SUMMARY OF MAJOR RESEARCH PROJECTS AT THE EXPERIMENTAL LAKES AREA DURING 1995

1 December 1995

Again in 1995, a broad range of ecological studies were conducted at the Experimental Lakes Area and on samples taken at the ELA. These studies were carried out by more than 200 research personnel representing a number of government agencies, universities, and corporations. Many of these studies were continuations of long-term research projects, often involving experimental manipulation of whole ecosystems; others were short term projects, often carried out in enclosures. The following is an attempt to summarize the major projects by providing some information about their purpose, design and, where possible, major results. It should be noted, however, that data analyses are ongoing and many of the results provided are prelimninary. These projects are grouped under several broad category headings.

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1. BIOMANIPULATION AND SYSTEM PRODUCTIVITY

As humans have perturbed and manipulated aquatic ecosystems for various purposes, unexpected impacts have frequently occurred. Often these impacts have been manifested in major population shifts and alterations of energy flow within the food chain. If we can better understand the factors which control system productivity and structure, and the food chain linkages affected by these perturbations, we will be better able to develop effective management and regulatory strategies for minimizing the adverse effects on aquatic ecosystems of many human perturbations. The following four projects are intended to improve our knowledge of these linkages.

1.1 Biomanipulation and Fertilization of Lake 227, and Biomanipulation of Lake 110

Lake 227 was fertilized with phosphorus for the 27th consecutive year in 1995. The original experiment was initiated in 1969 to demonstrate that atmospheric carbon dioxide could provide the carbon necessary for algal blooms in eutrophic lakes. Prior to 1990, all additions were with various combinations of nitrogen and phosphorus. Since 1990, only phosphorus has been added. The ratio of phosphorus to nitrogen was changed during the previous stages of the experiment to test whether this would influence the dominant algal groups. A series of nine papers in recognition of the 25 anniversary of this study was published in the Canadian Journal of Fisheries and Aquatic Sciences, Vol. 51(10), during the past year.

In May of 1993, 40 male northern pike, a piscivorous fish, were added to Lake 227. These fish were transferred from Lakes 222 and 663 at spawning time, when individuals could easily be sexed. An identical transfer of pike to Lake 110 was completed in the spring of 1993. Transfers of pike to Lakes 110 and 227 were undertaken after obtaining approval from the Ontario Ministry of Natural Resources. Major ions, nutrient chemistry, nitrogen fixation, primary production, zooplankton, benthos, and fish populations have been examined in both lakes and in reference Lake 240 throughout the study. Changes in background levels of mercury and organochlorines (PCB's) in fishes and other biota were also monitored during the experiment.

During 1995, phosphorus, as phosphoric acid, was added to Lake 227 surface waters for twenty consecutive weeks (2.5 litres per week) during the ice-free season. The acid was diluted with lake water in a plastic barrel and dribbled via *Tygon* tubing into the near-shore water. The required acid was carried to the lake weekly. Sodium bicarbonate, to be used as a neutralizing agent in case of an acid spill, is stored on site.

In the fall of 1995, Lake 227 was heavily fished to remove all adult pike. This lake will be monitored in 1996 to determine the success of this pike removal. Any additional adult pike which can be found will be removed.

1.1.1 The Stoichiometry Project

During the past four years, a joint research undertaking (The Stoichiometry Project), involving DFO and researchers from Arizona State University (Dr. J. Elser), the University of Texas at Arlington (Dr. T. Chryzanowski), and the University of Minnesota (Dr. R. Sterner), has investigated how changes in zooplankton community structure alter the relative availability of N and P supporting phytoplankton and bacterial production. This research centres on changes in the stoichiometry of N and P in two lakes, artificially-eutrophic L227 and oligotrophic L110, following introduction of piscivores.

Lake 227 is a high P:N ratio lake, because of the phosphorus additions. Extensive blue-green algal blooms develop in the lake during summer and we hypothesized that such blooms would not occur following the pike addition. Lake 110 is a naturally low P:N lake which has not been fertilized. We sought to determine if a similar effect on nutrient recycling occurs in this more typical Canadian Shield lake.

Results to date indicate important responses consistent with predictions of stoichiometric theory. In Lake 110, piscivore introduction dramatically reduced minnow abundance and produced a substantial decrease (35:1 to 20:1) in zooplankton N:P in the system between 1992 and 1993, as *Daphnia* abundances increased from 4% to 12% of total zooplankton biomass. In eutrophic L227, responses have been different. Following piscivore manipulation, phytoplankton community composition shifted from complete dominance by N-fixing cyanobacteria (*Aphanizomenon schindleri*) that had characterized the previous ten years to co-dominance by non-fixing blue-green algae (particularly *Microcystis aeruginosa*). Work continued in 1995, with limited funding, to quantify the disruption of N and P cycling at the whole-lake scale. Efforts were focussed on the graduate theses of M. Kyle (Univ. of Texas-Arlington), N. MacKay (Arizona State Univ.), and T. Adams (Univ. of Minnesota). In particular, researchers hope to learn how N-fixation rates have declined, how N and P losses to the sediments have changed, and how whole-lake nutrient budgets have been disrupted by piscivore introduction.

A new research proposal has been submitted to U.S. funding agencies requesting funds to continue the biomanipulation studies in Lake 110 for an additional two years. At the end of the study the pike will be netted out of this lake.

1.2 Biomanipulation of Lake 221

Lake 221 is the site of a biomanipulation experiment that started in 1987 when 123 northern pike were transferred to this lake from nearby Lake 222. Water chemistry, primary productivity, phytoplankton populations, zooplankton, zoobenthos, and fish populations have been studied in Lake 221, both before and after the pike addition. Zoobenthos studies were terminated in 1991.

In 1994, we removed as many pike as possible from Lake 221 to start the recovery phase of this experiment. A large fraction of the northern pike population was removed using gill nets. Netting continued in the fall of 1995 and 106 additional pike were removed. Only 25 perch were captured in 1995, whereas the lake was dominated by perch before the pike introduction. Most of the pike netted in 1995 were offspring of the original fish introduced to the lake in 1987. Netting to remove additional pike will continue in 1996.

1.3 Experimental Cropping of Lakes

Twenty-eight percent of the lake whitefish present in Lake 258 and 40% of the lake whitefish present in Lake 305 were removed in 1981 and 1982. We continue to monitor the recovery of these populations by indexed gill netting in each lake and in nearby reference Lakes 259 and 468. This monitoring continued in 1995 in Lakes 305, 259 and 468, but no netting was carried out in Lake 258.

1.4 Northern Pike Project - Macrophyte Removal

Currently funded under the federal Sustainable Fisheries Initiative, this project, in 1995, was in its second year of background data collection in preparation for a proposed experiment beginning in 1996. In consultation with the Kenora District of the Ontario Ministry of Natural Resources (OMNR), DFO researchers have proposed testing, in ELA Lake 191, the effects of removal of aquatic macrophytes (submerged, rooted vegetation, “weeds”) on the survivability of young-of-the-year northern pike.

OMNR is concerned that the increase in cottage development on the Lake of the Woods and other lakes in the region may be affecting recruitment of pike, walleye, and muskie populations. In short, is there a correlation between the decline of these fish species and the increase in cottage development? Cottagers are removing macrophytes from their shoreline areas, and aquatic macrophytes are belived to be important nurseries, providing protection and areas of food sources for the young of these species. Current OMNR guidelines permit cottagers to remove up to 20% of the macrophyte growth in their property area, but there is no clear scientific basis for this percentage. The results of this experiment should provide fisheries managers with data on the importance of aquatic macrophytes to the success of these economically valuable species, and provide them with guidelines for legislation imposing restrictions on macrophyte removal.

