S&E
SCIENCE AND THE ENVIRONMENT
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PUTTING THE PETAL TO THE METAL

Abandoned mines, industrial dumps and other contaminated sites may get a new lease on life thanks to an innovative form of bioremediation that uses plants to remove toxic substances from soil, sediment and ground and surface water. Known as phytoremediation, this solar-driven technology is proving to be less invasive, less costly and less energy-intensive than existing physical, chemical and thermal remediation methods.

Phytoremediation works on the principle that plants naturally take up trace elements and other substances from soil and water and either store, accumulate, metabolize, or volatilize them to the atmosphere. Plant roots also foster the growth of micro-organisms that biodegrade organic contaminants, and many plants produce and release substances that help degrade organic pollutants in the root zone. Unlike traditional remediation methods, which often destroy organic material and leave soil inert, planting terrestrial and aquatic species can target specific contaminants and, in the process, restore the site to some level of ecosystem health and productivity.

Canada is taking the lead globally in generating a comprehensive database on the use of this technology to stabilize, remove and recover heavy metals such as lead, mercury, iron, manganese, zinc and copper from contaminated ecosystems. This March, two years of intensive study by scientists in Environment Canada's Environmental Technology Advancement Directorate culminated in the release of PHYTOREM—an interactive electronic database of more than 700 plants, lichens, algae, fungi and bryophytes that have demonstrated an ability to tolerate, accumulate or hyperaccumulate a range of 19 different metals. Species that show considerable potential to date include sunflowers, ragweed, cabbage, Indian mustard, geranium and jack pine.

The sunflower is one of many plant species that have shown promise in removing toxic metals from contaminated soils and groundwater.

Accompanying this database are 35 different search fields containing additional geographical, regulatory and eco-physiological data on each species. This will make it possible for the owners and managers of contaminated sites to choose the species that suit their site conditions, and take the steps necessary to secure regulatory approval for their use.

Plants are effective at removing metals because, like humans, they require certain trace elements to survive. Some species, known as hyperaccumulators, can accumulate and tolerate very high concentrations of metals—some up to five per cent of their dry weight. This trait, combined with size and a speedy growth rate, determine whether or not a certain species is a cost-effective candidate for phytoremediation. Another advantage of phytoremediation is that once a crop has accumulated its optimum metal content it may be possible to harvest the crop and recover the valuable metal components from the contaminated biomass. Departmental scientists are experimenting with a variety of techniques, including drying, composting, compacting, leaching, and high-temperature decomposition.

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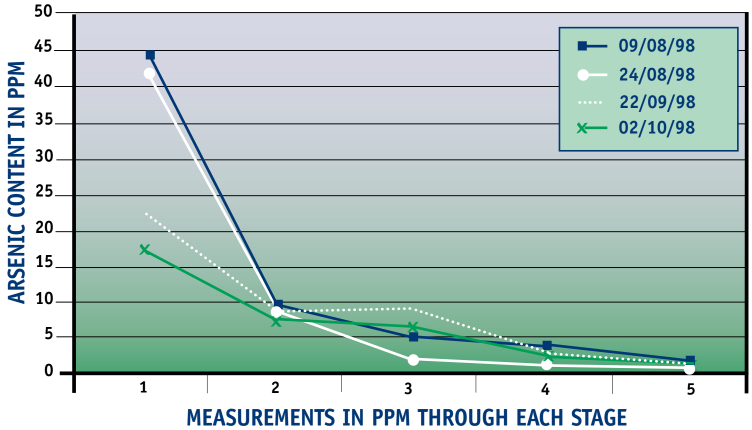
INSIDE



Graph showing removal of arsenic from contaminated surface water (1) as it passes through a constructed wetland with four "cells" containing various species of aquatic plants (2), trees (3), grasses (4) and cattails (5). The four lines represent tests carried out during early and late August, September and October 1998.

