"I believe, with Simone Weil, that the true definition of science is the study of the beauty of the world. The results of science are in fact the great art forms of this century"

.... 1974, G. Evelyn Hutchinson (1903-91) a.k.a. the Father of Modern Limnology and the Modern Darwin!

Soil & Water Conservation Society of Metro Halifax (`SWCSMH')

(a volunteer scientific stakeholder-group)

310-4 Lakefront Road, Dartmouth, NS, Canada B2Y 3C4

Email: limnos@chebucto.ns.ca   Tel: (902) 463-7777

Homepage: http://www.chebucto.ns.ca/Science/SWCS/SWCS.html

Ref.:	WAB0004	(total= 13 pg.+1 encl.)
To:	Chairman Dr. Wayne Stobo and Members, Halifax/Halifax County Watershed Advisory Board (**WAB**), HRM	
From:	S. M. Mandaville (Professional Lake Manage.), Chairman and Volunteer Exec. Director	
Date:	March 04, 2000	
Subject:	**ALUMINUM**- a major controversy! A critical summary based on some published and/or Federal literature	

As instructed by the Board during the closing hours of our Water Advisory Board (WAB) meeting in February 2000, I am herewith pleased to provide the following info for reflection, though there is a raft of literature I have to read and digest yet (atleast 75 published papers and journals, some extremely voluminous). I also consult some published `leading' specialists especially in **human toxicology** as well as in **animal toxicology**.

Table of Contents

RECOMMENDATION TO THE WAB, HRM BASED ON THE "PRECAUTIONARY PRINCIPLE" 2

LIME..3

While this discussion of lime is focused upon removal of phosphorus in lakes, nevertheless, same arguments seem to hold true in the treatment for phosphates in STPs as well! 3

(*cf.* Babin et al., 1989; Murphy et al., 1988; Murphy and Prepas, 1990; Murphy et al., 1990; Murphy et al., 1991; Prepas et al., 1990a and 1990b)..3

Phosphates, a sustainable future in recycling (CEEP, Centre Européen d'Études des Polyphosphates, 1998) 4

Feasibility of P-recovery 4

BACKGROUND..6

CANADIAN PRESS NEWS ARTICLE OF 1997...7

TOXICITY IN ANIMALS 8

EXTRACTS FROM THE HEALTH CANADA REPORT DATED NOVEMBER 1998 10

Health Considerations 11

Toxicity in Humans **11**
Alzheimer's Disease (AD) 12

REFERENCES **13**

Recommendation to the WAB, HRM based on the "precautionary principle"

Science, as we all know is an ever evolving domain, and one can never be 100% sure of anything until perhaps it is too late (economically or otherwise) more often than not. At the same time, because of the ever shrinking budget in the domain of pure as well as applied sciences in Canada, if not in all of the OECD countries, especially in the ecological related sciences, several international conferences, even those which are multi-disciplinary have always preached the dictum of the "precautionary principle" if we, i.e., `society' is really serious about our **ecology and the biosphere**.

1. HRM should consider switching from **`alum'** to **`lime'** in the following municipal treatment plants, especially since they discharge into freshwaters, and more importantly the STP at Lake Fletcher, an extremely important lake to all Mainland Nova Scotians as well as due to the long term superior ecological status of the entire Shubenacadie River headwater lakes:
   a) Lake Fletcher Enhanced Secondary STP and probably the Middle Musquodoboit Tertiary STP (if my memory serves me right):
      i) Consider switching from Alum to preferably Lime for the treatment of phosphorus. Lakes do not flush as much during dry periods, and even streams may not have too high a base flow during summers.
      ii) Also, if these treatment plants utilize alum as a coagulant, other alternates should be considered as published in the leading manuals of STPs.
      iii) It is quite possible that lime could create additional sludge volumes, but are the additional volumes not worth tolerating for its benefits?
      iv) Further, if HRM, at a future date, considers **recycling phosphates**, then the use of alum or iron reactants would preclude recycling (CEEP, 1998).
   b) As regards municipal water treatment plants at Pockwock, Lake Major and the Bennery Lake, we are not totally clear of the aluminum residuals in any overflows to the receiving water bodies.
      i) Since those plants supply drinking water, and since the jury is still out as regards effects of aluminum in drinking water on human health, perhaps this is not an issue right now! This is assuming the WTPs use aluminum salts for coagulation

since they are the preferred salts for their efficiency and low costs.

