ALUM APPLICATION TO LAKE ELSINORE, CALIFORNIA: RESPONSES TO QUESTIONNAIRE

By G. DENNIS COOKE, Ph.D.
August, 2001

1. DOES THE WATER CHEMISTRY AND SHALLOWNESS OF LAKE ELSINORE MEET THE CRITERIA FOR AN ALUM TREATMENT?

The water chemistry of Lake Elsinore may not make it an ideal lake for an alum application because of the lake's high pH and alkalinity. As described in more detail in questions 6-8, the high pH could mean that some of the added aluminum will appear in the aluminate form instead of the desired aluminum hydroxide form. The high alkalinity of the lake will buffer pH, meaning that alum addition may not drive the pH down to a pH of 7-8.

In an appendix to this questionnaire, I have described how this problem can be solved through the use of high acid alum.

The shallowness of Lake Elsinore is ideal. Sediment phosphorus (P) release in shallow lakes is a significant P source to the entire water column. In a P-limited lake like Lake Elsinore, sediment P release probably triggers most blooms of algae. In deep lakes the thermocline is a barrier to transport of P to surface waters, and in these lakes an alum application may have limited effectiveness. Historically, the best results of alum applications have been to shallow lakes (Welch and Cooke, 1999).

2. WHAT WILL BE THE CHANGE IN ALKALINITY FOLLOWING THE ALUM TREATMENT?

The expected change in lakewater alkalinity is a function of dose and buffering capacity. The dose proposed for Lake Elsinore is 48 gms. Al/ square meter . Using a treated area at 1240 feet elevation of 8,093,746 square meters and volume at 1240 feet of 47,512,801 cubic meters, the dose will be about 8 mg Al /liter. Alum (dry) produces about a 0.5 ppm loss of alkalinity per ppm of alum added. At this low proposed dose of standard alum, alkalinity loss in Lake Elsinore will be very small.

3. WHAT WILL BE THE CHANGE IN pH FOLLOWING THE ALUM TREATMENT?

If standard alum is applied, the pH change will be very small. Only a jar test of lake water prior to application can answer this question.

4. WHAT TYPE OF WATER QUALITY MONITORING NEEDS TO OCCUR DURING AND AFTER THE ALUM TREATMENT?

Monitoring of Lake Elsinore prior to, during, and after alum application is essential. I suggest three stations, one of them in shallow water.

Prior to application (at least 10 weeks before), weekly determinations will be satisfactory. During the application week, all determinations should be daily except pH and alkalinity, which should be done twice daily. P release rates and benthos species diversity and density should be done once before application, not at all during application, and then once again after treatment. Resume weekly monitoring throughout the year of application and then monthly in subsequent years. Determine sediment P release and benthos density/diversity annually in the summer. Impacts on fish are difficult to estimate unless there is mass mortality. I suggest fish tissue analysis for Al, using an untreated nearby lake as a control.

I recommend the following:

a. surface and bottom pH and alkalinity
b. surface and bottom total and dissolved aluminum
c. total phosphorus at meter intervals, surface to bottom
d. surface and integrated (pooled surface to bottom samples) chlorophyll
e. zooplankton and phytoplankton species identification and density
f. transparency
g. dissolved oxygen at meter intervals surface to bottom (Winkler method recommended)
h. temperature at meter intervals surface to bottom

i. sediment phosphorus release rate (in lab from cores or in lake from release rate chambers). Mass balance data (inflow and outflow phosphorus) and change in lake P content can be used to calculate net P release.

j. sediment benthos density and diversity

5. WHAT IS THE ESTIMATED FINAL THICKNESS OF THE ALUM FLOC ONCE IT HAS SETTLED TO THE BOTTOM?

The thickness of the floc will depend upon water chemistry. If pH is 7-8, a 5-10 cm. thick floc could form but it will consolidate with the sediments.

