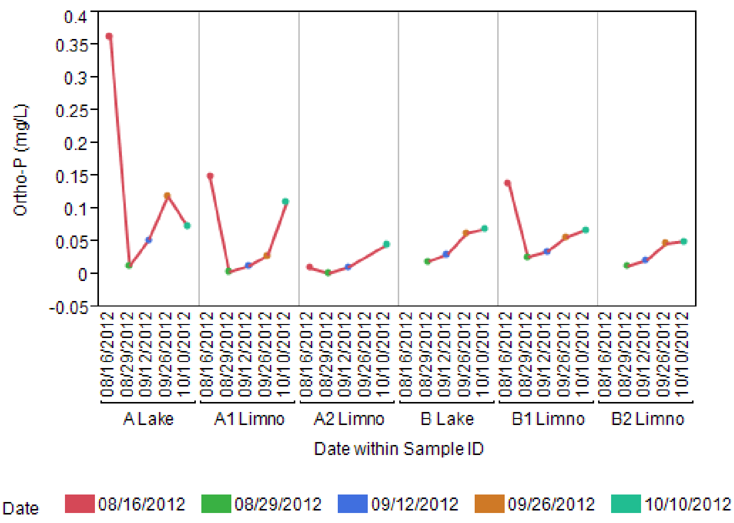
**Analysis of Variance**

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Ratio** | **Prob > F** |
|---|---|---|---|---|---|
| Sample ID | 5 | 0.37613379 | 0.075227 | 3.2951 | 0.0218* |
| Error | 23 | 0.52508000 | 0.022830 | | |
| C. Total | 28 | 0.90121379 | | | |

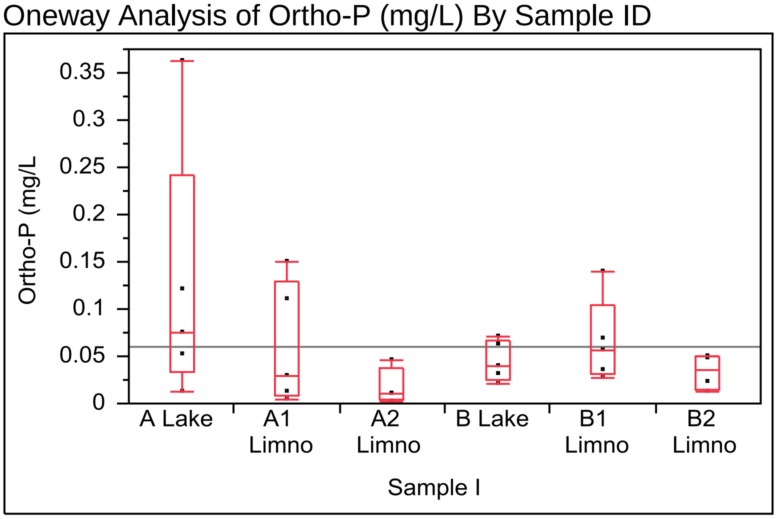
**Means for Oneway Anova**

| **Level** | **Number** | **Mean** | **Std Error** | **Lower 95%** | **Upper 95%** |
|---|---|---|---|---|---|
| A Lake | 4 | 0.510000 | 0.07555 | 0.35372 | 0.66628 |
| A1 Limno | 5 | 0.508000 | 0.06757 | 0.36822 | 0.64778 |
| A2 Limno | 5 | 0.246000 | 0.06757 | 0.10622 | 0.38578 |
| B Lake | 5 | 0.496000 | 0.06757 | 0.35622 | 0.63578 |
| B1 Limno | 5 | 0.448000 | 0.06757 | 0.30822 | 0.58778 |
| B2 Limno | 5 | 0.262000 | 0.06757 | 0.12222 | 0.40178 |

Orthophosphate by Site and Date




Oneway Analysis of Ortho-P (mg/L) By Sample ID




| | |
|---|---|
| Rsquare | 0.234796 |
| Adj Rsquare | 0.060886 |
| Root Mean Square Error | 0.069312 |
| Mean of Response | 0.06 |
| Observations (or Sum Wgts) | 28 |

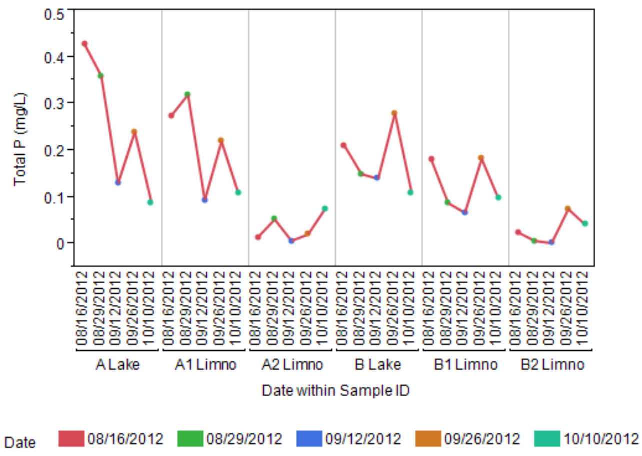
**Analysis of Variance**

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Ratio** | **Prob > F** |
|---|---|---|---|---|---|
| Sample ID | 5 | 0.03243005 | 0.006486 | 1.3501 | 0.2808 |
| Error | 22 | 0.10568995 | 0.004804 | | |
| C. Total | 27 | 0.13812000 | | | |

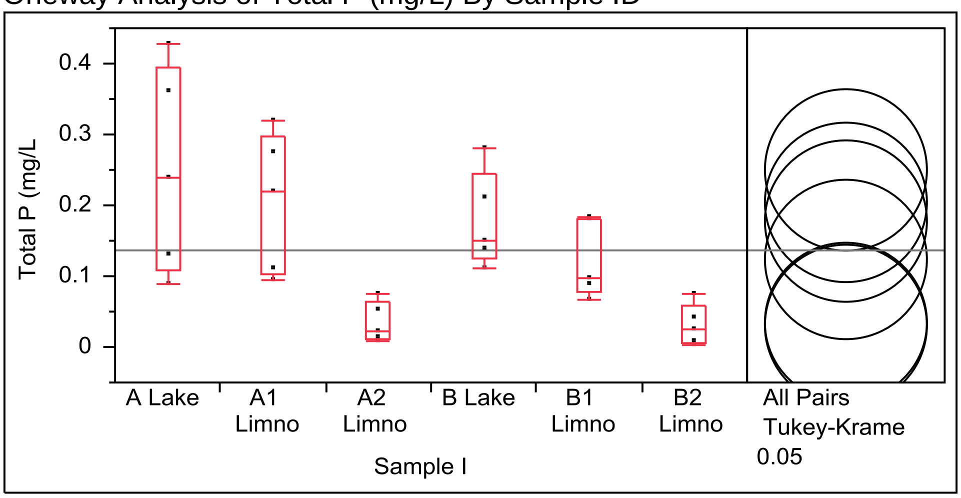
**Means for Oneway Anova**

| **Level** | **Number** | **Mean** | **Std Error** | **Lower 95%** | **Upper 95%** |
|---|---|---|---|---|---|
| A Lake | 5 | 0.124600 | 0.03100 | 0.0603 | 0.18888 |
| A1 Limno | 5 | 0.061000 | 0.03100 | -0.0033 | 0.12528 |
| A2 Limno | 4 | 0.017000 | 0.03466 | -0.0549 | 0.08887 |
| B Lake | 5 | 0.044800 | 0.03100 | -0.0195 | 0.10908 |
| B1 Limno | 5 | 0.065400 | 0.03100 | 0.0011 | 0.12968 |
| B2 Limno | 4 | 0.033250 | 0.03466 | -0.0386 | 0.10512 |