Lime

While this discussion of lime is focused upon removal of phosphorus in lakes, nevertheless, same arguments seem to hold true in the treatment for phosphates in STPs as well!

1. Lime is the only acceptable alternate. Indeed, Environment Canada scientists from the Lakes Research Branch, Burlington, Ontario have, as we understood, conducted numerous lake and pond restoration projects in the Canadian Prairies using lime.
2. Traditionally, alum or sodium aluminate (in the case of low pH lakes) has been the long standing methodology for precipitating phosphorus in lakes.
3. But there has been growing concern among leading ecologists about the \`long term impacts of the bioaccumulation of aluminum salts in the organisms'.
4. Environment Canada has taken a LEADERSHIP ROLE by going away from Alum and selecting Lime.

(*cf.* Babin et al., 1989; Murphy et al., 1988; Murphy and Prepas, 1990; Murphy et al., 1990; Murphy et al., 1991; Prepas et al., 1990a and 1990b)

1. While lime treatment has been extensively used to mitigate acidification effects, several studies of calcium carbonate precipitation led to the hypothesis that the addition of lime to lakes can also reduce eutrophication.
2. Proper application of lime (specifically calcium hydroxide) reduces chlorophyll *a* levels. Calcium hydroxide dissociates and forms calcium carbonate per

   $$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

   These newly formed calcite crystals are small and present a relatively large surface area for adsorption. Associated with phosphate adsorption onto calcite is the molecular exchange of CO_3^{2-} and PO_4^{3-} on the surface of growing calcite crystals as follows,

   $$3CO_3^{2-}(S) + 2PO_4^{3-}(L) \Leftrightarrow 3CO_3^{2-}(L) + 2PO_4^{3-}(S),$$

   where S and L denote calcite and aqueous phases, respectively.

   a) Although biological reactions must influence phosphorus biogeochemistry, the effect of lime treatment on phosphorus biogeochemistry can be easily explained via apatite formation. The generally accepted model for apatite formation is that phosphorus initially adsorbs to calcite and then a surface rearrangement produces phosphate heteronuclei that ultimately form the stable mineral apatite. If the surface application of calcium hydroxide was repeated for a number of years, the titration should exceed an end point, phosphorus and calcium should not redissolve, and phosphorus could be converted into apatite.

b) In lakes without fish, a large dose of $Ca(OH)_2$ should be used.

c) In lakes with valuable fisheries, alternative approaches to enhance apatite formation could include hypolimnetic injection of $Ca(OH)_2$ or larger surface applications of $CaCO_3$.

3. Lime has been added to several lakes and dugouts in Western Canada (Frisken, Figure Eight, Andorra, Beaumaris, Valencia, Halfmoon, Gour, Monnette, Desrosier, Frey, Fedora, Pederson, Sullivan, Schreger, Limno) to improve water quality. These hardwater lakes are eutrophic due to high natural, agricultural, or urban loadings of phosphorus. <u>Source control of phosphorus loadings would be extremely difficult at all sites</u>. Most of the lakes are primarily used for recreation but the dugouts have been used for human and agricultural water supplies. In two of the study sites, Figure Eight Lake and Frisken Lake, most of the sediment iron is converted into pyrite. These lakes have little reactive iron and presumably phosphorus biogeochemistry is not controlled by iron reactions.
4. The usual method for algal control is application of copper sulfate or alum. But copper sulfate is toxic to nontarget organisms, and its use can upset the ecostructure of lakes. The long term adverse effect of alum in the natural environment is unknown.

Phosphates, a sustainable future in recycling (CEEP, Centre Européen d'Études des Polyphosphates, 1998)

Feasibility of P-recovery

1. Iron and aluminum, which are generally used for chemical precipitation of phosphates, are effective precisely because they bond rapidly and tightly to the phosphates, rendering them insoluble. Unfortunately, these same properties render the phosphates, which are generally precipitated into the sewage sludge, poorly accessible to agricultural crops.
2. Furthermore, iron and aluminum reactants also render industrial recycling of the phosphates technically and economically unfeasible: they effectively prevent P-recovery by established methods and interfere with industrial purification processes.
3. The phosphates must be in a chemical form compatible with the phosphate industry's processes: i.e. free of impurities which disrupt these processes and form substances which cannot be readily separated (iron, aluminum).
4. Where biological P-removal is used, the phosphates present in the sewage sludge are in organic or polyphosphate forms useful to agriculture as a slow release fertilizer.

a) Also, biological P-removal can generate high concentrations of soluble phosphates at certain stages of treatment, often in a “side-stream” (small quantities of liquid or sludge diverted from the main flow of the sewage works).

