The 1999 Review of Acid Rain Science Programs in Canada

A report prepared to meet the requirements of *The Canada-Wide Acid Rain Strategy for Post-2000*

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About the Acid Rain Working Group

The Acid Rain Working Group was established by the National Air Issues Coordinating Committee* to ensure progress in implementing the Canada-Wide Acid Rain Strategy for Post-2000. The Working Group serves as a platform for sharing information among the federal, provincial, and territorial governments and for coordinating the work of developing new SO_2 reduction targets and schedules.

About the authors

The authors are members of the *ad hoc* scientific team established by the Acid Rain Working Group to conduct a review of acid rain science and monitoring in Canada, as required by the Canada-Wide Strategy. In their report, they refer to themselves as *the Review Team.* They are:

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Special thanks go to Giuseppe Muraca, who pulled together much of the information for this report and wrote significant parts of it, and to Dr. Tom Brydges for his support and very valuable advice. His deep and extensive knowledge of the issue made his input vital to the final product. We would also like to thank David Francis for editing the document.

Several parts of the report were borrowed from an earlier review by Environment Canada of its own acid rain science and monitoring program. We are particularly indebted to Dr. Dean Jeffries (National Water Research Institute) and to M. Robert Vet (Meteorological Service of Canada), who did most of that work.

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LIST OF SELECTED ACRONYMS

ELA	Experimental Lakes Area
APIOS	Acid Precipitation in Ontario Study
ARNEWS	Acid Rain National Early Warning System
CAPMoN	Canadian Air and Precipitation Monitoring Network
LRTAP	Long-Range Transboundary Air Pollution
NAMP	North American Maple Project
NAtChem	National Atmospheric Chemistry Database
NEG/ECP	New England Governors and Eastern Canadian Premiers
RAMP	Regional Aquatics Monitoring Program
RMCC	(Federal-Provincial) Research and Monitoring Coordinating Committee
TEEM	Terrrestrial Environmental Effects Monitoring
TEOM	Tapered Element Oscillating Microbalance
UN-ECE	United Nations Economic Commission for Europe

EXECUTIVE SUMMARY

When the Canada-Wide Acid Rain Strategy for Post-2000 was adopted in October 1998, it required the federal, provincial, and territorial governments to review the country's acid rain science and monitoring programs in order to ensure that we have "the capability to assess both the degree of environmental improvement achieved and the adequacy of the control programs." The present report, which presents the status of federal, provincial, and territorial acid rain science and monitoring programs, fulfills that commitment. The review on which this report is based was conducted in 1999. A summary of the review's findings was presented to Environment Ministers in November 1999 as part of the *1999 Annual Progress Report on the Canada-Wide Acid Rain Strategy for Post-2000.*

The review was carried out by a team of six federal and provincial scientists, comprising representatives from Environment Canada and the governments of Alberta, Ontario, Quebec, New Brunswick, and Nova Scotia. Stakeholders were invited to provide input into the review process at a consultation workshop in Montreal in June 1999. In addition, in-depth discussions among scientific experts were held in several regions of the country. In all, information was gathered from more than 40 experts in acid rain science from across the country, representing the federal and provincial governments, industry and the universities, and a variety of scientific disciplines.

Acid rain remains one of our major environmental problems. The most recent full scientific survey of the problem, the *1997 Canadian Acid Rain Assessment,* concluded that, in spite of our successes in reducing acidifying emissions of sulphur dioxide, our present control programs still do not go far enough to protect many sensitive ecosystems, especially in eastern Canada. To reduce the stress on these ecosystems, the Canada-Wide Acid Rain Strategy has called for the development of further controls on acidifying emissions. It has also set forth a commitment to "keep clean areas clean," in other words, to prevent problems from developing in areas that are presently not adversely affected by acidifying emissions.

In response to the main findings of the 1997 assessment and the objectives and commitments set forth in the Canada-Wide Acid Rain Strategy, the Review Team recommends that the primary purpose of acid rain science and monitoring in Canada should continue to be the verification of the effectiveness of emission control programs in reducing acid rain damage to lakes and forests. The Review Team further recommends that another full assessment of the acid rain problem in Canada be conducted by 2004. The 1997 assessment was based on data recorded up to the end of 1994. By 2004, however, information will be available to evaluate ecosystem responses to changes in emissions that took place between 1995 and 2000. This period is particularly important because it includes significant reductions in U.S. SO_2 emissions achieved under Phase 1 of the U.S. Clean Air Act Amendments. A 2004 report would provide a clearer picture of the impacts of emission reductions on the recovery of sensitive lakes in parts of eastern Canada. It would also provide better information for developing effective pollution control strategies based on critical loads and would improve our knowledge of important processes, particularly the role of nitrogen.

Science Needs

In assessing the impact of the significant reductions made in acid rain science programs in the second half of the 1990s, the Review Team examined whether the remaining scientific activities could provide an adequate basis for assessing future progress in resolving current acid rain problems. It also examined the capability of existing programs to detect new problems in areas that are exposed to acidifying emissions but have not as yet been adversely affected by them.

The Review Team concluded that, in order to measure the degree of improvement in environmental or public health conditions that have been achieved as a result of emission reductions, post-2000 acid rain science programs must continue to:

- monitor air and precipitation chemistry to determine the extent to which they respond to changing emissions, and
- monitor lake and river chemistry to determine the degree to which water quality is recovering.

In addition, the science program should address a number of important and unresolved science issues that were identified in the 1997 assessment. These relate to the failure of some ecosystems to recover when deposition levels are reduced, the loss of forest soil fertility, and the role of nitrogen in acidification. Specifically, the Review Team recommends that the post-2000 science program:

- evaluate the response of aquatic biota to deposition changes,
- assess the degree and geographical extent of losses of forest soil fertility and evaluate the further risk posed to Canadian forests, and
- assess the role of nitrogen in ecosystems, both as a nutrient and as an acidifying agent.

These scientific activities have particular importance for eastern Canada, where acid rain continues to cause serious damage to many ecosystems. The same activities, although carried out at a lower intensity, are also necessary to verify the effectiveness of pollution management measures in other regions where the priority is to "keep clean areas clean."

Monitoring Gaps

The Review Team found significant gaps in current monitoring programs. Several such gaps exist in the basic deposition networks for eastern Canada, where a substantial area receives twice as much sulphate as the local lakes and wetlands can absorb without suffering long-term damage. Surface waters in Nova Scotia, southern and central New Brunswick, southwestern Quebec, and the Parry Sound area of Ontario, in particular, are not properly monitored. A similar problem exists in northern Saskatchewan, where a number of sensitive lakes lie downwind of acidifying emissions from northern Alberta. Until these monitoring deficiencies are corrected, it will be impossible to assess whether controls are having the desired effect on valuable but sensitive environments, such as the salmon spawning rivers of southern Nova Scotia.

The Review Team is also concerned about the future of programs that monitor air and precipitation chemistry and map the deposition of acidifying pollutants. Experts predict that further reductions in the number of measurement sites could seriously jeopardize or even eliminate Canada's ability to produce reliable deposition maps. These maps not only show where the acid rain problem exists but also give an indication of multiyear trends. Although the measurement networks did not have sufficient density to provide data for the accurate mapping of deposition in northern Ontario, northern Quebec and Nova Scotia in 1996 (the last year for which maps were produced), some jurisdictions are nevertheless contemplating additional reductions to their networks. The Review Team has additional concerns about significant and growing delays in the production of these maps, which are published in a number of widely disseminated documents, including the biennial progress reports required by the Canada–U.S. Air Quality Agreement. In the next progress report, due in 2000, it will almost certainly be necessary to use a 1996 deposition map because more up-to-date data are not yet available.

Science Gaps

The Review Team found that current research programs are not adequate to address the major unresolved issues identified in the 1997 assessment, namely, the impacts of acid deposition on forest soils and forest health, nitrogen-based acidification, and the biological recovery of damaged ecosystems. Addressing these issues will require a substantial research commitment. We know that acid deposition increases the potential for soil nutrient deficiencies and other stresses on forest health and productivity, but a three-year effort will be required to assess and quantify the long-term risk to eastern Canadian forests. An equally substantial effort will be needed to estimate the threat posed to ecosystems by the continued deposition of nitrogen. Detailed investigations should be carried out at some of Canada's ecological research and monitoring sites to develop techniques that can later be used on a regional scale. The Review Team also recommends that biological recovery studies be carried out at the "Sudbury lakes," which are currently recovering from acidification and pollution with heavy metals. The ongoing recovery of these lakes has, in effect, provided scientists with a unique, large-scale "ecosystem manipulation experiment" from which they can gather a considerable amount of information that would otherwise be unavailable to them. Similarly, biological recovery studies should be carried out at the Experimental Lakes Area (ELA) in Ontario in order to complete ecosystem manipulation experiments there. Both studies will generate invaluable information for "managing" ecosystem recovery elsewhere.

The Review Team concluded that there are two major reasons why current science and monitoring programs cannot fulfill the requirements of the Canada-Wide Acid Rain Strategy for Post-2000. The first is that present science programs are not collecting enough data to support a full assessment of atmospheric and ecosystem responses to changes in emissions: key program elements are lacking or have been dismantled. The second is that not enough trained personnel are available to operate and coordinate the necessary monitoring programs and to analyze and assess the data collected. It will be necessary to address both of these deficiencies if we are to have sufficient capacity to conduct another full assessment in 2004.

In this report, the Review Team has identified key areas where science and monitoring efforts are needed to address the most significant gaps in our ability to verify that emission controls are working. More detailed work on options and costs as well as implementation plans will be done by the Review Team before the end of June 2000.

INTRODUCTION

In 1977, then Minister of the Environment Romeo LeBlanc reflected growing public concern about acid rain when he described it as "an environmental time bomb… the worst environmental problem Canada has ever had to face." Spurred by this concern, the federal government and several provincial governments launched a number of research and monitoring initiatives in the late 1970s and 1980s. Coordinated by the federal-provincial Research and Monitoring Coordinating Committee (RMCC), these initiatives began an ongoing process that has significantly expanded our scientific understanding of acidification and its effects.

Comprehensive assessments of acidification impacts and of the current scientific understanding of acidification processes have played an important part not only in furthering our understanding of acid rain but also in assisting the development of policies to combat it. The RMCC produced three such assessments, in 1983, 1986 and in 1990, and Environment Canada produced a fourth, in 1997, with help from several provinces. These assessments have given policy makers a sound factual basis for planning future controls on acidifying emissions and have also identified knowledge gaps and requirements for further research.

During the late 1980s and early 1990s Canada made remarkable progress in reducing acidifying emissions. However, as the *1997 Canadian Acid Rain Assessment* made clear, the problem of acid rain is still very much with us. Many sensitive ecosystems across Canada will remain vulnerable to acidification when present deposition targets are achieved. Further controls on emissions will therefore be necessary if these ecosystems are to be protected, and that, in turn, means that continuing scientific research and monitoring will be essential to determine the effectiveness of these controls.