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In response to the considerable interest industries and other stakeholders have expressed in this technology, Environment Canada has collaborated on a number of demonstration projects designed to test the viability of phytoremediation in controlled and experimental field plots. In British Columbia, scientists have created a series of hydroponic gardens to determine the effectiveness of various aquatic plants in removing zinc, cadmium, and arsenic at the COMINCO mine in Trail. Results from a pilot project at Île-aux-Corbeaux in the St. Lawrence River, where the shoreline was heavily contaminated with zinc and manganese from buried batteries, showed significant accumulations of these metals in American eelgrass and hornwort planted offshore after just over a month of growth.

In addition to testing the effectiveness of candidate species, Environment Canada scientists are also working with counterparts from the National Research Council and the United States Environmental Protection Agency to study biodiversity at metal-contaminated sites across Canada. Their work is aimed at determining whether seed banks can be established from these wild species, and whether they can be successfully propagated in greenhouses. This work could eventually lead to the creation of inventories of candidate cultivars that could be adapted for use at other metal-contaminated sites across Canada.

Scientists are hopeful that the next phase of the project—slated to begin this spring—will involve even more ambitious field trials. In the meantime, they continue to tackle other challenges, such as seeking further clarification on regulations that may apply to this non-traditional use of plants, improving understanding of how candidate species work and what makes contaminants accessible, developing protocols for determining efficiency and cost-effectiveness, and improving knowledge of the potential impacts of phytoremediation demonstration projects on wildlife. **S&E**

BIOTECHNOLOGY AND THE ENVIRONMENT

Virtually every aspect of our lives is touched in some way by the use of products and processes that have been created from living organisms—from methods of purifying our drinking water to the production of new vaccines. Already worth more than $3 billion and employing some 25 000 people, Canada's biotechnology industry is poised for expansion in the coming century.

Over the past 15 years more than 500 biotechnology companies have taken root across Canada—most of them in the health care and agricultural sectors. About 80 companies are exploring the use of biological technology for environmental purposes in such key areas as:

- **bioremediation—the use of microorganisms, the products of microorganisms, and plant-based products and processes to remediate, stabilize, and restore contaminated ecosystems;**
- **the development of biological methods of controlling diseases, pests and weeds to protect crops and trees and reduce the need for pesticides;**
- **the detoxification and reduction of waste streams and their conversion into new products (e.g., the production of specialty chemicals from food processing wastes);**
- **the production of chemicals and materials from biomass (e.g., bioethanol from pulp and paper wastewater) to reduce reliance on fossil fuels and other non-renewable resources and their contributions to climate change; and**
- **the development of biosensors, which can determine the presence of, identify and monitor different contaminants under a variety of conditions in the air, soil, and water.**

A recent survey conducted by a group of federal departments involved in biotechnology issues revealed that Canadians are not very familiar with biotechnology or its environmental implications, and therefore insist on a rigorous regulatory evaluation before new technologies are used. The vast majority also feel that such technologies must be pursued to maintain our current quality of life. The results of the survey are available on the World Wide Web at [www.strategis.ic.gc.ca/SSG/bh00239e.html].

MERCURY RISING

Snow isn't the only thing falling north of Canada's Sixty this time of year. Recent atmospheric data show that mercury is continuing to build up in the Arctic as a result of toxic downpours that occur each spring—and that these mercurial showers are expected to arrive again in the coming weeks.

Mercury poses a health hazard because it bioaccumulates in humans and other animals higher on the food chain.

Scientists from Canada, the United States and Norway are working to discover the geographic extent of this unusual phenomenon—the result of complex chemical and physical processes that are also responsible for a depletion in ground-level ozone over the Arctic each spring.