6. IS ALUM TOXIC TO BENTHIC INVERTEBRATES, FISH, PLANTS, AQUATIC BIRDS, REPTILES OR PEOPLE UNDER THE CONDITIONS PROPOSED FOR LAKE ELSINORE?
7. WHAT EFFECT DOES THE ALUM FLOC HAVE ON SPECIES DIVERSITY AND POPULATIONS OF BENTHIC INVERTEBRATES?
8. WHAT IS THE PRIMARY SPECIES OF ALUMINUM THAT WILL BE FORMED FOLLOWING THE ALUM TREATMENT? TO WHAT DEGREE IS THIS FORM TOXIC?

Aluminum is the Earth's most abundant metal and the third most abundant element (after oxygen and silicon). Normally it is complexed with elements like silicon in rocks and soil and has extremely low concentrations in fresh water. Organisms have not evolved with it, and consequently elemental aluminum, and some of its compounds, is extremely toxic. The chemistry of aluminum and its toxicity was reviewed in Poleo (1995) and Gensemer and Playle (1999), and these articles are the basis of some of the following discussion.

The solubility of aluminum, and the presence of toxic forms of the element, is pH dependent. Aluminum is relatively insoluble at pH 6-8, but solubility increases linearly under more acidic and alkaline pH. Minimum solubility is at pH 7.0. Understanding these facts is key to understanding aluminum toxicity.

When aluminum sulfate (alum) is added to water to clarify it for drinking purposes or to control sediment P release, a hydrolysis reaction occurs (release of hydrogen ions), pH declines at a rate dictated by water alkalinity, and aluminum hydroxide will form if pH is 6-8. Aluminum hydroxide is a colloidal, amorphous floc or solid with significant density so that it settles through the water column and deposits as a visible white floc on the lake bottom. As it sinks, it will carry particulate and dissolved organic matter with it (this is the basis of its use in drinking water treatment). When aluminum hydroxide settles on the sediment surface it will bind inorganic P, preventing its release to the water column. Formation of aluminum hydroxide is the goal of an alum treatment of a lake or of raw drinking water. Depending on sediment texture, the floc will sink into the sediments over time. In the pH range 7-8, aluminum hydroxide remains insoluble and has low or no toxicity to fish and invertebrates.

The aluminum hydroxide molecule sorbs inorganic P to its surface, preventing P release from the sediments to the water. If this release had been a significant P source (as is the case in Lake Elsinore), water column P concentration will decline after application and algal growth may be reduced if P is the limiting nutrient to algae. Lake Elsinore appears to be P-limited and a significant decline in algal biomass is expected through P limitation. Alum is not an algicide.

Lake Elsinore has a pH of 9.0 or greater, and a very high alkalinity (buffering capacity), according to the Black and Veatch study. This means that some aluminum hydroxide floc will form after application, that pH will not change greatly, and that half or more of the added aluminum will appear in the soluble aluminate form rather than the insoluble aluminum hydroxide form.

The toxicity of soluble aluminate is poorly understood, but it is unquestionably toxic. Almost all aluminum toxicity studies have been carried out in response to the acidification of streams and lakes by the emissions of coal-fired power plants. Toxicity of aluminum to aquatic species is most severe at pH 5-6, and lowest at pH 7. Little is known of the potential for toxicity at pH above 8.

ALGAE. pH is the dominant factor controlling toxicity to aquatic organisms. Maximum toxicity to algae occurs at pH 6, with decreases as pH approaches 4 and 7. Aluminum forms complexes with sulfate, phosphate, nitrate, silicate, and organic carbon. The toxicity of aluminum to algae at pH above 8 is not known.

AQUATIC INVERTEBRATES. Benthic invertebrates are more tolerant to aluminumthan fish, and there is no evidence of biomagnification of aluminum in aquatic food webs. Adverse effects are unlikely to vertebrates that consume aluminum-exposed invertebrates. There are several relevant case histories of benthic invertebrates exposed to alum applications. These are described below .