Three ELA lakes are targetted for the study: Lake 191 as the experimental site, and Lakes 164 and 165 as reference lakes. The proposal calls for a physical removal of a percentage of macrophytes from Lake 191, followed by monitoring of the effects on the pike population.

Methodologies:

Fish from all three lakes have been captured, tagged and released during 1994 and 1995. Methods of collection have included trap nets (May to mid-June), angling (ice-free period), and seine nets (mid-June through October). All fish are weighed, and total lengths and fork lengths are measured. Fish that are large enough are nicked on the dorsal fin and tagged with a numbered plastic "spaghetti" tag. . Minnows are weighed in bulk and subsamples taken for individual weights and lengths. Processed fish are then released into the lake, with very low handling-mortality rates
Water chemistry, light attenuation, phytoplankton and zooplankton were sampled on a monthly basis during 1994, and bi-weekly during 1995, using standard ELA methods.

During the 1995 field season, collections of macrophytes, invertebrates (micro- and macro-), reptiles and fish from all three lakes were made for carbon and nitrogen stable isotope analysis. Three distinct collections were made (spring, summer, fall). Samples from Ekman dredges, net sweeps, and incidental catches from the fishing geer were included. Samples were sorted and frozen pending analysis.

Macrophyte surveys were conducted in 1994 and again in 1995 to determine biomass, and species diversity and distribution. Divers swam along predefined transects collecting macrophytes for identification and, using a 1 m square grid, counted the number of plants in the grid at various depths along each transect.

Results to Date:

Lake 191 is a very productive lake relative to others in the ELA region. Populations of northern pike, yellow perch, and pumpkinseed are supported. Lakes 164 and 165 support populations of northern pike, white sucker, yellow perch, and blacknose and spottail shiners. Considerable success has been realized capturing young-of-the-year fish, and more than sufficient data have now been gathered to indicate that the pike population in Lake 191 is very healthy.

Most chemistry samples have now been analyzed. Zooplankton sampling indicated a huge biomass in Lake 191, but sample processing awaits a funding commitment. Processing of samples for isotope analysis should begin this winter. A report on the macrophyte survey should also be available soon.

1996 Study Proposal:

Two main questions remain to be answered regarding experimental design:

1. What percentage of macrophyte removal should take place?
2. How will the actual removal of macrophytes be carried out?

Three removal methods have been discussed: mechanical, chemical, light exclusion by opaque plastic sheeting. These issues should be resolved in a series of meetings this winter.

The other issue clouding the future of this project is current uncertainty about continued funding and the level of DFO staffing during 1996.

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2. PHYSICAL PERTURBATIONS

2.1 Experimental Lakes Area Reservoir Project (ELARP)

Large dams, and the reservoirs they create, have become increasingly common throughout the Canadian Shield, and elsewhere. While hydroelectric generation was once considered a "clean" energy source, there is an increasing recognition of environmental costs associated with these reservoirs. More quantitative information is necessary to permit fully informed assessment of their environmental impacts.

The ELARP has two primary objectives. The first is to improve the understanding of why fish in manmade reservoirs are consistently found to be contaminated by high levels of methyl mercury. The second is to determine if reservoirs are important sources of greenhouse gas (CH_4 and CO_2) emissions to the atmosphere.

To answer these questions, an experimental reservoir was constructed at ELA Lake 979, thereby flooding a 14 ha reservoir. This reservoir site was studied intensively for two years (1991 and 1992) prior to flooding, and has now been studied for 3 consecutive years (1993 through 1995) of flooding. In addition, a reference wetland (ELA 632), which was not experimentally manipulated, was studied in its natural state for the five-year period. Headed by Dr. J. Rudd (DFO) and Dr. C. Kelly (Univ. of Manitoba), the multidisciplinary research team assembled for this project has included researchers from government, from universities in Canada and the U.S., and from several corporations.

During 1995, the primary on-site participants were from DFO, from DOE, and from the universities of Manitoba (Dr. Kelly), McGill (Dr. N. Roulet and Dr. T. Moore) and Waterloo (Dr. S. Schiff). Much of the work was directly in support of graduate theses (T. Sellers, Manitoba; A. Bhardwaj, B. Fowle, A. Heyes, McGill; E. Mewhinney, C. Poschadel, Waterloo). Patterns observed in the flooded system during 1995 were similar to those observed during the previous two years.

Production of methyl mercury in the flooded 979 wetland increased by a factor of 30 (from 0.2 to 6 μg $MeHg.m^2.y^{-1}$). There were also large increases in bioaccumulation of methyl mercury by food chain organisms, including fish.

The after-flooding flux of CH_4 to the atmosphere increased by more than an order of magnitude (from 11 to 130 $gC.m^2.y^{-1}$ in the 979 wetland. This experimental wetland was also a sink for CO_2 (-120 $gC.m^2.y^{-1}$) before flooding, but became a large source of CO_2 (2700 $gC.m^2.y^{-1}$) after flooding.

The first phase (5 years) of the experiment is now complete. The coming year will be devoted primarily to data analyses and scientific paper writing. A series of meetings during the winter of 1995/96 will determine the direction of the second phase of ELARP. One option is to continue the experiment on the longer term to determine the duration of the large increases in methyl mercury and greenhouse gas production that were observed during the first three years of flooding. A second option may be to manipulate the reservoir to study the effect of drawdown on gas production and methyl mercury production. Alternatively, various suggested mercury amelioration techniques could be investigated.

2.1.1 Nutrient Status of Epiphytes on Submerged Herbaceous Plants

Based on previous nutrient status work on Lake 979, it was hypothesized that nutrients (primarily phosphorus) mobilized from the flooded areas surrounding the natural basin of Lake 979 were decreasing phytoplanktonic nutrient deficiency in the deeper water of the reservoir. During 1995, nutrient status was measured several times between June and September, both at the deep station and along two transects in the flooded areas of the lake. The data are still incomplete, but it appears that P is being released in these flooded areas (i.e. a decrease in P deficiency) and that, with a decrease in the N:P ratio, nitrogien fixation is initiated within the epiphyte (attached algae) community in response to these N deficient conditions.

See also the 979 Littoral Impact Study (No. 2.2, below).

2.2 Lake 979 Littoral Impact Study

The lake 979 littoral impact study attempts to connect the experimental flooding of the 979 wetland (as part of the ELARP, No. 2.1, above) with the creation of new aquatic habitat, its colonization by biota, and the use of these potential extra food resources by forage and predaceous fish. The study can be regarded as a mirror image of the Lake 226 Drawdown experiment (No. 2.3, below).

Nutrient status parameters measured in phytoplankton before and after flooding in the open water of Lake 979 revealed that phosphorus (P) deficiency decreased, whereas nitrogen (N) deficiency increased, probably because of increased nutrient mobilization (primarily P) from the flooded zone. Nutrient mobilization from the flooded zone into the main area of the lake was measured starting in 1994. Most sites in the flooded zone were primarily P deficient; several areas were more N deficient than P deficient during the summer, which suggested spatially highly variable nutrient mobilization. Nitrogen deficiency in the N deficient areas was satisfied by N fixation. Total epiphytic biomass (carbon) growing on herbaceous plants in the flooded zone will be estimated from nutrient composition data.

The flooding of Lake 979 shoreline provided benthic (bottom dwelling) macroinvertebrates with a variety of new niches to exploit. As a consequence, invertebrate emergence from the new shorelines increased almost 10-fold from the year before flooding (1992: mean emergence of Chironomidae was $\approx$700.m^{-2}) to the year following flooding (1993: mean emergence of Chironomidae was $\approx$6200.m^{-2}). Emergence of insects from aquatic habitats can be used as a rough measure of the productivity of those habitats. Emergence doubled in 1994 to $\approx$12000.m^{-2}, a rate that was maintained in 1995 ($\approx$14000.m^{-2}). Emergence from the open-water area of the lake has remained relatively stable ($\approx$1100-2100.m^{-2}) during the period 1992 to 1995. Artificial substrate samplers that were placed into the newly flooded peat shorelines to measure colonization by benthic invertebrates also revealed high numbers of invertebrates after flooding. Thus, newly flooded peat shorelines apparently provide ideal conditions for colonization by invertebrates.

