# A JAR TEST STUDY ON THE USE OF ALUM FOR TURBIDITY AND NUTRIENT REMOVAL IN CANYON LAKE, CA

## FINAL REPORT

Submitted to

MWH Americas, Inc.
Arcadia, CA

for

Elsinore Valley Municipal Water District
31315 Chaney St, Lake Elsinore, CA 92531

Submitted by

James A. Noblet

with research assistance by
Emmett Campbell and Graciela Cervantes

Department of Chemistry and Biochemistry
California State University-San Bernardino

December 6, 2012

## INTRODUCTION

It has been suggested that treatment of excessive turbidity and algal growth in the east bay and main body of Canyon Lake may be treated with alum (hydrated Aluminum Sulfate, $Al_2(SO_4)_3{\cdot}nH_2O$, where n=14-18) a coagulating agent traditionally used in water treatment. In treating water with alum, the natural alkalinity of the water may be used as shown in the following reaction:

$$Al_2(SO_4)_3{\cdot}nH_2O + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3\downarrow + 3CaSO_4 + nH_2O + 6CO_2 \qquad (1)$$

It is preferable that the natural alkalinity of the water be used to form the aluminum hydroxide precipitate rather than adding a base such a lime both in terms of cost and the inability to control mixing dynamics in a natural lake setting. The pH of Canyon Lake (pH= 9.1 for recently collected east bay samples) is typically above the optimum range for alum treatment (i.e., 5.5-8) [1], but it still may be effective in removing turbidity while not adding to the overall Al concentration of the lake water. Previous studies by Dr. M.A. Anderson's group at UC-Riverside (UCR) [2, 3] have shown that effective doses of alum up to 40 mg Al/L (i.e., ~500 mg alum/L) did not increase the residual water concentration of Al. The pH of alum treated waters dropped significantly within the first hour (8.5 to 6.5) but returned to nearly the ambient pH within 24 hours. The UCR data show that alum doses of up to 10 mg Al/L (or ~125 mg alum/L) have virtually no persistent effect on the pH of the water.

The natural alkalinity of the lake is thus a key parameter for determining the allowable dosing of the water with alum. CSUSB recently collected samples from the east bay at Canyon Lake. Water samples from Station 9 (Road Runner Beach) and Station 10 (Indian Beach) were analyzed for alkalinity and found to have Total Alkalinities 130 mg/L and 150 mg/L as $CaCO_3$, respectively. The corresponding carbonate alkalinities (i.e., the phenolphthalein alkalinity, or pH=8.3) were 36 and 42 mg/L as $CaCO_3$ respectively. The total alkalinities were in fair agreement with the values found by UCR in 2007, which was a lake wide average of 170 mg/L as CaCO3 (i.e., 3.4 meq/L). Quantitative application of equation (1) shows that for every 1 mg/L of alum applied, alkalinity decreases by 0.5 mg/L. Thus our recent alkalinity data suggest that applications of up to 80 mg/L Alum should not decrease the water pH to less than 8.3 at any time during the application. And the UCR data from 2007 suggest that alum doses up to 250 mg/L may have no long term effect on water pH. A survey of environmental engineering textbooks gave typical ranges of 5-50 mg alum/L as being effective for turbidity removal in most waters.

# METHODS and MATERIALS

## Sampling

Water samples were collected from four stations at Canyon Lake on August 27, 2012, two locations in the Main Body and two locations in the East Bay. Samples from the main body of the lake (8 L) were collected from below the thermocline (i.e., in the hypolimnion). Samples from the east bay were taken at approximately 1 meter depth as the lake at these locations was not stratified. Samples were collected at the same CSUSB monitoring stations that have been used for the past 6 years. The main lake body stations were 7 (near the dam) and 8 (middle of main channel). Samples from the east bay (10 L) were collected at monitoring stations 9 and 10, from the middle of the channel adjacent to Road Runner and Indian beaches, respectively.

