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THE EFFECTS OF SMOG ON THE HEALTH OF CANADIANS

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INTRODUCTION: SMOG AND HEALTH

A correlation between air pollution and its effects on health was first observed in 1952 in London, England, when 4,000 persons died from respiratory diseases aggravated by a high concentration of acid smog. The term "smog," which has for some 30 years been used to mean chemical air pollution, is a contraction of the words "smoke" and "fog." Smog is formed mainly above urban centres by concentrated human activities that include the combustion of fossil fuels and the smelting of ores. Smog is composed mainly of tropospheric ozone, produced by a photochemical reaction between volatile organic compounds and nitrogen oxides; primary particulate matter such as pollen and dust; and secondary particulate matter such as sulphur oxides, volatile organic compounds, and ammonia gas. The severity of smog is usually assessed by measuring ground-level ozone.

In Canada, air pollution is greatest in the four regions described below, where inhabitants are increasingly concerned about the effects of air pollution, particulate matter, and tropospheric ozone on their health.

The **Windsor-Quebec corridor** is a region including the north shore of Lake Erie and Lake Ontario and the north and south shores of the St Lawrence River as far east as Quebec. The pollution concentrated in this region results from activities there and in regions such as Ohio and cities such as Cleveland and Detroit in the United States. Windsor is the city most affected by smog.

Southern Ontario, especially rural southwestern Ontario, is the region in Canada most affected by pollution. Nearly 50% of this region's measured ground-level ozone, the main component of smog, results from air pollution from the United States.

The **Atlantic region** includes southern New Brunswick, southwestern Nova Scotia, and the Bay of Fundy. Saint John, New Brunswick, experiences 90% of the periods of smog in this region, most of whose pollution comes from the east coast of the United States.

The **Lower Fraser Valley** is in southern British Columbia and includes Vancouver. Approximately 80% of ground-level ozone in this region comes from local sources, particularly tailpipe emissions.

The scientific community is paying increasing attention to the effects of air pollution on health. Most studies are carried out on ozone, sulphates, or particulate matter. Increasingly, they show that there is no minimum threshold at which human beings are not sensitive to smog and that, to varying degrees, most persons may be affected. The federal government is providing itself with ever more legislative and technical tools to combat the situation. The next two sections of this document describe the various components of smog and their effects on health.

MAIN COMPONENTS OF SMOG

Smog, formed mainly above urban centres, is composed mainly of tropospheric ozone (O_3); primary particulate matter such as pollen and dust; and secondary particulate matter such as sulphur oxides, volatile organic compounds, nitrogen oxides (NO_x) and ammonia gas. The severity of smog in an urban area is usually assessed by measuring ground-level ozone.

Tropospheric Ozone: Sources, Composition, and Formation

Tropospheric ozone (O_3) is found as a ground-level polluting gas. This paper discuses only tropospheric ozone, not to be confused with stratospheric ozone, which forms a layer around the earth, protecting it from the rays of the sun. Tropospheric ozone is produced by the action of light and the chemical bonding of volatile organic compounds (VOCs) and nitrogen oxides (NO_x). The table below identifies the main sources of smog-forming pollutants.

As a result of heat from the rays of the sun, the concentration of ground-level ozone is highest in urban centres in the summer. Weather conditions also affect ozone formation; masses of stagnant air can hold pollutants at ground level for several days. In addition to the regions where pollution is greatest – the Windsor-Quebec corridor, southern Ontario, the Atlantic region, and the Lower Fraser Valley – , other urban centres, such as North York, London and Oakville, two or three times a year experience pollution higher than the maximum permissible concentrations of 82 parts per billion (ppb) per hour.

Pollutant	Sources, Both Natural and Human-Made
Volatile organic compounds (VOC)	Tailpipe emissions, evaporation of gasoline at service stations, surface coatings such as oil paints, solvents such as barbecue starters, fuel combustion, vegetation
Nitrogen oxides such as nitric oxide (NO) and nitrogen dioxide (NO_2)	Tailpipe emissions, manufacturing industries, electricity generating stations, fossil fuel powered plants, oil refineries, pulp and paper plants, incinerators
Sulphur dioxide (SO_2)	Non-ferrous metal smelting, thermal electricity generating stations, oil refineries, pulp and paper plants, incinerators
Particulate matter	Tailpipe emissions, volcanoes, wind erosion, forest fires, fossil fuel powered plants

Source: Anonymous, "Health Effects of Outdoor Air Pollution," *American Journal of Respiratory and Critical Care Medicine*, Volume 153, 1996; Health Canada, summary of recent research on the effects of ambient air pollution on health in Saint John, Health Canada Internet Site, 1997.