Preliminary results of studies of the food web of Lake 979 indicate that periphyton is the major carbon source for the invertebrate community of the lake. Of the four species of fish present in the lake, white sucker appear to be at the top of the food chain; white sucker are primarily zooplanktivorous in Lake 979. Links between fish and rapidly expanding macroinvertebrate populations have not yet been established.

Dace were cultured in pens over the open-water area of the lake and over the newly flooded peat zone. Dace in the newly flooded zone exhibited noticeably lower growth, probably as a result of severe depression of oxygen concentrations in the peat.

Most of the field part of the Lake 979 study has been completed. Identification of collections, and data analysis and sythesis remain to be done.

2.3 Lake 226 Drawdown Study

The purpose of the Lake 226 experiment is to study the impacts of winter water level drawdown, simulating the water level fluctuations in a hydroelectric reservoir. The lake has been intensively studied for one year (1994) prior to drawdown and for one year (1995) after drawdown.

In the winter of 1994-95, the Lake 226 water level was reduced by 2 m below natural levels. This drawdown was achieved by deepening the natural outlet channel by blasting. Precautions were taken to avoid fish mortalities during blasting by using reduced charge sizes, and by removal of all large fish from the bay adjacent to the outlet combined with the installation of a fish barrier at the head of the bay. No fish mortalities were observed. Approximately 30% of the lake volume was removed, resulting in a decrease of about 11% in lake surface area. The lake rose during the spring and early summer by about 0.5 m, but the level stayed relatively constant during the summer and fall at about 1.5 m below natural levels, as runoff into the lake was approximately balanced by evaporation.

Preliminary indications are that the following impacts occurred in the lake as a result of water level drawdown. Approximately 10% of surface area of the lake was dry in the summer and the productivity of this portion of the lake was lost to fish populations, although because of a warm summer the total number of emerging insects from the lake was only slightly reduced after drawdown. Standing stocks of benthic macroinvertebrates probably decreased in the shallow littoral zone of the lake. It appears that there was a year class failure of lake whitefish in the lake, probably due to the exposure of incubating eggs after spawning. Attempts to locate spawning areas by egg suctioning in the winter was not successful, however acoustically-tagged fish were followed during the 1995 fall spawning season. Analysis of stable isotopes of carbon and nitrogen indicated that lake whitefish were feeding mainly on food from the pelagic food chain, perhaps mostly *Chaoborus*. Submerged vegetation declined dramatically after drawdown, although terrestrial vegetation began to invade the exposed shores. Littoral algal production decreased due to loss of habitat and to and increased sedimentary character of the communities; spatial variability increased. Increased resuspension of fine sediments was less noticeable than expected. Phytoplankton species composition was unaffected although total biomass increased due to increased abundances of chrysophytes and dinoflagellates. Bacteria also appear to have increased.

The lake level will be drawn down by an additional 1.5 m during the winter of 1995/96, bringing the level to 3 metres below natural levels by late winter. Four 4-inch (100 mm) diameter siphon pipes have been installed to accomplish this drawdown. The amount of recovery of the lake level during the summer of 1996 will depend on the balance between natural precipitation and evaporation.

2.3.1 Nearshore Mapping in Lake 226

An associated project, now nearing completion, is the mapping of Lake 226 nearshore habitat in two separate surveys, before and immediately after drawdown, to determine the availability of habitat under two different hydraulic regimes. Using the fetch distance model developed in Project 4.2 (below), the change in wave parameters before and after drawdown will be estimated, as well as correlations between hydraulic energy, slope, and substrate type.

The purpose of this work is to provide estimates of habitat loss effected by drawdown as a model of reservoir operation by hydroelectric utilities. All field work has been completed and habitat maps before and after drawdown are being analyzed.

This project is expected to be completed by March 31, 1996.

2.3.2 Nutrient Status of Benthic Algae

The relative nutrient status of benthic algae and pelagic algae in ELA lakes has been unknown until now. This study, as an adjunct to the Lake 226 drawdown, attempted to compare these two communities within the same lake. Alkaline phosphatase activity, nitrogen debt activity, and suspended nutrient data were collected for samples of algae growing on two types of natural substrates within both basins of Lake 226.

To date, lake water chemistry data are still incomplete and the nutrient status data have not been analyzed.

2.4 Impact of Disturbances on the Lake 239 Watershed

Long-term hydrological and chemical monitoring in the calibrated catchments of this watershed continued during 1995. Portions of the watershed were perturbed by a major forest blow-down in 1973, and by forest wildfires in 1974 and 1980. The monitoring is intended to evaluate long-term effects of these natural perturbations on the lake ecosystems, and to calibrate other hydrological studies at the ELA. The watershed has been continuously monitored for 27 years. No chemical additions are made.

3. ACIDIFICATION AND RECOVERY

Acidification of aquatic ecosystems by anthropogenically-derived acidic precipitation has been widely recognized for almost two decades as a widespread environmental problem in many parts of eastern Canada, the northeastern United States, Scandinavia, and elsewhere. While certain legislative and regulatory measures have already been adopted to alleviate this problem, considerable uncertainty remains about the ultimate effectiveness of these measures and about the ability of natural ecosystems to spontaneously recover from significant acidification once acidic input has been reduced. The following five experimental studies are intended to provide legislators and managers with answers to remaining questions about the effectiveness of current control measures and the probable nature of ecosystem recovery from acidification.

3.1 Monitoring Recovery of the Lake 239 Wetland from Acidification

Simulated acid rain, composed of sulphuric and nitric acids, was added to a 2.66 ha portion of a small fen in the Lake 239 watershed from 1983 through 1990. Additions were made at monthly intervals during each ice-free season. The purpose was to evaluate effects of the simulated acid rain on wetland chemistry, vegetation, and downstream chemical exports (to Lake 239).

Beginning in 1991, no further acid additions were made, but monitoring of hydrology, outflow chemistry and plant growth have continued through 1995 to evaluate the recovery of this wetland system. In 1995, Dr. S. Bayley (Univ. of Alberta, Botany) measured growth of *Sphagnum* moss in spring and fall to obtain an annual measurement of growth. These data will be combined with ELA meteorological data to analyze the effect of climatic factors on *Sphagnum* growth. This long-term monitoring will continue if funding is available, but no new experimental work is planned.

3.2 Recovery of Lake 223 from Acidification

Lake 223 is the site of an acidification-recovery experiment that commenced in 1976. The surface waters of this lake were acidified using sulphuric acid from 1976 through 1983. The experiment provided ground-breaking evidence of the adverse impact of acid on the lake food chain, even at pH levels of 5.0 or higher. This evidence was instrumental in spurring international legislation for the control of anthropogenic sulphur oxide emissions to the atmosphere.

The research team has allowed a gradual pH recovery from 1984 to the present time. In 1994, the final phase of the recovery portion of the experiment began. No acid additions were made in 1994 or 1995; the lake has now returned to a “natural” pH level (6.5 - 6.8). Water chemistry, hydrology, primary productivity, algal populations, zooplankton, zoobenthos, and fish populations have been studied each year.