All water samples were collected using a 4.2 liter vertical beta type van Dorn sampler (with acrylic tube, Wildlife Supply Company). Repeat grab samples were collected at the appropriate depths until the desired volume was obtained. Samples were transferred to pre-cleaned 2.5 liter clear glass or 4.0 liter amber glass bottles. Samples were stored on ice in ice chests until returned to the lab, and then were stored in a walk-in refrigerator at 4°C until analyzed.

Depth profiles at each station were measured at 1 meter intervals using a Hach Hydrolab DS-5 water quality sonde. Parameters measured included depth, temperature, electrical conductivity, ORP, and turbidity. Dissolved oxygen data were not obtained as the LDO probe on the Hydrolab was not functioning properly. Data from the depth profile at each station were used to determine in the field at what depth to take the samples.

## Laboratory Analyses

*Jar Testing*

Jar tests were performed on the collected samples using 1.0 L samples, on a six stirrer Phipps and Byrd programmable jar test apparatus (Figure 1). Jar test were performed as follows: The appropriate amount of 10,000 ppm alum stock was added to each sample, and flash mixed at 220 rpm for 1.25 minutes, then followed by flocculation at 25 rpm for 30 minutes. The samples were then allowed to settle for 2-3 hours until all of the floc had fully settled. Before and after treatment samples were measured for pH, temperature, turbidity, conductivity, dissolved aluminum concentration, total organic carbon (TOC), total nitrogen and total phosphorus. The goal of the testing was to identify the dose of alum required to achieve a turbidity of less than 1.0 NTU. The tests were performed at doses of 0 (control, before), 10, 25, 50, 75, and 100 mg/L Alum. Based upon the results of the initial testing, two additional alum concentrations were tested, 125 and 150 mg/L.