Sulphates: Sources, Composition, and Formation

In normal concentrations, sulphur dioxide (SO_2) is not toxic; however, the acid pollutants into which it is chemically changed do have negative effects on health. Sulphur dioxide is found in the atmosphere as a result of the combustion of fossil fuels, the production of electricity, and the smelting of sulphur-containing ores (see table above). Winds then carry away sulphur dioxide, sometimes over long distances. After mixing with water vapour and undergoing complex changes including oxidation, sulphur dioxide turns into sulphuric acid (H_2SO_4) and sulphate ions or sulphates (SO_4^{2-}).(1) When these changes take place, some pollutants form acid precipitation, while others remain suspended in the air as dust or droplets. Sulphates account for a considerable proportion of all particulate matter in the air smaller than three microns (μm).

In Canada, almost half of sulphur dioxide is produced by the smelting of non-ferrous metals; in the United States, two thirds of sulphur dioxide is produced by thermal-

(1) Anonymous, "Health Effects of Outdoor Air Pollution," *American Journal of Respiratory and Critical Care Medicine*, Vol. 153, 1996, p. 3-50.

electricity generating stations. Of all emissions in both countries, 80% are concentrated in the east of the continent, east of the Manitoba-Saskatchewan border in Canada and east of the Mississippi River in the United States.

Particulate Matter: Sources, Composition, and Formation

Like other substances, particulate matter can come from natural sources, but industrial and other human-produced factors are responsible for the high concentration of particulate matter in the air (see table above). Sulphates account for most particulate matter, but it also includes nitrates (NO_3^{1-}) and other pollutants, such as metals. Particulate matter is found in the air in solid and liquid forms. It is measured in total suspended particulates (TSP) of all sizes; PM_{10}, particulate matter measuring 10 microns in diameter or less; and $PM_{2.5}$ and $PM_{2.1}$, fine particulate matter measuring 2.5 or 2.1 microns or less.(2) The smallest particulate matter easily penetrates the respiratory tract, causing health problems. It can also carry chemicals such as metals, polycyclic aromatic hydrocarbons (PAHs), and other pollutants into the lungs. Eastern Canada has a high concentration of particulate matter in the form of sulphates, while in western Canada there is a high concentration of nitrates.(3)

(2) Health Canada, "Air Quality and Health in Saint John: A Summary of Recent Research on the Effects of Ambient Air Pollution on Health," Health Canada Internet Site, 1997.

(3) Canada-United States Air Quality Agreement, Scientific and Technical Activities and Economic Research, *Progress Report*, 1996.

EFFECTS OF OZONE, SULPHATES, AND PARTICULATE MATTER ON HEALTH

Smog is formed mainly above urban centres by concentrated human activities including the burning of fossil fuels. Smog is composed mainly of: tropospheric ozone, the result of a photochemical reaction between volatile organic compounds and nitrogen oxides; primary particulate matter such as pollen and dust; and secondary particulate matter such as sulphur oxides, volatile organic compounds, and ammonia gas. The scientific community is paying increasing attention to the effects of air pollution on health. Most studies are carried out on ozone, sulphates, or particulate matter.

Persons at Risk

Studies show that air pollution has indisputable effects on human health. However, scientists have thus far been unable to establish links between specific pollutants and observed diseases because pollutants scattered throughout the air often come from the same source and are released at the same time, thus forming a mixture. As well, the effects of these pollutants can be influenced by a number of factors, including individual reactions, air pollutant concentrations, pollutant types, exposure, and types and levels of individual activity, all of which are investigated in the studies.

Individuals' health and age also influence their sensitivity to pollution. Senior citizens, people already suffering from lung problems such as asthma, and children, who spend more time outdoors and have faster heartbeats than adults, are particularly vulnerable to pollutants.(4)

Though these groups are particularly at risk, perfectly healthy adults are also sensitive to the effects of smog if they work or are active outdoors. Physical performance is lower when sustained physical effort is carried out in an urban setting at rush hour, when tailpipe emissions are high. This is because carbon dioxide (CO_2) bonds readily with the red blood corpuscles so that the oxygen supply of persons exposed to pollution is reduced.