## Total Phosphorous by Site and Date




## Oneway Analysis of Total P (mg/L) By Sample ID




| | |
|---|---|
| Rsquare | 0.560032 |
| Adj Rsquare | 0.468371 |
| Root Mean Square Error | 0.081857 |
| Mean of Response | 0.136467 |
| Observations (or Sum Wgts) | 30 |

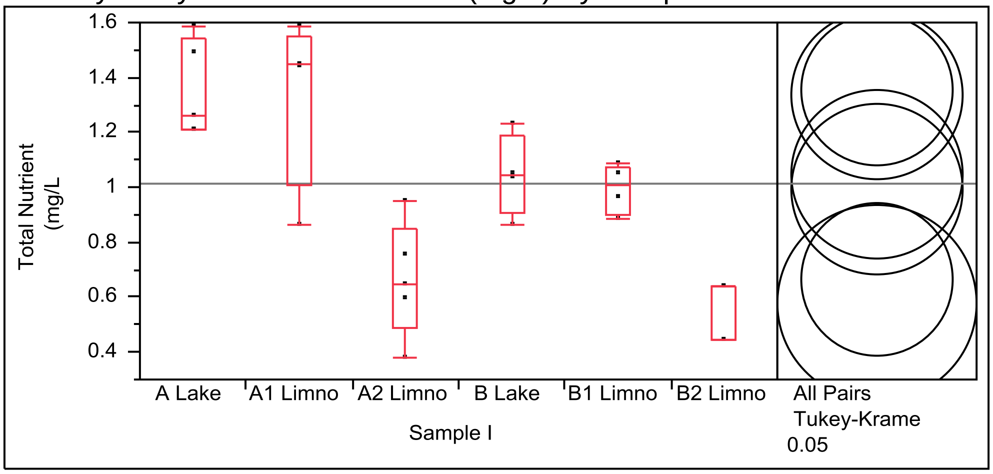
**Analysis of Variance**

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Ratio** | **Prob > F** |
|---|---|---|---|---|---|
| Sample ID | 5 | 0.20469907 | 0.040940 | 6.1099 | 0.0009* |
| Error | 24 | 0.16081440 | 0.006701 | | |
| C. Total | 29 | 0.36551347 | | | |

**Means for Oneway Anova**

| **Level** | **Number** | **Mean** | **Std Error** | **Lower 95%** | **Upper 95%** |
|---|---|---|---|---|---|
| A Lake | 5 | 0.249400 | 0.03661 | 0.1738 | 0.32495 |
| A1 Limno | 5 | 0.203800 | 0.03661 | 0.1282 | 0.27935 |
| A2 Limno | 5 | 0.034200 | 0.03661 | -0.0414 | 0.10975 |
| B Lake | 5 | 0.178000 | 0.03661 | 0.1024 | 0.25355 |
| B1 Limno | 5 | 0.123200 | 0.03661 | 0.0476 | 0.19875 |
| B2 Limno | 5 | 0.030200 | 0.03661 | -0.0454 | 0.10575 |

Oneway Analysis of Total Nutrients (mg/L) By Sample ID




Oneway Anova
Summary of Fit

| | |
|---|---|
| Rsquare | 0.749311 |
| Adj Rsquare | 0.68334 |
| Root Mean Square Error | 0.195991 |
| Mean of Response | 1.0132 |
| Observations (or Sum Wgts) | 25 |

Analysis of Variance

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Ratio** | **Prob > F** |
|---|---|---|---|---|---|
| Sample ID | 5 | 2.1814875 | 0.436297 | 11.3582 | <.0001* |
| Error | 19 | 0.7298385 | 0.038413 | | |
| C. Total | 24 | 2.9113260 | | | |

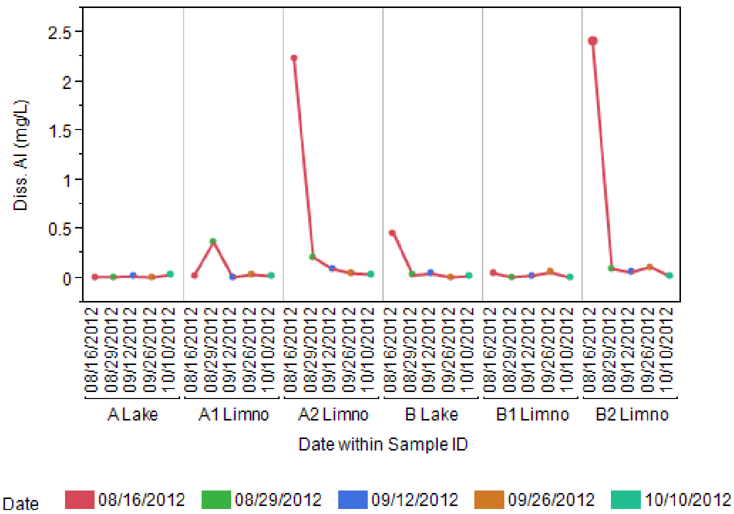
Means for Oneway Anova

| **Level** | **Number** | **Mean** | **Std Error** | **Lower 95%** | **Upper 95%** |
|---|---|---|---|---|---|
| A Lake | 5 | 1.35340 | 0.08765 | 1.1699 | 1.5369 |
| A1 Limno | 4 | 1.33550 | 0.09800 | 1.1304 | 1.5406 |
| A2 Limno | 5 | 0.66520 | 0.08765 | 0.4817 | 0.8487 |
| B Lake | 4 | 1.04675 | 0.09800 | 0.8416 | 1.2519 |
| B1 Limno | 4 | 0.99575 | 0.09800 | 0.7906 | 1.2009 |
| B2 Limno | 3 | 0.57500 | 0.11316 | 0.3382 | 0.8118 |