The biological recovery observed in 1995 continued to be mixed. Lake trout populations continue to show good recovery, and the fathead minnow population, which was particularly susceptible to acidification, is now doing very well. However, slimy sculpin have not yet successfully re-invaded the lake. A few isolated crayfish individuals have been observed in the lake, but no significant re-invasion has occurred. *Mysis* and amphipods are still absent as well. Other biological and chemical data for 1995 are still in the preliminary stages of analysis.

Monitoring will continue in 1996.

3.3 Recovery of Lake 302S from Acidification

During 1995, the south basin of Lake 302 (Lake 302S) completed its fourth year of controlled recovery from acidification to pH 4.5. The target pH was maintained at 5.8 for the second consecutive year, compared to pH 5.1 in 1992 and 1993. Approximately 160 litres of concentrated sulphuric acid were added during 1995 to prevent the pH from rising above the pH target of 5.8. Complete ecosystem analysis, including hydrology, water chemistry (including metals), and most components of both the pelagic and littoral food webs, continued as in past years.

Lake recovery continues to appear both incomplete and prolonged. Neither geochemical nor biological recovery are retracing their acidification trajectories, so that the lake is seeming to recover to a different state. Geochemical recovery, especially generation of internal alkalinity, continually appears to be slower than expected. Continued increases in iron concentrations may be linked to both internal reacidification and dinoflagellate biotoxicity. Some uneven biological recovery is occurring, albeit in the absence of fish other than pearl dace. Biotic composition and function remained highly variable, with littoral and pelagic recoveries differing in character.

It appears that simple reduction of acid inputs, by itself, is insufficient to (initially) restore the composition and function of the ecosystem at this intermediate pH (5.8). Decreasing the lake’s pH below 5 may also have impaired the lake’s ability to recover from acidification compared to those less severely acidified.

Our plans for 1996 remain to be discussed, and are contingent upon sufficient LRTAP funds being made available. It is likely that we will maintain the target pH at 5.8 during 1996 for a third year to assess whether recovery can proceed further beyond that seen in 1995. We will continue the complete suite of ecosystem measurements as in previous years if downsizing does not permit us from accomplishing our objectives. DAMSA, a research hatchery located in Nolalu, Ontario, has agreed to participate in controlled additions of limited numbers of Nipigon-strain brook trout to enclosures in 302S to preliminarily assess their viability in these acid waters. If successful, this could lead to a whole-lake addition of the brook trout to Lake 302S to better assess this management option for renovating acidified food webs. To better understand the causes of delayed recovery, we will attempt to initiate preliminary research to determine whether organic sediment inventories have been depleted (by a decreased balance in the ecosystem of photosynthesis : respiration) and are linked to reduced internal alkalinity generation. Dr. C. Trick et al. will also be continuing process-oriented research (see No. 3.6, below) to better understand the mechanisms underlying biotic toxicity associated with the dinoflagellate blooms occurring in acidified lakes; this will aid our ability to predict the success of attempts at biological restoration in recovering lakes.

3.4 Recovery of Lake 302N from Acidification

Lake 302N is the northern basin of Lake 302, separated from the south basin (described in 3.3, above) since 1981 by vinyl curtains. Experimental loading of $NaNO_3$, Na_2SO_4 and HCl had continued during 1992 and 1993, along with additions of H_3PO_4 at a rate of 1:10 P:N, as part of a study to define the role of phosphorus supply in the lake's internal generation of alkalinity.

The experiment served to demonstrate that phosphorus additions can stimulate internal alkalinity generation, thereby serving as a potentially cost-effective remediation strategy. Concern for increased risk to the fish populations dictated that experimental additions be stopped and that the recovery of the lake be monitored.

During 1995, this lake basin was in the second year of partial recovery from these additions. As in 1994, a limited amount of concentrated HCl (approximately 680 litres) was added to prevent the pH from rising above the target value of 5.8. Monitoring of various limnological parameters continued, with particular interest focussed on whether the additional carbon fixed in the basin because of fertilization of algae during previous years will have obvious effects within the food chain. The greater amount of acid required to maintain a pH of 5.8, relative to that required to maintain the same pH level in the south basin, seems to indicate that alkalinity generation in the north basin remains higher. The population of young lake whitefish in this basin seems to be particularly healthy.

3.5 Acid Phosphatase Activity in the Epilimnia and Metalimnia of Lakes 302S and 302N

It has been shown that Al-organic P complexes increase in temperate lakes as lake water pH decreases, and the literature suggests that phosphatase activity should increase in order to compensate for reduced availability of organic P. Two previous years of data (1991 and 1992) from Lake 302S has shown acid phosphatase activity to be higher thant alkaline phosphatase activity. This difference was much greater in 1991 than in 1992. In 1995, these measurements were repeated in both basins of Lake 302, as well as in the non-acidified Lake 239.

Preliminary data for 1995 again indicate that acid phosphatase activity was higher than alkaline phosphatase activity was higher than alkaline phosphatase activity in both basins of acidified Lake 302. The same measurements in neutral Lake 239 were much lower (alkaline phosphatase activity was similar to that in other non-perturbed ELA lakes), and were approximately equal to each other. The relationship of Al concentrations to these higher acid phosphatase rates has yet to be examined for 1995.

3.6 Causes of Fish Kills in Acidified Lakes 302S and 302N

In 1989, a fish kill occurred in Lake 302 South, and another fish kill occurred in Lake 302 North in 1993. Obvious choices of environmental causes (eg. lake anoxia) have been excluded as an explanation, and a biological agent has been implicated.

Starting in 1994, a research team from the University of Western Ontario has investigated the potential etiologic agents that may be responsible for the fish kills that occurred. During the summers of 1994 and 1995, experimental evidence was accumulated indicating that the causative agent for the fish kills is a bacterium associated with the outbreak of the freshwater dinoflagellate, *Peridinium*.

Environmental factors that led to blooms of *Peridinium* were investigated using long-term data sets of chemical and physical parameters and comparing the environment then with periods of dinoflagellate blooms. During the summer of 1995, the research aimed at verifying the presence of *Peridinium* and the environmental "trigger" leading to fish kills based on either fish bioassay experiments or *Daphnia* bioassay experiments.

Based on findings from the 1994 and 1995 summer seasons, the team has concluded:

1. Waters will only express a "fish kill" at the mid-to-later part of the summer season. Fish kills are not associated with *Peridinium* blooms prior to mid-June, and the team was unable to induce the *Peridinium* bloom to express toxicity prior to mid-June.
2. During the summer of 1995, the researchers were able to verify that the presence of "fish kill" activities is a function of the physiological changes of the bacterial population associated with large groths of dinoflagellates (predominantly *Peridinium* or *Gymnodinium* species).
3. Evidence leading toward a hypothesis that it is the bacteria associated with dinoflagellates, rather than the dinoflagellate itself, were investigated during 1995. Evidence includes:
   - "Fish kill" activity was not restricted to a single class size. Lake water (supplemented with the required iron) was size-fractionated into three fractions: greater than 105 μm, greater than 20 μm, and less than 5 μm. Each fraction was toxic in both fish and *Daphnia* bioassays, clearly implicating organisms less than 5 μm in size.
   - Bacteria isolated from the gills of toxin-killed fish have been grown in the laboratory and show the same iron-regulated toxin response against *Daphnia* as was predicted from the field experiments. Bacteria have not been tested in fish bioassays.
   - The research team has isolated several bacteria: one that can make the toxin and several that cannot, indicating that toxin production is an isolate-specific phenomenon. Current research is aimed at characterizing the taxonomic status of all bacterial isolates and to consider the physiological regulators of toxin production.

Two theses were defended in 1995 based on this research work:

- Murphy, K.-A. 1995. Microbial ecology of a freshwater fish kill. M.Sc. Univ. of Western Ontario, London. 124 p.
- Rooney, N.M. 1995. Phytoplankton community change in an experimentally acidified lake. M.Sc. Univ. of Western Ontario, London. 98 p.