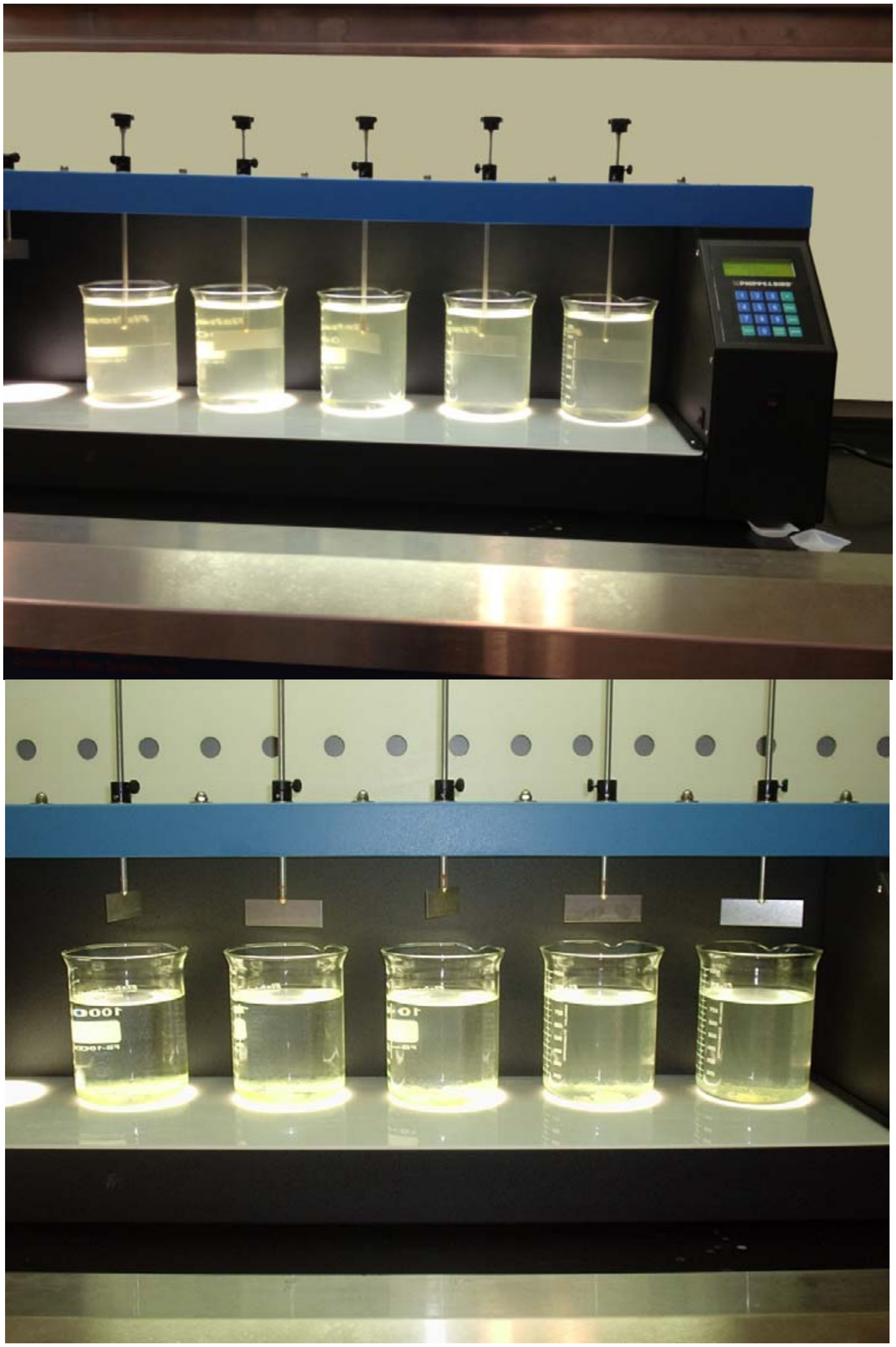

Figure 1. Phipps and Byrd jar testing apparatus used in this study, at the beginning (top) and at the end of the test procedure after settling of the flocs (bottom).

*Water Quality Analyses*

In the laboratory all water quality parameters were measured using methods and protocols as described in standard EPA methods or in *Standard Methods for the Examination of Water and Wastewater*, $21^{st}$ edition [4]. The temperature, pH and conductivity were measured using a WTW 350i multiparameter field probe. Turbidity was measured with a HF Scientific MicroPTW portable turbidimeter. TOC was measured on a Teledyne Tekmar Apollo 9000 combustion TOC analyzer. The total nitrogen (TN) and total phosphorus (TP) were measured on a LACHAT Quickchem 8500 Flow Injection Analysis (FIA) system. Samples were processed using the LACHAT method of persulfate digestion followed by simultaneous TN/TP analysis. The dissolved aluminum concentrations before and after treatment were measured using a Perkin Elmer AAnalyst 600 graphite furnace atomic absorption spectrophotometer, using the EPA Method 200.9 protocol [5]. Because of the critical nature of the dissolved aluminum concentrations, blank samples (i.e., deioniozed water) were subjected to the entire jar testing procedure to ensure that there was no aluminum contamination introduced by either laboratory cleaning and handling procedures or the testing apparatus. None of the blank samples analyzed showed detectable levels of aluminum.

## RESULTS and DISCUSSION

### Field Data

The results of the parameters measured in the field are shown in Tables 1-4. The results show that station 7 in the deepest part of the lake near the dam was well-stratified, as usual for that the time of year. Station 8 also in the main channel of the Lake was not really stratified with a thermocline appearing at approximately 1.5 meters above the bottom. Samples were collected at 8.5 meters and at 5.5 meters for stations 7 and 8, respectively. Plots of the temperature depth profiles for stations 7 and 8 are shown in Figures 2 and 3. Samples were collected at stations 9 and 10 at approximately 1 meter below the surface.

### Laboratory Water Quality Data

The results of the laboratory water quality analyses are shown in Tables 5-9. For the hypolimnion samples from stations 7 and 8, a dose of 25-50 ppm alum is sufficient to achieve a turbidity of ≤1.0 NTU. However, doses of 100 ppm are required to achieve the lowest dissolved Al concentrations, and maximum phosphorus removal. For the east bay water samples, it appears that a dose of 100 ppm alum is required to achieve both turbidity reduction and the lowest dissolved Al concentrations, and maximum phosphorus removal. It is noteworthy that the pH of the sample from station 10 (farthest into the east bay) dropped almost two pH units with a 100 ppm alum dose. However, pH and turbidity measurements taken after 24 hrs showed that pH had gone back up by 0.6 pH units while turbidity dropped slightly.