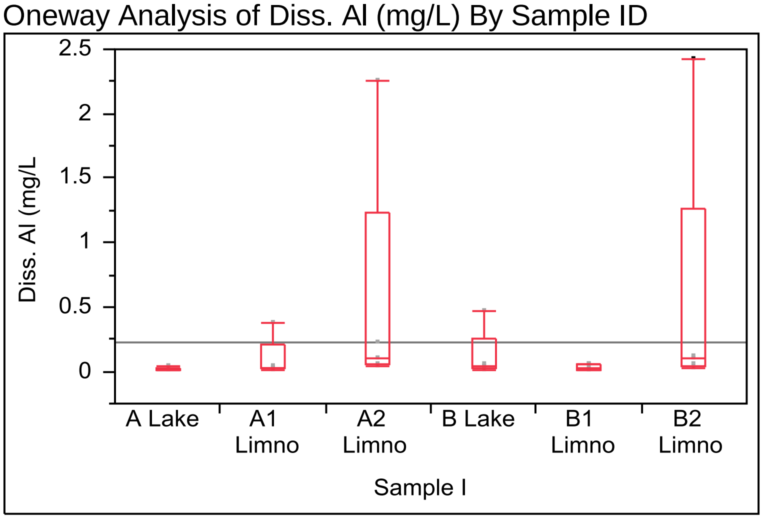
Std Error uses a pooled estimate of error variance

Generally, there was no significant difference between lake sites and the un-treated limno-corrals in terms of overall nutrient levels, with all of these being significantly higher than levels found in limno-corrals treated with alum. The largest difference between the lake sites/untreated limno-corrals and alum-treated limno-corrals was in levels of total P. This was to be expected given the alum treatments. Surprisingly, the alum treatments seemed to have some effect on levels of TKN also, with the alum-treated limno-corrals having significantly lower levels than un-treated sites.

Dissolved Aluminum by Site and Data




Oneway Analysis of Diss. Al (mg/L) By Sample ID




| | |
|---|---|
| Rsquare | 0.153246 |
| Adj Rsquare | -0.02316 |
| Root Mean Square Error | 0.589999 |
| Mean of Response | 0.224837 |
| Observations (or Sum Wgts) | 30 |

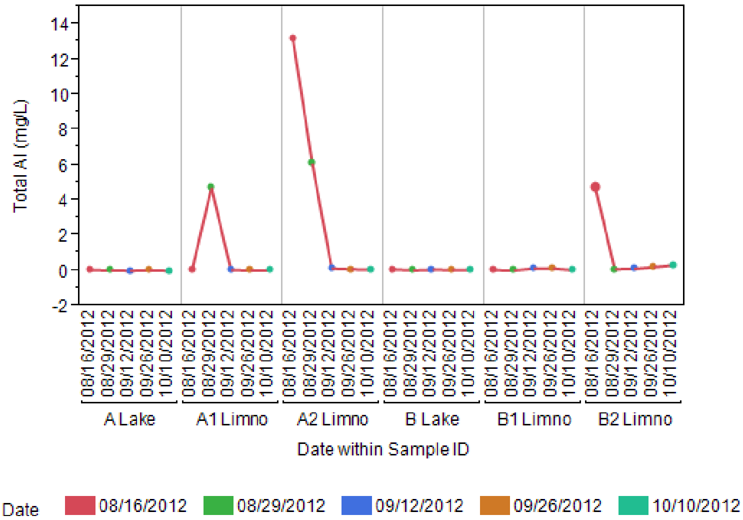
**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Sample ID | 5 | 1.5119816 | 0.302396 | 0.8687 | 0.5164 |
| Error | 24 | 8.3543815 | 0.348099 | | |
| C. Total | 29 | 9.8663631 | | | |

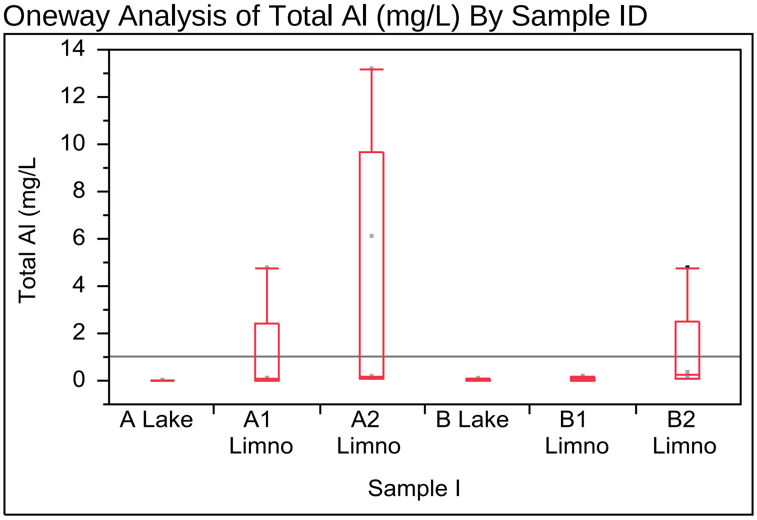
**Means for Oneway Anova**

| Level | Number | Mean | Std Error | Lower 95% | Upper 95% |
|---|---|---|---|---|---|
| A Lake | 5 | 0.021380 | 0.26386 | -0.5232 | 0.5660 |
| A1 Limno | 5 | 0.097200 | 0.26386 | -0.4474 | 0.6418 |
| A2 Limno | 5 | 0.532260 | 0.26386 | -0.0123 | 1.0768 |
| B Lake | 5 | 0.117920 | 0.26386 | -0.4267 | 0.6625 |
| B1 Limno | 5 | 0.034940 | 0.26386 | -0.5096 | 0.5795 |
| B2 Limno | 5 | 0.545320 | 0.26386 | 0.00075 | 1.0899 |

Total Aluminum by Site and Date




Oneway Analysis of Total Al (mg/L) By Sample ID




| | |
|---|---|
| Rsquare | 0.248909 |
| Adj Rsquare | 0.092432 |
| Root Mean Square Error | 2.656323 |
| Mean of Response | 1.02127 |
| Observations (or Sum Wgts) | 30 |

**Analysis of Variance**

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Ratio** | **Prob > F** |
|---|---|---|---|---|---|
| Sample ID | 5 | 56.12040 | 11.2241 | 1.5907 | 0.2007 |
| Error | 24 | 169.34520 | 7.0560 | | |
| C. Total | 29 | 225.46560 | | | |