Another Western Ontario student (M. Ray) is basing his thesis on this project as well.

4. MONITORING NATURAL CONDITIONS

In order to objectively assess the effects of anthropogenic perturbations on aquatic ecosystems, it is essential to systematically monitor non-perturbed systems over long time periods. Only thus can we hope to evaluate the effects of naturally-occurring events (weather, cyclic climatic oscillations) on these ecosystems and factor these effects into our interpretations of impacts resulting from human activities. A series of eight research papers relating to this topic, and commemorating 25 years of ecosystem monitoring at the ELA, was published in the Canadian Journal of Fisheries and Aquatic Sciences, Vol. 51(12), during the past year.

4.1 Lake Variation and Climate Study

Commencing in 1987, a seven-lake flushing series was selected for a long-term, fully integrated study to i) detect limnological changes due to global warming, ii) develop models that will predict effects of global warming on temperate, shield lakes and their fisheries, iii) establish limits/confidence for extrapolating results of ELA experimental studies to other lake types, and iv) provide a reasoned Precambrian Shield reference system that will improve researchers' abilities to detect, quantify and interpret effects of external perturbations. Emphasis was on detection of temporal and spatial changes/differences. No experimental additions or manipulations were made to these lakes; they were monitored in their natural states

Funding has not been available to continue this study during 1994 or 1995, and the project can now be considered complete. A number of reports have been published detailing the results from 1987 through 1993.

4.2 Nearshore Fish Habitat Mapping

A project is underway to map nearshore fish habitat in 5 natural ELA lakes (nos. 164, 165, 373, 377, 442) to inventory material types by depth class, and to compare the habitat (basin geology, slope, allocthonous/autocthonous materials, zone of deposition) between basins in an area of relatively homogeneous geology. Estimates of wave energy will be derived from a new Geographic Information Systems (GIS) Fetch Distance model for predicting properties of waves in lakes. Hydromechanical energy will be correlated with substrate and slope maps using GIS.

The purpose of this research is to develop methods that describe the 3-D form of nearshore habitat in detail, and to develop software applications for reconstruction of field data in digital format. All field work has been completed, the fetch distance model is nearing completion, and analysis of the substrate maps of the nearshore zones of the lakes is in progress with anticipated completion by 31 March 1996. This study is the basis of a graduate thesis (P. Cooley, Univ. of Manitoba).

4.3 Lake Monitoring for LRTAP (Long Range Transport of Atmospheric Pollutants)

Five small ELA lakes (Lakes 224, 239, 305, 373) are monitored as part of the DFO Long Range Transport of Atmospheric Pollutants (LRTAP) program. The ELA is the LRTAP monitoring site with the lowest loading of atmospheric pollutants of all DFO sites in Canada; hence it provides the baseline for the National Monitoring Programme. Other sites are located in central Ontario, Quebec, and Atlantic Canada. This program is necessary to fulfil Canada's obligations under the current air quality agreement with the United States.

1995 marks the tenth year for monitoring these lakes. Hydrology, water chemistry, benthic invertebrates, and fish are sampled annually according to methods established in a national protocol. Emphasis is placed on keeping these lakes in an undisturbed condition.

In addition, two artificially acidified lakes (223 and 302S), and one experimental lake (382) have been sampled for the past five years with the same monitoring methods. The acidified systems have been intensively studied and are now in a state of recovery. Biomonitoring in these systems serves both to calibrate sensitivity of the sampling methods and to document the recovery process. Monitoring of Lake 382 with the same set of methods means the recovery can be measured against undisturbed reference systems.

It is anticipated that sampling in 1996 will continue on all of the above lakes with the same frequency as in the past.

Data from the ELA have been incorporated in a CFAS technical report [Shaw, M.A. et al. 1995] which outlines starting point conditions during the first few years of the national program. CFAS Technical Report No. 1875 (1992) contains maps and descriptions of all sampling locations in each of the participating regions, and Report No. 1987 (1994) outlines the design and features of the Oracle database for the national programme.

4.4 Nutrient Status Assessment of Selected ELA Lakes

Each year, a number of ELA lakes, many of which have been studied for more than 5 consecutive years, are assayed for nutrient status. In 1995 the following lakes were monitored bi-weekly from May through October:

- 165 epilimnion
- 191 epilimnion
- 226NE epilimnion and metalimnion
- 226SW epilimnion and metalimnion
- 239 epilimnion and metalimnion
- 302N epilimnion and metalimnion
- 302S epilimnion and metalimnion
- 632 epilimnion
- 979 epilimnion.

Each lake was routinely assayed for alkaline phosphatase activity, nitrogen debt, and nutrient composition ratios.

In general, the results, while still incomplete for 1995, confirm the fact that most of these lakes are phosphorus deficient. However, perturbations (eg. lowering of pH in Lake 302N and Lake 302S, flooding in Lake 979, P additions to Lake 227) have been shown to decrease the degree of P deficiency and, in some cases, increase the tendency toward N deficiency. In additon, these indicators have shown that metalimnetic waters tend to be less nutrient deficient (P and/or N) than are epilimnetic waters at the ELA.

4.5 Studies of Dissolved Organic Matter and UV Radiation

Two University of Alberta research projects, under the leadership of Dr. David Schindler and Dr. P.J. Curtis (Okanogan Univ. College), were continued during 1995 at the Experimental Lakes Area: an enclosure experiment in Lake 239 and artificial stream experiments on the outflow stream of Lake 470. The focus of the experiments performed was on ultraviolet (UV) radiation: the changes in chemical, optical and absorbtive characteristics of lake water in enclosures and how they relate to UV radiation were investigated, as well as the effects of UV radiation and its associated photochemicals on community dynamics in artificial streams. A third study is attempting to correlate community changes to changes in dissolved organic carbon (DOC) concentration.

4.5.1 Removal and Photobleaching Rates of DOC

Removal and photobleaching rates of DOC, as well as photochemical accumulation, were studied in 16 enclosures in the east bay of Lake 239 from late May until early September. Two experiments were performed, involving: i) additions of Al (in the form $Al_2(SO_4)(H_2O)_4$) or Fe (in the form FeCl), and ii) varying the depths of enclosures from 0.75 m to 3.0 m, to mimic varying mixed-layer depths. Metal additions were performed twice weekly, and sampling once weekly. Organic constituents analyzed were fluorophores (by fluorescence relative to quinine sulphate), chromophores (by light attenuation at 340 nm), and concentrations of C, N, and P. In general, spectrofluorometric analysis of DOC samples indicated that a primary DOC fluorophore undergoes a decrease in absorptive capacity of UV radiation in samples from shallow enclosures (*ie*. it is photobleached), and this is an indication that UV penetration in shallow enclosures increases dramatically as a result of decreased DOC absorbance. Rates of DOC photobleaching were inversely proportional to the depth of the enclosure (mixed layer), but were independent of DOC loss rates. Changes in DOC mass have yet to be interpreted. Addition of metals (especially Fe) stimulated loss of organic fluorophores and chromophores, and, to a lesser extent, DOC. It was also shown that UV photochemical production is constant on an areal basis, and concentration is a function of the height of the water column; there are higher concentrations of H_2O_2 in shallow waters than in deep waters. Similar enclosure experiments will be performed next year; however the researchers will be focussing on changes in biological communities related to changes in the light and photochemical environments.