5. The two most frequently documented techniques for recovering phosphates in a form suitable for reuse by the phosphate industry are the formation of calcium phosphates and of struvites (magnesium ammonium or magnesium potassium phosphates).

a) Under certain conditions, phosphates will combine with calcium, forming various insoluble calcium phosphates that can precipitate out of water. This principle has been developed in a number of places, generally using a “crystallization” reactor to collect the calcium phosphates.
   i) Full scale reactors of this type have been developed in the Netherlands at Westerbork, Heemstede and Geestmerambacht (DHV process) and at three sewage works in Japan (Kurita process).

b) Calcium phosphate formation, onto seed material in a fluid or fixed bed reactor, can be induced with high calcium concentrations and a raised pH (by adding lime, which is inexpensive, readily available and free of environmental problems, or other chemicals). Up to 80% P-recovery has been achieved, but 50-60% may be more typical.

Background

1. It appears for starters that several scientists in human toxicology are quite concerned with the residual aluminum levels in the outflows of both WTPs (water treatment plants) as well as WWTPs (waste-water treatment plants or better known as STPs [sewage treatment plants]). This is where aluminum salts are used as ‘coagulants” in both types of treatment plants as well as the use of **alum**, principally as $Al_2(SO_4)_3.18H_2O$, in STPs for phosphorus removal as part of a tertiary process or an enhanced secondary process.
2. HRM STPs: As far as we can recall, there are only two (2) STPs in HRM which use alum salts for phosphorus removal, and the rest do not have tertiary removal of phosphorus at all. Package plants do nothing as regards advanced treatment even when functioning @100% efficiency.
   a) The municipal STPs which incorporate P-removal are the enhanced secondary treatment plant which discharges into Lake Fletcher, and probably the tertiary STP somewhere in the headwaters of the Musquodoboit River.
   b) At one time there was talk of upgrading the STPs in Bedford as well as Timberlea to incorporate phosphorus removal, but I am not current on the status, and the latest info can very easily be established by the HRM Planning staff rep. on the Board.
3. Generally as we understand so far, there is concern among freshwater researchers in the First World OECD countries about discharges from such plants into lakes, and to a lesser extent into streams. Lakes especially, since they flush poorly during dry days/weeks/months.
4. WTPs: The water treatment plants are a whole different issue since one drinks the water directly.
5. Attached is a copy of a news article from 1997 issued by the Canadian Press titled, “Feds seek aluminum link to Alzheimer’s”, and there have been brief statements by scientists from Health Canada and the USEPA (United States Environmental Protection Agency).
   a) We had indeed included the said news article in an `FYI’ package to the Board as part of Ref.# WAB9802, dated Dec. 17, 1998.

Canadian Press news article of 1997

(herewith attached)

1. Human toxicologist, Dr. Barry Thomas (recently retired) of Health Canada is quoted as: “Our position has always been that aluminum is a neurotoxin and if it gets into the CNS (central nervous system) it may have much wider effects than just Alzheimer’s disease.”
2. The news article also states, “The Health Department promised several years ago to introduce a national guideline for aluminum in water, but it failed to get an agreement from the provinces, who said they wanted more evidence.” The said article also states, “Such limits would require costly changes to many municipal treatment systems which use aluminum to remove waste particles from drinking water.”
3. The article goes on to state, “Four studies in Ontario have found the incidence of Alzheimer’s is higher in areas where the water has elevated concentrations of aluminum.” I think the four studies are by independant university professors but I have not tracked them down yet :(:(.
4. Amal Mahfouz of the U.S. Environmental Protection Agency, one of the experts attending a two-day meeting is quoted as, “There is rising public pressure to regulate aluminum based on health”.
5. Our Canadian Federal Health Department has proposed an international study and had invited experts from the U.S., U.K., Australia, Norway and a couple of other countries to conduct further studies. This was stated in the news article and re-confirmed by the Health Canada engineer I spoke with. The engineer alluded to slightly expanded terms of reference of the study, but he also warned me that they do not have sufficient funds yet. He speculated the study would take around 3 years or longer after commencement, and perhaps another 2-4 years for Government scrutiny and regulations, if yet another study gets off ground at all!