The present report reviews the status of federal, provincial, and territorial science and monitoring programs. It was prepared to meet the requirements of the Canada-Wide Acid Rain Strategy for Post-2000, adopted at Halifax, Nova Scotia, in October 1998 by the federal, provincial, and territorial Energy and Environment Ministers. These requirements are outlined in Commitment 7 of the Strategy:

> *"With the goal of ensuring the capability to assess both the degree of environmental improvement achieved and the adequacy of the control programs, federal/provincial/territorial governments (each determining its own level of involvement) will review the adequacy of acid rain science and monitoring programs and report, with recommendations, to Energy and Environment Ministers in 1999."*

The review was carried out by a team of six federal and provincial scientists, comprising representatives from Environment Canada and the governments of Alberta, Ontario, Quebec, New Brunswick, and Nova Scotia. Stakeholders were invited to provide input into the review process at a consultation workshop in Montreal in June 1999. In addition, in-depth discussions among federal and provincial scientific experts were held in several regions of the country. In all, information was gathered from more than 40 experts in acid rain science in Canada, representing the federal and provincial governments, industry and the universities, and a variety of scientific disciplines, including meteorology, limnology, biology, forestry, and soil science.

The review identifies work that needs to be done in the next few years in the acid rain science and monitoring program in order to conduct the next assessment, scheduled tentatively for publication in 2004.

CHAPTER 1: OBJECTIVES OF THE ACID RAIN SCIENCE PROGRAM

Scientific understanding of acid rain has greatly improved during the past 20 years. Scientists now have a more accurate picture of the nature and extent of acidification in Canada as well as a better idea of what is needed to help ecosystems recover.

The objectives of acid rain science and monitoring programs have also evolved during this period. When the federal and provincial governments began to devise their acid rain strategy in the early 1980s, their objectives were primarily to describe and understand acid deposition and its effects in Canada so that adequate measures could be taken to protect Canadian ecosystems. Scientific research had identified the long range atmospheric transport of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) as the main cause of acid rain, and reasonably good empirical data available at the time suggested that a deposition target load of 20 kg of wet sulphate per hectare per year (kg/ha/yr) would provide adequate protection for moderately sensitive aquatic environments. Although the data provided strong justification for the Canadian position in the politically charged negotiations then taking place with the United States, ministers and the scientific community were nevertheless aware of the tentative nature of the target load derived from them. In particular, they realized that the potential for soils and bedrock to neutralize acid rain is highly variable, that very sensitive basins would not be protected, and that re-evaluation was to be expected as more information was obtained.

The *1990 Canadian Long-Range Transport of Air Pollutants and Acid Deposition Assessment Report* analyzed the effectiveness of Canadian and U.S. SO_2 control programs. It predicted major improvements in lake chemistry and biota for Ontario and Quebec but not much improvement in aquatic conditions in the very acid-sensitive areas of New Brunswick, Nova Scotia, and southern Newfoundland. The 1990 assessment also produced the first map of critical load values for wet sulphate deposition. The critical load is an estimate of the amount of deposition that a region can receive without significant damage to its ecosystems. For aquatic ecosystems, it is designed to maintain at least 95% of the lakes in a region at a pH of 6.0 or higher. Critical load values vary widely, from more than 20 kg/ha/yr in the more tolerant watersheds to less than 8 kg/ha/yr in the most sensitive.

As a result of the 1990 assessment, the primary objective of our acid rain science and monitoring programs changed, and the main priority shifted to assessing the effectiveness of emission controls. With this change, emphasis was placed on the monitoring of atmospheric and aquatic responses to changes in emissions and on addressing unresolved science issues, namely the causes of forest decline and identification of the human health effects of acid rain-related pollutants.

The *1997 Canadian Acid Rain Assessment* concluded that, in spite of their successes, our present control programs do not go far enough to protect many sensitive ecosystems, especially in eastern Canada. Even after full implementation of the U.S. acid rain program in 2010, many sensitive ecosystems in Canada will continue to receive acid deposition in excess of their critical loads. The assessment also points to the need for continuing the monitoring program, and it identifies a number of unresolved science issues that need to be addressed. These include understanding the reasons for the lack of recovery of some ecosystems, assessing the loss of soil fertility and the risk it poses for the health and productivity of Canadian forests, and assessing the ecological role of nitrogen both as a nutrient and as an acidifying agent.

Given the main findings of the 1997 assessment and the commitment in the Canada-Wide Acid Rain Strategy to "keep clean areas clean," the Review Team advises:

Recommendation No. 1

that the primary objective for acid rain science and monitoring in Canada should continue to be the verification of the effectiveness of emission control programs in reducing acid rain damage to lakes and forests.

Since concerns about acid deposition stem from its impact on the environment and public health, the science program must determine satisfactory ways of measuring improvements in environmental conditions and public health resulting from emission controls and must report the results on a regular basis to the Ministers and the public. The Review Team therefore advises:

Recommendation No. 2

that another full assessment of the acid rain problem in Canada be conducted by 2004.

Sufficient information should be available by that time to evaluate ecosystem responses to changes in emissions between 1995 and 2000. This period is critically important because it includes significant reductions in U.S. SO_2 emissions achieved under Phase 1 of the 1990 U.S. Clean Air Act Amendments.

Unfinished Business: The 1997 Findings

Before specifying the components that should be included in the post-2000 program, it is useful to review the main findings of the 1997 assessment. These have important implications for future research and monitoring.

(a) Air and precipitation monitoring

Air and precipitation measurements up to 1995 show that while the existing emission target for sulphur dioxide has been achieved and sulphate deposition has decreased, these reductions have not been matched by a similar reduction in precipitation acidity. This unexpected outcome is a consequence of a decline in air concentrations of acid-neutralizing bases, such as the salts of calcium and magnesium. This means that, while there is less sulphate in precipitation, it is not being neutralized to the same extent as it did in the 1970s. The reasons for the decline in concentrations of acid-neutralizing bases are not yet clear. Similar declines have also been observed for that period in parts of the United States and Europe.

(b) Lakes and rivers

Surface water quality, as expected, is improving gradually. Sulphate concentrations have declined in the majority of lakes, concurrent with modest reductions in lake acidity. Of 202 lakes that have been monitored in southeastern Canada since the early 1980s, 33% have recorded reduced acidity, 56% have shown no change, and 11% have become more acidic.

The most striking improvements have been seen in the Sudbury area, where damage to lakes had been particularly severe and where there were very substantial reductions in sulphur dioxide emissions from local smelters as well as reductions in the quantity of airborne sulphates arriving from outside the region. The least improvement has occurred in the Atlantic provinces, although acidification in this area had not been as severe as in some parts of Ontario and Quebec. A large area of eastern Canada continues to receive twice as much sulphate as the local lakes and wetlands can tolerate without suffering long-term damage.

(c) Aquatic biota

Outside of the Sudbury area, recovery of lake biota is yet to be observed in any substantive way. There is no evidence to date of recovery in Atlantic salmon or brook trout populations in severely affected Nova Scotia rivers. In fact, a 1997 survey of eight salmon rivers in southern Nova Scotia and New Brunswick indicates that they have continued to acidify.

(d) Forests

There is now documented evidence that nutrients, such as calcium and magnesium, that are essential for tree growth and health are being lost from soils exposed to acid deposition and that forest decline symptoms are related to nutrient deficiencies and imbalances. The 1997 assessment shows a clear correlation between tree mortality and exceedances of critical loads of sulphate and nitrate. There were also increases in forest decline symptoms in areas where critical loads were exceeded. Trees in nutrient-depleted areas initially show reduced growth, with more visible signs of damage, such as defoliation, appearing later.

Striking results were obtained from the liming of sugar maples at Forêt Duchesnay near Quebec City. Both the nutritional status of these trees and their growth rate improved very significantly when the missing calcium was restored to the soil. These results provide strong evidence that declines in forest productivity and health are being caused by the loss of soil nutrients as a result of acid rain and reductions in the amount of calcium deposited from the atmosphere.

(e) Materials

Pollutants such as sulphur dioxide, nitrogen oxides, and ozone greatly accelerate the corrosion of steel, zinc, aluminum, copper, bronze, stone, paint, electric contact materials, and other substances. Canada participates in an international science program that has produced quantitative estimates of corrosion rates for these materials. These estimates indicate that decreasing trends in the concentration of acidifying air pollutants have resulted in decreasing corrosion rates of exposed materials. Such information could be used to appraise some of the benefits resulting from emission controls.

(f) Human health

A growing body of evidence indicates that fine airborne particles composed of sulphates and other pollutants are a significant health hazard. Epidemiological studies have identified strong links between elevated concentrations of these particles and increased hospital admissions for heart and respiratory problems, as well as higher death rates from these ailments. Furthermore, there is a strong connection between the pollutants that cause acid rain and those that contribute to the formation of inhalable particulates.

(g) The impact of nitrogen

Nitrogen deposition is increasingly worrisome because it contributes to a number of problems in ecosystems, such as eutrophication (excess fertilization), changes in species composition, and acidification. Nitrogen has generally contributed much less to acidification damage than sulphates, mainly because much of it is taken up by plants and other organisms for which it is an essential nutrient. However, when more nitrogen is deposited to the soil than the plants and soil organisms can use, acidification takes place. A number of watersheds in eastern Canada are now demonstrating early signs of becoming nitrogen-saturated. This means that if nitrogen deposition continues at present levels, it will eventually erode the benefits gained from reductions in emissions of sulphur dioxide. Consequences for the longer term include re-acidification of ecosystems and accelerated loss of nutrients from forest soils.

There has been little change in emissions of nitrogen oxides over the past decade and consequently little change in nitrate deposition. A number of measures are anticipated or have already been put in place in various jurisdictions to help contain future growth in NO_x emissions. Although these measures have been designed primarily to improve air quality in regions such as the lower Fraser Valley in British Columbia and the Windsor–Quebec City corridor in Ontario and Quebec, they will have ancillary benefits for the acid rain problem.

Implications for Acid Rain Science and Monitoring

The 1997 assessment makes it clear that acid rain is a stubborn problem, particularly in eastern Canada. The assessment also reveals some important gaps in our understanding of how ecosystems respond to changes in acidification. In particular, it noted some important surprises, when ecosystems responded differently than expected. Researchers were able to detect these unexpected responses because of the long and continuous supply of good data available to them from the networks of air, water, and terrestrial monitoring stations established by the federal and provincial governments in the 1970s and 1980s. These data are also helping them understand why these responses occurred and are giving them further insight into how ecosystems work and how they are likely to respond in the future. This experience confirms, in the opinion of the Review Team, the importance of continuing to monitor atmospheric and ecosystem responses to changes in emissions and deposition.