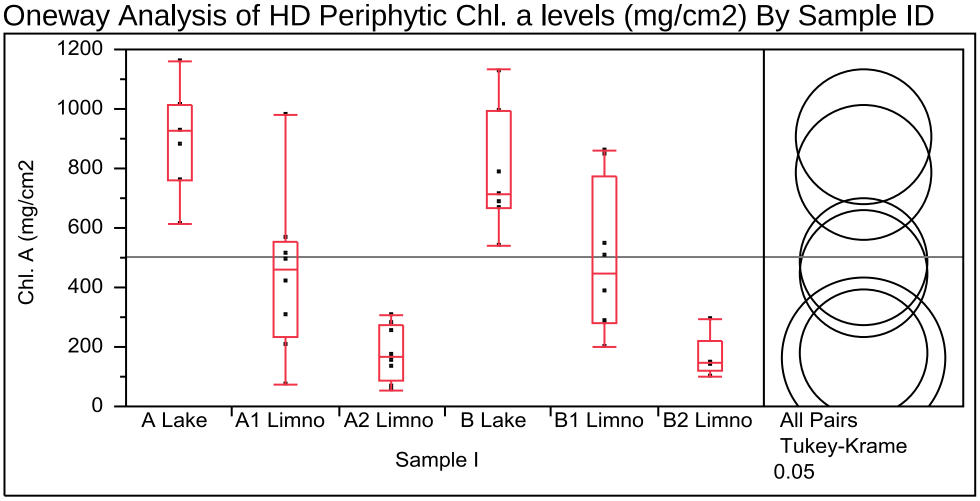
**Means for Oneway Anova**

| **Level** | **Number** | **Mean** | **Std Error** | **Lower 95%** | **Upper 95%** |
|---|---|---|---|---|---|
| A Lake | 5 | 0.02350 | 1.1879 | -2.428 | 2.4753 |
| A1 Limno | 5 | 0.97448 | 1.1879 | -1.477 | 3.4263 |
| A2 Limno | 5 | 3.91500 | 1.1879 | 1.463 | 6.3668 |
| B Lake | 5 | 0.04922 | 1.1879 | -2.403 | 2.5010 |
| B1 Limno | 5 | 0.07128 | 1.1879 | -2.381 | 2.5231 |
| B2 Limno | 5 | 1.09414 | 1.1879 | -1.358 | 3.5459 |

The alum treatments effect(s) on total and dissolved alum concentrations found in the water was short-lived only showing a significant difference between un-treated sites occurring only at the very beginning of the experiment. It appeared that the floc formed quickly settled to the bottom of the treated limno-corrals and onto the sediment with little or no residual left in the water column.

<u>Biological</u>

Oneway Analysis of HD Periphytic Chl. a levels (mg/cm2) By Sample ID




Oneway Anova
Summary of Fit

| | |
|---|---|
| Rsquare | 0.679178 |
| Adj Rsquare | 0.635824 |
| Root Mean Square Error | 200.9988 |
| Mean of Response | 502.2609 |
| Observations (or Sum Wgts) | 43 |

Analysis of Variance

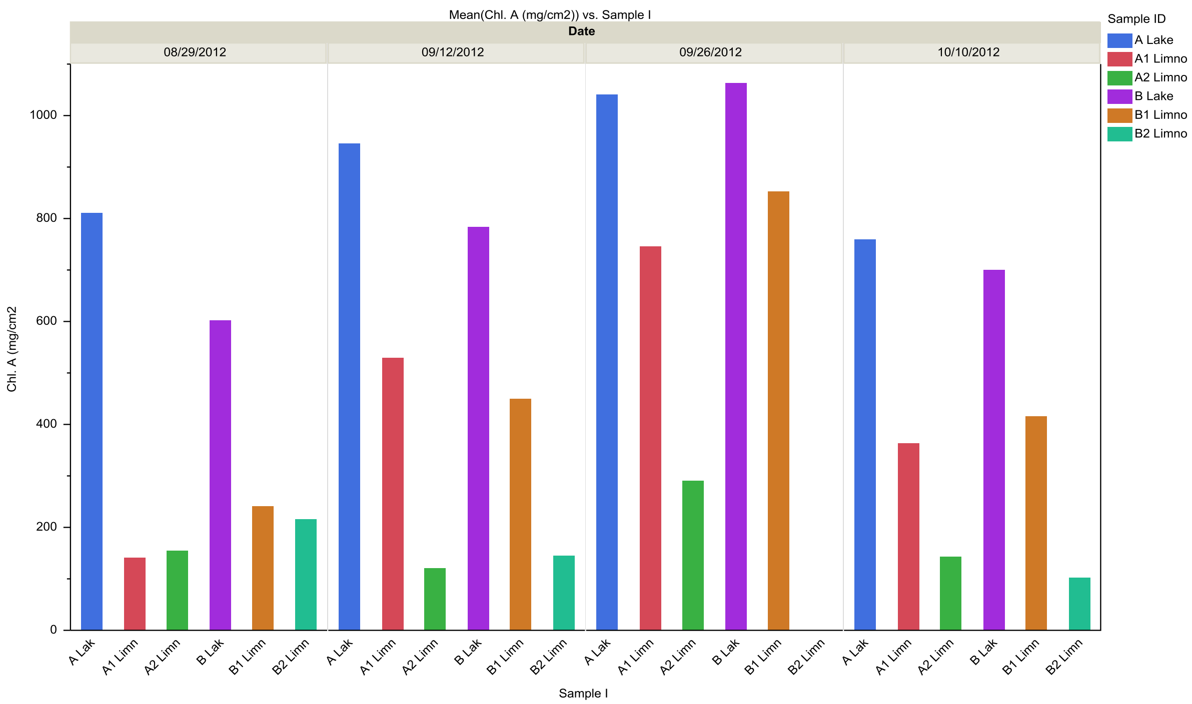
| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Ratio** | **Prob > F** |
|---|---|---|---|---|---|
| Sample ID | 5 | 3164521.6 | 632904 | 15.6658 | <.0001* |
| Error | 37 | 1494818.9 | 40401 | | |
| C. Total | 42 | 4659340.4 | | | |

Means for Oneway Anova

| **Level** | **Number** | **Mean** | **Std Error** | **Lower 95%** | **Upper 95%** |
|---|---|---|---|---|---|
| A Lake | 7 | 908.224 | 75.970 | 754.3 | 1062.2 |
| A1 Limno | 8 | 445.551 | 71.064 | 301.6 | 589.5 |
| A2 Limno | 8 | 177.165 | 71.064 | 33.2 | 321.2 |