These initial results show that alum is very effective in reducing the turbidity and phosphorus, and to lesser extent nitrogen content of the waters from throughout the lake, but the residual aluminum concentrations exceed the EPA chronic ambient water quality criterion for protection of aquatic biota, which is 87 µg/L for chronic toxicity (the acute toxicity criterion is 750 µg/L) [6]. In response to the initial results showing dissolved Al concentrations above the chronic criterion, two additional concentrations of alum were evaluated, 125 and 150 mg/L alum. The results of the higher concentrations showed that an alum dose of 150 mg/L was able to reduce the residual dissolved Al concentrations significantly to a range of 89-106 µg/L. This is only slightly above the chronic criterion and thus these residual concentrations may be acceptable. The EPA website showing the current ambient water quality criteria for protection of aquatic life has three footnotes associated with the water quality criteria for Al [6]:

1. The value of 87 µg/l is based on a toxicity test with the striped bass in water with pH = 6.5–6.6 and hardness <10 mg/L. Data in "Aluminum Water-Effect Ratio for the 3M Plant Effluent Discharge, Middleway, West Virginia" (May 1994) indicate that aluminum is substantially less toxic at higher pH and hardness, but the effects of pH and hardness are not well quantified at this time.
2. In tests with the brook trout at low pH and hardness, effects increased with increasing concentrations of total aluminum even though the concentration of dissolved aluminum was constant, indicating that total recoverable is a more appropriate measurement than dissolved, at least when particulate aluminum is primarily aluminum hydroxide particles. In surface waters, however, the total recoverable procedure might measure aluminum associated with clay particles, which might be less toxic than aluminum associated with aluminum hydroxide.
3. EPA is aware of field data indicating that many high quality waters in the U.S. contain more than 87 µg aluminum/L, when either total recoverable or dissolved is measured.

These statements highlight the fact that predicting Al toxicity in surface waters is complicated. It was decided to measure dissolved Al concentrations rather total Al concentration due to concern expressed in the latter part of footnote 2. Given the statements in footnotes 1 and 3, and the fact that Canyon Lake water has slightly higher pH after treatment, and relatively high hardness, the levels of residual aluminum of 89-106 µg/L may be acceptable for the protection of aquatic life within the lake.

## SUMMARY OF RESULTS

The results of this study show that in-lake treatment with alum may be an effective way to remove both existing turbidity and nutrients from Canyon Lake water. The removal of nutrients will reduce the potential for future water quality problems in the lake. For Stations 7 and 8 below the thermocline, and for Station 9, an alum dose of 50 mg/L was sufficient to drop turbidity to less than 1.0 NTU. This dose also resulted in reductions in total nitrogen of 6%, 36%, and 28% for stations 7, 8 and 9 respectively. Even greater relative reductions in total phosphorus were achieved; with reductions of 86%, 86%, and 74% for stations 7, 8 and 9, respectively. The water samples from station 10 required a higher alum dose of 100 mg/L to drop the turbidity to less than 1.0 NTU. The 100 mg/L alum dose resulted in reductions in total nitrogen and total phosphorus of 64% and 92%, respectively. All of the alum doses studied resulted in residual dissolved aluminum concentrations below the EPA acute toxicity criterion for the protection of aquatic life, 750 μg/L. An alum dose of at least 150 mg/L is required to reduce the residual dissolved aluminum concentration in the treated waters to levels close to the EPA chronic ambient water quality criterion for the protection of aquatic life. Even higher doses of alum may be effective in lowering the residual Al concentrations, but practical doses are limited by the drop in pH and the natural alkalinity of the lake. While the results of these laboratory studies are promising, limited in-lake treatment studies should be conducted to determine the actual effects of alum treatment on the *in situ* water quality in Canyon Lake.