To be effective, monitoring programs must be designed for the long term – at least 15 to 20 years. That is because biological responses to changes in acidification occur much more slowly than changes in air or water chemistry. Moreover, the causes of biological responses are often difficult to establish because of numerous additional factors, such as climatic variations. In the case of forests, for example, one of the most important effects of acid deposition, the alteration of soil chemistry, is chronic and has taken several decades to manifest measurable effects.

Although a sound air pollution management program should address both human health and ecosystem effects, the Review Team decided not to evaluate the scientific programs related to human health. That is because acidifying emissions also contribute to urban smog, and thus both pollutants give rise to the same health effects. Since other groups, in Canada and elsewhere, are making recommendations to address current science gaps in this area, there is no need for further, independent investigation under the acid rain program.

The Review Team therefore advises:

Recommendation 3

that in order to fulfill the objectives of the Strategy, the post-2000 acid rain science and monitoring program should:

- **monitor air and precipitation chemistry, and changes in response to changing emissions,**
- **monitor lake and river chemistry, to determine the degree of recovery,**
- **evaluate the response of aquatic biota to deposition changes,**

- **assess the extent and degree of the loss of forest soil fertility, and evaluate the further risk posed to Canadian forests, and**
- **assess the role of nitrogen as a nutrient and as an acidifying agent.**

These activities are particularly important in eastern Canada, where acid rain continues to be a problem. The same activities, carried out at a lower intensity, are also required in areas where acid rain is not a problem in order to verify the effectiveness of pollution management measures designed to "keep clean areas clean."

The Review Team noted that the effects of air pollution on materials have not been considered specifically in the formulation of the Canada-Wide Acid Rain Strategy for Post-2000. In view of the modest cost of the program and the potential importance of the results to urban air quality issues, the Review Team advises:

Recommendation 4

that the science program on the effects of air pollution on materials be maintained by continuing participation in the United Nations Economic Commission for Europe (UN-ECE) program.

CHAPTER 2: STATUS OF FEDERAL, PROVINCIAL, AND TERRITORIAL ACID RAIN SCIENCE AND MONITORING PRORAMS

Since the emergence of acid rain as a major environmental issue in the 1970s, a number of federal, provincial, and territorial programs have been involved in research and monitoring activities. In the 1980s, these programs were formally coordinated by the RMCC, which had representatives from the ten provinces and various federal departments. This committee was abolished in the early 1990s. Since then, the Meteorological Service of Canada (formerly the Atmospheric Environment Service) has been the main coordinating agency for the federal government.

Federal Programs

The following federal departments are currently inolved in or were recently involved in acid rain science and monitoring.

a) Environment Canada

Environment Canada has the lead role in atmospheric and aquatic research and monitoring. It is responsible for the following activities:

- coordinating the federal acid rain research and monitoring program;
- coordinating joint projects with the provinces and the United States;
- reporting on the response of the environment to changing acid deposition levels;
- monitoring atmospheric deposition of major ions;
- modelling proposed reductions to determine how they affect deposition;
- determining acceptable deposition loading levels;
- verifying the rate and extent of lake and river recovery in response to decreasing atmospheric deposition;
- providing scientific advice to policy makers (e.g., during international acid rain negotiations).

Between 1981 and 1997, Environment Canada also provided interlaboratory quality assurance and control for all participants (federal, provincial, territorial, academic, and private sector) in the Canadian acid rain program.

b) Department of Fisheries and Oceans (DFO)

DFO initiated a program in 1980 to monitor the biological effects of acidification in aquatic systems. It also has been involved in assessing risks under different deposition scenarios, detailing the thresholds of damage within aquatic systems, and evaluating the prospects of system recovery in response to emission reductions. At the present time, however, DFO is not involved in any acid rain–related activities.

c) Canadian Forest Service (CFS)

In 1984, CFS established the Acid Rain National Early Warning System (ARNEWS), a national network of monitored forest plots, to detect early signs of damage to Canadian forests and to monitor changes in forest vegetation and soils, whether caused by natural factors such as insects, diseases, and weather or by human-related factors such as management practices or air pollution. Another survey, the North American Maple Project (NAMP), was established in the late 1980s in collaboration with the United States Forest Service to document changes in the condition of sugar maples in eastern Canada and the northeastern United States and determine possible causes of decline.

The service has also been conducting an intensive study of white birches in the Bay of Fundy region from the mid-1980s to the present to investigate links between the deteriorating condition of the trees and acid deposition by fog.

d) Health Canada

The department's program for investigating the health effects of atmospheric pollutants includes animal toxicology research, human clinical studies, population studies, and specialized monitoring studies. The program has provided valuable information to the scientific and regulatory communities and has helped to identify significant associations between the substances responsible for acid deposition and adverse health effects.

Provincial Programs

Federal programs are complemented by a number of provincial and territorial initiatives. The combined federal, provincial, and territorial efforts are summarized in the following tables.

The following information was available to the Review Team during the preparation of this report:

ONTARIO

ACTIVITY	FEDERAL	PROVINCIAL
AIR & PRECIPITATION	EC operates 7 Canadian Air and Precipitation Monitoring Network (CAPMoN) stations in Ontario, which include: • Precipitation sites at Bonner Lake and Warsaw Caves • Air and precipitation site at Longwoods • Ozone, air, and precipitation sites at ELA., Algoma, Chalk River, and Egbert	OME operates acid precipitation monitoring stations in Ontario – the Acidic Precipitation in Ontario Study (APIOS) Network – to determine the concentrations and the levels of wet and dry deposition of acids, sulphates, nitrates, and trace metals in the province. OME currently operates 17 sites – 14 of which are regionally representative and 3 Sudbury-representatives. Of the 14 regional sites, 13 take air and precipitation measurements on a 28-day basis and 1 on a daily basis. OME will likely cease operating most of its APIOS stations in April 2000.
AQUATIC CHEMISTRY	EC monitors water chemistry and stream export year-round at the Turkey Lakes Watershed site north of Sault Ste Marie, Ontario. Four lakes are sampled bi-weekly (monthly in winter) and 6 streams are sampled weekly (more frequently during spring runoff). NWRI also monitors meteorology, solar radiation, UV-B, and snowpack chemistry. NRCan, DFO, Canadian Wildlife Service (CWS - Ontario Region), Ontario Ministry of Natural Resources, 4 universities, and 4 industrial partners were all active at this site in 1997. Air toxics, climate change, mercury (minor), and UV-B (minor) are also studied at Turkey Lakes.	An OME/Trent University partnership monitors water chemistry of 28 lakes in south-central Ontario (the District of Muskoka, Haliburton County, Parry Sound County) in the ice-free season. Eight lakes (the core set of study lakes) are monitored monthly while 20 additional lakes are sampled 2 to 4 times per ice-free season. Seventeen inflowing streams and 8 outflows of the core lakes are monitored continuously for hydrology and sampled at least bi-weekly, often much more frequently, for chemistry. The chemistry and hydrology measurements are used to generate lake and catchment mass balances. Atmospheric deposition is measured at 4 sites in the study area. A range of meteorological, hydrologic, physical, and chemical parameters is measured routinely. In addition to acid rain–related work, studies of climate effects, nutrient cycling, and mercury are carried out and extensive modelling is conducted. There are many collaborators from close to a dozen universities involved in the studies, and a number of other agencies/institutes from other countries participate. A partnership between OME, OMNR, Laurentian University, Inco Ltd., Falconbridge Ltd., and EC monitors water chemistry in a number of lakes in northeastern Ontario, within about 100 km of Sudbury. Forty-three lakes are sampled once annually and an additional 10 lakes are sampled monthly during the ice-free season. Some of these lakes are located in Killarney Provincial Park, a national Ecological Monitoring and Assessment Network (EMAN) monitoring site. Major

		objectives of this monitoring program are the evaluation of lake recovery from acidification and the investigation of the influences of multiple stresses on aquatic ecosystems. The effect of climate change on the recovery of acidified lakes is of particular current interest. The monitoring program addresses both the effects of regional sulphur emissions from the Sudbury smelters and the effects of long-range acid transport. Various collaborators from Canadian and international institutions and agencies are involved in these studies.
AQUATIC BIOTA	Ontario region monitors and models the chemical and biological effects of acid rain on three clusters of small lakes and wetlands. From the outset, the Ontario wildlife program has taken an integrated, whole-ecosystem approach, collecting and analyzing data on water chemistry, watershed characteristics, and the structure and biodiversity of aquatic food chains. Developing from earlier research activities, the Canadian Wildlife Service Long-Range Transboundary Air Pollution (LRTAP) Biomonitoring Program was established in 1987. With the discontinuation of the DFO Biomonitoring Program, this program is now the only extensive monitoring program undertaken in eastern Canada to assess progress in reducing biological effects following the implementation of Canadian and U.S. emission controls.	The biota of the 8 core lakes identified above are monitored on a regular basis by OME/Trent U./York U. Phytoplankton samples are composited to provide ice-free average biomass and species composition. Zooplankton samples are collected monthly, while benthic invertebrates are sampled in the littoral zone each fall. In addition, the inflows (17) of the core lakes are monitored annually for benthic invertebrates, using a rapid bioassessment procedure. Benthic invertebrates are also monitored annually on a subset of the 20 additional lakes described above, and periodically surveys of larger numbers of lakes are conducted for benthos and zoo-plankton. Collaborators from a large number of universities and institutes participate in these studies. The ten most frequently sampled Sudbury-area lakes are routinely sampled for zoo-plankton and phytoplankton. The 43 annual monitoring lakes are sampled for zoo-plankton at 5-10 year intervals. Periodic surveys of fish communities and benthic invertebrates are conducted on some selected lakes. Some of these lakes are also sites for paleolimnological investigations of diatom and chrysophyte histories used to infer long-term chemistry patterns related to acidification and climate change.
FORESTS		In 1985, the Ontario Ministry of the Environment and Energy initiated a forest health survey of the tolerant hardwood forests in Ontario. The objective is to provide a province-wide database on the visual condition of the predominantly sugar maple forest. By periodically re-evaluating the same trees and comparing the results with earlier data, the intent is to identify trends in changing tree conditions and allow comparisons between geographic areas across the province. The survey is based on plots containing over 14,000 trees across the range of the sugar maple. The visual symptoms of decline are pale green or yellowed foliage, small leaves, and dieback of the fine twig structure followed by the death of main branches.