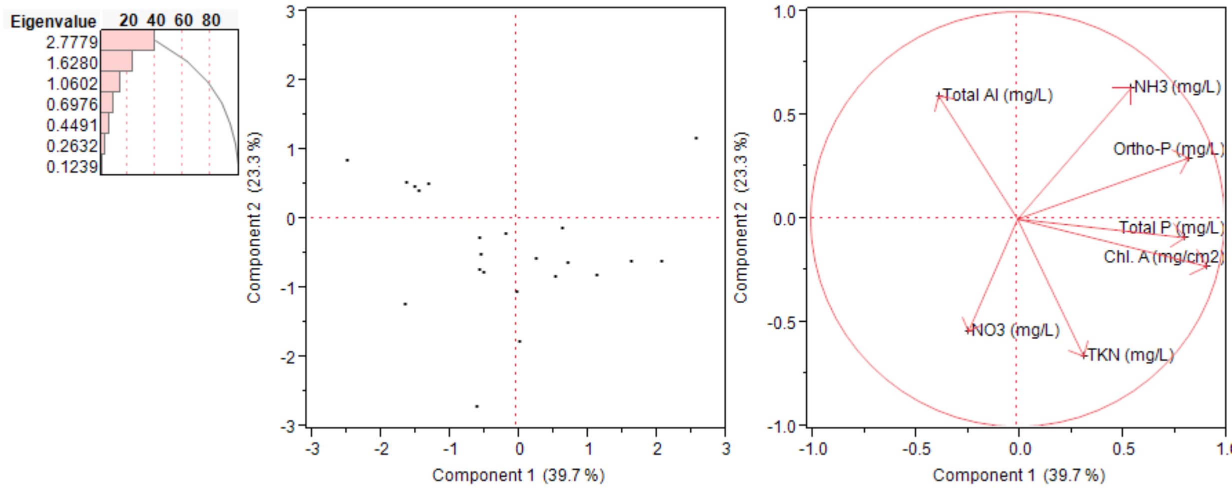
| Level | Number | Mean | Std Error | Lower 95% | Upper 95% |
|---|---|---|---|---|---|
| B Lake | 7 | 787.910 | 75.970 | 634.0 | 941.8 |
| B1 Limno | 8 | 489.404 | 71.064 | 345.4 | 633.4 |
| B2 Limno | 5 | 165.464 | 89.889 | -16.7 | 347.6 |

Mean H-D Periphytic Chl a Levels ($mg/cm^2$) By Site and Date




Levels of periphytic chlorophyll *a* were significantly lower in the limno-corrals treated with alum than either the lake sites or the untreated limno-corrals. The un-treated limno-corrals also had lower chlorophyll-a levels than the lake sites. This is likely due to decreased light transmittance inside the limno-corrals (~85% of incident light levels) than within the lake. Water clarity and the availability of light are thought to be more important factors for periphyton growth than phytoplankton.

PCA of All Nutrients and HD Periphytic Chlorophyll *a*




Judging by the PCA biplot, the most important nutrient for periphytic levels of chlorophyll-a is total P followed by orthophosphate and TKN. Total Al, as expected, had an inverse relationship with chlorophyll-a and total P.

**Discussion**

Algal populations are among the most environmentally patchy assemblages known. They are difficult to representatively sample and quantify. Often, patterns and significant correlations with environmental variables can only be observed once algae cells can be concentrated. Periphyton is a concentration of sorts and seems more appropriate than grab samples of phytoplankton in limno-corrals. Dr. Walker is working with ADEQ on the fabrication of a size-fractionated algal sampling device that will concentrate samples from lakes and reservoirs. In reservoirs that might have a high biovolume but increased spacing of individual colonies (e.g., *Gloeotrichia* spp.) or in reservoirs that do not have high concentrations of algal biomass, some method of concentrating algal cells to get a representative sample of algal diversity and number is recommended.

At full pool, Watson Lake contains 36,816,765 $m^3$ of water or 36,816,756,000 liters. The average levels of total P at sites A and B within the lake were 0.214 mg/L for a whole lake P load of 7,878,788 mg or 7.9 kilograms. Total P levels were lowest from the alum-treated limno-corrals of sites A and B (0.03mg/L) which, if we extrapolate to the volume of the lake, would be 1,104,503 mg or 1.1 kg. A difference of 6.8 kg for a total reduction of 86% total P.

Mean periphytic chlorophyll *a* concentrations from the lake at sites A and B were 848.06 $mg/m^2$ Mean periphytic chlorophyll *a* concentrations from the alum-treated limno-corrals at sites A and B were 171.31 $mg/m^2$ with a total difference of 676.75 $mg/m^2$ for a total reduction of 80%. This is close to a 1:1 ratio between chlorophyll *a* and total P, however, there is also an incident light decrease within the limno-corrals of 15%. To calculate this effect on periphytic biomass, the difference between the un-treated limno-corrals and the lake in terms of mean periphytic chlorophyll *a* levels is (mean for the un-treated limno-corrals is 467.47 $mg/m^2$) 380.59 $mg/m^2$ or 55%. Using the mean between 80% and 55% gives a more-representative corrected value of 67.5% periphytic biomass loss between the lake and alum-treated limno-corral. So, it appears that an 86% loss of total P results in a periphytic loss of chlorophyll *a* of roughly 67.5% for an efficacy ratio of P uptake by periphyton of approximately 78%.

Periphyton occupies a different ecological role than phytoplankton, however, the manner in which either periphyton or phytoplankton responds to nutrient limitation should be similar and total P reduction should result in a similar drop in biomass. For example, If phytoplanktonic chlorophyll *a* levels are 30 mg/L and total P levels are 0.5 mg/L, then lowering the total P levels to 0.07 (86% reduction) should result in a decrease of chlorophyll a levels to 9.75 mg/L.

The study suggests that, even in the presence of various forms of nitrogen, that phosphorous can be made a limiting nutrient to algal growth. It is possible that simultaneous reductions in N levels, whether in-lake or delivered to the lake, would result in even greater reduction in algal biomass.

The mean volume of the limno-corrals treated with alum during this study was approximately 6.0 $m^3$ or 6,000 liters. The average total Al concentrations immediately following alum dosing was approximately 9 mg/L. On a volumetric-by-weight scale, that's 54,000 mg of alum on average in the treated limno-corrals (0.54 kg or 0.009 g/L). To achieve the same dose in the entire volume of the lake at full pool would require 331,350,804 grams or 331,351 kg of alum.

Based upon experience using alum, it is a treatment that needs to be constantly repeated and is best used early in the Spring and repeated throughout the Summer in smaller doses to prevent toxicity and anoxia. It has been suggested that both dissolved and total Al levels need to be carefully monitored along with other pertinent biological and chemical data. Alum treatment(s) need to be constantly assessed by a limnologist familiar with Watson Lake. Lake management requires a thorough understanding of physical, chemical, and biological processes all interacting simultaneously, and is multi-disciplinary in scope. Efforts to examine any one of those processes in isolation will not result in desired outcomes and can result in an overall loss of dollars and time spent. In other words, the calculations given above are estimates and on-going lake management and monitoring is essential to reduce the effects of eutrophication within Watson Lake.

## Management and Treatment Options

*It is beyond the scope of this report to engineer systems or provide a detailed cost-benefit analysis of each suggestion or suggestions in tandem. This report provides generalities by which further analysis of management and treatment options can begin.*

No restorative action or management option exists in isolation. It is often necessary to perform restorative actions simultaneously based upon current lake conditions. Also, lake conditions change seasonally and annually depending on variables such as climate, seasonality, and changing watershed uses and conditions, etc. No management plan should be static. Monitoring should be on-going to determine the best course of action, if any, depending upon current, changing, and anticipated lake condition. For example, Watson Lake undergoes rather severe seasonal anoxia and reducing conditions within the hypolimnion. We observe higher ammonia levels and P within the hypolimnia during these times. This autochthonous ("from within") nutrient recycling/cycling within the lake could be mitigated through aeration or dredging of oxygen-demanding sediments. It is doubtful, however, that dredging alone would result in outcomes that meet all biological, physical, and chemical requirements of the lake. Lake management, and subsequent restorative measures, are performed with the goal of pushing the lake back to an earlier trophic status. This often means going against the ecological grain of what a lake or reservoir wants to become given its age and internal and external nutrient loading. A combination of aeration, dredging, alum and other treatments might be required to achieve stated goals.