Toxicity in Animals

1. **Guideline: The concentration of total aluminum should not exceed 0.005 mg/L in waters with a pH equal to or below 6.5. The concentration of total aluminum should not exceed 0.1 mg/L in waters with a pH greater than 6.5 (CCME, 1995).**
2. At low pH (CCME, 1995):
   a) Aluminum can be acutely toxic to white sucker fry (*Catostomus commersoni*); a 50% mortality occurred at concentrations as low as 0.05 mg/L at pH 5.
   b) Early developmental stags of salmonids also appear to be sensitive. Sac fry of lake trout (*Salvelinus namaycush*) exhibited 25% mortality at an aluminum concentration of 0.07 mg/L and pH 4.6-5.6.
   c) A 27% mortality of cleavage embryos of rainbow trout (*Salmo gairdneri*) occurred at a concentration of less than 0.02 mg/L and pH 4.5.
   d) A 90% mortality in 4- to 8-d rainbow trout occurred at a concentration of 0.075 mg/L.
   e) The 96-h LC_{50} for rainbow trout alevins was 0.12 mg/L at pH 4.5.
   f) The toxicity of aluminum is greatly reduced at circumneutral pH values.
   g) Under very acidic conditions, the toxic effects of the high hydrogen ion concentration are more important than is the presence of aluminum. Aluminum has actually been shown to mitigate the effects of low pH (4.2-4.8) for certain aquatic life stages.
3. Under alkaline conditions, aluminum toxicity to fish also increases (CCME, 1995):
   a) A concentration of 0.52 mg/L (total aluminum) produced 44% mortality in rainbow trout fingerlings after 45 d at pH 9.
4. The toxicity of aluminum to aquatic organisms other than fish has been investigated (CCME, 1995):
   a) A 37% mortality occurred in the chironomid *Tanytarsus dissimilis* (2nd and 3rd instars) after 55 d at an aluminum concentration of 0.8 mg/L and pH 6.8.
   b) 4th instar dipteran larvae, *Chaoborus punctipennis* and *Chironomus anthrocinus*, showed no increase in mortality at a concentration of 1 mg/L and pH 3.5-6.5.
   c) However, the cladocerans *Daphnia catawba* and *Holopedium gibberum* had a 20-35% increase in mortality over controls at the same concentration and pH 4-5.
   d) The 48-h LC_{50} for *Ceriodaphnia* occurred at a concentration of 0.3-0.5 mg/L and pH 5.5-6.0.
   e) At an aluminum concentration of 0.68 mg/L, *Daphnia magna* showed a 50% reproductive impairment after 3 weeks at pH 6.5-7.5.

5. Amphibians are also susceptible to aluminum toxicity. American toad (*Bufo americanus*) egg hatching success was reduced from 75% (for controls at pH 4.3) to 56% with the addition of 0.01 mg/L aluminum (CCME, 1995).
   a) The level of no significant effect was 0.005 mg/L (Clark and LaZerte, 1985).
6. Complexing agents also affect the availability of aluminum to fish. The addition of fluoride, citrate, calcium and organic ligands such as humic acids (DOC) all reduce the availability. But the guideline cannot take these relationships into account until further data are available (CCME, 1995).
7. **OME, Ontario Ministry of the Environment (1991) states that: "in most natural waters the ionized or potentially ionizable aluminum would be in the form of anionic or neutral precipitates, concentrations of 0.1 mg/L or greater of these would be deleterious to growth and survival of fish."**