## REFERENCES


1. Viessman, W. and Hammer, M.J. *Water Supply and Pollution Control*, 5th ed., 1993 Harper Collins. p.415-416.
2. Anderson, M.A. *Sediment Nutrient Flux and Oxygen Demand Study for Canyon Lake with the Assessment of In-Lake Alternatives*, June 25, 2007. Final Report to San Jacinto Watershed Council.
3. Anderson, M.A. *Predicted Effects of In-Lake Treatment on Water Quality in Canyon Lake*, December 31, 2007. Final Report to San Jacinto Watershed Council.
4. APHA, AWWA. *Standard Methods for the Examination of Water and Wastewater,* Centennial 21st ed. 2005.
5. EPA Method 200.9, *Trace Elements in Water, Solids, and Biosolids by stabilized temperature graphite furnace atomic absorption spectrometry revision 3.0*. 1998.
6. EPA Ambient Water Quality Criteria for the protection of aquatic life: http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm.

**Table 1.** Depth profile data for Station 7.

| **Station 7** | 8/27/2012 | 8:44 am | | | |
|---|---|---|---|---|---|
| **Depth** (m) | **Temp** ($C^o$) | **pH** | **ORP** (mV) | **EC** (mS/cm) | **Turb** (NTU) |
| 0.5 | 28.5 | 8.60 | 199 | 1088 | 5.3 |
| 1.0 | 28.5 | 8.62 | 189 | 1087 | 5.9 |
| 2.0 | 28.5 | 8.58 | 185 | 1087 | 6.1 |
| 3.0 | 28.5 | 8.56 | 183 | 1088 | 5.8 |
| 4.0 | 28.5 | 8.48 | 182 | 1090 | 5.4 |
| 5.0 | 27.0 | 7.39 | 213 | 1096 | 10.7 |
| 6.0 | 23.3 | 7.11 | 290 | 1041 | 10.5 |
| 7.0 | 19.7 | 7.04 | 317 | 1006 | 7.2 |
| 8.0 | 17.6 | 7.05 | 329 | 991.4 | 6.3 |
| 9.0 | 16.1 | 7.00 | 335 | 985.3 | 5.8 |
| 10.0 | 15.5 | 6.97 | 340 | 984.6 | 5.1 |
| 11.0 | 15.2 | 6.94 | 343 | 990.3 | 5.9 |
| 12.0 | 15.0 | 6.85 | 346 | 992.8 | 6.5 |
| 12.5 | 14.9 | 6.85 | 348 | 993.3 | 11.6 |
| 13.0 | Bottom | | | | |

**Table 2.** Depth profile data for Station 8.

| **Station 8** | 8/27/2012 | 9:30 am | | | |
|---|---|---|---|---|---|
| **Depth** (m) | **Temp** ($C^o$) | **pH** | **ORP** (mV) | **EC** (mS/cm) | **Turb** (NTU) |
| 0.5 | 28.7 | 8.59 | 40 | 1095 | 5.9 |
| 1.0 | 28.7 | 8.58 | 34 | 1095 | 6.5 |
| 2.0 | 28.6 | 8.55 | 33 | 1096 | 6.0 |
| 3.0 | 28.5 | 8.51 | 33 | 1095 | 6.0 |
| 4.0 | 28.4 | 8.40 | 36 | 1095 | 6.8 |
| 5.0 | 27.9 | 7.64 | 204 | 1103 | 9.3 |
| 6.0 | 22.15 | 7.08 | 310 | 1033 | 10.9 |
| 6.4 | bottom | | | | |