There are many types of lake treatments that would help push back the trophic status of Watson Lake, and there are many that honestly would be a waste of time and money. Many have never been thoroughly examined or appear in the peer-reviewed literature for good reason; they likely do not work and in some cases might cause more harm than good. “Beneficial” bacteria, barley straw, and a few others come to mind. In other words, treatments should be proven to be effective, with repeatable results, in order to be considered viable options.

Terrestrial and semi-terrestrial organisms and species have far different requirements than do wholly aquatic organisms. The area surrounding the lake definitely should be managed to enhance, create, and/or protect terrestrial and semi-terrestrial species, however, these projects may have a minimal effect on increasing water quality and pushing back trophic status within the lake itself. For example, it is entirely possible to have verdant riparian habitat that benefits birds and many other species but the water may at the same time be toxic to wholly aquatic species. We see this in many instances with constructed wetlands for treated effluent and in effluent-dependent waters in many areas. There are obvious connections between aquatic, semi-terrestrial, and terrestrial ecosystems, however, this report only addresses those restorative actions that would be most directly beneficial to wholly aquatic organisms and any potential human health risks in the lake. Many in-lake restorative actions may also secondarily benefit terrestrial and semi-terrestrial wildlife. For example, aeration may indirectly benefit waterfowl by decreasing the amount of solubilized metals within the lake making them less available for uptake by aquatic organisms eaten by shorebirds. Also, dredging may remove potential toxicants from the lake or otherwise make them unavailable for biological uptake by aquatic organisms and, therefore, terrestrial predators ingesting them.

*Aeration*

Aeration may be the treatment capable of being the most beneficial toward the goal of increasing water quality and simultaneously protecting wholly aquatic organisms within Watson Lake. This is for several reasons:

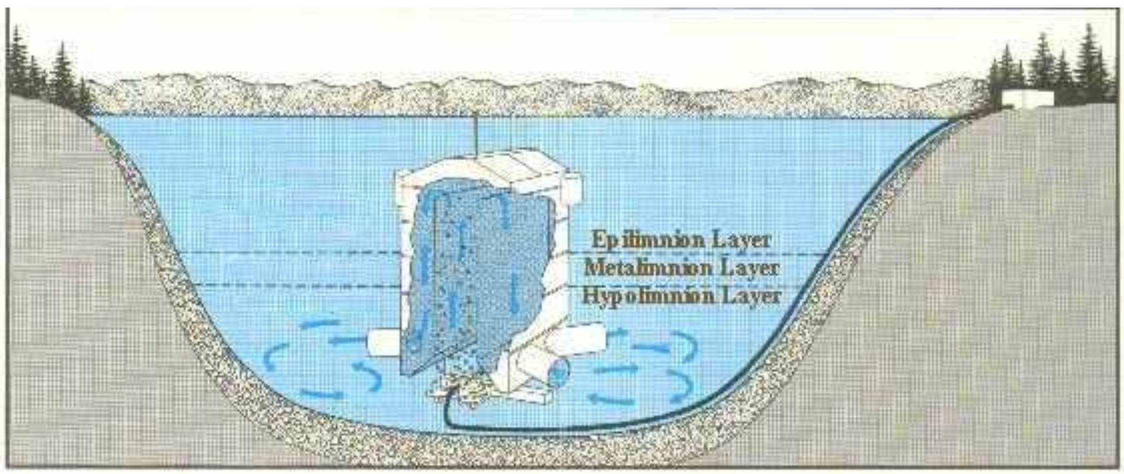
- Aeration can greatly help prevent fish kills due to anoxia,
- Aeration generally decreases the amount of potentially toxic or noxious cyanobacteria that has been observed in the lake,
- Destratification/aeration can cause an increase in algal diversity and may increase zooplankton biomass favoring the fisheries resource.
- Aeration can change sediment microbial communities favoring those that precipitate metals, including Fe, so inactivation of P is mediated.
- If engineered correctly, aeration should greatly reduce the amount of nutrient cycling/recycling, and
- Aeration has proven to be effective in many lakes and reservoirs for decades.

There are many different types of aeration systems and engineering a system for Watson Lake is beyond the scope of this report. This option, however, should be explored further and potential designs discussed to determine feasibility.

Recommendations of treatments following aeration are difficult to ascertain. Obviously, alum and dredging are viable options but the degree to which either might be needed is unknown following aeration because these effects haven't been either modeled or quantified. It is likely that an added option other than aeration alone will be needed. Aeration, however, will likely have some of the same effects on water quality as alum and dredging.

Grossly, there are at least two types of aeration systems in lakes and reservoirs; hypolimnetic and direct aeration or de-stratification. Experience with both types lends itself to the recommendation of a combination of both types within Watson. Hypolimnetic aeration is more effective at maintaining an oxidized environment at depth, especially at the water sediment interface. This interface is where many of the chemical reactions occur that often lead to nutrient cycling/recycling within lakes. Also, hypolimnetic aeration can maintain lower water temperatures at depth longer in the summer than can direct aeration. There is nothing wrong with the colder water within the hypolimnon, it's when this water becomes anoxic due to limited or no atmospheric aeration that problems occur.

Example of Hypolimnetic Aeration System (http://www.airation.com/hypolimnetic_aeration.htm)




Given the highly reducing conditions found within Watson Lake during the summer and early fall, nutrient cycling from the sediments into the water (autochthony) is likely a significant source of algal nutrients in the lake. Even if the cleanest water possible is delivered to the lake, the feedback mechanisms of authochthony can maintain a lake in a eutrophic condition for many years. Hypolimnetic aeration can significantly reduce, if not eliminate, this autochthony thereby resulting in decreased amounts of bioavailable P and reduced forms of, potentially toxic, ammonia within the lake.

Direct aeration or de-stratification has been proven many times to greatly reduce the amount of noxious and potentially toxic cyanobacteria in lakes and reservoirs. Planktonic cyanobacteria do not prefer well-mixed waters and in such places, other forms of phytoplankton predominate (e.g., chrysophytes and chlorophytes). These other forms of phytoplankton are far more ingestible and prone to grazing by zoo- and ichthyoplankton. If provided within an oxic environment at the sediment-water interface, ingestion and defecation by zoo- and ichthyoplankton can greatly reduce nutrient retention time in the water by these nutrients being deposited within the sediments. An added benefit is that the fisheries resource is often healthier post-aeration.