Lake Morey, VT, a soft-water lake (alkalinity of 35 mg CaCO3/liter vs. 200 mg CaCOa3/liter for Lake Elsinore), was treated with a dose of 44 gms. Al/square meter in 1986 (Lake Elsinore proposed dose is 48 gms. Al/ square meter). Lake Morey was not an ideal lake for treatment because of its low alkalinity and thus low buffering capacity. pH shifts and the appearance of toxic aluminum forms were likely despite the addition of buffering agents. Benthic macroinvertebrates (insects) at the 9 meter depth declined by 90% in the first year after application. There was no effect at 12 meters (deepest area). Insect density returned to pre-treatment levels by 1988, new species appeared in 1990, and species richness doubled by 1997. The authors attributed the increasing insect diversity to increased dissolved oxygen at depth, which in turn was caused by the significant increase in water clarity from the alum treatment (Smeltzer et al., 1999).

Lamb and Bailey (1981) conducted acute (pH 7.8) and chronic (pH 6.8) tests of alum toxicity to midge larvae. In the acute tests, there was no apparent effect at exposure up to 96 hours at doses between 0.6 and 78 mg Al/liter (dose to Lake Elsinore would be about 8 mg Al/liter). In the chronic tests, a dose of 10 mg Al/liter had less than 37% mortality, after 55 days of exposure. Insect larvae used the floc material to build feeding tubes, and consumed algae mixed with the floc. Larvae did not pupate, however. No tests were performed at the higher pH levels which are typical of Lake Elsinore.

Narf (1990) found that benthic invertebrates in five Wisconsin lakes that had been alum-treated were apparently unaffected by alum, even in a very low alkalinity lake. Oxygen levels increased and algae species switched to more edible (to invertebrates) species. One species of insect was unaffected by alum in the pH range 7.6-8.5.

Toxicity tests at pH 9.0 or above have not been conducted. This is the pH in Lake Elsinore before treatment. At this pH and above, the toxic aluminate ion will be present if standard alum is used. I do not expect significant negative impacts to benthic invertebrates following an alum application to Lake Elsinore. This conclusion is based upon the apparent hardiness of and absence of toxicity to benthic invertebrates in previous applications to buffered lakes, and to the expectation that an alternative form of alum will be used at Lake Elsinore (see below).

FISH. Aluminum is a gill toxicant to fish, and is acutely toxic at pH below 6 (Poleo, 1995). Of 47 studies of aluminum toxicity to fish, only 2 involved exposing fish to aluminum at a pH greater than pH 8 (see review by Sparling and Lowe, 1996). Thus the toxicity of aluminate, which dominates at pH 9 and above, is poorly known.

When pH is lowered from pH 10, aluminum polymerizes rapidly as aluminum hydroxide, producing low fish mortality. High concentrations of calcium and dissolved organic matter (typical of Lake Elsinore) provided a protective effect on trout exposed to 4 and 9 mg. Al/liter at pH 8 and 8.6 for 96 hours and for 16 days (Gundersen et al., 1994).

The presence of copper reduces the threshold concentration of aluminum needed to reach toxicity in fish (Gensemer and Playle, 1999). According to the Black and Veatch report, Lake Elsinore has substantial levels of copper in its sediments. I cannot estimate the significance of this problem. Most alum-treated lakes have had extensive copper applications. But, there have been no reports of alum toxicity to fish after application except for the Lake Morey, VT application.

Freeman and Everhart (1971) carried out one of the few tests of aluminum toxicity (to rainbow trout fingerlings) over a wide pH range. In order to examine the impact of acidified streams on fish, they used a continuous exposure flow bioassay, providing continuous exposure of fish to aluminum. In contrast, exposure in a lake application of alum to control sediment P release is normally limited to floc settling time unless the alum produces soluble forms (high and low pH) or the floc is disturbed. Therefore, results with rainbow trout continuous exposure tests may not be representative of results which could occur with a lake treatment and with common lake fish species. At pH 9, Freeman and Everhart (1971) found that 97% of the added aluminum appeared in the soluble aluminate form. There was heavy rainbow trout mortality within 48 hours from the aluminate ion at an aluminum dose of 5.2 mg Al/liter. After 4 days of exposure, pH was returned to pH 7 (pH of minimum solubility) and after 60 days, weights of survivors climbed to 77% of controls. The authors concluded that continuous exposure to 5.2 mg Al/liter , whether at pH 7 or 9,would seriously disturb a natural population of rainbow trout.