Extracts from the Health Canada Report dated November 1998

1. The Report commences with the official position as: "There is no consistent, convincing evidence that aluminum in drinking water causes adverse health effects in humans, and aluminum does not affect the acceptance of drinking water by consumers or interfere with practices for supplying good water. Therefore, a health-based guideline or aesthetic objective has not been established for aluminum in drinking water."
2. The Report continues, "In recognition of advancing research into the health effects of aluminum and in an exercise of the precautionary principle, water treatment plants using aluminum-based coagulants should optimize their operations to reduce residual aluminum levels in treated water to the lowest extent possible. For plants using aluminum-based coagulants, operational guidance values of less than 0.1 mg/L (100 µg/L) total aluminum for conventional treatment plants and less than 0.2 mg/L (200 µg/L) total aluminum for other types of treatment systems (e.g., direct or in-line filtration plants, lime softening plants) are recommended. These values are based on a 12-month running average of monthly samples."
   a) To continue, "Any attempt to minimize aluminum residuals must not compromise the effectiveness of disinfection processes (i.e., microbiological quality) or interfere with the removal of disinfection by-product precursors."
3. "Aluminum is the most abundant metal on Earth, comprising about 8% of the earth's crust. Canada is the world's third largest producer of aluminum."
   a) "Because aluminum is ubiquitous (i.e., present everywhere) in the environment and is used in a variety of products and processes, daily exposure of the general population to aluminum is inevitable."
4. "Levels of aluminum in Canadian drinking water vary over a wide range. The highest levels in Canada have been recorded in Alberta, where, during 1987, the mean level in 10 major urban centres was 0.384 mg/L; one water sample attained a level of 6.08 mg/L."
   a) "35% of shallow wells sampled at 17 sites in the Atlantic provinces in the fall of 1993 had high aluminum concentrations, ranging from 0.05 to 0.6 mg/L."
   b) "The global mean level of aluminum in distributed water in Canada, after treatment, has been reported to be 0.17 mg/L."
   c) "In a U.S. nationwide survey of 80 surface water treatment plants that used alum, the mean total aluminum concentration in the finished water was 0.085 mg/L."
5. "The total intake of aluminum from all food sources (excluding over-the-counter drugs) for an adult is 8-9 and 7 mg/d (adult men and women, respectively) in the United States. This estimate is probably a reasonable assessment of Canadian intake, owing to the similar food habits and widespread exchange of food products in North America."

6. "Average levels of aluminum in Canadian ambient air vary over a wide range. In urban locations, the range is from about 0.17 µg/m^3 in Victoria, B.C. to 3.6 µg/m^3 in Edmonton, Alberta. Atmospheric aluminum concentrations in industrial areas are often in the milligram per cubic metre range."
7. "Based on the above figures, approximately 97% of the normal daily intake for an adult is from food and the remainder is from drinking water; the contribution from ambient air is insignificant."

Health Considerations

1. "The degree of aluminum absorption in animals depends on a number of parameters, including pH, aluminum speciation and dietary factors."
   a) "Aluminum absorption does not appear to occur in the stomach, where most aluminum is converted to soluble monomolecular species at low pH."
2. "Although aluminum concentrations in brewed tea are 10-100 times those in drinking water, aluminum in tea is present almost exclusively (91-100%) in the form of high-molecular-weight organic complexes, which are not readily absorbed."
3. "A critical review of the scientific literature suggests that certain diseases enhance the gastrointestinal absorption of aluminum. For example, there is some evidence that patients suffering from chronic renal insufficiency or uraemia absorb aluminum more readily than normal individuals."
4. "Because aluminum in drinking water constitutes only a small fraction (about 3%) of the total oral intake of aluminum, it is important to determine the relative bioavailability of aluminum from drinking water and food."

Toxicity in Humans

1. "On acute exposure, aluminum is of low toxicity. In humans, oral doses up to 7200 mg/d (100 mg/kg bw per day) are routinely tolerated without any signs of harmful short-term effects."
   a) "However, two healthy individuals who drank water accidentally contaminated with an aluminum sulphate solution (aluminum concentrations ranged from 30 to 620 mg/L) experienced ulceration of the lips and mouth."
2. "Intake of large amounts of aluminum can lead to a wide range of toxic effects, including microcytic anaemia, osteomalacia, glucose intolerance of uraemia and cardiac arrest."
3. "Elderly persons with elevated serum aluminum levels exhibit impaired complex visual-motor co-ordination and poor long-term memory."
4. "There is extensive literature on the impairment of various aspects of central nervous system function in humans following inadvertent parenteral exposure to aluminum."
5. "The most studied aluminum-related syndrome is dialysis encephalopathy, chronic symptoms of which include speech disorders, neuropsychiatric abnormalities and multifocal myoclonus."

