TOXICITY OF LAKE ENRICHMENT NUTRIENTS

TO AQUATIC LIFE

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Introduction

The Lake Enrichment Program adds nutrients to lakes in British Columbia to increase their productivity as nurseries for sockeye salmon fry (Stockner, 1987). Since 1985, the nutrients used have been a mixture of urea ammonium nitrate (32-0-0 or 28-0-0) and ammonium polyphosphate (10-34-0), both of which are supplied in concentrated liquid form. Before 1997, these nutrients were added to the lakes by spraying a fine mist onto a designated 'application zone' from aircraft (twin engine airplanes or helicopters) fitted for crop dusting. Currently, nutrients are added by introducing the liquid nutrient mix directly into the propeller wash from a boat cruising on the lake.

The goals of this study were to:
1. Determine the toxicity of the concentrated nutrient solutions to aquatic life,
2. Determine which chemical species is the toxic fraction, and
3. Compare the toxicity levels to the concentrations that would be found during an application of nutrients to the lake.

Methods

Toxicity Tests

Toxicity testing was carried out at the Pacific Environmental Science Centre in North Vancouver, Canada in 2001. 96-hr acute lethality tests were performed on

rainbow trout (*Oncorhynchus mykiss*) for both the 28-0-0 and the 10-34-0 solutions. A 48-hr a acute lethality test was performed on the freshwater microcrustacean, *Daphnia magna* (Figure 1). The 96 hour LC50 is the concentration of sample that is calculated to be lethal to 50% of the test fish over an exposure period of 96 hours.A 72-hr IC50/IC25 growth inhibition test was performed on the green alga, *Selenastrum capricornutum* using the 10-34-0 solution.

Figure 1. *Daphnia magna*, a test organism for freshwater aquatic life toxicity studies.

The rainbow trout LC50 tests followed protocols outlined in McLeay (1990, 2001) and the *Dapnia* LC50 test followed protocols outlined in (Miller et al. 2000). Both tests were conducted using well water as the contol and the diluent for the test concentrations. Five test concentrations were used: 5600, 3200, 1800, 1000, 560 and 320 mg/L and a control. Each concentration had one replicate with 10 test organisms per replicate in 30 kg of test solution for the Rainbow trout and 200 mL for the *Daphnia*. Rainbow trout mortality was recorded after 5, 10, 20, 40, 80 minutes and 24, 48, 72, 96 hours of exposure at 15+1^{o}C. Cumulative *Daphnia* mortality was recorded after 24 and 48 hours of exposure at 20+2^{o}C. The 96-hr and 48-hr mortality data, respectively for rainbow trout and *Daphnia*, were analyzed using the Stephan Program to calculate the LC50 and 95% confidence intervals. A phenol reference test was conducted for the rainbow trout, and a sodium chloride reference test was

conducted for the *Daphnia*, to ensure that the organism sensitivity was within acceptable quality control warning chart limits.

The *Selenastrum* growth inhibition test followed protocols outlined in (McLeay, 2000). Tests were conducted using de-ionized water as the control and the diluent for the test concentrations, which were: 10000, 5000, 2500, 1250, 625, 312.5, 156.3, 78.1, 39.1, 19.5 mg/L and a control. Each concentration had five replicates with an initial approximate concentration of 10,000 organisms per replicate in 220 μL of test solution. Algal cell yield was recorded using a Coulter (particle) Counter after 72 hours at 23+1^{o}C. Algal cell yield data was analyzed using ToxStat V3.5 to calculate the IC50, IC25 and 95% confidence intervals. The 72 hour IC50 and IC25 is the concentration of sample estimated to cause a 50% and 25% inhibition in growth of the algae over an exposure period of 72 hours. A copper reference toxicant test was conducted to ensure that the organism sensitivity was within acceptable quality control warning chart limits.

Chemical Analyses

Nutrient solution chemistry samples from both solutions were prepared at the LC50 or IC50 concentrations following the toxicity tests. The chemistry samples were analyzed for total metals, nitrogen ammonia, nitrogen nitrate and nitrite, and total nitrogen using an ICAP spectrophotometer and standard methods, respectively.

Application Dilution

The nutrient solution is added to the lake by filling tanks or the hold on a boat with the solution and cruising down the middle of the lake while pumping the nutrients into the propeller wash behind the boat (Figure 2). The propeller wash is an extremely turbulent zone of water that spreads out behind the boat in three dimensions.