QUEBEC

ACTIVITY	FEDERAL	PROVINCIAL
AIR & PRECIPITATION	EC operates 3 CAPMoN sites in Quebec, including: • air and precipitation sites at Chapais and Sutton • precipitation site at Mingan Another site, near Lac Edouard, will soon become operational. This site replaces the Montmorency site. EC also operates 2 $PM_{2.5}$ sites (Saint Anicet, L'Assomption) and 2 ozone sites (Saint Anicet, Ste Françoise)	The Quebec Ministry of the Environment uses various sampling networks to monitor air and precipitation quality. The precipitation sampling network (REPQ) is made of 35 sampling sites located in the more densely populated areas of southern Quebec. Weekly samples of wet deposition (rain and snow) are gathered from automated collectors. The following parameters are analyzed and expressed as both concentrations and loadings: pH, acidity (H), alkalinity (HCO_3), SO_4, NO_3, NH_4, Cl, Ca, Mg, Na, K. The Air Quality Monitoring Network is made of 77 sampling stations where measurements of gaseous pollutants and fine particulates are conducted. The number of pollutants measured and the instrumentation vary greatly among sites (some sites monitor only one pollutant, while others sample as many as 12).
AQUATIC CHEMISTRY	EC traditionally monitored surface waters at a network of lakes and at the calibrated basin of Lac Laflamme. The primary purpose of the network is to provide information on long-term (i.e., multi-year) regional acidification trends. In 1994, the number of monitored lakes was decreased from 64 to 43, and the sampling frequency has been reduced. The last assessment of the data was done in 1997. EC monitored water chemistry and stream export at Lac Laflamme, North of Quebec City, until early 1999. Samples were taken every 2 weeks year-round – weekly during spring runoff.	The Quebec Ministry of the Environment has conducted the Quebec Lake Survey (RESSALQ network) during the 1986 to 1990 period. This statistical survey was conducted on 1253 remote sensitive lakes (> 10 hectares) on the Canadian Shield in southern Quebec (south of 51N). Winter samples were gathered in March. A second sampling phase is still planned sometime in the future for the 3 most affected areas (southwestern Quebec). The Ministry is also conducting the Noranda Project, which consists of a 75-lake network surrounding Rouyn-Noranda. The lake sampling is conducted every 5 years. Previous surveys were made in 1982, 1991, and 1996. Other small networks are in use to assess episodic acidification in trout lakes and to address the transfer of adapted acidophylous brook trout stocks from the North Coast into recently acidified Portneuf lakes.
AQUATIC BIOTA		The only ongoing project on biota deals with transfer of adapted acidophylous brook trout stocks from the North Coast into recently acidified Portneuf lakes. Experiments are conducted at 3 lakes and 2 river outlets.
FORESTS		The Réseau de surveillance des écosystèmes forestiers (RESEF) Network for the monitoring of forest ecosystems was established in 1988 to collect information on climate, nutrient status of ecosystems, precipitation, and air quality. Linkages exist with other networks operated by the Departments of Agriculture and Environment

		and Wildlife of Quebec, and the CAPMoN of Environment Canada. A total of 30 sites exist, covering various ecological regions of Quebec. The network compiles data on the effects of natural and anthropogenic stresses on forest ecosystems, particularly on their biological diversity and growth. Analyses of data have not yet been published. Intensive monitoring is carried out at 3 calibrated watersheds, each being representative of large forested zones of Quebec.

NOVA SCOTIA

ACTIVITY	FEDERAL	PROVINCIAL
AIR & PRECIPITATION	EC operates two CAPMoN sites, including: • a precipitation site in Jackson • an ozone, air, and precipitation site in Kejimkujik	Nova Scotia operates one precipitation monitoring station at Sherbrooke, which is a cooperative site with Environment Canada. Another precipitation site is being set up as part of the Pockwock Watershed Project, a forestry-based ecosystem research study. The province also operates an ambient air network in urban and industrialized areas, although not solely for acidification assessment. These sites measure SO_x, NO_x, ground-level ozone, and fine particulate on a continuous basis. As well, SO_x monitors are operated by industry near major point sources.
AQUATIC CHEMISTRY	EC monitors 3 streams weekly (year-round) and 2 lakes weekly (spring and summer) at the Kejimkujik EMAN site in south-central Nova Scotia. Parks Canada (PC) and the University of New Brunswick (Forestry) are significant partners. Mercury, climate change, and UV-B (and their interaction with acidity) are also studied at Kejimkujik. EC conducts surface water monitoring at middle levels of the monitoring hierarchy in Nova Scotia. All stations are lakes, and many of them are remote, requiring helicopter access. EC also monitors lakes in Cape Breton and another set in south-central Nova Scotia twice yearly. Monitoring of 12 of the Nova Scotia lakes is accomplished in partnership with Parks Canada, which collects the samples. (EC analyzes the samples and resulting data.) Without this partnership, fewer lakes would be included.	Nova Scotia is carrying out a lake study as part of the Pockwock Watershed Project. Water quality parameters necessary to assess changes related to acidification, eutrophication, and siltation are being measured on a monthly basis at 4 lake and 2 pond locations within the watershed.
AQUATIC BIOTA	In 1978, EC initiated monitoring of 3 lake systems in Kejimkujik National Park, Nova Scotia, to characterize the water quality and biological populations typical of the park and surrounding area. The work was able to relate low fish production to the low reproductive success of water birds, especially loons. Since	

	1988, the Canadian Wildlife Service has monitored the reproductive success of common loons and other waterfowl on Kejimkujik's 25 lakes.	
FORESTS		The Pockwock Watershed Project is investigating the impact of acid precipitation on forest productivity, forest soils, and soil nutrient changes within a managed forest landscape.

NEW BRUNSWICK

ACTIVITY	FEDERAL	PROVINCIAL
AIR & PRECIPITATION	EC operates one CAPMoN precipitation site, situated at Harcourt.	There is no ambient air monitoring in New Brunswick specifically for the purpose of acidification assessment. There are several networks measuring sulphur dioxide and nitrogen oxides, but these are either urban or located around major point sources of SO_2. New Brunswick operates a comprehensive acid rain network, in cooperation with NB Power. This consists of 13 precipitation samplers located around the province. All laboratory analysis and data analysis is handled by the NBDOE. Fine particulate monitoring was initiated in 1996 with the installation of two continuous Tapered Element Oscillating Microbalance (TEOM) samplers in the city of Saint John. These units were sited in an eastern suburb which is affected by local emissions. Subsequently, one rural, regionally representative $PM_{2.5}$ site was equipped with a TEOM sampler (St. Andrews) in 1998. This site is especially useful for characterizing transboundary flows. In 1999, an additional $PM_{2.5}$ TEOM began operation in Fredericton, sited to be representative of the city suburbs and middle Saint John River valley. Extra sites in Moncton and Bathurst are expected to come on-line during 1999. Collectively, these sites will provide assessment information which will contribute to the understanding of fine particulate levels across the province. The data will have applicability in health studies as well as studies dealing with smog transport and chemistry.
AQUATIC CHEMISTRY		A set of 95 acid-sensitive headwater lakes in areas remote from direct human impacts was designated in the early 1980s in the southwest and central areas of New Brunswick to be used for the investigation of long-term acidification effects. These lakes, located on poorly buffered bedrock, are sampled every 3-5 years and analyzed for major inorganic ions. Samples were most recently collected in 1998 and 1995.
AQUATIC BIOTA	In 1986 and 1987, the influence of wetland acidity on waterfowl use was studied in 173 wetlands in southwestern New Brunswick. Wetland water chemistry and the diversity and abundance of various aquatic biota (including common loons) were monitored. Since 1995, common loon	Approximately 50 locations per year have been sampled for benthic invertebrates over the past 5 years across New Brunswick as part of the NBDOE's routine surface water monitoring programs. These samples are taken to characterize environmental quality in specific watersheds and in support of establishing and applying biodiversity indices for use in the classification of provincial waters. The number

	monitoring has been renewed on 25 of the lakes in southwestern New Brunswick. While originally driven by acidification concerns alone, this monitoring has been integrated with a larger effort to define the combined effects of acidity and mercury on common loon reproduction, breeding behaviour, and health. It is becoming clear that the effects of acidification and mercury are associated in Maritime lakes.	of sites will rise to about 100 during 1999. This information has potential use in the assessment of acidification effects.
FORESTS		Since the mid-1980s Forestry Canada and UNB researchers have been carrying out detailed investigations of the effects of acid deposition on forests along the Bay of Fundy, where paper and mountain paper birches were observed to be in decline in the late 1970s and early 1980s. The NBDOE has cooperated in this work and collaborated on a number of publications.

NEWFOUNDLAND

ACTIVITY	FEDERAL	PROVINCIAL
AIR & PRECIPITATION	EC operates two CAPMoN sites, including: • a precipitation site in Bay D'Espoir • a precipitation site in Goose Bay, Labrador	Newfoundland operates 5 precipitation monitoring sites (Burgeo, Lochleven, Terra Nova, Cormack, Wooddale) and a cooperative site with Memorial University at Salmonier.
AQUATIC CHEMISTRY	EC conducts surface water monitoring at middle levels of the monitoring hierarchy in Newfoundland. The stations are lakes, and many of them are remote, requiring helicopter access. As of September 1997, the Atlantic Region was monitoring 12 lakes in Newfoundland. All are sampled twice per year. Monitoring of all the Newfoundland lakes is accomplished in partnership with PC, which collects the samples. (EC analyzes the samples and resulting data.) Without this partnership, fewer lakes would be included. Monitoring of 21 Newfoundland lakes was discontinued in 1999.	