All forms of aeration will directly add oxygen back into the water to varying degrees, however, the solubility of oxygen in water is temperature-dependent. It is far more difficult for oxygen to solubilize into warmer rather than cooler water. The hypolimnetic aeration design contains a contact basin wherein water and compressed air are kept in contact for a given period thereby enhancing oxygen's solubility into the water. Many things other than temperature can affect the amount of dissolved oxygen in water such as oxygen demand which can take many forms. There are biological, chemical, and sediment oxygen demands just to name a few of the major groups. Aeration, the amount of flow and volume needed as well as in what locations, is never static an a thorough understanding of the sources and sinks understood for aeration to be a successful lake management tool.

*Alum*

There are many methods to reduce internal loading of P in lakes and reservoirs. The most common, widely used, and proven techniques to reduce internal P loading from sediments include chemical treatment, oxidation, and dredging. Often, combinations of these techniques are required to achieve significant results in pushing a lake back to an earlier trophic state. Alum is often chosen as the chemical treatment of choice due to its dual mode of affinity for binding P. Alum reacts with P to form an insoluble precipitate and also forms an insoluble aluminum hydroxide floc at pH 6-8. Both of these actions can bind, and make biologically unavailable for algal growth, large amounts of P. Because a portion of aluminum sulfate dis-associates into sulfuric acid in water, and because alum binds P most tightly at pH 6-8, aluminum sulfate is often added as a buffer to maintain this pH range. It is estimated that hundreds of lakes worldwide have been treated with alum since the early 1970's. Alum is far safer and less toxic to aquatic organisms than are copper-based algaecides. As with any treatment, careful monitoring is needed to insure safety.

Within lakes and reservoirs, iron also binds P quite effectively, however, under anoxic and reducing conditions, iron (Fe) becomes soluble and gives up its affinity to bind P. This is the nexus behind nutrient recycling and autochthonous loading during times of thermal stratification. Alum continues to bind P even under strongly reducing conditions. If the sediments can remain oxidized, and reduction decreased within the hypolimnion, then Fe will maintain its affinity to bind P much more so than without aeration. Alum might still be needed following aeration, but its dosage and frequency of addition may be greatly reduced.

The efficacy of alum to reduce internal loading of P and decrease algal biomass, also depends on the amount of external P loading. Although some external loading of P is to be expected, the longevity of an alum treatment is dependent upon the external loading of P. Therefore, effort(s)t to reduce the amount of P loading to Watson Lake from the watershed should be implemented prior to the establishment or use of an alum treatment program to the lake itself.

A side effect of alum treatment is water clarification through flocculation. This clarification would also result in increased light penetration. The use of alum would likely result in available light for photosynthesis being increased to a greater depth within the water column. Aguatic macrophytes obtain the majority of their nutrients for growth from their roots within lake sediments and not from lake water. Therefore, alum would have a different effect on aquatic macrophytes than it would phytoplanktonic algae and may, in fact, exacerbate the growth of the former. Aquatic macrophytes can also interfere with the physical and chemical efficacy of alum by blocking it from reaching lake sediments and by maintaining a pool of P by bringing it up from deeper in lake sediments to the surface of the sediment-water interface. Aquatic macrophytes in lakes act as P sources and sinks. They are sinks when they are actively growing and sources when they die back. The use of alum in Watson Lake would likely have an un-wanted side effect by exacerbating the growth of aquatic macrophytes and, perhaps, periphytic algae as well. Although alum is a cost-effective and relatively longer-term treatment, its use in Watson should not be considered until, 1) P loading from the watershed is abated and 2) some type of restoration or management plan for the aquatic macrophytes has been established, implemented, and proven to be successful. Also prior to the implementation of alum in Watson Lake, lab studies using different formulations of alum, lake water, and sediment should be performed. These tests should be done to determine optimum alum formulation under differing conditions and to protect aquatic species from any potential harm.

Alum treatments require specialized equipment and a limnologist well-versed in the positive and potentially negative effects of alums use. Although many conditions would need to be met within the lake and watershed prior to the use of alum in Watson Lake, it is a highly-effective method of controlling P, and therefore algae, within lakes. Alum has a long and proven track record of success in many lakes and reservoirs around the world. The use of alum in Watson Lake should be considered under the following conditions:

- External sources of P are minimized.
- Some program or treatment plan to control aquatic macrophytes has been established.
- The effects of aeration are better understood.

Alum treatment and subsequent floc formation in Mountain Lakes New Jersey (www.mtnlakes.org)

Alum treatment in Lake Rebecca, Minnesota
(http://www.startribune.com/local/west/108015094.html)

*Dredging*

The reasons for dredging within Watson should be two-fold, to deepen an area of the lake that is choked with aquatic macrophytes (which might lead to dissolved oxygen depletion via bacterial respiration when they die back seasonally) and to remove nutrients from the lake that might be causing part of the nutrient recycling. An additional benefit to dredging is that it removes a good portion of all algal nutrients including species of N and P. For the most part, nutrients accumulate within lakes in sediments and the vast majority of nutrients that have either flowed into, or have been recycled within, the lake remain there sequestered within the sediment.. Sediments can act as sources and sinks of nutrients either from or to the overlying water. Mostly, sediments act as sinks for nutrient sequestration; however, if even a fraction of all the nutrients that have ever entered the lake solubilize and become available for biological growth, this amount of recycling is more than enough to keep a lake in a eutrophic condition.

There is no real downside to the long-term effects of dredging, especially in areas where excessive aquatic macrophyte growth occurs. In the short-term, disturbing oxygen-demanding sediments can result in hypoxia of aquatic species and increase the possibility of a fish kill. Since aquatic macrophytes may cause an overall loss of dissolved oxygen, deepening these areas, especially if alum is to be used, would be a large, overall net benefit. These areas aren't, however, the only areas that should be dredged to increase water quality. Severe seasonal anoxia exists in the area by the dam and at mid-lake. Although these areas would not have to be dredged as deeply as the riverine area of the lake, they should still be considered in any dredging operation as removal of the surficial, most oxygen-consuming and nutrient-laden sediments, would likely improve water quality conditions in those areas that currently suffer from hypolimnetic anoxia. Sediments, especially organically-enriched sediments, can exert a large oxygen demand on overlying water.

All sediments within Watson Lake exert an oxygen demand and can release nutrients and metals, under reducing conditions, back into the water. Ideally, dredging would occur in all areas of the lake from the riverine end to the dam. This may be infeasible given that the lake would essentially need to be emptied, and kept emptied during dredging, for this to occur. It would be far more feasible to dredge the riverine to transitional areas of the lake. This would remove sme, but not all, nutrients sequestered in lake sediments. It would also be possible to greatly reduce the amount of aquatic macrophytes growing in the riverine end of the lake if deepening of this area could occur. The depth that would be needed to eliminate/reduce aquatic macrophytes depends on water clarity and amount of light available for photosynthesis.

