SUMMARY OF MAJOR RESEARCH PROJECTS AT THE EXPERIMENTAL LAKES AREA DURING 1994

1 December 1994

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 three studies are intended to improve our knowledge of these linkages.

1. Biomanipulation and Fertilization of Lake 227, and Biomanipulation of Lake 110

Lake 227 was fertilized with phosphorus for the 26th consecutive year in 1994. 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.

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 being monitored during the experiment.

During 1994, phosphorus, as phosphoric acid, was added to the Lake 227 surface 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.

a. The Stoichiometry Project

During the past three years, a joint research undertaking (The Stoichiometry Project) involving DFO and researchers from Arizona State University and the University of Texas at Arlington has investigated how changes in food webs that produce changes in zooplankton community structure alter the relative availability of N and P supporting phytoplankton and bacterial production. This research centres on changes in pelagic ecological 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.

Before this project began, little was known about relative N:P ratios at critical points in lake food webs, and hypotheses regarding mechanisms responsible for shifts in N and P cycling response to trophic structure alterations were untested. Results to date indicate important responses consistent with predictions of stoichiometric theory. For example, studies of species-specific body N:P in zooplankton have expanded the knowledge base on body N:P and substantiated the apparent contrast between *Daphnia* and calanoid copepods. Evaluation of manipulation responses depend on analyses of accumulated 3-year data sets and will be completed this winter. However, 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 is continuing to quantify the disruption of N and P cycling at the whole-lake scale. In particular, researchers hope to examine 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 research proposal has been submitted requesting funds to continue the biomanipulation studies for an additional two years. To date, this research has provided a basis for one Ph.D. and two M.Sc. theses. At least eight research papers have been published or are in preparation. At the end of the study the pike will be netted out of each lake.

b. Interactions between Contaminants, Trophic Conditions, and Food Web Structure

The main objective of this study is to determine the effect of variations in nutrient loadings and food web structure on the transfer of contaminants to fish. The research team, from DFO and the universities of Minnesota and Arizona State, have been primarily concerned with organochlorines (OCs) and mercury (Hg). The research has two components. First, the researchers are comparing contaminant dynamics in a naturally oligotrophic lake (Lake 110) and an artificially eutrophied lake (Lake 227) to examine the hypothesis that eutrophication leads to decreased bioavailability of contaminants to fish. Second, before pike were added to these lakes in 1993, both lacked piscivores, and stocking of pike has initiated a trophic cascade that is expected to result in large changes in food web structure and, possibly, contaminant dynamics.

To date, the research has focussed primarily on two aspects of contaminant cycling: 1) effects of variations in trophic conditions on air-water exchange of OCs, and 2) effects of trophic conditions on the bioaccumulation of contaminants by fish and other biota. Only preliminary results are available.

In the past, it usually has been assumed that lakes of similar size and location receive comparable inputs of OCs from atmospheric sources. In opposition to this, the ELA researchers hypothesized that gas exchange of OCs may vary with trophic conditions. Many OCs are hydrophobic and have a strong affinity for lipids and carbon. Increases in the carbon and lipid content of water from eutrophication may increase the fugacity gradient between air and water, resulting in greater loadings of OCs. The researchers are examining this hypothesis in two different ways. First, they have been monitoring concentrations of OCs in air, water and particles (primarily phytoplankton) in Lakes 227 and 110. Secondly, they are using paleolimnological techniques to examine long-term changes in accumulation rates of OCs with the eutrophication of L227 in 1969. Preliminary results from the sediment traps indicate that average PCB fluxes in eutrophic L227 are approximately twice as high as those in oligotrophic L110. Assuming that sedimentation patterns in L110 and 227 are similar, these results suggest that atmospheric loadings of OCs may be greater to the eutrophic lake.