Medical Lake, WA is a deep lake (maximum depth of 18 meters), with a very high alkalinity (750 mg CaCO3/liter) and a pH of 8.5-9.5. It has an area of 64 hectares (158 acres). It received a dose of 936 metric tons of alum (12.2 mg. Al/liter), with 4 surface and 7 deep applications. Following application, dissolved aluminum (probably mostly aluminate ion) ranged from 0.09 to 0.42 mg Al/liter, and total aluminum levels were always less than 1.0 mg Al/liter. Nearly all of the aluminum precipitated to the lake sediments as aluminum hydroxide, apparently because the applicators may have further acidified the alum with sulfuric acid and also because they used a high alum dose. High levels of aluminum were found in zooplankton, but it is unknown whether this aluminum was adsorbed to body surfaces, in guts following ingestion (some zooplankton species are filter feeders), or actually in tissues. Rainbow trout were stocked in the lake in the years after treatment, and high levels of aluminum were found in liver and kidney tissues, but not in muscle. No fish mortality that could be attributed to alum was observed (Buergel and Soltero, 1983). There are no other reports in the literature of an alum treatment to a high alkalinity-high pH lake.

There have been many alum treatments of lakes in the U.S. The only reported case of negative impacts of an alum application to fish is that of Lake Morey, VT (Smeltzer et al., 1999). As described earlier, this lake is a poorly buffered, soft-water lake that does not meet the criteria for an alum application. Perch relative weight declined 11-20%, and perch density declined. Recovery of weight and density was found 5 years after application. Changes in perch were attributed by the authors to sub-lethal aluminum toxicity.

AQUATIC PLANTS. There have been no cases reported of toxicity to rooted aquatic plants.

BIRDS, REPTILES, AND AMPHIBIANS. There are almost no data regarding the impact of an alum treatment to species of these groups of animals. Aluminum does not biomagnify so food chain acquisition of the element is unlikely. Direct exposure to the floc is unlikely. However, Sparling (1990) did examine the impact of aluminum in the diets of black ducks when the ducks were also put on a regimen of low calcium and phosphorus. Under this condition, high aluminum diets (5,000-10,000 mg Al/kg body weight) were toxic. When diets had normal calcium and phosphorus levels, and dietary aluminum was 1,000 mg Al/ kg or less, there was no evidence of toxicity. Low calcium-phosphorus conditions are expected in the acid rain environment of this study, but are not expected at Lake Elsinore.

HUMANS. The risk of aluminum ingestion by Lake Elsinore users is minimal. At the proposed dose, and if all of the added aluminum is dissolved evenly in the lake water instead of precipitating to the sediments, lake concentration at pH 9.0-9.5 would be about 8 mg. Al/liter, dissolved aluminum. Dietary consumption of aluminum ranges from 1.5 to 100 mg Al. per day, total aluminum (Orme, 1985). The average intake is 20 mg. Al per day (Driscoll and Letterman, 1988). Most surface water potable supplies are treated with alum as a coagulant prior to disinfection. In USEPA Region IX (California and Nevada), 52% of finished drinking water samples had aluminum concentrations above 0.05 mg Al/liter (Miller et al., 1984). Persons consuming antacids may ingest 3000-5000 mg Al. per day. Antiperspirants are rich in aluminum. The minor amounts of lake water ingested by swimmers is not likely to add to the body burden of aluminum.

There is a relationship between aluminum intake and Alzheimer's Disease (AD), but no causal link has been established (Hoveland, 1990). A clinical study (Graves et al., 1990) did not demonstrate a consistent relationship between aluminum in antiperspirants and antacids and AD. There is a strong genetic component to AD.