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(4) Health Canada, "Air Quality and Health in Saint John: A Summary of Recent Research on the Effects of Ambient Air Pollution on Health," Health Canada Internet Site, 1997.

Studies to Date

Studies carried out to date on the effects of smog on health have used three main methodologies. Epidemiological studies use field data such as the ambient concentrations of pollutants and their actual effects on a given population. Clinical studies expose healthy, at-risk subjects, such as persons with asthma, to pollutants synthesized in the laboratory in concentrations similar to those existing in the natural environment (see table below). Toxicology studies expose animals, tissues, or human cells to pollutants synthesized in the laboratory. Three studies are described in greater detail below; the table illustrates the effects observed from applying the various methodologies.

Study No 1: Effects of Ozone on Persons at Risk(5)

An ozone concentration of 0.12 parts per million (ppm) is not unusual in urban centres in the summer but, according to this study, even a controlled concentration of 0.08 parts per million caused lung problems among the subjects studied. Whether or not these effects are reversible is not known. Repeated exposure to pollution does attenuate the observed effects, apparently suggesting adaptation, and scientists are studying the effects of intermittent exposure on this supposed adaptation. Other studies would have to be carried out on the public in order to assess chronic long-term effects.

According to a number of epidemiological studies, persons with asthma are, in the short term, hospitalized more often when exposed to lower concentrations of ambient ozone than cause reactions among healthy persons. Scientists are studying the effects of ozone on persons with more severe asthma and persons with allergies.

In the short term, ozone causes irritations and symptoms including coughing and painful breathing.

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(5) Anonymous, "Health Effects of Outdoor Air Pollution," *American Journal of Respiratory and Critical Care Medicine*, Volume 153, 1996, p. 3-50.

Effects of Air Pollution on Health

Study	Methodology	Pollutants	Subjects	Effects on Health	Comments
Study No.1	Review of clinical and epidemiological studies, 1978-1993	Ozone	• Healthy adults and children • Athletes and persons working outside • Persons with asthma	• Reduced respiratory functions • Increased reactivity of respiratory passages • Lung inflammation • Increased respiratory symptoms • Reduced exercise capacity • Increased hospitalizations	• Effects increase with exercise. • Ozone is more harmful than sulphates. • Effects seem to be combined with those of acid aerosols and particulate matter.
Study No.1	Review of clinical and epidemiological studies	Sulphates (sulphur dioxide) (PM_{10})	Persons exposed to ambient concentrations of between 30 and 150 $\mu m/m^3$ • Healthy adults • Persons with asthma • Children	• Increased reactivity of respiratory passages • Reduced respiratory functions • Increased respiratory symptoms and infections	Effects occur at indoor ambient concentrations if there are unventilated sources of combustion.
Study No.2	Epidemiological study: regression statistics	Ozone, sulphates	Urban air concentrations between May and August	• Increased hospitalizations for respiratory illnesses such as asthma, infections, and chronic obstruction of respiratory passages	• Ozone is more harmful than sulphates. • There is a correlation between temperature and mixture of ozone and sulphates. • sulphates' effect is intensified by an excess of positive ions in the air.
Study No.3	Review	Particulate sulphates		• Increased hospitalizations for cardiovascular and respiratory illnesses • Increased respiratory symptoms • Reduced respiratory functions • Links between airborne particulate matter and premature deaths attributable to cardio-pulmonary and respiratory illness	

Source: Anonymous, "Health Effects of Outdoor Air Pollution," *American Journal of Respiratory and Critical Care Medicine*, Volume 153, 1996; The Acidifying Emissions Task Group, Towards a National Acid Rain Strategy, presentation to the National Air Issues Co-ordinating Committee (NAICC).

Study No 2: Effects of Ozone and Sulphates on Hospitalization Rates[6]

This study was carried out in 168 hospital emergency rooms in Ontario. It shows a significant positive correlation between hospitalizations for respiratory illnesses and concentrations of ozone and sulphur in the air. The presence of these substances was noted on the day of, and up to three days before, admissions to hospital, from May toAugust and from 1983 to 1988. Of hospitalizations, 5% were linked to the concentration of ozone and 1% to the concentration of sulphates. Ozone was seen to have a greater influence on hospitalizations than sulphates. Causes of hospitalization were asthma, chronic illnesses obstructing the respiratory passages, and infections. These findings applied to all age groups; children suffered most from a mixture of ozone and sulphates, accounting for 15% of hospitalizations, while senior citizens suffered least. The study was carried out in a circular area, 1,000 kilometres across, with 8.7 million inhabitants. With respect to the possible influence of other factors on the link between hospitalizations and ozone and sulphate concentrations, temperature seems to have an effect, but relative humidity and air pressure apparently do not. Where pollutants are concerned, an excess of positive ions in the air seems to influence sulphate concentration. Other studies show a correlation between sulphate concentration and particulate matter in the air.