Concentrations of PCB's in biota from Lakes 227 and 110 varied considerably. In all cases, organisms from eutrophic L227 had lower concentrations of PCB's and Hg. These differences were observed despite potentially higher OC loadings to L227 and similar OC concentrations at the base of the food web (phytoplankton). Preliminary results suggest that the lower concentrations of contaminants in biota from L227 are the result of higher growth rates. Our results suggest that variations in trophic conditions and food web structure can strongly affect contaminant concentrations in fish and other biota.

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 22,1 both before and after the pike addition. Zoobenthos studies terminated in 1991.

In 1994, we removed as many pike as possible from Lake 221 to start the recovery phase of this experiment. Over 90% of the northern pike population was removed using gill nets. Netting will continue in 1995 to remove as many of the remaining individuals as possible. Analyses of 1994 data are underway.

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. Each year we 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 1994.

Physical Perturbations

4. ELA 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. This experiment is designed to i) improve understanding and devise mitigation procedures concerning the mercury contamination of fisheries in hydroelectric reservoirs, and ii) determine if hydroelectric reservoirs are significant sources of greenhouse gases (CH_4 and CO_2) to the atmosphere. the goal is to determine how the mercury problem begins, how it is manifested in the ecosystem, and how long it can be expected to remain a concern.

Two wetlands are being studied. One (Lake 632) is a reference wetland which will be maintained in its natural state for the duration of the experiment. A second wetland (Lake 979) was first flooded in June of 1993, following two years of pre-flood data collection. The 979 wetland does not receive any artificial additions of substances, other than water. A dam at its outflow is used to manipulate the water level within the watershed to control flooding of the *Sphagnum* and peat. Intensive monitoring of mercury concentrations, gas exchange and various biological responses are conducted both in this system and in the 632 reference watershed. This project involves researchers and support from various universities, hydro utilities, and government agencies in Canada and the U.S.

During 1993, large increases (at least 26 fold) in the production of methyl mercury were observed in reservoir 979 following flooding. The increased methyl mercury concentrations resulted in elevated levels of mercury in fish and food chain organisms. Large increases in the production of greenhouse gases were also observed following flooding, resulting in large increases in the flux of these gases to the atmosphere.

1994 was the fourth field season for the ELARP project. The 979 wetland was reflooded in early summer, and intensive monitoring continued following flooding. Early analyses of the data show that the production of methyl mercury in the reservoir remained high during the second year of flooding. Concentrations and fluxes of greenhouse gases were higher in 1994 than in 1993, suggesting that their production will be a long-term phenomenon. The water level in this experimental reservoir was again returned to the pre-flood elevation in late fall, prior to freeze-up.

Benthic invertebrate input to the ELARP included studies of the effects of reservoir creation, and repeated draining and reflooding, on community structure of aquatic invertebrates. The areas of interest in the reservoir (Lake 979) included the original lake bottom and the peatlands surrounding the lake (both flooded and unflooded parts). Samples were collected from these areas using an Ekman grab and emergence traps. Plans are to repeat all except the shoreline sampling in 1995. Changes in community structure will be charted over time.

The role of benthic invertebrates in transmission of methyl mercury to fish was also examined in the ELARP mainly as part of an M.Sc. thesis. Benthic invertebrates were collected from the Lake 979 shoreline (using a pond net), from the original lake bottom (Ekman grab), and emerging insects were collected (emergence traps) in order to examine mercury levels in invertebrates from various lake habitats. Analyses of some of this material are currently underway; no data are yet available. The ultimate goal is to contribute this information to a model of mercury dynamics currently being developed for the ELARP.

Current plans call for the experimental wetland (979) to be reflooded in the late spring of 1995.

5. Lake 226 Drawdown Study

The objective of this experiment is to assess the environmental impacts of winter water level drawdown on fish populations and fish habitat in a Precambrian Shield lake. Lake 226 at the ELA is being used a the site of this lake manipulation experiment. This lake was the site of an historic eutrophication study during the 1970's, but has since returned to its natural state. The lake has also been used during the past 5 years by AECL researchers for studies of radioisotope movement and fate (see project 18, later in this report) . The lake whitefish population, and many of the limnological and hydrological parameters, have been under study since 1973.