Application concentrations were calculated from conditions found in lake enrichment projects in British Columbia. The diluted concentration of nutrients when it first enters the water can be calculated from the total amount of nutrient solution added per trip or from the instantaneous addition rate:

$$C_N = \frac{N_T}{D_T * A_{XS}}$$

$$C_N = \frac{F_A * \rho * 60}{V_B * A_{XS}}$$

where: C_N is the final concentration of the nutrient solution (in mg/L), N_T is the total amount of nutrients added (in kg), D_T is the total distance travelled during the application (in km), A_{XS} is the cross sectional area influenced by the propeller wash (in m2), F_A is the flow of nutrients into the lake during application (in L/min), ρ is the specific gravity of the nutrient solution (about 1.4, dimensionless), V_B is the velocity of the boat (in km/hr), and 60 is a factor that converts hours to minutes.

The concentration of the nutrient elements (N and P) would be proportionately less, according to which source nutrient was used. The 28-0-0 contains 28% N as a combination of ammonia, nitrate and urea. The 10-34-0 contains 10% nitrogen and 34% phosphorus as P_2O_5, which translates to about 14.6% elemental P.

Figure 2. Application vessel for the Adams Lake Enrichment Project, 1997.

Results and Discussion

Toxicity Tests

The test results indicate that the N-rich 20-0-0 is about twice as toxic to trout as the P-rich 10-34-0 (Table 1).

Table 1. Toxicity levels of fertilizers used in Lake Enrichment Program

Chemical	Test Organism	Type of Test	Length of Test	Effective Concentration	95% C.I. (mg/L)
28-0-0	Trout.	LC50	96 hrs	585.1 mg/L	454-745
10-34-0	Trout.	LC50	96 hrs	1341.6 mg/L	1000-1800
10-34-0	Daphnia	LC50	48 hrs	1229.4 mg/L	1000-1800
10-34-0	Selenastrum	IC50	72 hrs	1745.0 mg/L	1674-1818

Chemical Composition of Test Solutions

Heavy metals were all below detection limits (0.03 mg/L or 0.005 mg/L, depending on the element) for all test solutions (including the toxic heavy metals: aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, tin and zinc). The total nitrogen concentration of the 'lethal' solutions is very similar for rainbow trout and *Daphnia* at approximately 130-150 mg/L (Table 2). This indicates that it is probably nitrogen, in some form, that causes the lethality. The nitrogen content of the 28-0-0 is approximately 1/3 ammonia and 1/3 nitrate. The other major component is urea, which was not analysed from these samples. It is possible that the urea degraded into ammonia, which is known to be toxic (Sigma, 1983), over the duration of the test.

Table 2. Concentrations of nitrogen compounds in the test fertilizers at the lethal concentrations.

Organism	Rainbow Trout	Rainbow Trout	Daphnia	Selenastrum
Fertilizer	28-0-0	10-34-0	10-34-0	10-34-0
Test Solution Concentration	585 mg/L	1341 mg/L	1229 mg/L	1745 mg/L
Ammonia	42 mg/L	115 mg/L	112 mg/L	160 mg/L
Nitrite	<0.002 mg/L	<0.003 mg/L	<0.003 mg/L	<0.003 mg/L
Nitrate	42.2 mg/L	8.3 mg/L	11.6 mg/L	<0.2 mg/L
Total N	130 mg/L	149 mg/L	139 mg/L	209 mg/L

In-Lake Dilution

At the Adams Lake Enrichment Project, the boat travels approximately 20 km in the application zone, discharging 7000 kg of nutrient solution. The boat travels at 10 km/hr and discharges the nutrient solution at about 42 L/min. I estimate that the propeller wash of the vessel shown in Figure 2, fully loaded with nutrient solution, causes a turbulent zone approximately 4 m wide by 3 m deep. The smaller vessel used on the Great Central Lake Enrichment Project causes a smaller turbulent zone (~3m wide by 2 m deep), but it discharges nutrients at less than half the rate of the Adams Lake project.

Inserting the Adams Lake conditions into the formulae shows that the nutrient solution is diluted to about 29 mg/L within the propeller wash. This value is about 5% of the LC50 value for the most toxic of the nutrient solutions on the most sensitive species. However, this is the highest concentration of the nutrient entering the lake water. The nutrient solutions are extremely soluble and continue to disperse and dilute so rapidly that water sampling a day or two later cannot find a gradient in nutrient concentrations in a lake being enriched.

Conclusions

The inorganic fertilizers that are used to enrich lakes can be toxic to aquatic life in high concentrations. However, such high concentrations are not likely to be encountered during standard techniques of adding nutrients to lakes because of the turbulence of the immediate application zone and the rapid dilution with surrounding lake water.

References

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