**Table 3**. Depth profile data for Station 9.

| **Station 9** | 8/27/2012 | 10:00 am | | | |
|---|---|---|---|---|---|
| **Depth** (m) | **Temp** ($C^o$) | **pH** | **ORP** (mV) | **EC** (mS/cm) | **Turb** (NTU) |
| 0.5 | 28.2 | 8.78 | 40 | 1255 | 13.0 |
| 1.0 | 28.2 | 8.64 | 31 | 1256 | 12.7 |
| 2.0 | 27.9 | 8.40 | 37 | 1259 | 12.0 |
| 3.0 | 27.8 | 8.46 | 35 | 1255 | 11.2 |
| 4.0 | 26.3 | 7.01 | 313 | 1274 | 19.7 |
| 5.0 | 20.2 | 6.86 | 352 | 1285 | 19.7 |
| 5.5 | Bottom | | | | |

**Table 4**. Depth profile data for Station 10.

| **Station 10** | 8/27/2012 | 10:30 am | | | |
|---|---|---|---|---|---|
| **Depth** (m) | **Temp** ($C^o$) | **pH** | **ORP** (mV) | **EC** (mS/cm) | **Turb** (NTU) |
| 0.5 | 28.3 | 8.71 | 10 | 1272 | 19.7 |
| 1.0 | 28.1 | 8.68 | 10 | 1278 | 20.0 |
| 2.0 | 27.6 | 8.46 | 18 | 1293 | 21.4 |
| 2.2 | Bottom | | | | |