Pre-drawdown observations were made on Lake 226 during 1994. This monitoring included sampling of fish populations, fish spawning, invertebrate population studies, nutrients and primary productivity, sedimentation rates, physical characteristics such as water temperature and clarity, and hydrological parameters. In addition, the researchers plan to sample lake whitefish eggs after ice formation on the lake.

Spring and fall sampling was done in Lake 226 to establish baseline community structure of benthic invertebrates in the littoral zone of the lake prior to lake drawdown. Sampling was confined to the shallow littoral zone that will be directly affected by drawdown (kick nets were used) and to the sublittoral zone that will be below the drawdown level (Ekman grabs were used). The samples are currently stored in unsorted condition at the Freshwater Institute. Plans are to repeat the sampling in 1995, after the winter drawdown has been effected, and to compare the benthic communities from before and after drawdown.

In addition, Lake 226 nearshore areas were mapped in detail in the summer of 1994, prior to the planned drawdown experiment. Aerial photographs of Lake 226 were obtained in October, 1994. Prediction of habitat loss due to drawdown will be made following preparation of digital files of the shoreline and littoral habitats during winter 1994/95.

Drawdown of water levels will start in the winter of 1994/95, and will proceed in three or four stages. The first stage will be by removal of existing beaver dams at the lake outlet, the next two stages will proceed by blasting of a deepened outlet channel, and the forth stage, if needed, will be by siphoning.

Water levels will be restored to as close to natural levels as natural runoff in the basin will allow in the spring and summer of 1995. Observations on the lake after drawdown are planned for the next two or, hopefully, three years. Researchers from the AECL Whiteshell Laboratories intend to participate in the drawdown experiment by measuring radionuclide levels in biota following drawdown, by making radionuclide inventories in littoral sediments converted to soil and in riparian vegetation (and perhaps crops) colonizing the newly exposed shoreline, and by measuring the distribution of radionuclides in lake sediments three years following drawdown (at completion of the study). At the conclusion of the study, the lake outflow will be restored to its natural topographic contours.

6. Impact of Disturbances on the Lake 239 Watershed

Hydrological and chemical monitoring in the calibrated catchments of this watershed continued during 1994. Portions of the watershed were perturbed by a major forest blow-down in 1973, and by forest fires 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 26 years. No chemical additions are made.

Acidification and Recovery

Acidification of aquatic ecosystems by anthropogenically-derived acidic precipitation has been widely recognized for more than a decade as a widespread environmental problem in many parts of eastern Canada 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.

7. 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, water chemistry and plant growth have continued through 1994 to evaluate the recovery of this wetland system. Major conclusions have not changed since the 1993 report.

8. Acidification and Recovery of Lake 223

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 to 1983. 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 occurred in 1994; the lake was allowed to return to a “natural” pH level (6.5 - 6.8) for the first time since 1975. Water chemistry, hydrology, primary productivity, algal populations, zooplankton, zoobenthos, and fish populations have been studied each year.

The primary biological changes in 1994 occurred in Lake 223 fish populations. Abundance of lake trout increased for the first time in the recovery portion of the experiment, and abundance of fathead minnow increased to levels similar to that prior to acidification. Other biological and chemical data for 1994 are still in the preliminary stages of analyses but it appears that the gradual recovery of lake biota is continuing at all trophic levels.

9. Acidification and Recovery of Lake 302S

The Lake 302S whole-lake experiment is in its third year of controlled recovery from experimental acidification to pH 4.5 using sulphuric acid. Lake 302S is the southern basin of a double-basin lake, and was separated from the northern basin (Lake 302N) in 1981 using reinforced vinyl "curtains". Experimental acidification commenced in 1982, and sufficient sulphuric acid was added to its epilimnion during each open-water season to maintain the epilimnetic pH at annual target levels. Following several years at pH 4.5, the pH was permitted to increase during 1992 and 1993, when the target was pH 5.1. Acid handling procedures are similar to those outlined for the Lake 223 study in 8 (above).