9., ACCORDING TO THE SCIENTIFIC LITERATURE THE UPPER CONCENTRATION LIMIT FOR TOXIC DISSOLVED ALUMINUM IS 50 MICROGRAMS PER LITER. WILL THE ALUM DOSE PROPOSED FOR LAKE ELSINORE INDEFINITELY REMAIN UNDER THIS LIMIT?

The USEPA (USEPA, 1988) has set acute exposure limits to total aluminum at 0.75 mg Al/liter (750 micrograms per liter) and chronic exposure at 0.087 mg Al/liter (87 micrograms per liter). These criteria were set for waters between pH 6.5 and 9.0. Likely these limits are erroneous because they are based on the very few studies of toxicity where pH was greater than pH 7. The toxicity of the dissolved aluminate form (pH > 9) is very poorly understood.

The concentration of dissolved aluminum in Lake Elsinore could exceed the USEPA chronic exposure limit because the lake's pH is so high and standard alum may not lower it enough to prevent formation of the dissolved aluminate form.. This is why I recommend jar testing with alum and high acid alum (see below). Alkalinity, pH, total and dissolved aluminum (must use the appropriate methods for determination of these fractions) would be determined from well-mixed control and alum-added flasks, before and after alum addition. The high acid alum will be much more effective in lowering the lake's pH as it is added, forcing the formation of the desired aluminum hydroxide and eliminating the formation of high concentrations of toxic aluminate.

If lake pH after treatment remains in the pH 7-8 range, dissolved aluminum will remain below the USEPA limit This has been the experience at the many other alum-treated lakes. Maintenance of lake pH in this range could happen because the high pH of Lake Elsinore is partly from the photosynthesis of the huge algal biomass. If P is lowered significantly by the action of aluminum hydroxide in preventing sediment P release, algal photosynthesis will be much less and pH should be lower.

10. IF BOATERS, BATHERS OR FISH DISTURB THE ALUM FLOC LAYER, WHAT IS THE EFFECT ON PEOPLE OR FISH FROM INCIDENTAL INGESTION? IS THERE ANY RECORD OF THIS SCENARIO OCCURRING?

This question is addressed in questions 6,7, and 8. I am unaware of an incident of human ingestion of the floc in a treated lake. Human aluminum ingestion from other sources (e.g. food such as pickles, drinking water) is continuous and much more significant.

Rough fish ingestion of floc is more likely. Toxicity to fish appears to be only to gills, and only from dissolved aluminum and aluminum that polymerizes on gill surface as pH rises from 5 to 7. High concentrations could appear in liver and kidneys after fish ingestion of floc, but vertebrates eliminate aluminum via these organs. Sport fishing has continued in all of the many alum-treated lakes.

11.IS THERE EVIDENCE THAT A HIGH ROUGH FISH POPULATION CAN SIGNIFICANTLY LOWER THE EFFECTIVENESS OF AN ALUM TREATMENT? WHAT IS THE RECOMMENDED MAXIMUM DENSITY IN POUNDS OF ROUGH FISH PER SURFACE-ACRE FOR AN ALUM APPLICATION TO BE EFFECTIVE?

The role of rough fish in disturbing an alum treatment is unknown. Carp play a significant role in sediment re-suspension and in the excretion/defecation of nutrient-rich materials. The roles of wind and motorboats in Lake Elsinore are likely to be important as well, particularly in maintaining suspension of particles re-suspended by bottom-browsing fish. Fish may retard consolidation of the aluminum hydroxide floc with the sediments. The maximum permissible density of rough fish for an effective alum application is unknown. The only published case history is that of Delavan Lake, WI, which had a massive biomass of European carp. These fish were eliminated, along with all other fish, by a rotenone application prior to alum application. It was believed that the carp would continue to disturb sediments and release nutrients through egestion/excretion, and would interfere with the treatment's success. The Wisconsin DNR also wanted to re-structure the lake's food web.

12. ALUM TRANSPORT. FOLLOWING THE APPLICATION, CAN THE ALUM FLOC BE TRANSPORTED DURING PERIODS OF HIGH WATER, SUCH THAT SPILL-OVER TO THE BACK-BASIN WETLANDS OR DOWNSTREAM TO TEMESCAL WASH NEGATIVELY AFFECT THOSE ECOSYSTEMS?