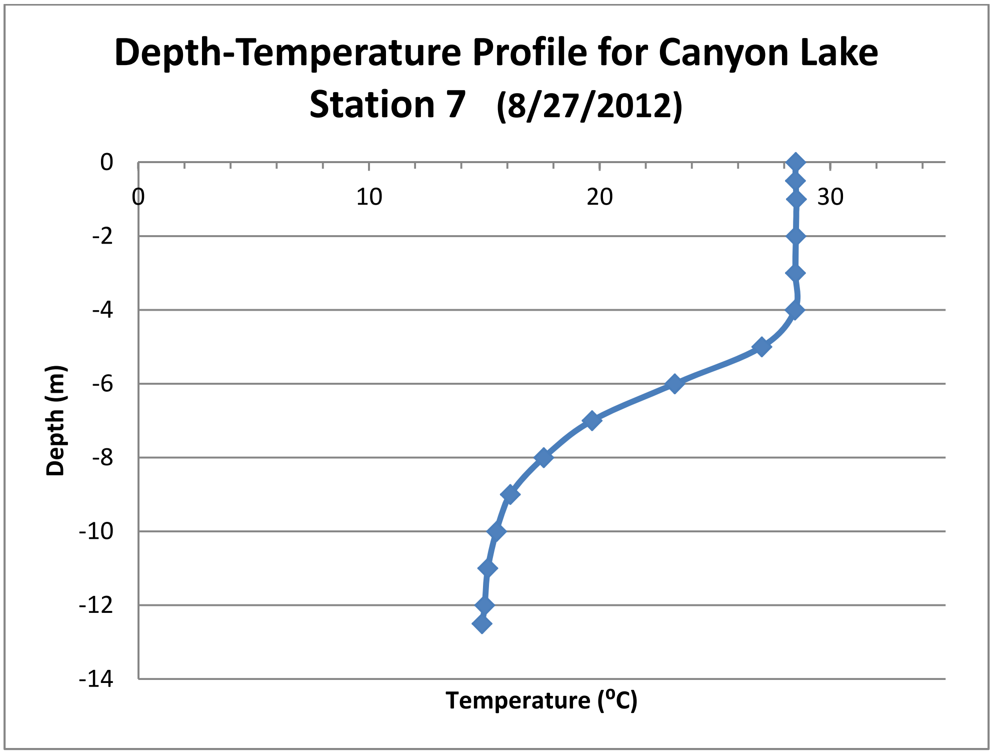


**Figure 2**. Depth-Temperature profile for Station 7, Canyon Lake.

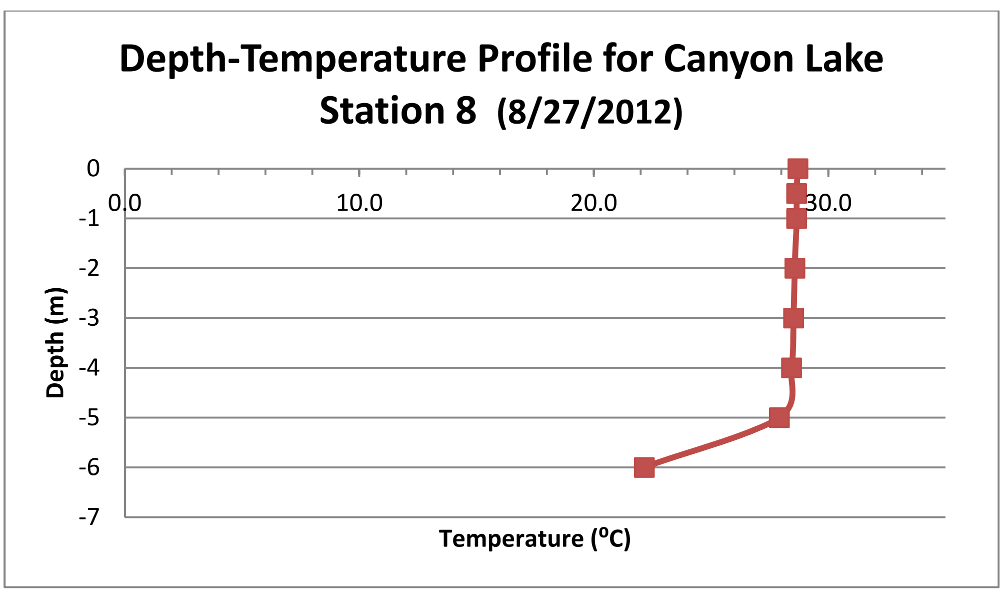


**Figure 3**. Depth-Temperature profile for Station 8, Canyon Lake.

**Table 5.** Jar test results for water from Station 7.

**Station 7** (hypolimnion, 8.5 m)

| **Alum Dose (mg/L)** | **pH** | **Temp (°C)** | **Turbidity* (NTU)** | **Cond. (μS/cm** | **Diss. Al (μg/L)** | **TOC (mg/L)** | **Tot N (mg/L)** | **Tot P (mg/L)** |
|---|---|---|---|---|---|---|---|---|
| 0 | 7.57 | 22.1 | 90.25 | 1032 | 72 | 11.1 | 2.290 | 1.010 |
| 10 | 7.45 | 21.3 | 1.51 | 1030 | 289 | 12.9 | 2.310 | 0.803 |
| 25 | 7.50 | 21.6 | 0.91 | 1032 | 366 | 12.1 | 2.210 | 0.455 |
| 50 | 7.44 | 21.5 | 0.54 | 1036 | 321 | 10.9 | 2.160 | 0.139 |
| 75 | 7.30 | 21.7 | 0.43 | 1037 | 298 | 9.2 | 2.060 | 0.067 |
| 100 | 7.29 | 21.3 | 0.89 | 1042 | 258 | 10.8 | 1.770 | 0.033 |
| 125 | 7.05 | 21.2 | 0.18 | 1037 | 86 | | | |
| 150 | 7.00 | 21.2 | 0.22 | 1044 | 89 | | | |

* High Turbidity was due to a precipitation reaction that occurred during storage at 4°C.
Field turbidity was around 6.0 NTU