During 1994, the target pH was 5.8, and almost no acid was added because the lake has been reacidifying itself.

Initial recovery continues to be incomplete. Neither geochemical nor biological recovery are proceeding along their acidification trajectories so that the lake appears to be recovering to a different state. Geochemical recovery, especially internal generation of alkalinity, continues to be slower than expected, with the epilimnetic pH between 5.0 and 5.4 during much of 1994 despite the target pH of 5.8 (see attached graph). Some 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.

The researchers are planning to leave the target pH at 5.8 during 1995 to assess whether recovery will proceed further beyond that seen in 1994. 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.

Decreasing the lake's pH below 5 may also have impaired the lake's ability to recover from acidification compared to lakes less severely acidified (eg. Lake 223).

10. Acidification and Alkalinity Generation in Lake 302N

Lake 302N is the northern basin of Lake 302, separated from the south basin (described in 8, 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 1994, this lake basin was in the first year of partial recovery from these additions. A limited amount of HCl was added to prevent the pH from rising above the target value of 5.8. Monitoring of various limnological parameters continued.

11. 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 investigated the combination of environmental factors that may lead to the outbreaks of toxic water blooms. Since the aim of the study was to verify the causative organism, the 1994 summer research project focused on describing the activities of the phytoplankton species and associated bacterioplankton. Early samples revealed that cyanobacteria were never prevalent in the water samples, whereas freshwater dinoflagellates (*Gymnodinium, Peridinium*) dominated the standing stock during the mid-to-late summer season. Members of these two groups are often associated with fish kills.

To ascertain the relationship between the presence of a taxon and water quality, the researchers employed a weekly series of fish bioassay experiments to investigate the fish-killing potential of the waters of the lake basins and of limnocorrals placed in each lake basin. For the 1994 season, the team concluded:

1. The "fish-kill" potential of the waters is temporally restricted to the mid- to later-part of the summer season. In the fish bioassays, the researchers were able to induce the toxic nature of the waters only from mid-July to early August. This timing corresponds to the reported dates of the original fish kills.
2. The "fish-kill" potential of the waters was determined through a series of minnow bioassay experiments. Each series of experiments included the examination of water from each limnocorral and the two lake basins with the addition of nitrate, phosphate or iron. During the seasonal period when the "fish-kill" response could be induced, only the addition of iron enhanced the rate of fish kill, with one-half of the fish killed within the first hour after the addition of the nutrient supplement. The addition of nitrate or phosphate or iron-chelators to reduce available iron resulted in complete fish survival for over 24 hours (the full length of the fish bioassay). Controls of adjacent waters supplemented with extra iron never induced a fish kill, indicating that the etiologic agent was present in all Lake 302 samples and was not a direct response to the addition of iron.
3. There were small differences between the phytoplankton species composition in the limnocorrals and in the effectiveness of iron to stimulate fish kill activity. At present, the research team is examining the relationship between phytoplankton species composition and the potential for fish kill activity.
4. Minnows removed from the experiments are being examined for the physical characteristics associated with exposure to fish toxins. Bacteria samples have been collected from the limnocorral waters and from the surface and gill areas of the fish that died during the bioassays for comparison with bacteria obtained from fish exposed to the non-toxic nutrient addition bioassays.

In preparation for the 1995 summer season, the researchers have installed six limnocorrals (3 in each basin). They plan to reaffirm the link between iron addition and "fish-toxicity", replicating the nutrient addition experiments and developing experiments to ascertain if the toxin is "extracellular" or bacterial in origin, and to relate toxin production to photosynthetic processes. Methods for the collection and extraction of bioactive compounds will be employed for possible structural characterization of the toxin during the 1995 winter season. In addition, the means of iron mobilization in Lake 302 will be considered to investigate the extent and frequency of high iron intrusions into the meta- and epilimnetic regions of the lake.

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.

12. 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. 1994 was to have been the eighth consecutive year of detailed monitoring of this lake series.