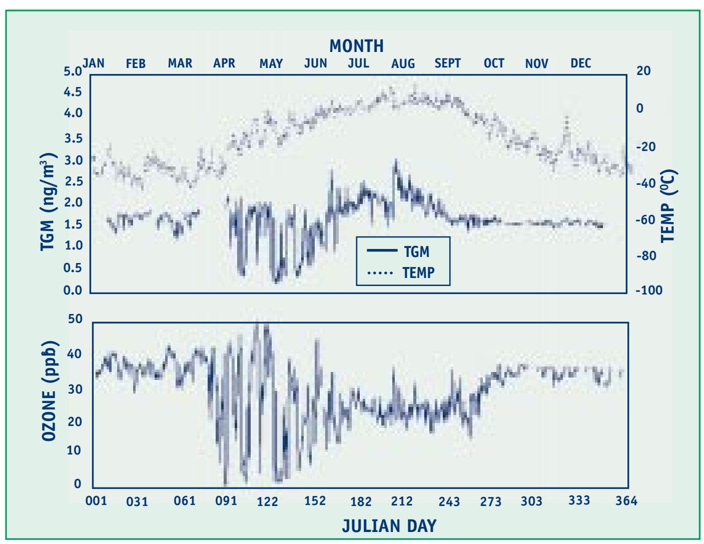
Although mercury is released into the atmosphere from a variety of natural sources, rising global mercury levels began with the Industrial Revolution in the mid-18th century. Still released through industrial use, mercury remains of considerable concern because of its environmental persistence, toxicity and ability to bioaccumulate in humans and other species high on the food chain.

These mercurial storms were discovered in early 1995 by Environment Canada researchers who had begun measuring concentrations of gaseous mercury at an air chemistry observatory near Alert, at the northern tip of Ellesmere Island. Although their readings remained relatively constant through the winter, in late March they began to fluctuate wildly—plummeting rapidly and then shooting up again, the process repeating itself numerous times before finally quieting down about eight weeks later.

Initially, researchers thought their equipment was malfunctioning, but new equipment received the following year recorded the same phenomenon. A separate set of tests and subsequent measurements showed that mercury was being transformed from a gas into a solid in the frigid polar atmosphere after sunrise—a development that has intrigued scientists. This aerosol mercury falls to the earth's surface much faster than gaseous mercury, and accumulates in the ice, snow and spring meltwater in an oxidized form that is much more easily taken up into the food chain.

This phenomenon is active primarily in the earth's boundary layer, the area within a kilometre of its surface. Levels of gaseous mercury stay fairly constant during the six weeks of winter darkness and begin to fluctuate wildly with the return of the sun. Scientists believe the conversion of mercury into aerosol form is closely related to ground-level ozone destruction, because these changes occur only in areas where tropospheric ozone has been depleted over the frozen surface of the Arctic Ocean. Sunlight causes chemical reactions in sea salt found on Arctic pack ice, generating bromine atoms that attack and destroy ozone near ground level. When this occurs, bromine oxide is created—which likely oxidizes the mercury vapours and converts them into particles. A number of scientists worldwide are currently working to better understand the chemistry involved in this fascinating natural phenomenon.

Mercury's newly revealed behaviour, at least in the polar regions, is scientifically significant. Until now, it was widely believed that mercury vapour in the atmosphere was inert. However, this Canadian discovery indicates a need to re-examine the traditional understanding of mercury's atmospheric characteristics. Furthermore, because these mercury showers take place in the spring as the ecosystem is coming to life, they expose the area's humans, plants, animals and fish to yet another form of insidious toxic pollution. S&E



Average values for concentrations of surface total gaseous mercury (TGM) and ozone at Alert, 1995. During the three-month period after polar sunrise in mid-March, there is a dramatic increase in fluctuation.

BIO-MARKERS CLUES IN CHEMICAL SLEUTHING

Their feathers soaked with oil from a spill, a flock of murres founders on the open sea, unable to keep warm or stay afloat. Days later, a team of Environment Canada scientists begins analyzing the gooey substance clinging to the bodies that have washed ashore—a form of chemical sleuthing that can pinpoint the source of a spill with amazing accuracy.

Thousands of litres of oil wash up on Canada's shores each year, many from "mystery" spills caused by sea-going tankers.