**Table 6.** Jar test results for water from Station 8.

**Station 8** (hypolimnion, 5.5 m)

| **Alum Dose (mg/L)** | **pH** | **Temp (°C)** | **Turbidity (NTU)** | **Cond. (μS/cm** | **Diss. Al (μg/L)** | **TOC (mg/L)** | **Tot N (mg/L)** | **Tot P (mg/L)** |
|---|---|---|---|---|---|---|---|---|
| 0 | 7.97 | 22.10 | 5.89 | 1100 | 83 | 14.5 | 1.100 | 0.313 |
| 10 | 8.06 | 22.20 | 2.00 | 1117 | 374 | 15.0 | 0.960 | 0.205 |
| 25 | 7.91 | 21.60 | 1.03 | 1124 | 389 | 14.7 | 0.809 | 0.081 |
| 50 | 7.66 | 22.00 | 0.71 | 1118 | 355 | 12.8 | 0.705 | 0.043 |
| 75 | 7.41 | 21.60 | 0.62 | 1118 | 276 | 11.3 | 0.676 | 0.020 |
| 100 | 7.31 | 22.00 | 0.18 | 1127 | 236 | 9.7 | 0.688 | 0.010 |
| 125 | 7.16 | 21.00 | 0.16 | 1130 | 106 | | | |
| 150 | 7.01 | 21.00 | 0.18 | 1141 | 101 | | | |

**Table 7.** Jar test results for water from Station 9.

**Station 9** (East Bay, Road Runner Beach)

| Alum Dose (mg/L) | pH | Temp ($^oC$) | Turbidity * (NTU) | Cond. (μS/cm | Diss. Al (μg/L) | TOC (mg/L) | Tot N (mg/L) | Tot P (mg/L) |
|---|---|---|---|---|---|---|---|---|
| 0 | 8.55 | 21.8 | 2.17 | 1270 | 134 | 18.7 | 1.348 | 0.098 |
| 10 | 8.01 | 21.3 | 1.96 | 1299 | 287 | 20.4 | 1.460 | 0.064 |
| 25 | 7.81 | 21.6 | 1.37 | 1290 | 331 | 19.5 | 1.210 | 0.045 |
| 50 | 7.64 | 21.3 | 0.95 | 1290 | 285 | 16.6 | 0.971 | 0.025 |
| 75 | 7.52 | 21.8 | 0.52 | 1305 | 231 | 14.4 | 0.813 | 0.013 |
| 100 | 7.33 | 21.3 | 0.69 | 1299 | 146 | 13.2 | 0.647 | 0.004 |
| 125 | 7.00 | 20.9 | 0.19 | 1306 | 107 | | | |
| 150 | 6.81 | 20.9 | 0.23 | 1299 | 104 | | | |

* Turbidity changed during storage at $4^o$ C. Field turbidity was 12.7

**Table 8.** Jar test results for water from Station 10.

**Station 10** (East Bay, Indian Beach)

| Alum Dose (mg/L) | pH | Temp ($^oC$) | Turbidity* (NTU) | Cond. (μS/cm | Diss. Al (μg/L) | TOC (mg/L) | Tot N (mg/L) | Tot P (mg/L) |
|---|---|---|---|---|---|---|---|---|
| 0 | 8.56 | 22.1 | 7.84 | 1277 | 17 | 20.7 | 1.635 | 0.106 |
| 10 | 8.06 | 22.1 | 4.60 | 1286 | 607 | 17.3 | 1.480 | 0.094 |
| 25 | 7.66 | 21.8 | 3.55 | 1287 | 511 | 19.7 | 1.310 | 0.079 |
| 50 | 7.17 | 21.9 | 1.77 | 1294 | 456 | 18.1 | 0.994 | 0.043 |
| 75 | 6.95 | 22.0 | 1.47 | 1296 | 441 | 16.0 | 0.801 | 0.028 |
| 100 | 6.69 | 22.0 | 0.71 | 1297 | 280 | 13.8 | 0.585 | 0.009 |
| 125 | 6.91 | 21.1 | 0.29 | 1332 | 136 | | | |
| 150 | 6.76 | 20.9 | 0.24 | 1329 | 106 | | | |

* Turbidity changed during storage at $4^o$ C. Field turbidity was 20.0 NTU

**Table 9.** The pH and turbidity values for Station 10 jar test after 24 hours.

| Alum Dose (mg/L) | pH | Turbidity (NTU) |
|---|---|---|
| 0 | 8.56 | 7.84 |
| 10 | 8.10 | 4.04 |
| 25 | 7.88 | 2.70 |
| 50 | 7.63 | 1.85 |
| 75 | 7.46 | 1.46 |
| 100 | 7.30 | 0.53 |