No field research activities were conducted on this study during 1994. Funding considerations dictated that this study be discontinued, at least temporarily. It may be resumed if new funding sources can be found.

During 1994, five additional publications were produced containing results from this study.

Some related work was conducted in these seven lakes during 1993 and 1994, as part of an M.Sc. thesis. Aerial photographs of all seven lakes (149, 164, 165, 373, 377, 442, 938) were obtained, and AutoCad files produced for the shorelines of lakes 165, 373 and 442.. Detailed near-shore mapping has been completed and the files are currently being processed to construct overlays of habitat on shoreline. These overlays subsequently will be entered into a GIS (IDRISI) to analyze areas of different habitats in relation to slope, fetch, and material classes. Lakes 164 and 377 were mapped in detail during the summer of 1994 and will be used to test predictions of habitats, based on results of analyses of the previous three lakes. Digital files of lakes 164 and 373 should be completed this winter. If this work continues, it will probably concentrate on developing additional layers in the GIS files (eg. woody debris, shoreline vegetation and soils, macrophyte growth, etc.).

13. Lake Monitoring for LRTAP (Long Range Transport of Atmospheric Pollutants), and Related Lake Monitoring Activities

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.

1994 marks the ninth 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 four 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 1995 will continue on all of the above lakes with the same frequency as in the past.

Data from the ELA are currently being incorporated in a CFAS technical report which outlines starting point conditions during the first few years of the national program (publication expected in this fiscal year). 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.

14. Studies of Dissolved Organic Matter

A research team from the University of Alberta began a series of studies in 1994 to examine factors influencing the production and degradation of dissolved organic matter (DOM) in ELA lakes. The following studies were conducted during the summer of 1994:

a. Comparative study of Dissolved Organic Matter in low order Shield lakes

Surface water samples were collected from 15 lakes throughout the summer. Lakes were selected to span a gradient in relative catchment area (ratio of terrestrial drainage area to lake surface area, A_d:A_0) and flushing rate. Concentrations of dissolved organic carbon (DOC) and of hydrophobic humic substances (HS) decreased with increasing A_d :A_0 and flushing rate. Using meteorological data, the researchers plan to calculate partial residence times for DOC and HS.

b. DOM degradation and production in response to addition of inorganic and organic nutrients

Experiments were conducted in enclosures to deduce the role of nutrients in regulating loss rates of terrestrial DOM and production of autochthonous DOM. Nutrients did not affect loss rates of terrestrially derived DOM (as inferred from changes in the apparent colour of water). Loss rates of DOM in reference treatments were similar to loss rates of colour. Loss rates of DOM were much slower in response to nutrient addition relative to colour; thus DOM was effectively diluted by autochthonous DOM. Autochthonous DOM also had no effect on the rate of loss of allochthonous DOM.

The University of Alberta researchers are planning the following DOM studies in 1995:

i) Susceptibility of DOM to flocculation by multivalent metals:

They intend to conduct short-term (months) experiments in enclosures to infer the relative importance of multivalent metals for removing DOM by flocculation. They will manipulate the loading of multivalent metals (Fe, Al, Mn) to enclosures as simple metal salts. They will monitor changes in DOM concentration and quality over time.

ii) Dependence of UV activation on microbial degradation of DOM:

They intend to conduct further experiments in enclosures to deduce the role of UV photodegradation in the loss of DOM. The hypothesize that photolysis of allochthonous DOM renders the fragments more biologically available than the parent molecules. It is possible that these experiments will be conducted in a factorial design with part of the flocculation experiments.

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.

15. Organochlorines and Poly-Aromatic Hydrocarbon Study

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 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. Fish recaptured subsequent to injections have been 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 1994, as in previous years. Signs along the lake shore alert any passers-by that some of the fish in this lake may not be fit for human consumption.

This study formed the basis of a Ph.D. thesis (P. Delorme) that is now completed. Results indicate that these organic contaminants can significantly impair fish growth, reproduction and survival.