When the *Exxon Valdez* ran ashore off the coast of Alaska ten years ago, there was no doubt as to the source of the oil that washed over the coastline and threatened the fragile ecosystem. However, millions of litres of oil wash onto Canada's shores each year, much of it from sources unknown. While nearly a third of this comes from municipal wastewater runoff, another significant source is ships that knowingly or unknowingly discharge oil into the ocean. In order to effectively enforce the laws against dumping, both the source and location of the discharge must be proven. And thanks to a chemical "fingerprint" known as a bio-marker, the forensic tools are now at hand.

Every oil contains a bio-marker—a chemical compound that is not readily degraded and that identifies the product in a unique way. In order to find the bio-markers in a wide range of commercial oils, Environment Canada scientists in the Atlantic region and at the Environmental Technology Centre in Ottawa had to characterize more than 300 other compounds found in these products.

To track down the source of a spill, bio-markers detected in a site sample are compared to those detected in the lab. These fingerprints may be the ratio of various compounds found in the oils, or the presence or absence of certain twin compounds. Bio-marker comparisons also tell scientists how much an oil has evaporated, biodegraded or separated, making it possible for them to not only identify the commercial product, but also determine the scene of the crime by figuring out how far it has travelled.

During the past year, there were "mystery" spills between California and British Columbia that caused oil to wash ashore every day for weeks. By using the bio-marker methodology on oil samples, scientists determined that there were actually two separate spill events—one close to shore near California, and the other a more northerly spill that occurred further out to sea. Bio-markers have also been used effectively in several actions in Atlantic Canada to enforce laws designed to protect the environment against oil spills that are either deliberate or caused by carelessness.

Environment Canada is currently developing a statistical program on oil signatures that can indicate the exact probability that two samples, identified as a match by chemical analysis, are the same oil. Interest in this new technology has already attracted the attention of countries all over the world, including China, the United States and Spain. S&E

Dozens of thick-billed murres washed ashore near Glace Bay, Cape Breton, earlier this year, the victims of an offshore oil spill.

TOXIC AIRBORNE CONTAMINANTS IN THE ST. LAWRENCE RIVER VALLEY

How pollutants travel through the air, the physical and chemical changes they undergo during their life cycle, and the factors that influence their transfer between air, land and water are of vital importance to scientists in eliminating or mitigating the effects of toxic contaminants on our land and water resources.

Because large bodies of water are major sources and sinks for such contaminants, a team of Environment Canada scientists in Quebec is studying the atmospheric life cycle of toxic airborne contaminants in the St. Lawrence River valley. Their work, which was started in 1993, focuses on three families of organic compounds—polycyclic aromatic hydrocarbons (PAHs), organochlorine pesticides, and polychlorinated biphenyls (PCBs)—as well as on heavy metals such as mercury, copper, lead, zinc, arsenic and cadmium. Their goal is to not only determine the origin, distribution, concentration and annual deposit of these substances, but also ascertain the overall contribution of atmospheric pollutants to the river's chemical contamination.

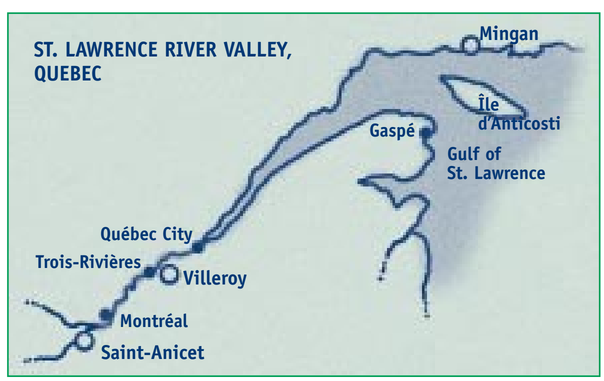
Airborne compounds undergo numerous physical changes during their life cycle, including being captured by other particles and carried away, deposited on the ground or mixed with precipitation. They also undergo chemical changes when they come into contact with other molecules—changes that alter their composition or degrade them, as in the case of oxidation. Although some compounds have short life cycles and decompose within days, others are active for long periods of time. PCBs, for example, last for about a year after being released, so they can be carried long distances in the air, fall to the earth and remain volatile until they are destroyed or immobilized.