Study No 3: Particulate Sulphates[7]

A number of studies link particulate sulphates with increases in premature deaths, hospitalizations, asthma symptoms, bronchitis and other respiratory illnesses. Senior citizens and persons with existing cardiovascular and respiratory illnesses appear to be more sensitive than the rest of the population.

Some scientists link these effects with fine particulate matter, measuring 2.5 microns in diameter or less ($PM_{2,5}$); others, with particulate matter combined with other

(6) Richard T. Burnett, *et al.*, "Effects of Low Ambient Levels of Ozone and Sulphates on the Frequency of Respiratory Admissions to Ontario Hospitals," Environment Canada, Health Canada, Statistics Canada, *Environmental Research*, Vol. 65, 1994, p. 172-194.

(7) The Acidifying Emissions Task Group, *Towards a National Acid Rain Strategy*, presentation to the NAICC.

pollutants such as ozone, sulphur dioxide, and metals.(8) The studies on particulate sulphates state that, even at ambient concentrations of between 30 and 150 microns per cubic metre, these pollutants are linked with increased fatal cardiovascular attacks, particularly when combined with high-risk activities such as smoking. These pollutants are also linked to child hospitalizations, school absences, and increased use of medication by asthmatics.

Effects on Health

The effects on health can be chronic or acute. Chronic illnesses include permanent degeneration of respiratory functions, new cases of bronchitis, and increased deaths linked to sustained exposure to air pollution. Acute effects include temporary changes in respiratory functions, more hospitalizations for cardio-pulmonary attacks, and more deaths linked to short episodes of high pollution.(9) The studies also observed other health problems such as aggravated respiratory infections, asthma, emphysema, coronary pathology, and lung cancer.

Although scientists have thus far been unable to establish precise links between specific types of particulate matter and particular effects, these studies show that exposure to these air pollutants increases the frequency of cardiovascular and respiratory illnesses and mortality.

For further information, consult the following Health Canada site:

http://www.hc-sc.gc.ca/main/hc/web/datahpb/dataehd/English/IYH/smog.htm (updated August 1998)

(8) Richard T. Burnett, *et al.*, "The Role of Particulate Size and Chemistry in the Association between Summertime Ambient Air Pollution and Hospitalization for Cardio-respiratory Diseases," *Environmental Health Perspectives*, Vol. 105, No. 6, 1997.

(9) Richard T. Burnett, *et al.*, "Association between Ozone and Hospitalization for Respiratory Diseases in 16 Canadian Cities," *Environmental Research*, Vol. 72, 1996, p. 24-31.

LEGISLATIVE MEASURES ADOPTED BY CANADA TO REDUCE AIR POLLUTION

Studies show that air pollution has indisputable effects on human health (see the section entitled Effects Of Ozone, Sulphates, and Particles on Health). In order to alleviate the many effects of these pollutants and prevent still more serious problems, the federal government and various governmental partners have developed and adopted a number of legislative tools. In addition, a broad range of programs on the same lines are being planned, discussed and established. An overview of the various legislative tools follows; readers wishing to learn about these programs are referred to the section in this document entitled Present and Future Federal Approaches.

Legislative Tools: Legislation, Policies, and Agreements

Where air pollution is concerned, the federal government exercises jurisdiction under the *Canadian Environmental Protection Act (CEPA)*, particularly Part V, International Air Pollution, to prevent the formation of the main components of smog: tropospheric ozone, sulphates, and particulate matter (see the section of this document entitled Main Components of Smog). The House of Commons is now considering Bill C-32, proposing amendments to *CEPA*. If Bill C-32 is adopted, Part V will become Division 6, and a number of new sections, including a Division on Vehicle, Engine and Equipment Emissions, will be included in the legislation.

A number of Regulations made under CEPA help combat smog, either directly or indirectly. Those listed in the table below are designed to eliminate one or more of the main components of smog directly; others, not included in the table, help eliminate smog indirectly by targeting other sources of air pollution.