ALBERTA

ACTIVITY	FEDERAL	PROVINCIAL
AIR & PRECIPITATION	EC operates a CAPMoN ozone, air, and precipitation site, located at Esther.	Ambient air quality and deposition monitoring data are submitted to a provincial data warehouse, developed under the direction of a multistakeholder committee of the Clean Air Strategic Alliance and currently managed by Alberta Environment (AENV). Data from the CAPMoN site at Esther are also submitted to the data warehouse by EC. AENV operates a network of ambient air quality monitors (mainly in Calgary and Edmonton). The data are archived in the data warehouse and are also reported to the National Atmospheric Chemistry Database (NAtChem). AENV also operates a network of 10 precipitation quality (wet deposition) monitors; the data from this network are also submitted to the data warehouse and provided to NAtChem. The Wood Buffalo Environmental Association (headquartered in Fort McMurray, AB) operates a network of 8 air monitoring sites, including 3 intensive sites at which deposition data are collected. Data are reported annually to stakeholders and AENV. The West Central Airshed Society (headquartered in Drayton Valley, AB) operates a network of sites which include active and passive monitoring for acidifying substances. Data are reported annually to stakeholders and submitted to the data warehouse. Many industries operate monitors for acidifying substances in air as part of their compliance monitoring programs. Data are reported annually to AENV. AENV is testing the Regional Air Pollutant Inventory System to determine if it is suitable for storing and retrieving air emission inventory data, including data about acidifying substances.
AQUATIC CHEMISTRY		AENV maintains a database of alkalinity, pH, calcium, and total dissolved solids for lakes province-wide in order to create provincial maps of surface water sensitivity to acidic deposition. Over 1100 lakes have been measured, most of which are not acid sensitive. In 1998, Alberta-Pacific Forest Industries Inc. (AlPac) and AENV sampled 165 lakes in northeastern Alberta, 139 of which had not been sampled previously. This information is being added to the lake sensitivity database These data, and those collected in future surveys, will be used

		to update provincial maps of aquatic sensitivity. Three tributaries of the Athabasca River (the Muskeg, Steepbank, and Firebag rivers) have been examined for the occurrence of a transient spring pH depression. To date, data have been collected for the spring melt periods of 1989, 1990, 1996, 1998, and 1999. A program designed to monitor the long-term effects of acidifying emissions from regional industries on acid-sensitive lakes in northeastern Alberta will be initiated in 1999 by the multi-stakeholder Regional Aquatics Monitoring Program (RAMP). AENV and AlPac are members of the committee. Thirty lakes, most of which have alkalinities less than 15 mg/L $CaCO_3$, have been selected along a gradient of predicted potential acidifying input radiating from the oil sands development area north of Fort McMurray. The lakes have been divided into two groups on the basis of dissolved organic carbon content to ensure that both organically buffered and mineral-buffered lakes are well represented. It is proposed that these lakes be sampled initially on a yearly basis, and following the period of annual sampling, every three years.
FOREST, VEGETATION AND SOIL		AENV operates a network of seven soil monitoring sites for detection of soil chemistry effects due to acid deposition. Sites were established between 1981 and 1984. During the establishment of the sites, soil samples were obtained and analyzed. Each site has been sampled on a 4- to 6-year cycle. The program is expected to continue, with sampling occurring on a 6- to 10- year cycle beginning in 1999 or 2000. The Wood Buffalo Environmental Association operates a Terrestrial Environmental Effects Monitoring (TEEM) program for the detection of acid deposition effects in jack pine and aspen forests. There are currently 21 sites in the program (10 jack pine, 11 aspen). Each site is visited annually for basic observation (tree condition), and every 5 years for intensive monitoring. The intensive monitoring includes soil and vegetation sampling and analysis, and measurements of tree condition and growth. Sites were established in 1997 and 1998, with the first intensive monitoring of jack pine sites occurring in 1998. Intensive monitoring of aspen sites will occur in the summer of 1999. The TEEM program also includes an evaluation of the effects of air emissions on resources harvested and used in traditional Aboriginal communities (to be initiated in 1999) and an evaluation of heavy metal content in plant and

		animal tissues (to be initiated in 2000). While neither program has been developed to directly address acid deposition issues, both programs will provide supporting data for the forest monitoring program described above.
HEALTH		The Athabasca Oil Sands Community Exposure and Health Effects Assessment Program deployed and retrieved personal passive sampling devices ("badges") every 24 hours for four consecutive months. The devices were carried by 300 participants, and participants were rolled in and out of the program over the course of 16 months. The program also included data collection on PM. Participants wore an active pump continuously for each of the four 24-hour exposure periods of their participation. Each of the participants involved in the measurement of PM also wore the personal passive samplers. The data collected included both PM_{10} and $PM_{2.5}$ data. The analysis included some metals speciation. Using the passive and active samplers, data on individual exposure of 300 participants in the city of Fort McMurray to NO_2, O_3, SO_2, VOCs, PM_{10}, and $PM_{2.5}$ were collected.

MANITOBA:

- A CAPMoN-like precipitation site was operated near Island Lake by Manitoba Environment with contributions by INCO and EC until 1998.

BRITISH COLUMBIA:

- EC operates a CAPMoN ozone, air, and precipitation site in Saturna.

PRINCE EDWARD ISLAND

- PEI operates one precipitation monitoring site at Cardigan, for which EC (regional lab in Moncton) provides lab analyses.

SASKATCHEWAN

- Saskatchewan Environment and Resource Management is developing a program to monitor lakes between 56°N and 58°N for acid deposition.

YUKON, NORTHWEST TERRITORIES, and NUNAVUT

- Northwest Territories' Environmental Protection Service, in partnership with EC, operates a CAPMoN precipitation site situated at Snare Rapids (N.W.T.).

The Components of Canada's Acid Rain Science and Monitoring Program

For the purposes of this report, "monitoring" is taken to mean the ongoing, long-term measurement of acid-related variables, and a "monitoring program" is considered to include all the elements necessary for the collection, quality control, and dissemination of this information.

Scientific research has been integrated with monitoring to answer specific questions. Research activities have included:

- devising methods for estimating dry deposition amounts
- evaluating the process, extent, and reversibility of chemical and biological recovery
- modelling acidification effects
- assessing the role of nitrogen-based pollutants in aquatic acidification
- determining the effects of acid rain on tree physiology
- determining effects on soil chemistry, and
- using models to estimate critical loads.

Canada's acid rain science and monitoring program depends on five key elements:

- The Canadian Air and Precipitation Monitoring Network (CAPMoN)
- Provincial deposition monitoring networks
- The National Atmospheric Chemistry Database (NAtChem)
- Surface water monitoring
- Aquatic biota monitoring.

These components of the program have been and continue to be the backbone of acid rain science and monitoring in Canada. They provide data which, combined with information from other sources, allow scientists to assess whether acid rain control programs are effective in protecting aquatic ecosystems. It is from these data that we know that current emission control programs are insufficient to protect sensitive aquatic ecosystems in eastern Canada and that further reductions of SO_2 and NO_x emissions are required. Similar data, supplemented by information gleaned from models, are also being used to devise air pollution management programs in parts of western Canada, where emissions of acidifying pollutants are significant but where ecosystems are relatively well buffered against acidification. Other science and monitoring components (e.g., the forest health component) provide a basis for more comprehensive assessment reports.

a) The Canadian Air and Precipitation Monitoring Network

The Canadian Air and Precipitation Monitoring Network (CAPMoN) is Environment Canada's national daily network for monitoring regional-scale air and precipitation quality. CAPMoN is intended to provide data for:

- the determination of spatial patterns and temporal trends in atmospheric pollutants related to acid rain and smog,
- the evaluation of long-range transport models,
- aquatic and terrestrial effects research, and
- assurance of compatibility with provincial and U.S. measurements.

Both precipitation and air quality are measured, although the latter is measured at fewer sites. The measurement of air quality makes it possible to assess whether emission changes are producing desired changes in the atmospheric burden of pollutants. Air quality measurements are also used to estimate the magnitude of the dry component as a percentage (believed to be somewhere between 20% and 50%) of the total deposition.

CAPMoN started taking measurements in the late 1970s. CAPMoN sites were chosen in non-urban areas to avoid any local pollution sources and to minimize local influences on precipitation quality and quantity, thus providing regionally representative results. Scientists involved with the measurement of atmospheric pollution in urban centres would consider most CAPMoN sites to be remote and pristine. At all CAPMoN sites, precipitation is collected as a 24-hour integrated sample. The chemical components measured are pH, sulphate, nitrate, chloride, ammonium, sodium, calcium, magnesium, and potassium.

CAPMoN collects 24-hour integrated air filter measurements at a subset of 10 sites, although as many as 16 sites were once engaged in this activity. These sites provide data on particulate sulphate, nitrate, chloride, ammonium, sodium, calcium, magnesium, and potassium, as well as vapour phase nitric acid and SO_2. Hourly averages of tropospheric (ground-level) ozone measurements are made at 6 sites. Conducting measurements of several chemicals at one location has two important benefits: it reduces operating costs, and it allows scientists to study the interaction between different pollutants.

There have been as many as 43 CAPMoN sites, but no more than 26 have operated simultaneously. Presently, there are 18 sites. When CAPMoN was originally established in the mid-1980s, the exceedingly sparse coverage provided by its sites was deemed acceptable, since many provinces also operated deposition networks and their data could be combined (see NAtChem description below). Many CAPMoN sites were in fact situated to fill in holes in provincial networks. The policy of relying on combined federal/provincial deposition monitoring now seems to be flawed, as some provincial networks are being or have been drastically reduced or eliminated.

CAPMoN activities encompass all field, laboratory, and administrative operations associated with the collection of air and precipitation samples, their chemical analysis, and the delivery of data to NAtChem. These include, but are not limited to, the purchase and maintenance of sampling equipment, the operation and maintenance of sampling sites (often in partnership with other governments or organizations), field personnel contracts and training, sample transport, chemical analyses, quality assurance and quality control (QA/QC), data management, and data analysis.

Many partnerships have been formed with outside agencies to facilitate CAPMoN site operations. Such partnership arrangements range from rent-free use of property to the provinces paying all field expenses. Seventy percent of all site operators are under contract to Environment Canada. In addition, two "CAPMoN-like" sites, operated by partners, measure precipitation quality: these are Sherbrooke in Nova Scotia, operated by Nova Scotia Environment, and Snare Rapids in the Northwest Territories, operated by the territorial government. A third such site, Island Lake in Manitoba, was operated until recently by Manitoba Environment and INCO. The site closed in January 1998, however, after Manitoba Environment withdrew its support.

b) The National Atmospheric Chemistry Database

CAPMoN data are stored along with precipitation chemistry data from other federal, provincial, and U.S. networks, in the National Atmospheric Chemistry Database and Analysis Facility (NAtChem). It is the only comprehensive, multinetwork database for precipitation chemistry in North America. It is currently being expanded to include atmospheric particle and toxic chemical data.

The NAtChem facility is maintained by Environment Canada. It archives data from CAPMoN and 13 other provincial and U.S. monitoring networks (146 precipitation monitoring sites operated in Canada in 1999). It also performs quality assurance and quality control functions and provides retrievals, annual reports, and data analyses. The main purpose of NAtChem is to provide regional-scale analysis of precipitation chemistry in order to improve scientific understanding of the long-range transport of air pollutants. NAtChem, for example, provided the spatial distribution maps of wet deposition and associated analyses used in the 1997 assessment. Such maps provide a qualitative indication of the progress being achieved through control programs. NAtChem is able to produce such analyses effectively because it can merge data from all available sources. Except in a few cases, this kind of work could not be done with CAPMoN data alone.

c) Surface water monitoring

Surface water monitoring has been conducted in southeastern Canada by Environment Canada, the Department of Fisheries and Oceans, and the Canadian Forestry Service. Several provincial environment ministries also monitor surface waters, with the Ontario, Quebec, and New Brunswick ministries being the most active. Environment Canada's surface water monitoring activities were established in the early 1980s to augment existing provincial programs.