Monitoring equipment used to measure toxic fluxes between the soil and air.

To study the lifetime cycles of these toxic contaminants, three air quality stations were established at Saint-Anicet (south-west of Montréal), Villeroy (between Trois-Rivières and Québec City) and Mingan (on the north shore of the Gulf of St. Lawrence). Each station is a low platform equipped with samplers and automatic analyzers that gauge the presence and quantities of compounds in the air as well as in rain and snow. The Saint-Anicet location is unique because it uses instruments positioned directly over the river to measure fluxes in air-water exchanges of mercury and compare them with air-soil fluxes measured at a ground station two kilometres inland. Early data suggest that wind promotes the escape of mercury from the soil to the atmosphere up to eight times faster than it does from the water.

Although the collection and analysis of data on many compounds has already been completed, studies of the origin, transport and distribution of mercury and lindane will continue for another five years. A detailed report on findings to date, to be published early this year, will provide a blueprint of atmospheric pollution over the St. Lawrence and serve as a useful tool for designing effective pollution control strategies. S&E

Environment Canada has set up air quality monitoring stations in Saint-Anicet, Villeroy and Mingan, Quebec.



WATERTOX: TESTING THE WORLD'S WATER

While in most parts of Canada, safe drinking water is as close as a turn of the tap, more than 2.5 billion people the world over are without access to this basic resource. The problem is particularly severe in developing countries, where regulations governing waste disposal and the use of toxic chemicals are lax. The dangers this poses to human health are exacerbated by the fact that water quality testing is simply too costly for many communities to carry out.

Contaminated drinking water is a common health hazard in developing countries around the world.

For the past two years, Environment Canada scientists in Burlington and Montréal have been working to help transfer simple, cost-effective water toxicity testing technologies to scientists in developing countries so they can identify grossly contaminated water sources. Their efforts—an integral component of the International Development Research Centre's (IDRC) WaterTox program—include developing and refining bioassays, training scientists, providing technical support to lesser developed laboratories, preparing contaminated water samples, assessing results, and producing a resource manual.

The first challenge faced by the scientists was to find tests that could be carried out using basic equipment and readily available supplies. Six bioassays—tests that involve exposing small, living organisms to liquid samples and measuring the effects—were chosen from a list of more than 25. In two of these tests—the lettuce seed germination test and onion root inhibition test—toxicity is indicated by slowed plant growth. In the *Daphnia magna* acute toxicity test, 96-hour hydra test and nematode toxicity and growth inhibition test, the mortality rate of tiny invertebrates serves as an indicator. All are easily visible and unambiguous indicators of toxic contamination.

Scientists from institutions in Costa Rica, Colombia, Mexico, Argentina, Chile, Turkey, India, the Ukraine and Canada attended a two-week workshop in Cornwall, Ontario, to learn how to perform these bioassays, and were given supplies and test organisms to take back to their labs. As an initial training exercise, they were then sent a set of 24 samples containing metals, organics and pesticides for analysis, and asked to return the results for examination.

These results revealed large discrepancies in quality control and reproducibility among the participating labs. Some problems were caused by the lack of full-time staff devoted to bioassay testing, while others were localized problems, such as lack of air-controlled growth facilities, the variability of distilled water supplies, and the closure of labs due to civil disruptions. Lack of proper facilities affected the seed and onion tests, which tended to sprout or rot during storage.