If floc formation occurs and settles to the lake-sediments, there is little likelihood of transport out of the lake. Aluminum hydroxide will consolidate with the lake sediments. However, if there is a history of high water removing lake sediments to these ecosystems, then floc may be transported with them.

13. ALUM TRANSPORT. COULD AN AERATION SYSTEM DISTURB THE FLOC MAKING IT AVAILABLE FOR MOVEMENT/TRANSPORT DOWNSTREAM DURING FLOOD EVENTS WHEN THE LAKE IS OVERFLOWING?

Artificial circulation could disturb the floc in the areas of the diffusers. Aluminum hydroxide is heavy and the floc should settle rapidly in zones away from the diffusers. I am unaware of a case history wherein artificial circulation was used after an alum application. There may be less disturbance in the area of air injection in the case of a Speece Cone. I would assume that a circulation system would be shut off during a flood event.

14. HOW EFFECTIVE IS IT TO APPLY ALUM ONLY TO THE CENTRAL PORTION (2,000 ACRES) OF LAKE ELSINORE AND NOT THE REMAINING SHALLOW AREAS (1,300 ACRES)?

Application should be made to all areas of significant P release from lake sediments. What fraction of P internal loading is from the 2,000 acres? In addition to fish activities and periodic low dissolved oxygen in deeper waters, high pH induces P release from iron complexes, even in completely oxic shallow water. I recommend treatment of all areas of 1 meter or more in depth unless it can be demonstrated that certain areas do not release significant amounts of P.

15. HOW WOULD THE ALUM TREATMENT AFFECT THE TOTAL DISSOLVED SOLIDS CONCENTRATION? (CURRENT TDS IS ABOUT 1,350 PPM).

Total dissolved solids concentration could change significantly, depending upon the ions of which Lake Elsinore's TDS is composed. I recommend a jar test of this question.

16. CONSIDERING THAT ALUM IS ALUMINUM SULFATE, DOES THE ADDED SULFATE RESULT IN AN INCREASE IN THE FORMATION OF HYDROGEN SULFIDE?

Sulfide forms when dissolved oxygen is absent and microbes are forced to use sulfate as an electron acceptor during their respiration. An alum application adds sulfate to the lake and sulfide formation will occur in the absence of oxygen after all of the available iron has formed iron sulfide. Zero dissolved oxygen occurs in Lake Elsinore during brief calm periods when the lake temporarily stratifies, but is restored to high oxygen levels when wind mixing resumes. Most lakes are naturally rich in sulfate. Hydrogen sulfide should never be a significant problem at Lake Elsinore.

17.GIVEN THE LARGE SIZE OF LAKE ELSINORE, CAN THE LAKE REMAIN OPENED TO BOATERS IF THEY ARE EXCLUDED FROM THE ALUM DRIFT ZONE AND KEPT A REASONABLE DISTANCE FROM THE TREATMENT GRID UNDER APPLICATION?

The lake can remain open to boaters during application. The applicator may have restrictions, perhaps based upon insurance company policies.

18. COULD pH "HOTSPOTS" OCCUR DUE TO ALUM DISTRIBUTION INEFFICIENCIES? CAN THIS BE AVOIDED?

"Hotspots" of low pH could occur, especially if there is an equipment malfunction. Lake Elsinore is not pH sensitive due to its high alkalinity, meaning that a pH hotspot would occur only with a large alum spill. Applicators will make absolutely every effort to prevent this from happening.

SOLUTION TO THE HIGH pH PROBLEM IN LAKE ELSINORE. There is a solution to the high pH-high alkalinity problem at Lake Elsinore. Raw drinking water from surface sources is normally treated with alum to remove organics and particulates prior to chlorination. Chris Lind of General Chemical Corporation (the primary supplier of alum in the United States) has reported to me that many water supply systems have high pH raw water, making standard alum use dangerous because of the formation of aluminate ion. Lake Erie (Ohio, Pennsylvania, Michigan) is an example. The industry has solved this problem by using high acid alum, which lowers pH to pH 8 or less, promoting 100% aluminum hydroxide floc formation and safe, clarified drinking water. This is the appropriate product to be used in Lake Elsinore. Its use should eliminate potential toxicity problems to fish and invertebrates.