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.

16. 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. Most of this cadmium is now located in the sediment of the lake. In 1992, long-lived lake trout, white sucker, and unionid mussels continued to accumulate cadmium. The fish exhibited, in some organs, cadmium levels which, from laboratory studies, would be expected to cause cellular damage, yet no overt adverse effects were observed in these free-ranging individuals or populations.

In 1994, as in 1993, no cadmium was added to Lake 382. The experimental strategy was thus to examine the response of the lake ecosystem to the "zero discharge strategy". Data collected on the fate of Cd in water, sediments and biota will be applied to the predictive fate and effects model for the addition and recovery phases of the experiment.

Only two major sets of results will be discussed here:

a. Fate of Cd in water: Cadmium concentrations declined markedly in the water column in 1993 and 1994. Figures 1 and 2 show [Cd] in 1994. Concentrations were between 25-35 $ng.L^{-1}$ in the water column after ice-out in May 1994 and over most of the summer were below the limits of detection, 15 $ng.L^{-1}$. By turnover in October 1994, [Cd] was about 20 $ng.L^{-1}$ in the water column. During late August 1994 there was a short-term elevation of [Cd] in the metalimnion and hypolimnion. At 8 m water depth, where the pH was low, almost half this Cd was "ionic" and bioavailable. Higher [Cd] deeper in the water column were chemically bound, and largely not bioavailable. The hypothesis arising from the 1993 and 1994 results is that Cd loaded to a lake moves from the water column to the sediment, but at certain times of the year a small amount feeds back to the water column in a largely chemically-bound, non-bioavailable form. The amount of feedback damps with time. As a consequence of the rapid fall of [Cd] in the water column in the "zero discharge" years, Cd can no longer be measured in whole water or fractions with the methods available in FWISL.

b. Contents of Cd and metallothionein in large fish: Figures 3 and 4 show that the Cd content in posterior kidney of lake trout and white sucker from Lake 382 in 1993 increased only slightly in white sucker, but continued to increase in lake trout. Figure 5 shows that metallothionein (MT), the metal-binding protective protein, continued to increase in 1993 in Lake 382 white sucker kidney. As a consequence of these data, it is hypothesized that if these large fish were to continue to be exposed to the CWQG of 200 $ng.L^{-1}$ the Cd content of the kidney could reach the 15 $ug.g^{-1}$ wet weight level found in mammals to be associated with renal histopathology. There is concern as to whether MT is reaching maximum production in the Lake 382 fish. If so, if [Cd] continued to climb in the kidney, there may be a "spill-over effect" with a rapid onset of toxicity, loss of renal function, and histopathology, caused by the excess, unbound cadmium.

c. No changes in populations at various trophic levels attributable to Cd were recorded in 1993 and 1994, so far as data are analyzed.

It is proposed in 1995 to resume the additions of Cd to bring the epilimnion to 200 $ng.L^{-1}$ for most of the ice-free season.

17. 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 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. The researchers are continuing to pursue funding for the study, and wish to proceed in 1995 if funding is in place. No major changes to the experimental design are contemplated.

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 a range of studies at the ELA in recent years. During 1994, seven papers or reports describing this research were published.

18. Whole-Lake Radioisotope Studies

The nuclear fuel waste management program at AECL is investigating the possible disposal of used nuclear fuel waste within a rock vault 500 to 1000 meters below the earth's surface. Radionuclides stored in such a vault might travel with deep groundwater flow to the surface at some future time, so models must be developed to evaluate the environmental impact of such an event. Little information is available on the action and partitioning of nuclides entering the hypolimnion of a lake; this experiment was designed to fill this knowledge gap. An AECL plan for this experiment was approved by OMNR, OMOE, and DFO in 1989.

In 1989, staff of AECL's Whiteshell Laboratories added small quantities of radionuclides to the hypolimnion of Lake 226. The partitioning of these isotopes between sediment, water, and biota was monitored immediately after the additions, and each year thereafter. AECL again monitored the fate of these 1989 additions during the 1994 field season.