To standardize and calibrate these tests, the process has recently been repeated using fewer samples and bioassays. After the second round of

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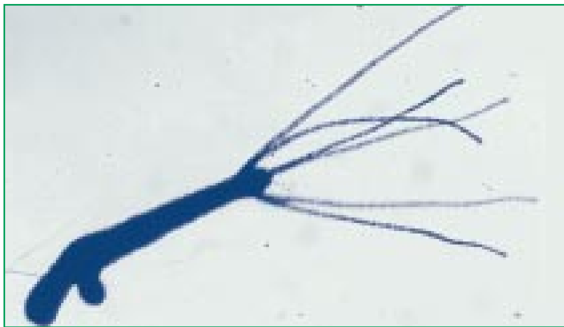
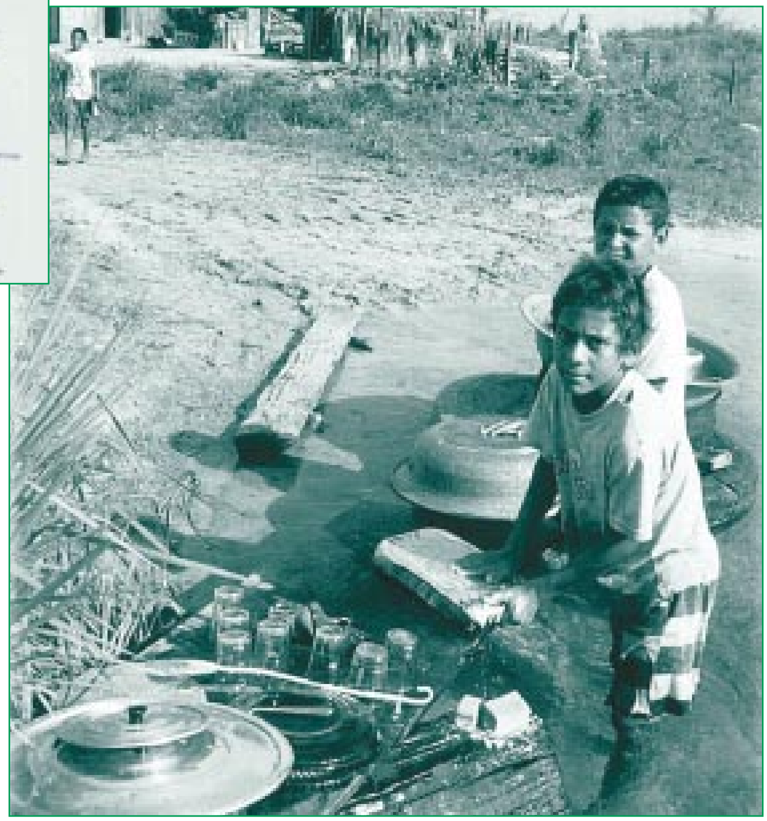


Normally shaped like a tiny tree trunk with tentacles, the hydra is a highly visible indicator of chemical contamination because it changes shape when it dies.



Boys washing dishes in a lake near their home. Contaminated water is the norm rather than the exception in developing countries.

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results has been collated this spring, the labs will begin analyzing natural environmental samples. In the meantime, university scientists in Bogota, Colombia, are working to develop simple methods for concentrating natural samples, so contaminants will be detectable within the parts-per-million range—the limit for most bioassays.

One of the results of this project will be to produce a resource manual for interested laboratories that documents testing protocols and quality control procedures, and interprets results for the core battery of bioassays. It is hoped that the institutions currently involved in WaterTox will eventually transfer their newly acquired technologies to other labs in their home countries.

IDRC recently applied some of the WaterTox technologies, along with simple bacteriological procedures, to its new AQUAtox 2000 program—which began in February of this year. Under the program, dozens of public and high schools in Canada and around the world are carrying out environmental tests for bacterial pollution and the presence of toxics. By providing people with the tools to measure water quality, these programs are raising international awareness of the hazards of contaminated water, and enabling citizens to make more informed decisions about their health. S&E

A L L A B O U T

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SCIENCE AND THE ENVIRONMENT BULLETIN

is a bi-monthly publication produced by Environment Canada to provide information on leading-edge environmental science and technology to Canadians.