4.5.2 Effects of UV Radiation on Artificial Streams

Six artificial stream sections (2.2 m by 0.19m) were naturally seeded using water piped from the outflow of Lake 470, and plexiglass was used to control whether on not a particular stream was exposed to ambient UV radiation. Indications of possible effects of UV radiation on trophic interactions were observed, including increases in apparent algal chlorophyll *a* and decreases in numbers of invertebrates (including microcrustaceans, chironomids, simuliids, and hydropsychid tricopterans) in those streams exposed to UV radiation, relative to those shielded from UV radiation. Algal biomass estimates are in the process of being made. However, preliminary results seem to support the hypothesis that thick algal mats, as they grow more thick, may function as a UV-shield for some of the invertebrate grazers. Further counting will show whether later sloughing of the algal mats causes changes in the invertebrate communities attributable to increased UV exposure. Similar experiments will be performed next summer;

however the location of the streams may be changed to the outflow of Lake 240 because of high Fe in Lake 470 and its interference with H_2O_2 accumulation. This work forms a major portion of the PhD thesis of W. Donohue (Univ. of Alberta).

4.5.3 Correlation of Diatom Community Changes with DOC Concentrations

A post-doctoral fellow, Dr. J. Huvane (Univ.of Alberta), is reconstructing from sediment cores the historical diatom communities of several lakes (239, 240, 373, 383) in an attempt to correlate community changes to changes in DOC concentrations and inferred UV environments. This is unique in that Dr. Huvane will be able to use data from the long-term records of measurements taken at the ELA as a control against which to calibrate recent reconstructed sediment records, before inferring changes that may have occurred over the last several hundred years.

5. PERSISTENT TOXICANTS

Certain substances, when released into natural ecosystems, may persist for years in a toxic form, and may bioaccumulate within the food chain to create health problems for higher organisms, including humans, particularly when exposures are chronic. While such persistent toxicants are often experimentally studied under laboratory conditions, only studies conducted in real ecosystems can effectively examine the complexity of ecosystemic pathways and compartments in which these substances move and accumulate. We require some controlled experimentation in real ecosystems to validate existing and proposed regulatory standards for these substances.

In addition, these experimental studies with persistent toxicants provide an opportunity to determine the physiological bases of ecosystem effects, thereby identifying indicators of stress at lower (physiological, histological) levels of biological organization. Once identified, these indicators can be extremely useful for the assessment and remediation of environmental problems.

5.1 <u>Organochlorines and Poly-Aromatic Hydrocarbon Study</u>

The purpose of this study was to evaluate the population-level effects of chlordane, toxaphene, and a dibenzofuran on fish through mark-recapture experiments. Both chlordane and toxaphene are major contaminants in the Great Lakes, despite being withdrawn from both the USA and Canadian markets by 1985. These compounds bioaccumulate, but their effects on fish growth, survival, and reproduction have been unclear. This study formed the basis of a Ph.D. thesis (P. Delorme, Zoology, Univ. of Manitoba) that is now completed.

This study took place in Lake 260 where approximately 150 lake trout and 200 white suckers were injected during 1988-1989 with either 25 ppm chlordane, 25 ppm toxaphene, or 1 ppb dibenzofuran. Other fish were injected with corn oil as experimental controls. Fish recaptured subsequent to injections were assessed for effects on growth, survival, and reproduction (individuals were stripped of eggs and milt; fertilized eggs were incubated in Lake 260 or at the Freshwater Institute). No further injections have been made since 1989. Monitoring of all injected fish continued during mark-recapture studies in 1995, as in previous years. Signs along the lake shore alert any passers-by that a few of the fish in this lake may not be fit for human consumption.

Results indicate that these organic contaminants can significantly impair fish growth, reproduction and survival.

In the fall of 1995, the fish population of Lake 260 was surveyed using trap nets. Of 209 fish captured, 1 fish previously injected with toxaphene and 4 fish injected with corn oil were recorded. We will continue to monitor the lake trout and white sucker in subsequent years to determine if longer term effects occur on their growth and survival. The study was the first of its kind conducted with free ranging fishes in a lake, and we believe it is a partial alternative to whole-lake additions of deleterious substances, when effects on fishes are the primary focus of the study.

5.2 Cadmium Addition to Lake 382

Many metals, including cadmium, are recognized as persistent toxicants within aquatic ecosystems. While concentration guidelines currently exist for the protection of aquatic species and habitats, there is little quantitative information available about the adequacy of these guidelines for protecting against chronic contamination effects in real ecosystems. The deliberate release of cadmium into the environment is now prohibited in Ontario, but quantities of this metal are still being released as a bi-product of the combustion of fossil fuels and the smelting of metals. As part of the study of long-range transport of atmospheric pollutants (LRTAP), cadmium additions to Lake 382 were initiated in 1987. Levels of cadmium in Lake 382 were gradually raised each ice-free season so that approximately 200 nannograms per litre ($ng.L^{-1}$) were present during the summers of 1991 and 1992. This is still almost 2 orders of magnitude below the Canadian drinking water standard, but at a level where biological impacts would probably occur if the treatment were chronically maintained. By the end of 1992, a total of 7 kg of cadmium had been added to Lake 382. No cadmium was added in 1993 or 1994, but monitoring continued.

Funding

In 1995/96, the experiment was funded in the amount of 82.7 K by the Green Plan Toxic Chemicals Program. Unexpectedly, the Great Lakes Action Plan (GLAP) 2000 funding received in previous years (eg. 35 K in 1994/95) was not available to DFO projects in 1995/96. In November 1995, an additional 26.9 K has been granted by the Toxic Chemicals Program for completion of a number of chemical and community analyses during 1995/96 that would otherwise not be done because of the lack of GLAP funding. 1996/97 is the last year of the present Green Plan Toxic Chemical program and the projected funding for this project is 88.0 K, less internal taxes.

Proposals to the Green Plan Toxic Chemicals Program for funding for exploring the feasibility of using near-infrared spectroscopy to 1.) develop methods for rapid assessment of sediment organic matter and metal bioavailability and 2.) develop methods for rapid assessment of condition in unionid mussels (used in biomonitoring) were not funded.

Sampling

In 1995, no Cd was added to Lake 382. Data were collected to observe the response of the lake to the third year of the "zero discharge strategy". The routine suite of physical, chemical, and biological parameters were measured as in several past years. Specifically, samples were collected to determine fate of Cd in water and suspended sediments, crayfish, large and small fish, and macrophytes. Despite considerable searching by divers, no mussels were found. Unauthorized collecting several years previously apparently depleted the population of this important biomonitoring species. Populations of phytoplankton, zooplankton, crayfish, and fish were monitored for possible effects from Cd. Primary production and water chemistry were also monitored. Metalimnetic sediments were sampled for preliminary studies to attempt to predict K for Cd with near-infrared reflectance spectroscopy (NIRS) and for geochemical fractionation of heavy metals.

Hypolimnetic sediment was sampled to determine the toxicity of Lake 382 sediment, as measured by four standard chronic bioassays. This work was done in collaboration with Dr. Trefor Reynoldson, DOE, CCIW .

Results

The Cd concentration in epilimnetic water under the ice on 24 March 1995 was <15 ng/L, lower than at the same time in 1994, when it was about 35 ng/L. In July and September 1995, epilimnetic Cd was 10-15 ng/L, with slightly higher concentrations of 20-30 ng/L in the metalimnion and hypolimnion. By 27 September, pH in the water column had dropped, particularly in the metalimnion, and Cd was 30 ng/L in the epi, 60 ng/L in the meta, and 30 ng/L in the hypolimnion. By 24 October, the entire water column again was at 14-15 ng/L Cd. These results suggest that during each year of recovery, the Cd concentrations in the water are declining, but seasonal changes in water chemistry cause temporary elevations in Cd concentrations presumably due to feedback of Cd from sediments. Results reported by Stephenson *et al*. (1995) suggest that Cd is internally loaded from the sediments and that this will attenuate recovery of the water column Cd toward background levels.