The federal-provincial network originally conformed to a widely accepted conceptual framework that included monitoring, modelling, and assessment. The framework was formulated in Canada with the purpose of facilitating policy development (e.g., for establishing emission controls). The monitoring structure was concisely described in an assessment of the Integrated Monitoring Program, which operates under the auspices of the UN-ECE in support of the Convention on Long-Range Transboundary Air Pollution:

> *A national monitoring program to evaluate the environmental effects of acidic deposition is best organized in an integrated, hierarchical manner. At the apex (of the hierarchy) is a small number of intensively monitored process research or ecological monitoring sites. Beneath the apex is a series of regional networks that employ progressively less frequent sampling at progressively more sites. The base of the monitoring hierarchy is composed of national or provincial "surveys" in which sampling may occur as infrequently as once per decade.*

Environment Canada's monitoring activities contribute to the top and middle portions of the hierarchy. The provinces have usually contributed at the middle and lower levels, although Ontario's historically large program also contributed at the top. Significantly, for this review, the ECE description ended with the following warning:

> *discontinuation of any given monitoring level in the hierarchy may lead to collapse of the framework and an inability to effectively perform environmental assessment.*

Five examples of whole-ecosystem or ecological monitoring sites in eastern Canada that have a major focus on research and evaluation of acid rain effects are Kejimkujik, Nova Scotia; Lac Laflamme, Quebec; Dorset, Ontario; Turkey Lakes, Ontario; and the ELA in Ontario. Until recently, all had associated CAPMoN stations. To cope with budget cuts, however, Environment Canada closed the CAPMoN station at Lac Laflamme in April 1997, as it was the network's most expensive station to operate. (Environment Canada now supports weekly precipitation sampling and chemical analysis at Lac Laflamme but has had to adopt less frequent surface water sampling and reduced data evaluation activities to make this accommodation.)

Because of the significant costs of operating whole-ecosystem studies, monitoring can be conducted at only a small number of such sites and only in partnership with other organizations. Participating organizations typically take advantage of the existing infrastructure at these sites to conduct studies on other environmental issues (although many of these are "air" issues).

Major chemical constituents (ions, organic carbon, dissolved oxygen, etc.), nutrients (nitrogen and phosphorus species), some metals (iron, aluminum, zinc, etc.) and other common water quality variables (colour, conductivity, etc.) have generally been measured. Measurements of meteorological and radiation variables, stream flow, water temperature and transparency, and other physical quantities are also commonly made. For streams, continuous measurements of stage, and hence flow, are combined with the less frequent chemical measurements to produce records of the export of chemical species (i.e., chemical flux) from the basin. The frequency of chemical analysis for some variables has been reduced to deal with recent reductions in financial resources.

The studies and data at the five sites are used to answer the most difficult "why" questions associated with acidification and recovery or the lack thereof. These data are also the best available for detecting surprises, such as the link between climatic variation and delayed recovery. Additionally, they are used to develop and validate ecosystem models for predicting regional responses at lower levels of the monitoring hierarchy. The models used to evaluate regional critical loads are an example of this type of application.

Surface water monitoring at middle levels of the monitoring hierarchy is carried out in Newfoundland, Nova Scotia, Ontario, and Quebec. Collectively, these stations are commonly termed the "temporal" acid rain network. Their primary purpose is to provide information on long-term (i.e., multiyear) regional acidification trends. That is, the resulting data are used to answer the "what is happening" and "where" questions associated with the acidification issue. Ecosystem models developed with information from the intensive monitoring sites are applied to the temporal network lakes to project what will happen under various scenarios, such as changes in emission controls or climate.

Sampling at temporal stations occurs between two and six times per year. Many of the stations are remote, requiring helicopter access. Essentially the same group of chemical constituents measured at ecosystem monitoring sites is measured at the temporal sites, although analyses of some lower-priority variables have recently been discontinued or reduced in frequency in response to funding cuts.

Extensive provincial surveys were conducted in some regions during the 1980s and very early 1990s, but with minor exceptions they have not been repeated.

d) Aquatic Biota Monitoring

Aquatic biota monitoring has been conducted by the Department of Fisheries and Oceans, the Ontario Ministry of the Environment, and the Canadian Wildlife Service of Environment Canada. The Biomonitoring Program conducted by DFO and Ontario was established in 1980 to document biotic changes that occur in response to SO_2 emission controls. It included six lakes from the Experimental Lakes Area, four lakes from the Turkey Lakes watershed in central Ontario and four lakes from the Parry Sound district of Ontario, twelve lakes from the Muskoka-Haliburton area of Ontario, four lakes in the Parc de la Mauricie, six rivers along the north shore of the St. Lawrence, three lakes in Kejimkujik National Park, and six rivers along the south shore of Nova Scotia. Most of the Biomonitoring Program has now ceased.

Monitoring of water birds and their habitats is still conducted by the Canadian Wildlife Service of Environment Canada. This program was established in the mid-1980s to verify the biological recovery of acidified systems. It emphasizes small lakes and wetlands important to aquatic birds. Various biological indicators are monitored within four regional clusters: 240 sites in each of the Algoma and Muskoka regions of Ontario, 160 sites in the more acidified Sudbury area of Ontario, and 46 sites in the Kejimkujik area of southern Nova Scotia. The Canadian Wildlife Service also uses the volunteer-based Canadian Lakes Loon Survey to obtain data to assess the reproductive success of the common loon.

CHAPTER 3: ARE EXISTING PROGRAMS ADEQUATE TO MEET THE REQUIREMENTS OF THE ACID RAIN STRATEGY?

In Chapter 1, the Review Team recommended that an acid rain assessment report be completed in 2004. By that time, information should be available to evaluate ecosystem responses to reductions in emissions, including the significant U.S. Phase 1 reductions, that took place between 1995 and 2000. To complete the assessment effectively, the post-2000 acid rain program needs to carry out the tasks specified in Recommendation 3 of Chapter 1, namely:

- **monitor air and precipitation chemistry, and changes in response to changing emissions,**
- **monitor lake and river chemistry, to determine the degree of recovery,**
- **evaluate the response of aquatic biota to deposition changes,**
- **assess the extent and degree of the loss of forest soil fertility, and evaluate the further risk posed to Canadian forests, and**
- **assess the role of nitrogen as a nutrient and as an acidifying agent.**

It is necessary to continue monitoring atmospheric and ecosystem responses to changes in emissions in order to determine *what* changes are occurring and *where*. It is also necessary to have sufficient information to determine *why* changes occur, to establish whether they are due to changes in emissions of acidifying pollutants, to understand why, in some cases, ecosystems respond differently than expected, and to determine whether changes in policy are required.

Air and Precipitation Monitoring

Monitoring of the wet deposition of major ions in precipitation has made it possible to verify reductions in the wet deposition of sulphates that have resulted from cutbacks in sulphur dioxide emissions during the past several years. As the Canada-Wide Acid Rain Strategy for Post-2000 is implemented, a sound monitoring program will continue to be essential. Detecting the effects of a further 50% cut in eastern Canadian emissions should be possible with the current network, but it will take several years to detect the signal with reasonable statistical confidence. This time lag is due to large year-to-year meteorological variability and high levels of pollutants from American sources.

Up to 1995, the monitoring program showed that while sulphate deposition was decreasing, there was also a widespread decline in deposition of acid-neutralizing base cations, particularly calcium and magnesium. Because of this decline in neutralizing capacity, the decrease in sulphate concentrations has not been matched by a decrease in precipitation acidity. This is an important finding, but the current program has not explained why the deposition of base cations has changed, and so it has not determined whether such changes will continue in the future.

During the past decade, the federal CAPMoN network has been downsized from a maximum of 26 simultaneously operating sites to 18. Several provincial sites were also moved or closed during the same period. In most cases, though, the closures were accomplished in such a way as to minimize the impact on the usefulness of the overall database. In 1996, the number of measurement sites in the combined networks was adequate to produce maps of wet deposition for major ions in southern areas of eastern Canada, but the situation has deteriorated since then because of the lack of personnel dedicated to data management activities, particularly in Ontario.

Across northern Ontario, northern Quebec, and Nova Scotia, the combined networks do not have sufficient density to provide the data needed for accurate deposition mapping. Without more stations on the northern periphery of the system, it will not be possible to reliably measure progress towards meeting critical loads in acid-sensitive areas such as central Ontario, western Quebec, and some of the salmon spawning grounds of Atlantic Canada.

A further concern relates to delays in the production of wet deposition maps. Production of these maps is a large task that ultimately involves the collection, interpretation, quality assurance, interpolation, mapping, gridding, exporting, and checking of data from several North American wet deposition networks and over 700 monitoring sites. Because some environment departments lack the staff to complete necessary data management and quality control activities, the time lag between the completion of a set of measurements and the production of a map is three years or more. As of March 2000, for example, 1996 was the latest year for which maps were available. As a result, it was still impossible at that time to report, with confidence, on how deposition in eastern Canada had been affected by the substantial reductions in sulphur dioxide emissions that had occurred in the U.S. in 1995.

In western Canada, monitoring requirements are very different from those in the East. Because the West has considerably fewer acid-sensitive areas than the East, the purpose of the network there has been to produce spot measurements rather than the denser data coverage needed for the production of reliable deposition or concentration maps. An important effort has recently been made under the aegis of multistakeholder organizations including the Clean Air Strategic Alliance, the Wood Buffalo Environmental Association, and the RAMP to establish a number of sites in areas of the province that are sensitive to acid deposition and that are most likely to have deposition loads closer to critical loads. In addition, there is a need for more capacity to monitor the acid-sensitive region of northern Saskatchewan, which is exposed to sulphates from primary processing activities in both Alberta and Manitoba. The CAPMoN station near Esther, Alberta, serves an important purpose in this regard, but an additional site is needed in northern Saskatchewan itself.

The role of nitrogen in acidification is also becoming more important, but our knowledge of total (wet + dry) nitrogen deposition is inadequate for a proper assessment of its effects on Canadian ecosystems. We need better methods to estimate total nitrogen deposition.

Aquatic Monitoring

Aquatic ecosystems are sensitive to changes in acid deposition and are therefore effective indicators for assessing the effects of changes arising from emission controls. As there is no doubt that further emission controls are required to reduce the critical load exceedances that presently exist, it is important to maintain an effective aquatic science and monitoring program to evaluate the effectiveness of these controls. However, large portions of the program have been terminated or are threatened by chronic underfunding.

Acid rain science and monitoring in Canada has benefited considerably from the use of the three-tiered aquatic monitoring hierarchy described in Chapter 2. Regional surveys carried out by a few provinces, mostly in the 1980s, have provided good data on the extent and severity of the acidification of lakes and rivers, while the temporal network has generated valuable information on annual trends in water chemistry. The intensive monitoring sites have provided valuable insights into why ecosystems respond as they do and have been particularly useful in explaining unexpected results.