During 1994, AECL activities in Lake 226 included collection of sediment cores, water samples (vertical profiles in late winter (March), during spring turnover, and in late summer), and aquatic biota (periphyton, fish, and macrophytes) to measure residual (5-year) ^{60}Co and ^{134}Cs activities within the lake. This data set concludes the AECL commitment to monitor the fate of these isotopes following their experimental addition to the lake. Most of the samples for 1994 are still in the process of being counted. The results from the sediment cores will be made available as a Technical Record in 1995, and it is anticipated that two papers (one dealing with the radionuclide concentrations in whitefish and the other dealing with the behaviour of the radionuclides in the lake and biota over the five year period) will be available in 1995.

Subsequently, in 1994, AECL researchers used sediment traps to measure fluxes and concentrations of natural and historically added radionuclides in settling particles and surface sediments. This work will be used primarily to evaluate the importance of resuspended particles to the overall settling particle flux in Lake 226, on a seasonal basis, but also supports the whole-lake drawdown experiment by providing pre-manipulation data on radionuclide concentrations and particle fluxes in the lake prior to the drawdown. Although AECL Research funded this work in 1994, continued participation in the experiment will depend upon the availability of funding through the project sponsors.

In addition, a method to collect large periphyton samples at the sediment/water interface was developed and tested in order to assess the importance of periphyton in the transfer of sediment-associated radionuclides up the food chain. This involved the colonization of wood lattices (anchored just above the sediment/water interface) by periphyton and the collection of the periphyton from the lattices periodically over the summer. Samples were collected at 1, 2, 3, and 4 m depth, and will be analyzed for ^{60}Co, ^{134}Cs , and ^{14}C concentrations. Researchers also measured the decomposition of poplar leaf litter with depth in Lake 226N over a six month period. This will provide a measure of benthic community activity (microbial metabolism) in the lake and uptake (bioavailability) of radioactivity by decomposing detritus with depth. These projects, together with the data collected on radionuclide concentrations in the lake and biota over the past 5 years, including 1994, will provide an excellent data base of pre-drawdown conditions in Lake 226. Further, AECL photographed nearly the complete shoreline of Lake 226N and Lake 226S to record pre-drawdown conditions, and collected littoral sediment cores to measure the release of ^{14}C from these cores as sediments are converted to soil under laboratory conditions.

19. Identification and Characterization of Deep Ground Water Discharge Areas in Lakes

While many lakes at the ELA have little ground water contribution to their hydrologic budgets, a few lakes have significant inputs. Lake 625 has a very deep ground water input to the lake, and provides an excellent opportunity to determine how such ground water input can affect the hydrological and chemical cycling processes within these lake ecosystems. This knowledge will have implications both for the proposed deep storage of nuclear fuel waste (see project 18, above), and for our general understanding of ecosystem processes in lakes.
Since 1990, staff from AECL Research, Pinawa, have measured natural tracers of groundwater movement in the water and sediments of Lake 625 at the ELA. This study is now completed and all markers and equipment have been removed from the lake.

Overall, AECL researchers conclude that deep-seated fractures transmit conspicuous amounts of excess radiogenic helium to Lake 625. Associated with this excess He, slight increases of salinity are observed in bottom water near the discharge zone. Sediment core studies have shown that very strong He and salinity gradients exist in sediments up to a depth of 2 metres. Anomalous ^{210}Pb inventories have been observed in several cores, but these may be caused by high concentrations of ^{222}Rn discharged by shallow-flow groundwater. Direct (submersible video camera) observations of the discharge zone indicate the presence of an apparent Fe-rich floc of probable microbial origin at the sediment-water interface; however, microbial studies completed in 1994 show little evidence of unusual microbial assemblages at the discharge zone in Lake 625, when compared with assemblages at other sites in the lake, or in reference lakes.