There is a relevant case history. Medical Lake, WA, treated with alum in 1977, apparently is the only other high pH-high alkalinity lake which has been alum-treated. In this case, applicators may have used sulfuric acid with the alum in order to lower pH into the pH 7-8 range. Over 900 tons of alum were added to this lake, and dissolved aluminum did not exceed 0.42 mg Al/liter and total aluminum did not exceed 1.0 mg. Al/liter. I would expect much less dissolved and total aluminum in Lake Elsinore if the appropriate dose of high acid alum is used. The applicators at Medical Lake did not have this formulation of alum. Instead they apparently mixed sulfuric acid with their standard alum and added the mixture until the pH fell (Dr. Eugene Welch, Tetra Tech, Inc, Seattle, WA, personal communication).

I recommend jar tests with high acid alum to determine the dose needed to lower Lake Elsinore pH into the range where 100% aluminum hydroxide floc forms. High acid alum is a product that General Chemical has developed. It is more costly than regular alum and the dose to the lake may be higher than you have planned. You may wish to consult the alum industry expert, Mr. Chris Lind (800-631-8050). He has volunteered to assist with jar tests and to provide high acid alum for the tests. You also may wish to consult with the most experienced applicator, Tom Eberhardt (800-428-9900) of Sweetwater Technology. I recommend that you test whether the floc will solubilize if water column pH returns to high levels. This can be done with sediment-water microcosms.

Phosphorus inactivation is a proven technique to control sediment phosphorus release. It is effective, long-lasting, and with few or no reported adverse effects to lake biota. There were significant side effects only in a lake which should not have been treated. I recommend this technique for Lake Elsinore if the high acid alum is used and appropriate jar testing is conducted to determine dose and to determine the fate of the floc if pH returns to the pH 9.0-9.5 range.

LITERATURE CITED.

1.Black and Veatch. 1994. Lake Elsinore Water Quality Management Plan.

2. Buergel, P.M. and R.A. Soltero. 1983. The distribution and accumulation of aluminum in rainbow trout following a whole-lake alum treatment. J. Freshwater Ecol. 2: 37-44.

3. Driscoll, C.T. and R.D. Letterman. 1988. Chemistry and fate of Al (III) in treated drinking water. J. Env. Engin. Div. ASCE 114: 21-37.

4. Eberhardt, T. 2001. Personal Communication. Sweetwater Technology. Aitkin, MN.

5. Freeman, R.A. and W.H. Everhart. 1971. Toxicity of aluminum hydroxide complexes in neutral and basic media to rainbow trout. Trans. Amer. Fish. Soc. 100: 644-658.

6. Gensemer, R.W. and R.C.Playle.1999. The bioavailability and toxicity of aluminum in aquatic environments. Crit. Revs. Environ. Sci. Technol. 29: 315-450.

7. Graves, A.B., E. White, T.d. Koepsell, B.V. Reifler, G. vanBelle, and E.B. Larson. 1990. The association between aluminum-containing products and Alzheimer's disease. J. Clin. Epidemiol. 43: 35-44.

8. Gundersen, D.T., S. Bustaman, W.K. Seim and L.R. Curtis. 1994. pH, hardness, and humic acid influence on aluminum toxicity to rainbow trout (Oncorynchus mykiss) in weakly alkaline waters. Can. J. Fish. Aquatic Sci. 51: 1345-1355.

9. Houeland, T. 1990. Aluminum and Alzheimer's disease: Is there a causal connection? Environ. Geochem. and Health 12: 173-177.

10.Lamb, D.S. and G.C. Bailey. 1981. Acute and chronic effects of alum to midge larvae (Diptera . Chironomidae). Bull. Environ. Contam. Toxicol. 27: 59-67.