Some Federal Regulations Applicable to Smog

Regulations now in effect
Contaminated Fuel Regulations Diesel Fuel Regulations Gasoline Regulations Fuels Information Regulations Pulp and Paper Mill Effluent Chlorinated Dioxins and Furans Regulations Benzene in Gasoline Regulations, to limit to 1% the quantity of this carcinogenic substance starting on 1 January 1999
Regulatory initiatives planned for 1998-99
Gasoline Regulations to change fuels used in automobile racing Sulphur in Gasoline Regulations, to reduce polluting vehicle emissions by controlling sulphur in gasoline
Regulatory initiatives planned for 1999-2001
Gasoline Dispensing Rates Regulations Toxins from Gasoline Regulations (Gasoline Composition)

Source: Environment Canada, *1998-99 Estimates, Part III: Report on Plans and Priorities*, 1998.

The federal government also exercises jurisdiction over environmental protection and the health of Canadians through Environment Canada, Transport Canada, Natural Resources Canada, and Health Canada, in co-operation with the provincial governments, or in partnership with other countries. Examples of legislative tools follow:

- in 1996, on the initiative of Transport Canada, the *Motor Vehicle Safety Act* set compulsory limits on new vehicle emissions of carbon monoxide (CO), nitrogen oxides, hydrocarbons, and particulate matter produced by diesel engines;

- on the initiative of Environment Canada and Health Canada, Canada-wide air pollution standards, particularly on ozone and particulate matter, are to be set by the fall of 1999; and

- national ambient air quality standards set by the federal and provincial governments have established the maximum allowable ground-level ozone concentration at 82 parts per billion per hour.

Internationally, the following agreements allow the federal government to work with the United States to eliminate sources of transboundary pollution:

- the 1991 *Canada-United States Air Quality Accord* is aimed at reducing emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_x). The planned reduction of sulphur dioxide is 40%, an objective Canada has exceeded; the planned reduction of nitrogen oxides is 10% by the year 2000. Initially the Accord dealt with acid rain; now the possibility of adding a schedule dealing with smog is being considered;

- the 1991 *International Volatile Organic Compounds Protocol* signed by Canada and the United States is aimed at reducing emissions of volatile organic compounds and managing their transboundary flows: by 1999 Canada must reduce its emissions of volatile organic compounds by 30%, particularly in the Fraser Valley and the Windsor-Quebec corridor, and stabilize its nationwide emissions at their 1998 level; and

- the 1988 *International Nitrogen Oxides Protocol* entered into by Canada, the United States, and a number of European countries made it possible to stabilize emissions of nitrogen oxides at their 1987 levels by 1994; a second agreement is being negotiated.

Many initiatives are also being taken by the provinces, municipalities, industry, the private sector, non-profit organizations, and the public. For further information, consult the following sites.

http://www.ec.gc.ca/smog/beingdone.htm (updated August 1998)

http://www.ccpa.ca/english/library/RepDocsEN/NERMEng/smog.pdf (updated September 1998)

PRESENT AND FUTURE FEDERAL APPROACHES

Studies show that air pollution has indisputable effects on human health (see the section in this document entitled Effects Of Ozone, Sulphates, and Particles On Health). In order to alleviate the many effects of these pollutants and prevent still more serious problems, the federal government and various governmental partners have developed and adopted up a number of legislative tools. In addition, a broad range of programs in this area are being planned, discussed and set up. Following is an overview of the various programs; readers wishing to learn about the various legislative tools are referred to the section entitled Legislative Tools for Reducing Air Pollution in Canada.

Action Plan on Health and the Environment (APHE)

In partnership with Environment Canada, Health Canada carries out numerous studies to assess the effects of pollutants on the health of Canadians, particularly in cases of direct exposure. Health Canada monitors human exposure by providing target populations with portable devices for measuring the pollutants with which they come into contact; thus individual exposure can be compared with measured concentrations in the regions being monitored. In addition, under the APHE, programs are set up to monitor various pollutants and assess the risks they pose to health. Health Canada is also considering developing standards and regulations for allowable concentrations of certain pollutants. Described below are efforts to date for assessing the effects of smog on health, increasing scientific knowledge of these pollutants, and developing strategies to eliminate them from the environment in Canada.

Tailpipe Emission Inspection Clinics

For the 12th consecutive year, in 1998 Environment Canada is organizing free clinics for inspecting tailpipe emissions in order to raise public awareness of the importance of maintaining motor vehicles and reducing air pollution. Poorly maintained vehicles, which account for 20% of vehicles on the road, are responsible for 80% of total tailpipe emissions. Environment Canada also provides Canadians with access to the Canadian Weather Office, which issues information on smog conditions.