Before the start of the Cd additions to Lake 382, a simple finite numerical difference model was prepared to estimate the Cd inputs required to reach particular epilimnetic Cd concentrations (Lawrence *et al*.). The model predicted fairly well epilimnetic Cd concentrations during the addition periods, but overestimated the concentrations when Cd was not added (Fig. 1a). A revision of the model fit the measured concentrations better, but still overestimated them (Fig. 1b). The model does not take into account deep burial of Cd in the sediments, e.g. by binding with sulfides (Lawrence *et al*.).

Lawrence *et al*. calculated rates of disappearance of Cd from the water column over the years of addition which agree well with the increase in Cd in the sediment inventory (Stephenson *et al*.). Almost 99.9% of the 6.7 kg of Cd added to Lake 382 can be accounted for in the sediments, in the water column, including biota, and as loss through the outflow (Lawrence *et al*.). As a result of the experimental additions of Cd to Lake 382, no adverse effects have been observed on the phytoplankton community (Findlay *et al*.), zooplankton community (Chang and Malley, 1995), crayfish (Malley b), macrophytes, benthic, or fish communities so far as analyses have been completed.

Fig. 1. Total Cd concentration in the epilimnion predicted by a simple finite numerical difference model using a sediment mixing depth of a) 4 cm and b) 12 cm.

Canadian exploration of the feasibility of applying rapid, nondestructive NIRS to limnological parameters began in the early 1990s with samples from Lake 382 (Malley *et al*. 1993). Carbon, N, P, and organics-binding Cd in seston have been estimated by NIRS (Malley *et al*. 1993; Malley *et al*. a). Recently, C, N and P in Lake 382 has been estimated by NIRS. NIRS is being used to characterize the organic matter binding seven heavy metals, including Cd, in Lake 382 sediments (Malley *et al*. b, c).

Proposal for 1996

We propose to sample sediments of Lake 382 in March 1996 to repeat the measurement of the total Cd inventory and distribution of Cd between erosional and depositional sediments in Lake 382. No new sampling or experimental procedures are planned for 1996. A suite of routine samples will be taken in 1996.

Scientific Productivity

Groups of manuscripts describing the Lake 382 experiment and related Cd studies are scheduled for publication in the Canadian Journal of Fisheries and Aquatic Science (CJFAS). The first group of five is nearly completed. Three manuscripts (Holoka and Hunt, Stephenson *et al*. a, and Findlay *et al*.) have completed external peer review and final revisions. One (Lawrence *et al*.) is still in peer review and the overview manuscript (Malley, a) is in preparation. A second group (including Stewart, Wesson, Malley b, Chang *et al*.) is in preparation for submission to CJFAS in 1996. A third group focussing on fish is planned. Other scientific productivity from Lake 382 is indicated below.

The Lake 382 experiment is planned to be one of the case studies included in the DFO National Contaminant Assessment Report planned to be published in March 1997.

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5.3 Effect of Metal Mixtures on Availability of Cadmium to Eriocaulon

During the summer of 1995 (July 13 - September 27) the effect of metal mixtures on the availability of Cd from the sediment to *Eriocaulon* was examined in a field experiment. Availability of metals from sediments is a timely topic, as sediment quality guidelines are being developed by the Federal government and several provinces. Little of the information for the setting of sediment quality guidelines comes from controlled field experiments such as can be performed at the Experimental Lakes Area. This PhD study (Robin Stewart, Botany, Univ. of Manitoba) emphasizes the field aspect, and is a more unique approach to metal mixture studies than those done in the laboratory.

The effect of metal mixtures on the availability of Cd to the rooted macrophyte *Eriocaulon septangulare*, was determined by spiking natural sediment taken from a sheltered bay in Roddy Lake (468). The metals were mixed with the sediments at the ELA field station. The spiked sediment was put into 1' x 2' plastic planter trays with the plants, and placed in 0.5 m of water along the shore in the Roddy bay. Several kilograms of left-over sediment were put into bags, frozen, and returned to the Freshwater Institute for future experiments in the laboratory. As planned, the experiment consisted of 4 treatments and 2 replicates. Enough metal was added to raise background sediment Cd six times (in all 4 treatments), and Cu, Zn, Pb and Ni, two (treatment 2), four (treatment 3) and six times (treatment 4). Approximately 34.2 mg of Cd, 85.5 mg Cu, 769.5 mg Zn, 307.8 mg Pb, and 119.7 mg Ni was added in total to the sediments.

The planter trays containing the spiked sediment will be removed from the lake in the spring of 1996 and disposed of at a hazardous waste facility.

Analysis of the metal concentrations in the sediments and plants will begin in January 1996. No similar experiments are being planned for 1996.

5.4 Fish Exposure-PCB Experiment

In January of 1994, permission was sought and received by DFO researchers to conduct an experiment in which individual, free-ranging fish would be individually exposed to PCB's, and their responses monitored in a natural lake system at the ELA.

Sufficient funding was not received by the research team to enable them to undertake this study in 1994 or 1995. Given the uncertainties of federal support for freshwater research, it seems unlikely that funding for this study will be forthcoming in 1996.

6. RADIONUCLIDES AND GROUND WATER

Researchers from the Environmental Sciences Division of the Whiteshell Laboratories of Atomic Energy of Canada Limited (AECL), Pinawa, Manitoba, have been conducting several studies at the ELA in recent years. During 1995, research funds for continuation of these studies were severely limited, and most of the ongoing AECL work at the ELA was discontinued. AECL staff did continue to participate in studies related to the drawdown project (No. 2.3, above) on Lake 226.

6.1 Whole-Lake Radioisotope Studies

The main focus of AECL research at the ELA in 1995 was on the fate and availability of the trace amounts of ^{14}C, ^{60}Co, and ^{134}Cs found in the sediments of Lake 226 as a result of historic experimental radionuclide additions. This involved both terrestrial and aquatic studies.

The scenario wherein contaminated lake sediments are converted to soil and used for agriculture is of particular importance in assessing the impact that nuclear fuel waste disposal might have in the distant future. Therefore, two garden plots were planted in former littoral sediments, freshly exposed as a result of the lowered lake level, to determine the bioavailability of sediment-associated radionuclides (^{14}C, ^{60}Co, ^{134}Cs) to garden vegetables. In addition, riparian vegetation that colonized the exposed sediment was collected to determine plant radionuclide concentrations. Changes in the inventory of radionuclides in the exposed sediment and the depth of the sediment profile were monitored over the summer.

In the lake, researchers are interested in the long-term redistribution of the radionuclides and their bioavailability to aquatic biota. The decomposition of leaf litter and uptake of radionuclides by the litter was measured again this year to assess how drawdown has affected lake metabolism and radionuclide bioavailability. Periphyton was also collected at three depths just above the water/sediment interface to assess the bioavailability of the radionuclides remaining in the lake. In addition, sediment cores were collected along two transects at approximately 1 and 2 m depth in both the north and south bays of Lake 226NE to assess the effect that drawdown may have on nuclide inventories and littoral sediment erosion. The complete shoreline of Lake 226 was also photographed this year to record the visual (before and after) effect of drawdown. Finally, AECL scientists are monitoring radionuclide concentrations in aquatic biota (collected by DFO staff) to determine whether drawdown affects their bioavailability. Presently, samples are being archived until funds are available for radionuclide analysis.

Plans for 1996 are to continue AECL involvement in the Lake 226 drawdown experiment. Because of budget restrictions, and the AECL research focus on addressing issues that arise concerning the environmental impact statement on deep burial of radioactive wastes submitted to the Canadian Environmental Assessment Agency, it is not anticipated that any new AECL studies will be proposed for the ELA in 1996. The current uncertainties over the future of the AECL Whiteshell facilities also place the 1996 AECL research activities in some doubt.