11.Lind, C. 2001. Personal Communication. General Chemical Corporation. Syracuse, NY.

12. Miller, R.G., F.C. Kopfler, K.C. Kelty, J.A. Stober, and N.S. Ulmer. 1984. The occurrence of aluminum in drinking water. J. Amer. Water. Works Assoc. 76: 84-91.

13.Narf, R.P. 1990. Interactions of Chironomidae and Chaoboridae (Diptera) with aluminum sulfate treated lake sediments. Lake and Reservoir Management 6: 33-42.

14. Orme, J. 1985. Personal Communication. Letter of 4 November 1985 from USEPA Office of Drinking Water, Health Effects Branch to J. Smith, IEP, Inc.

15. Poleo, A.B.S. 1995. Aluminum polymerization- a mechanism of acute toxicity of aqueous aluminum to fish. Aquatic Toxicol. 31: 347-356.

16. Smeltzer, E., R.A. Kirn and S. Fiske. 1998. Long-term water quality and biological effects of alum treatment of Lake Morey, Vermont. Lake and Reservoir Management 15: 173-184.

17. Sparling, D.W. 1990. Acid precipitation and food quality: Inhibition of growth and survival in black ducks and mallards by dietary aluminum, calcium, and phosphorus. Arch. Environ. Contam. Toxicol. 19: 457-463.

18. Sparling, D.W. and T.P.Lowe. 1996. Environmental hazards of aluminum to plants, invertebrates, fish, and wildlife. Rev. Environ. Contam. Toxicol. 145: 1-127.

19. USEPA. 1988. Ambient water quality criteria for aluminum – 1988. EPA 440/5-86-008. Washington, D.C.

Subj:	**Question 15. 14 September 2001**
Date:	9/14/01 7:05:07 AM Pacific Daylight Time
From:	*dcooke@kent.edu (dennis cooke)*
To:	*PFKilroy@aol.com*

I am glad that you requested clarification of this answer because I can see that I did not provide enough explanation about the word "significant."

If the application is made in such a way that copious aluminum hydroxide floc forms, there may be a significant reduction in lake TDS. This would likely occur because the floc removes particulate material, and may create precipitates from dissolved materials. I am unaware, however, of empirical data in this regard. This is why I suggested that you carry out jar tests in which you determine the effect of floc formation on several variables, including TDS. There should be another question asked, and that deals with the rate of return of pre-application TDS in the months after the treatment. In other words, will dissolved materials be re- introduced to the water column from watershed and sediment sources?

I hope that this paragraph clarifies my answer to question 15.

----------------------- Headers -----------------------

Return-Path: <dcooke@kent.edu>
Received: from rly-ye05.mx.aol.com (rly-ye05.mail.aol.com [172.18.151.202]) by air-ye02.mail.aol.com (v80.17) with ESMTP id MAILINYE21-0914100507; Fri, 14 Sep 2001 10:05:07 -0400
Received: from smtp04.net.kent.edu (smtp04.net.kent.edu [131.123.250.220]) by rly-ye05.mx.aol.com (v80.21) with ESMTP id MAILRELAYINYE51-0914095638; Fri, 14 Sep 2001 09:56:38 -0400
Received: from cooke (dcooke-rm41.biology.kent.edu [131.123.253.166])
by smtp04.net.kent.edu (8.11.2/8.11.2) with SMTP id f8EDuZS22148
for <PFKilroy@aol.com>; Fri, 14 Sep 2001 09:56:35 -0400
Message-Id: <3.0.5.32.20010914100350.009346f0@pop.kent.edu>
X-Sender: dcooke@pop.kent.edu
X-Mailer: QUALCOMM Windows Eudora Light Version 3.0.5 (32)
Date: Fri, 14 Sep 2001 10:03:50 -0400
To: PFKilroy@aol.com
From: dennis cooke <dcooke@kent.edu>
Subject: Question 15. 14 September 2001
Mime-Version: 1.0
Content-Type: text/plain; charset="us-ascii"