Alzheimer's Disease (AD)

1. "Aluminum has also been suggested as having a causal role in the onset of AD. Numerous other causes have been suggested for AD, including genetic and environmental factors, but none of them has been proven."
2. "There have been many attempts to study the relationship between AD and exposure to aluminum from an epidemiological point of view. Most of the published epidemiological studies (nearly 20) have been ecological in nature and have examined whether there was any link between exposure to aluminum in drinking water and the incidence of AD."
3. "In a controversial cross-sectional epidemiological study purporting to demonstrate an increased incidence of AD in areas of England and Wales where the aluminum levels in drinking water were high, mean aluminum levels in water over the previous 10 years were obtained from waterworks agencies and were stratified in five groups by concentration, from 0.01 to 0.2 mg/L. .... four hundred and forty-five patients were classified as having probable AD."

References

Babin, J., Prepas, E.E., Murphy, T.P., and Hamilton, H.R.. 1989. A test of the effects of lime on algal biomass and total phosphorus on concentrations in Edmonton stormwater retention lakes. Lake and Reserv. Manage. 5(1):129-135.

(CCME) Canadian Council of Ministers of Environment. Canadian Water Quality Guidelines. September 1989, Revised to April 1995.

(CEEP) Centre Européen d'Études des Polyphosphates. 1998. Phosphates, a sustainable future in recycling. CEFIC, European Chemical Industry Council, Belgium. 19p.

Clark, K.L., and LaZerte, B.D. 1985. A Laboratory Study of the Effects of Aluminum and pH on Amphibian Eggs and Tadpoles. Can J. Fish. Aquat. Sci. 42:1544-1551.

France, R.L., and LaZerte, B.D. 1987. Empirical hypothesis to explain the restricted distribution of Hyalella azteca (Amphipoda) in anthropogenically acidified lakes. Can. J. Fish. Aquat. Sci. 44(6):1112-1121.

Health Canada. 1998. Aluminum. (a synopses only). 22p.

LaZerte, B.D., Chun, C., and Evans, D. 1988. Measurement of Aqueous Aluminum Species: Comparison of Dialysis and Ion-Exchange Techniques. Environ. Sci. Technol. American Chemical Society. 22(9):1106-1108.

LaZerte, B.D. 1989. Aluminum speciation and organic carbon in waters of Central Ontario. In Environmental Chemistry and Toxicology of Aluminum. T.E. Lewis (ed.). p.195-207.

LaZerte, B.D., and Findeis, J. 1994. The relative importance of oxalate and pyrophosphate extractable aluminum to the acidic leaching of aluminum in Podzol B horizons from the Precambrian Shield, Ontario, Canada. Can. J. Soil. Sci. 75:43-54.

Murphy, T.P., Prepas, E.E., Lim, J.T., Crosby, J.M., and Walty, D.T. 1990. Evaluation of calcium carbonate and calcium hydroxide treatments of prairie drinking water dugouts. Lake and Reserv. Manage. 6(1):101-108.

Murphy, T.P., and Prepas, E.E. 1990. Lime treatment of hardwater lakes to reduce eutrophication. Verh. Internat. Verein. Limnol. 24:327-334.

Murphy, T.P., Hall, K.G., and Northcote, T.G. 1988. Lime treatment of a hardwater lake to reduce eutrophication. Lake and Reserv. Manage. 4(2):51-62.

Murphy, T.P., Prepas, E., and Babin, J. 1991. Limnology of Figure Eight Lake in 1988. Effects of 1986 and 1987 lime treatments on water quality. National Water Research Institute Report No. 91-13. 52p.

(OME) Ontario Ministry of the Environment. Water Management- Goals, Policies, Objectives and Implementation Procedures. November 1978, Revised May 1984, and July 1991.

Prepas, E.E., Murphy, T.P., Babin, J.M., and Lim, J.T. 1990a. Farm water dugouts. A manual on the use of lime to provide good water quality. National Water Research Institute Report No. 90-16. 8p.

Prepas, E.E., Murphy, T.P., Crosby, J.M., Walty, D.T., Lim, J.T., Babin, J., and Chambers, P.A. 1990b. Reduction of phosphorus and chlorophyll a concentrations following CaCO3 and Ca(OH)2 additions to hypereutrophic Figure Eight Lake, Alberta. Environ. Sci. Technol. 24(8):1252-1258.

Yokel, R.A., and Golub, M.S. 1997. Research Issues in Aluminum Toxicity. Chapter 2, Aluminum in Water. Taylor & Francis Publishers, Washington, DC, USA. p.17-45.