20. Behaviour of Radionuclides at the Sediment-Water Interface in Lakes

The movement and bioaccumulation of radionuclides (both from natural sources and from anthropogenic contamination) within ecosystems is recognized as a real and potential hazard to humans and other living organisms. Much more information is needed about the behaviour of these elements within ecosystems for us to make informed regulatory decisions and develop adequate disposal protocols.

In 1993, staff from AECL placed three small (5 m in diameter and 7 m deep) "limnocorral" enclosures in the deepest portion of Lake 304 at the ELA. The limnocorrals were tested to ensure a good seal with lake sediments and to test the feasibility of conducting studies throughout the year. In 1994, AECL researchers sought and obtained permission to add radionuclides to the corrals to study water-to-sediment transfer rates, partition coefficients, and food chain effects of key radionuclides of concern to the Nuclear Fuel Waste Management Program. Unfortunately, due to fiscal constraints and other obligations, this study could not be initiated in 1994. It is anticipated that the study will be able to proceed in 1995, and may include additions to littoral corrals to study food chain effects, providing funding is available.

Studies in Terrestrial Catchments

21. 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. A research team from the University of Waterloo, in cooperation with DFO, are planning 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 define 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.

During 1994, the following work was realized.

i) Catchment Upgrading:

The experimental catchments had not been used for a few years and required some repairs. Notably, the concrete deflector walls were covered with a new coat of epoxy paint and the weir covers were rebuilt to allow work to begin early in the spring of 1995. New throughfall and stemflow collectors were added to catchments U1 and U3.

ii) Mass-balance:

Four catchments were constantly monitored from early June to early September. Three weirs are equipped with F-recorders and one with and A-recorder. Each rain event was monitored. One chemistry sample was taken at the weirs during the rising and one during the falling limb of the hydrograph for each event. In addition, catchments U1 and U3 are equipped to monitor "internal" fluxes (throughfall and stemflow collectors, several types of lysimeters). For each type of device, one or two samples per catchment were collected per event. Catchments U1 and U3 have gauged forested and bedrock sub-plots. The forested sub-plots were monitored in August. Complete chemical characterization was requested for all water samples.

iii) N-mineralization assay:

The mineralization of N is a key component of N cycling in forested catchments. The researchers tested two assay procedures during 1994. They will settle for the simplest one (buried bags) to follow the changes in N mineralization dynamics for the next two years.

iv) Measurement of N-pools:

The researchers have almost completed measurement of N-pools in catchments U1 and U3. The pools measured were soil N, tree biomass and understorey biomass. Soil N will be assessed from the cores sampled during the N-mineralization assay, and with a GIS model (developed by Dr. C. Allan) representing soil volume. The researchers have measured the diameter at breast height of all trees in catchments U1 and U3. Tree biomass will be estimated using published DBH/biomass allometric relationships. Understorey (moss, lichens, herbs) was measured with a 0.0125 m^2 quadrat randomly placed along transects laid over either bedrock or forested areas.

v) Vegetation growth:

A full assessment of vegetation dynamics is beyond the scope of this study. However, the research team has set up a simple monitoring system to gain some insight into vegetation responses upon N addition. They have marked 20 Jack pine, 20 black spruce, and 20 black spruce saplings in catchments U1, U2, and U3. Diameter at breast height will be measured once or twice a year for each tree. They have also permanently marked 10 colonies of the moss, *Racomitrium microcarpon*, colonizing bedrock areas in U1, U2 and U3. Radial growth of the colonies will be measured by taking photographs once each year.

In 1995 and 1996, 40 kg $N\text{-}NO_3^-.ha^{-1}.yr^{-1}$ will be applied to catchment U3, while catchments U1, U2 and U8 will be used as reference systems. The added nitrate will be doubly-labelled with the isotopes ^{15}N and ^{18}O to help follow the path taken through the catchments by the added N. The researchers will continue regular monitoring for N-mineralization and vegetation growth. They hope to collaborate with other ELA researchers to measure N gas fluxes in the experimental catchment and in one of the reference catchments during the experiment.