7. STUDIES IN, AND LINKAGES WITH, TERRESTRIAL CATCHMENTS

7.1 Impact of Elevated Nitrogen Deposition on Forested Catchments

The enrichment of the atmospheric nitrogen (N) pool from the burning of fossil fuels has caused a dramatic increase of atmospheric N deposition to terrestrial and freshwater ecosystems in North America and Europe. The long-term impact of elevated N deposition is not well known, but it is a suspected causal factor in lake acidification, forest decline, and the eutrophication of estuaries. Understanding the links between forested catchments and lakes is particularly important with elevated N deposition because uptake of excess N by forests will initially protect downstream ecosystems. However, this buffering capacity is limited , so it is important to define the critical loads of N that will not exceed buffering capacity.

A research team from the University of Waterloo (led by Dr. S. Schiff and PhD candidate S. Lamontagne) , in cooperation with DFO, are conducting an experimental addition of nitrogen to small boreal forest catchments located in the watershed of Lake 302 at the Experimental Lakes Area. In combination with traditional methods, the researchers are developing new isotopic techniques to study the internal cycling of nitrogen in the catchments.

The objectives of this study are twofold:

1. to quantify the pools, fluxes, and the internal cycling of nitrogen in the ELA upland catchments prior to, and following, the experimental addition of nitrate, and
2. to develop new stable isotope techniques to study N-cycling in forested catchments.

Work Realized in 1995

i) First year of $NaNO_3$ addition:

Forty kg $N.ha^{-1}.y^{-1}$ as $NaNO_3$ were added to upland catchment U3. This nitrate was labelled with the stable isotopes ^{15}N ($300^0/_{00}$) and ^{18}O ($30^0/_{00}$). Catchments U1, U2, and U8 were monitored as reference systems (U8 is also a long-term reference for similar catchments in the Atikokan LTER project). Runoff volume and chemistry was monitored continuously from April to mid-October. In U1 and U3, bedrock and forested subcatchments were monitored from May to October.

ii) N-Mineralization:

Under pristine conditions, most N needed for plant growth is obtained by internal recycling of organic N. In addition, increase in nitrification (conversion of ammonium to nitrate) is believed to be a good indicatior of the onset of “nitrogen saturation” of a forest. Beginning this year, N mineralization was measured separately in forest and in thin bedrock soils. High rates of mineralization were found over bedrock areas (which comprise about 60% of the catchments). In addition, although nitrification is nil in forest soils, it was high in bedrock soils (1-4 kg $N.ha^{-1}.y^{-1}$). The researchers hypothesized that higher soil temperature and a different composition of soil litter promoted higher mineralization rates in bedrock soils.

iii) Vegetation growth:

The growth (diameter at breast height) of 20 jack pine, 20 black spruce, and 20 black spruce saplings is being followed in catchments U1, U2, and U3. Thus far, no difference in growth rates have been observed. In the same catchments, the yearly radial growth of 10 colonies of the moss *Racomitrium microcarpon* is followed using photographs.

iv) N-fixation:

The fixation of atmospheric N in soils and lichen was assessed using acetylene-reduction incubations on four occasions in 1995. Very small rates were observed (<<1 kg $N.ha^{-1}.y^{-1}$). The researchers acknowledge the assistance of L. Hendzel from DFO in the planning of the assays and for performing the acetylene-ethylene concentration measurements.

v) Isotopes:
Plant and soil samples are collected twice a year in catchments U1, U2, and U3 for C:N ration and ^{15}N isotopic content. The ^{15}N signature will be used as a tracer to determine storage of the added nitrate. Work is ongoing in the laboratory to further develop the methodology to measure the ^{18}O content of nitrate. The significance of the latter assay is that "natural" nitrate (i.e. arising from nitrification) has a much different ^{18}O signature than pollution or fertilizer nitrate. In this study, the researchers plan to use the ^{18}O signature of runoff nitrate from U3 to determine the retention efficiency of the nitrate experimentally added to the catchment.

Work Planned for 1996

The Univ. of Waterloo researchers plan to carry on with the second year of $NaNO_3$ addition to catchment U3. Experiments will be set up to determine the mechanisms generating the differences in N-mineralization rates observed in forest and bedrock soils. They also plan to collaborate with DFO researchers to determine whether denitrification is a significant process for the removal of N from the catchments.

Long-term Prospects

Much of the adverse impact of elevated N deposition is expected to occur upon long-term exposure to elevated N deposition. Unlike sulphate-based acidification, elevated N-deposition is if concern to areas of the boreal forest located at the periphery of prairie regions. Current N deposition at the ELA may be twice as large as prior to European settlement. Much of this extra N probably originates from fertilizers applied to upwind agricultural areas.

Funding agencies will be contacted in 1996 to plan a 10-year N addition experiment to catchment U3. Researchers plan to continue with a 40 kg $N.ha^{-1}.y^{-1}$ loading rate, which is the highest deposition rate presently observed in North America, and eight-fold the deposition rate presently observed at the ELA.

The form of N would probably be switched to a mixture of ammonium nitrate/ammonium sulphate. These forms of N are available at low cost and can be applied as slow-release pellets which require far less frequent application. Intensive monitoring of the site would only occur after 5 and 10 years to minimize cost. The researchers expect a cost of $6000 per year would maintain this experiment in "off" years.

7.2 Contribution of Forest Litterfall to Lake Nutrient Inputs

In conjunction with a catchment-scale study of the effectiveness of current Ontario forest harvesting buffer strip guidelines on fish habitat, P, N, and C inputs to lakes via litterfall from the forest edge is being measured at the Coldwater Lakes Experimental Watersheds (near Atikokan) and the Experimental Lakes Area in northwestern Ontario. This study is currently funded under the federal Sustainable Fisheries Initiative.

At the ELA, P inputs from 100 year old and fire regeneration jack pine stands along the shores of Lake 239 are being investigated. In the summer of 1995, pans containing distilled water were set out in two pairs of transects from the water's edge to the centre of the lake, at distances of 0, 1, 3, 9, 30, 90, and 250 m from shore. Samples were collected at two-day intervals from mid-May to mid-October, and filtered through 1.2 μm filters. After identification of large particles, filters and filtrate were analysed for total P, N, and organic C.

The pans collected various vegetative materials (pollen, conifer needles and flowers, leaves, seeds, bits of bark and lichen), spiders, and insects (including faecal material and eggs). Jack pine pollen dispersal in late June and early July was responsible for the largest single input; it was also the most evenly distributed over the whole lake. Leaf fall in autumn was important, but almost entirely restricted to within 3 m of shore. Insects comprised a major part of the litter, were found in samples throughout the summer, and were widely distributed across the lake. They are problematic to the analysis in that some had presumably emerged from the lake, and thus did not constitute an addition to the lake nutrient load. Numerically however, the majority of insects collected in the pans were of terrestrial origin. Most insects found in pans were also caught in occasional sweeps of the lake surface.

P analysis of a small subset of litter pans sampled over the open water season on Lake 239 has been completed. P inputs into pans within 10 m of shore averaged 459 $\mu g.m^{-2}.d^{-1}$; further offshore P inputs were 118 $\mu g.m^{-2}.d^{-1}$. Total P input by litterfall over the open-water season was calculated to be 0.3 $kg.ha^{-1}$ (of lake surface area); this can be compared to traditional measured P inputs in precipitation and runoff ranging from 0.3 $kg.ha^{-1}.y^{-1}$ in dry years to 0.9 $kg.ha^{-1}.y^{-1}$ (22 year period of record).

Litterfall collection began this summer at the Coldwater Lakes Experimental Watershed and will be continued through the planned forest harvesting experiment to determine whether nutrient inputs via litterfall are affected by clearcutting to the lake's edge.