All three levels of the monitoring hierarchy are important because data from one level can be used to explain or extrapolate results and findings from another level. Combining data from the 200-odd lakes in the temporal survey with data from past regional surveys of several hundred more lakes makes it possible to assess the response on a regional scale to changes in deposition. Understanding provided by intensive monitoring and research sites helps explain responses observed at other sites. But while the overall concept of the monitoring hierarchy is sound, the individual components of the system are not presently adequate to meet the requirements of the Canada-Wide Acid Rain Strategy for Post-2000.

a) Large-scale surveys: tracking regional changes

Large-scale regional lake surveys require considerable effort, but they provide the only true documentation of the acidification status of lakes and rivers in areas that are, or may be, affected by acid rain. To remain valid and useful, however, they must be repeated every few years. As data from lake surveys become older and less representative of current conditions, it becomes increasingly difficult to extrapolate conclusions from the temporal network across a larger region.

Major lake surveys were carried out by a few provinces in the 1980s, but most of these have not been repeated since then. Significant exceptions are the surveys of the Sudbury area in Ontario, the Rouyn-Noranda area in Quebec, and acid-sensitive headwater lakes in New Brunswick that have been carried out by the respective provincial environment ministries. In the West, Alberta Environment, in collaboration with stakeholders, carries out lake monitoring and maintains a database describing lake chemistry and sensitivity to acid deposition. Additional lakes are added to the database every few years.

The surveys have shown that sulphate concentration in lake waters decreases as the distance from the local source of sulphur dioxide increases. What is particularly useful about these results is that they reflect total deposition (and not just wet deposition, as measured by deposition networks) and thus show how total deposition changes as a function of distance from the emission source.

Analyses of the Rouyn-Noranda data, derived from a sampling of 75 lakes in 1986, 1991, and 1996, also clearly show a reduction in lake sulphate concentration between surveys. Reductions closest to the town are primarily the consequence of local emission reductions, while reductions in lakes farther from the town show the increasing influence of emission reductions in other parts of eastern Canada and in the northeastern U.S.

A more ominous indication in the Rouyn-Noranda data, however, is that nitrate concentrations in lakes within 50 kilometres of the town seem to have increased between 1982 and 1996. This apparent increase occurred even though there was no significant increase in emissions of nitrogen oxides and nitrogen deposition. If this change is confirmed, it would indicate that nitrogen retention by watersheds has decreased in recent years, and it could be an early sign that nitrogen saturation is taking place. River quality monitoring at two sites inside this area shows an increasing trend in nitrate concentration in surface waters, beginning around 1990.

Such results indicate the importance of continuing existing programs, as well as repeating older surveys that have not been done since the 1980s.

b) The temporal network: tracking changes over time

Our ability to detect year-to-year changes and multiyear acidification trends in lakes depends on the temporal network. Among the important results that have emerged from the temporal network was the discovery that decreases in lake acidity are not keeping pace with decreases in sulphate concentration. Because of funding shortfalls, however, the network's coverage in eastern Canada is declining and there are insufficient staff to interpret data that have been collected.

In 1995 the eastern network consisted of 202 lakes. In its current state, the network is not extensive enough to provide information that is representative of all affected regions in eastern Canada, including such ecologically sensitive areas as the southern uplands of Nova Scotia (where there are important salmon spawning grounds), southern and central New Brunswick, and the Parry Sound area of Ontario.

In western Canada there is little coverage of sensitive lakes in Manitoba and northern Saskatchewan, although clusters of lakes in acid-sensitive areas of Alberta and some parts of Saskatchewan are being monitored under the aegis of RAMP.

c) Ecological monitoring and research sites: explaining changes

Ecological monitoring and research sites play a crucial role in determining why ecosystems respond as they do to acid rain and other atmospheric stresses.

The function of these sites goes beyond monitoring, however, and includes intensive experimental work (such as the experimental acidification of lakes at ELA in order to study acidification impacts and subsequent recovery). The knowledge gained from this work assists in the interpretation of measurements from the temporal network and lake surveys. These sites are also important components of EMAN, a national network of approximately 80 long-term, multidisciplinary research and monitoring sites used in the study of ecosystem responses to environmental stress.

Each of these sites offers an excellent platform for a variety of ecological research projects, but the network as a whole offers researchers the added benefit of being able to compare how different ecosystems with different pollution and climatic regimes respond to similar stresses. There are also important benefits to be gained from comparing results from ecological monitoring and research sites in Canada with those from equivalent sites in other countries.

Studies at ecological monitoring and research sites have made an enormous contribution to our understanding of how ecosystems respond to acidification, and they have a critical role to play in answering many of the questions that remain. In particular, they can provide valuable information about the role of nitrogen in ecosystems, the loss of nutrients from soils (and the impact of nutrient loss on forest productivity and health), the release of sulphur stored in soils and/or wetlands, and other processes that regulate the acidification and recovery of terrestrial and aquatic ecosystems. These sites can also help us understand the interactions between acid rain and other factors, such as climate variability and change or mercury contamination, that affect ecosystem recovery. This work cannot go ahead, however, until sufficient resources are available to support it.

d) Do we need the hierarchy of aquatic monitoring networks?

The Review Team considered whether it would be wise to abandon the three-tiered hierarchy of aquatic monitoring networks and allocate all the remaining resources to only one of the components of the program. For example, if all remaining resources were applied to enhance the work at the integrated monitoring sites, we could strengthen efforts to assess the role of nitrogen in acidification and to examine linkages between acid rain and other environmental issues such as climate change, mercury contamination, and biodiversity. However, our ability to define the geographical extent and variation of acidification trends across eastern Canada would be lost if resources were directed only toward the integrated monitoring sites.

In contrast, if all the remaining resources were applied to improving temporal monitoring, the network could be made more representative and would be able to provide data on multiyear acidification trends in ecologically sensitive areas that are affected by acid rain. However, without the integrated monitoring sites, there will be no information on the causes of observed changes and whether the changes are related to emission control programs. Operating only the temporal network would eliminate our ability to understand why trends are happening, to assess the role of nitrogen, and to understand interactions between acid rain and other environmental factors.

The Review Team concluded that all three components are required.

Aquatic Biota

The importance of acidic deposition as a continuing threat to aquatic biota in eastern Canada cannot be overstated. Acidic deposition is one of the most serious threats to biodiversity at the ecoregion level. Increased acidity negatively affects many species of phytoplankton, zooplankton, benthic invertebrates, and fish. Most effects on birds occur through changes in the quality and quantity of their foods. Acidification effects may combine with other factors, such as climate change, mercury contamination, and increased UV-B exposure, to produce even broader-scale deleterious effects. Experimental studies show that there is a time lag between improvements in chemical conditions and improvements in biological conditions. Biological recovery of strongly acidified lakes may occur more slowly than in less acidified lakes, and the biological communities in the recovered lakes may differ from those that were originally present.

Most of the aquatic biota science and monitoring that is related to acid deposition has been terminated, although monitoring of water birds and their habitat is still conducted in Ontario and southern Nova Scotia. This level of activity is not enough, however, to permit us to assess the effectiveness of acid rain control programs in protecting aquatic biota.

Determining the components of a biomonitoring program would require two or three scientific workshops to examine existing databases, to review current knowledge and understanding of biological recovery, and to carry out other essential tasks. This represents too large an undertaking for the Review Team in 1999, and we therefore recommend that it be done in 2000. It should be noted that such workshops would be of value for assessing ecosystem responses to a number of stresses and not just those resulting from acid deposition.

Forest Effects

Canada has developed very informative databases on forest health through the ARNEWS network, established in 1984 by the Canadian Forest service), several provincial networks, and the joint Canada-U.S. NAMP. In addition, the scientific research work investigating effects of acid rain on forests has uncovered a number of direct and indirect effects of air pollution on trees. The clearest connection between regional pollution and adverse effects on forests can be seen in the decline of white birches in the Bay of Fundy area of New Brunswick. The relationship between pollution and hardwood forest health is complicated by a number of factors, however, including substantial differences in the sensitivity of soils to acid deposition.

Critical loads are a useful tool for assessing the link between forest decline and regional air pollution, because they take soil buffering capacity into account. Critical loads of sulphur and nitrogen were calculated for ARNEWS sites and published in the *1997 Canadian Acid Rain Assessment*. They provide a crucial, quantitative yardstick for measuring the effectiveness of pollution control programs aimed at preventing the acidification and eutrophication (overfertilization) of forests. Critical load maps show the forested areas that are particularly sensitive to acid deposition. Exceedance maps show whether sulphur and nitrogen deposition exceeds critical loads and by how much. This knowledge is important because, as soils acidify, the availability of toxic metals like aluminum and manganese increases and the loss of base cations accelerates, thus enhancing the potential for nutrient deficiencies, nutrient imbalances, and adverse effects on trees. Studies of the dieback of sugar maples in eastern Canada have shown that tree mortality is greater in areas where critical loads are exceeded than in areas where they are not.

Adopting a critical load approach represents a definite shift in the way that the effects of acid rain on forests are assessed in Canada. It not only provides a framework for prioritizing forest science and monitoring activities but also a context for re-analyzing and interpreting the excellent data available (most forest monitoring programs in Canada have strong quality assurance and quality control components). In the opinion of the Review Team, some important unanswered questions regarding impacts of acid deposition (and other anthropogenic stresses) on forest ecosystems can be tackled using the critical loads approach and a three-tiered monitoring network. Such questions include: How extensive is the loss of soil nutrients from sensitive forest ecosystems? How much of our forest is at risk of degradation from continued acid deposition? and What are the cumulative impacts of air pollution on forest ecosystems?

It makes sense to adopt a three-tiered framework for both aquatic and forested ecosystems because much of Canada's forest area includes surface waters and wetlands. There is a fundamental link between these waters, acid deposition, and the surrounding forest. Forest soils may accentuate or minimize impacts of acidic deposition on surface waters within the forested landscape.

Producing a more thorough assessment of the forested area at risk requires a more complete use of existing data sets to compile more detailed and accurate maps of critical loads than those that were made for the 1997 assessment. A forest mapping project of this kind was proposed in the acid rain work plan adopted by the Conference of New England Governors and Eastern Canadian Premiers (NEG/ECP) in October 1999. The project would make it possible to produce detailed maps of critical loads for sulphur and nitrogen deposition on forest soils in eastern Canada within the next three years.These maps would provide additional scientific information for devising nitrogen control programs.

The level of effort required to produce such maps is not trivial, however, and no single jurisdiction can undertake the task on its own. It must be done jointly by several partners. It would also be desirable to involve Ontario in the project, since adding Ontario data to the analysis would not be a major undertaking and would result in a map that covers all parts of eastern Canada that are affected by acid rain.

Human Health Effects

The Review Team decided not to evaluate scientific programs relating to the effects of acidifying emissions on human health. Other groups, in Canada and elsewhere, are working on this issue and have made recommendations to address current science gaps in this area.