It has been suggested to dredge the riverine area of the lake and create a wetland to decrease nutrient loading to the rest of the lake. This idea has merit, however, like most restorative techniques, it has drawbacks as well. Wetlands and wetland plants do not always sequester nutrients and, as stated earlier, aquatic plants obtain nutrients primarily from sediments and not as much from overlying water. Also, these areas can act as sources of nutrients to the lake if not heavily managed and biomass constantly removed when they die back seasonally. These areas can also become large oxygen sinks due to the expected organic enrichment that wetlands create and can, in fact, result in oxygen loss of in-coming lake water. Constructed wetlands can also become vectors of disease to humans, wildlife, and domestic animals by harboring bacteria, viruses, and their mosquito vectors. West Nile, dengue, malaria, Western equine encephalitis, and many other potentially harmful viruses and bacteria are routinely found in constructed wetlands. The idea of wetland construction in the riverine area of Watson Lake is feasible and could potentially decrease nutrient loading to the lake but it would take very careful engineering and forethought to avoid the potential drawbacks just mentioned. Also, the long-term O&M costs involved with the management of such an area would be high.

Dredging operations work best for water quality if dredged material is physically removed from the lake. It is possible to use some dredged material for wetland construction or the construction of other habitat, however, this also means this material can leach nutrients back into the lake wherever this sediment comes into contact with water. Some material can remain, however, for water quality purposes, the majority should be removed to an off-site facility.

It appears there are, at least, 3 options or scenarios to dredging Watson Lake.

1) Dredging of the riverine and transitional areas during times of water levels low enough to bring in needed heavy equipment. No creation of a constructed wetland.

2) The same as above with the creation of a constructed wetland.

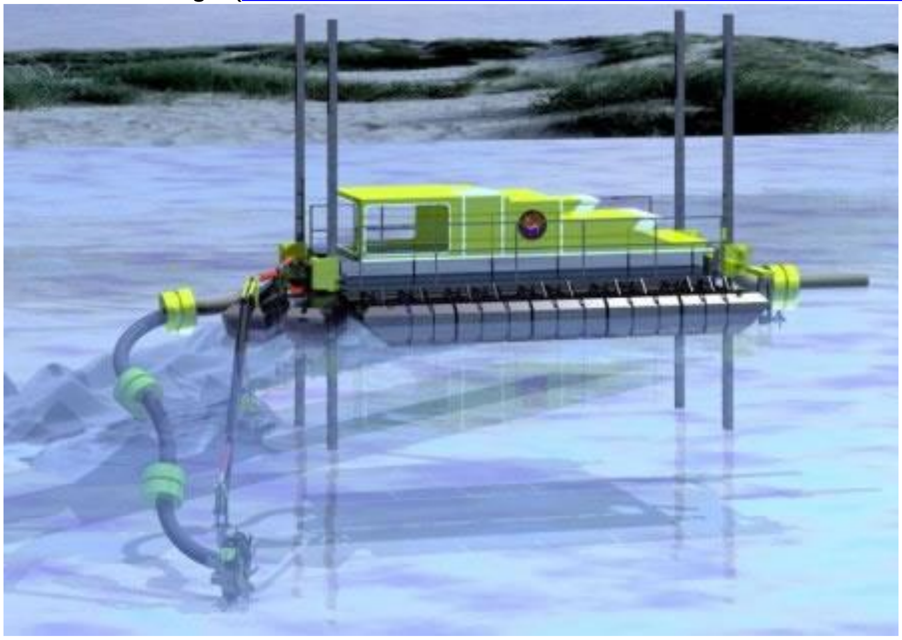
3) Either 1 or 2 above with suction dredging in the lacustrine area of the lake to remove the most organically-enriched surficial sediments.

Suction dredging means removing sediments from the lacustrine area of Watson Lake without the need to draw down water levels or empty the lake. This, combined with dredging of the riverine area of the lake, would results in a substantial amount of nutrients removed from the lake. Suction dredges, while not as effective as a deepening type of dredge operation, can still have many positive benefits. Most of the labile nutrients within lake sediments are near the sediment-water interface. Although little deepening could occur with suction dredging, they could still remove the most nutrient-enriched layer of sediments.

Suction dredges usually consist of a large, Crisafulli-style pump mounted on a controllable pontoon barge with a cutting/suction end attached to a moveable arm extending to the sediement. Dredged material is suctioned from the lake bottom, through the pump and floating lines, to a contained area for de-watering and subsequent transport to an off-site facility. I know that, at one time, the Salt River Project owned such a suction dredge.

Dredging of any kind is logistically quite difficult. If dredging of any type is to be considered, the sediments would need to be checked in many places for potential toxicants including metals and organic toxicants such as herbicides and pesticides.

A suction dredge (http://www.wyremarine.co.uk/Services/SDredging.html)



Dewatering and dredging (http://mbpondandlagoon.com/slide-show.php)

**Summary**

These 3 treatments, aeration, dredging, and alum, offer the most promise in terms of increasing water quality within Watson Lake. Not all treatments need to be, nor should they be, implemented simultaneously. Due to potential interactions between these 3 treatments, and the inability to determine the exact impact of any one in particular, aeration followed by a year's worth of monitoring is recommended. If this fails to produce desired outcomes, partial dredging is recommended followed by another year's worth of monitoring and then, if needed, regularly-scheduled alum dosing depending upon lake conditions. If needed, algaecide and/or herbicide treatments could be included in a lake management plan as another level of treatment. Due to issues with toxicity and long-term costs, such treatments cannot be recommended as a primary lake restorative technique.

A generalized summary of the potential strengths and weaknesses of viable treatment options for Watson Lake are given below. The (subjective based upon experience) scale of 1 to 5 is based upon 1 being the worst and 5 being the best. This is not an exhaustive list of all potential strengths and weaknesses and obviously other variables should be considered.

| **Treatment** | **Upfront Cost** | **Long-term Cost and O&M** | **Logistical Difficulty in implementation** | **Potential to meet stated goals/objectives** |
|---|---|---|---|---|
| Aeration | 2 | 3 | 2 | 4 |
| Alum (long-term use) | 4 | 2 | 3 | 3 |
| Dredging (no wetland construction) | 1 | 5 | 1 | 3 |
| Dredging (wetland construction) | 1 | 2 | 1 | 3* |

* The success of wetland construction is dependent upon initial design and subsequent O&M efficacy. The scoring given here is assuming a properly-designed and constructed wetland with a plan in place for long-term O&M.

Lakes and reservoirs are highly dynamic ecosystems and change over time. There isn't any treatment or restorative measure that, on its own, would likely be able to be implemented that would result in desired outcomes without refinement and continued monitoring. Limnology is highly multi-disciplinary and a lake manager needs to be able to determine not only how all the components of a highly dynamic ecosystem work, but also the interactions between these components. This is difficult and takes decades of experience. It can take upwards of ten years of post-treatment monitoring before a lake or reservoir is understood to a degree where confidence in how such an ecosystem works can be established. Active and on-going management of Watson Lake is the most essential component for its successful remediation and to meet future goals and objectives.