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Media representatives and others interested in conducting further research may obtain the names and phone numbers of departmental scientists involved in these and related initiatives by contacting the *Bulletin*'s editor, Paul Hempel. He can be reached by e-mail at Paul.Hempel@ec.gc.ca and by telephone at (819) 994-7796. Readers are welcome to e-mail their comments and suggestions to this same address.

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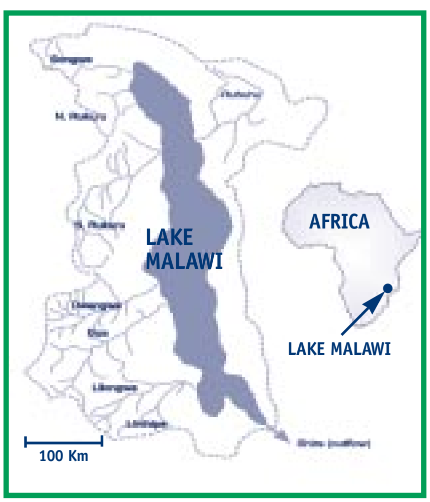
LAND USE PRESSURES THREATEN FISH BIODIVERSITY IN LAKE MALAWI

Lake Malawi, a deep lake in south-east Africa, is a critical resource not only to the people of Tanzania, Mozambique and Malawi—who rely on it for food, drinking water, irrigation and hydroelectricity—but also as one of the most biologically diverse ecosystems on the planet. It contains more species of fish than any other lake in the world, with 300 already identified and double that number estimated—more than in all of North America. The fact that most of these species are found nowhere else makes the lake a unique and irreplaceable scientific resource.

As the region around the lake becomes more developed, concerns over the impact of intensified agricultural and deforestation practices on critical fish habitats are growing. To assess the problem—and to encourage action before it is too late—scientists with Environment Canada's National Water Research Institute are working with colleagues from Fisheries and Oceans Canada, the United States and Africa to assess the lake's water quality and determine the threats to its sustainability. With funding from the Canadian International Development Agency and the World Bank, the research team is using its expertise in ecology, limnology, chemistry and other disciplines to evaluate the lake and provide recommendations for its sustainable management.



Lake Malawi and its many tributaries. The lake is located in the Great Western Rift Valley in south-east Africa.

The scientists have discovered that the subsistence agricultural practices of the increasing populations have accelerated soil erosion, water runoff and sediment transport, and caused a deterioration in the water quality of many rivers that feed into Lake Malawi. Eutrophication and excessive sedimentation caused by this phenomenon pose a serious threat to endemic fish species. The burning of biomass to clear lands and renew soil fertility has also increased the atmospheric deposition of nutrients to the lake—a condition that may favour the proliferation of blue-green algae, which are potentially toxic to humans, domestic animals and aquatic life. There is also evidence that concentrations of persistent organochlorines in the lake's fauna may be rising due to atmospheric deposition and the increasing land use of the drainage basin.

To maintain the biodiversity of Lake Malawi and support the economic needs of the people who live in the region, the scientists recommend that reduced population growth, sustainable economic development, productive agricultural practices and appropriate fisheries management be implemented as soon as possible. Although the Lake Malawi Biodiversity Project will be completed at the end of July, the people of Tanzania, Mozambique and Malawi will use these findings to develop a sustainable management plan for the conservation and protection of this unique and vital resource. **S&E**

WHY SO MANY SPECIES?

Lake Malawi is one of the oldest freshwater lakes in the world—the descendant of a body of water that has been continuously present in the Malawi rift valley for nearly a million years. Because they have had such a long time to evolve and diversify, virtually all of the hundreds of species in Lake Malawi are from the same "flock"—in that they have a common ancestor that arrived there long ago from an inflowing river. Only lakes Baikal and Tanganyika, which also have species flocks, are older. Although its great age partially explains Lake Malawi's rich biodiversity, the question of why there are so many species in a single lake continues to draw scientists from all over the world to this unique resource.