Damage to Materials

A number of studies have clearly documented the fact that air pollution accelerates the corrosion of various materials that are used extensively in our cities. In particular, the International Cooperative Program on Effects of Air Pollution on Materials, established under the UN Convention on Long-Range Transboundary Air Pollution, has developed dose-response relationships for the effects of pollutants such as sulphur dioxide, nitrogen oxides, and ozone on stone, paint, and a number of commonly used metals. Canada participates in this work and provides, at very little cost, data that are important to the rest of the program. It would be interesting and profitable, in return, to use the existing dose-response relationships in order to produce corrosion maps for Canada. These maps would show approximate corrosion rates for a number of urban and rural centres in Canada and could be used to estimate the reductions in corrosion that would result from pollutant emission controls.

Overall Conclusion

The Review Team concludes that current science and monitoring programs are not adequate to fulfill the requirements of the Canada-Wide Acid Rain Strategy for Post-2000. There are two major problems. The first is that existing science programs are not collecting enough data to support a full assessment of atmospheric and ecosystem responses to changes in emissions: key program elements are lacking or have been dismantled. The second is that not enough trained personnel are available to operate and coordinate the necessary monitoring programs and to analyze and assess the data collected. It will be necessary to address these deficiencies if we are to have sufficient capacity to conduct an adequate assessment in 2004.

CHAPTER 4: RECOMMENDATIONS

The Review Team recommends that a number of actions be initiated in order to ensure that the science and monitoring program has adequate capacity to gather and analyze the information needed to produce a comprehensive assessment in 2004. These recommendations are presented in detail in the rest of the chapter.

The Review Team also recommends that an additional assessment be conducted after 2004 to evaluate the impact of the next wave of emission reductions under the Canada-Wide Acid Rain Strategy for Post-2000 and of further reductions in the United States. The 2004 report, however, will provide a clearer picture of the impacts of current emission reductions on the recovery of sensitive lakes in parts of eastern Canada. By providing better information on critical loads and improved knowledge of other aspects of the issue, particularly the role of nitrogen, it will also make an important contribution to the development of effective pollution control strategies.

The Review Team has already identified key areas where science and monitoring efforts are needed to address the most significant gaps. More detailed work is required to examine options and costs and to develop implementation plans. The Review Team intends to complete this task before the end of June 2000.

General Recommendations

- Maintain the air and lake monitoring components of the existing program and do not subject them to further cuts.
- Put in place a small team of scientists with the expertise required to assess the role of nitrogen on surface water acidification and forest productivity in Canada. Assessing the role of nitrogen is a substantial piece of work that will require contributions by several scientists for a period of a few years. The Review Team believes that findings reported in 2004 are likely to be preliminary and that further work will be needed beyond that date.
- Maintain the ecological research and monitoring sites that will host many of the more specific science research activities (nitrogen, base cation depletion, geochemical pathways, etc.). These sites are especially necessary for research on nitrogen cycling.
- Investigate important processes that regulate the acidification and recovery of terrestrial ecosystems, including the release of sulphur stored in soils and/or wetlands and the loss of base cations from ecosystems. Ecological monitoring sites will provide a major contribution to this research.
- Investigate the relationships and synergies between global change factors, such as acid rain, mercury, climate warming, etc. Assess the co-benefits of SO_2, mercury, and greenhouse gas controls on acidification and contamination recovery.
- Re-establish a science and monitoring coordinating committee, similar to the RMCC, to improve overall coordination between jurisdictions and collaboration amongst scientists.

- Upgrade the Integrated Assessment Model (IAM) in order to include nitrogen species and update other information in the model.
- Reinstate the LRTAP round-robin interlaboratory comparison quality assurance program.
- Maintain a strong partnership with the NEG/ECP stakeholders to share information and resources.

Specific Science and Monitoring Activities Needed to Address Knowledge Gaps

1. Deposition

Science needs:

i) Implement suitable methods of estimating nitrogen deposition.
ii) Investigate whether combined use of Lagrangian models and data will provide a useful tool for improving deposition analyses.
iii) Investigate whether passive sensors provide useful information on deposition in western Canada where, in contrast to eastern Canada, dry deposition is a more important factor.
iv) Review the CAPMoN-AIR dry deposition network to ensure adequate regional coverage.

Monitoring needs:

i) Review the process of environmental reporting (i.e., the means by which observed data and analyses are reported) in order to accelerate the process and improve information outreach.
ii) Add three monitoring sites to better assess deposition and trends at the northern edge of the geographical regions most affected by acid rain (i.e., northern Ontario, northern Quebec, and Nova Scotia).
iii) Establish a station in northern Saskatchewan to identify deposition trends in that sensitive area of western Canada, and determine whether that site compensates for the closure of the Island Lake station in Manitoba.
iv) Develop an inventory for emissions of base cations.
v) Install fog water collectors in coastal areas or at high elevation sites.

2. Surface waters

Science needs:

i) Assess the impact of nitrogen and nitrogen saturation on surface water acidification and eutrophication.
ii) Research the causes and effects of base cation depletion in surface

waters and its relevance to lake and river recovery from acidification.

iii) Develop acidification models, or modify existing ones, that can provide critical load estimates for both sulphate and nitrogen (nitrates).

iv) Assess the geochemical pathways of sulphur- and nitrogen-induced acidification at the watershed level through calibrated watershed studies.

v) Evaluate costs and options to determine whether aquatic biota are responding to emission decreases and lake chemical recovery in areas where surface water chemistry has changed.

vi) Evaluate the relationship between acid pulses and fish kills in salmon rivers of Atlantic Canada.

vii) Initiate research and monitoring of " brown-water " systems in order to estimate their role in surface water acidification and their critical loads. Such ecologically rich ecosystems are of great importance for Saskatchewan and several areas of eastern Canada.

Monitoring needs:

i) The most urgent task is to ensure that lake and river monitoring (i.e., sampling of sites included in the " temporal " networks) be carried out in 2000. This sampling, traditionally carried out by Environment Canada, has been seriously threatened by underfunding in the past few years. Emergency funding was provided to carry out a sampling campaign during the 1999 season. The Review Team is particularly concerned that multiyear time series of surface water chemistry measurements may be broken unless adequate resources are available for the next sampling season, in the spring of 2000. **The Review Team considers it of critical importance that this component of the aquatic program be continued without interruption.**

ii) Additional temporal sites need to be added in ecologically sensitive areas currently covered by the temporal network (e.g., surface waters in southern and central New Brunswick, western Quebec, the Parry Sound area of Ontario, sensitive lakes in northern Saskatchewan, and salmon spawning rivers in the southern uplands of Nova Scotia).

iii) The ecologically sensitive portions of spatial lake and river surveys conducted in the 1980s should be repeated in order to quantify the benefits of emission reduction programs in North America.

3. Forests and soils

Science needs:

i) Support and participate in the forest mapping initiative promoted by the eastern provinces and New England states. This project involves a two-way approach (site-specific and ecological areas interpolation) to the development and adaptation of the Steady Mass Balance (SMB) model for calculating critical loads of nitrogen and sulphur in forest ecosystems. The main goal is the production of critical load maps and exceedance maps for forested areas of northeastern Canada.

ii) Assess the role of acidic deposition (both nitrogen and sulphur deposition) and the resulting base cation depletion on forest fertility and productivity. Evaluate the environmental and economic risks to Canadian forests and forest exploitation.

4. Materials

Science needs:

i) Continue Canada's involvement in the *International Cooperative Program on Effects of Air Pollution on Materials, Including Historic and Cultural Monuments* carried out under the aegis of the UN-ECE Convention on Long-Range Transboundary Air Pollution.

ii) Apply some of the results of the program to Canadian needs (e.g., produce a map of corrosion rates for parts of Canada).

5. Human Health

As research and monitoring activities in this area are being carried out under other programs, there is no need for similar studies to be carried out as part of the acid rain science program. The Review Team stresses, however, that mechanisms must be in place in order to improve cooperation and foster collaborative studies and assessments.

APPENDIX

List of Consultation Meetings and Attendees

Acid Deposition Science and Monitoring
Sackville, New Brunswick, Consultation Meeting, September 8, 1999

Attending:
Rob Hughes, NB Environment
Roger Cox, Forestry Canada
Michael Hingston, NS Environment
John MacMillan, NS Fisheries
Deborah McLellan, NS Power
Todd Fraser, PEI Environment
Guy Fenech, Environment Canada
Neil Burgess, Environment Canada
Leo Burns, NB Power
Vince Zelazny, NB Natural Resources (Forestry)
Gilles Lacroix, DFO
Des Cousens, NS Power
Darrell Taylor, NS Environment
Tom Clair, Environment Canada
Billie Beattie, Environment Canada
Paul Quinn, Environment Canada

Acid Deposition Science and Monitoring
Quebec Consultation Meeting, September 9, 1999

Attending:
Jacques Dupont, Environnement Québec
Guy Fortin, Centre St. Laurent
Guy Fenech, Environment Canada
Ghislain Jacques, Environnement Québec
Rock Ouimet, Quebec Forestry Service
Paul Quinn, Environment Canada
Raynald Brulotte, Environnement Québec
Alain Kemp, Centre St. Laurent

Acid Deposition Science and Monitoring
Alberta Stakeholder Consultation Meeting, September 14, 1999

Attending:
Guy Fenech, Environment Canada
Ken Foster, Alberta Environment
Peter Hunt, Energy and Utilities Board
Ron Pauls, Syncrude Canada
Lawrence Cheng, Alberta Environment
Paul Quinn, Environment Canada
David McCoy, Husky Oil
Sheila Chernys, Suncor Energy
Dave Ballagh, Saskatchewan Environment and Resource Management (by telephone)
Karen McDonald, Environment Canada
Chow-Seng Liu, Alberta Environment
Neil Dibble, Mobil Oil
Wendy Davis, Canadian Forest Service
Allan Legge, Biosphere Solutions
Monique Richard, Alberta Environment
Lisa Holmes, Alberta Environment

Acid Deposition Science and Monitoring
Ontario Consultation Conference Call, September 16, 1999

Attending:
John Kelso, (DFO-GLLFAS)
Dean Jeffries (EC-NWRI)
Peter Dillon (MOE-Dorset)
Joe Muraca, Environment Canada
Don McNicol, CWS, Ontario Region
John Gunn (MNR/Laurentian)
Mike Turner and Ray Hesslein (DFO-ELA)
Guy Fenech, Environment Canada
Neville Reid, Ontario Ministry of the Environment
Fred Conway, Environment Canada

Acid Deposition Science and Monitoring
Ontario Consultation Meeting, September 20, 1999

Attending:
Marius Marsh
Bill McIlveen
Bill Gizn
Dave MacLaughlin, Ontario Ministry of the Environment
Murray Dixon