Management Plan for Nitrogen Oxides and Volatile Organic Compounds (VOC)

In 1990, the Canadian Council of Ministers of the Environment (CCME) adopted the Management Plan for Nitrogen Oxides and Volatile Organic Compounds; by 2005 this aimed to reduce (to 82 parts per billion) emissions of pollutants that contribute to the formation of tropospheric ozone. This Plan, the first of three phases, initially included 80 national and regional pollutant-reduction initiatives, most of which were successful. At that time, considerable gaps in the scientific data were noted and, as a result, in 1992 the Atmospheric Environment Service (AES) set up the Nitrogen Oxides and Volatile Organic Compounds Science Program. Under this program these two types of substances were scientifically assessed in order to obtain the data required by policy-makers in developing emission reduction strategies. The full 1996 report on this assessment of nitrogen oxides and volatile organic compounds can be seen at the following website.

http://www.ec.gc.ca/phase2/science_e.htm (updated August 1998)

On 7 November 1997, the Government of Canada, in partnership with Environment Canada, Natural Resources Canada, and Transport Canada, published Phase 2 of the Federal Smog Management Plan (the name of the plan changed after Phase 1 was completed in 1990). Phase 2, emphasizing transportation and industry, included 32 sub-initiatives grouped into the following four main initiatives:

- national and federally led initiatives affecting ozone and particulate matter;
- further initiatives to reduce ozone and particulate matter;
- continuing initiatives to understand and track smog; and
- international initiatives to reduce transboundary flows of smog.

Phase 2 describes provincial initiatives, achievements to date, future phases, recommendations for future federal action, regional initiatives and proposed federal initiatives. Also presented are regional initiatives and programs, proposed action by Canada and the United States, and Phase 3 of the plan. Phase 1, completed in 1990 by the federal and provincial governments, reduced smog, gathered data, and identified a need for Canada-wide air pollution standards. For further information, consult the following site.

http://www.ec.gc.ca/phase2/execsum_e.htm (updated August 1998)

The 1995 CCME Cleaner Vehicles and Fuels initiative is aimed at applying tailpipe emission standards to bring into service vehicles that produce 10% fewer nitrogen oxides and 7% fewer volatile organic compounds.

Canada-Wide Accord on Environmental Harmonization

On 29 January 1998, the federal and provincial governments, with the exception of Quebec, signed this Accord, aimed at improving environmental co-operation and protection in Canada. The Accord will allow these governments to retain their environmental jurisdiction while co-ordinating their work. Where environmental performance is concerned, the governments' roles will be better defined, and results will be made public. Also signed were sub-accords on environmental assessments; inspection activities; and the development of standards for air, water and soil quality. Standards on tropospheric ozone and particulate matter are also to be approved under this accord.

POTENTIAL BENEFITS OF SMOG REDUCTION

Smog is formed mainly above urban centres in the summer, and is composed chiefly of tropospheric ozone and particulate matter. The scientific community has made numerous studies of the effects of smog on health. Increasingly, these studies show that there is no minimum threshold at which humans are not sensitive to smog and that, to varying degrees, most persons can be affected. There have also been numerous studies on the financial costs of smog.

The studies consulted agree that, although the benefits of reducing smog are clear,(10) an accurate estimate of their monetary value is less so, given the multiplicity of possible sources of error.(11)

These studies were carried out using mathematical models producing quantitative estimates of the benefits of reducing air pollution. Where quantitative estimates were impossible, qualitative estimates were made. These studies dealt with tailpipe emissions, sulphur dioxide, nitrogen oxides, volatile organic compounds, and particulate matter measuring 10 microns in diameter or less. The hypothetical pollution reduction protocols used in these models varied depending on whether the studies were based on strategies developed at Rio, emission standards adopted at Los Angeles, the British Columbia Clean Vehicles and Fuels Program, or the United States Acid Rain Program.

Quantifiable factors cited were the costs of health care and of deaths, taking into account hospitalization and lost income; some models also attempted to quantify indirect costs such as pain and discomfort. The qualitative estimates indicate that reducing air pollution would have benefits in terms of mitigating its effects on health, for example by decreasing the number of premature deaths and the incidence of illnesses

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(10) Environment Canada estimates that reducing smog would save Canada nearly $10 billion annually.

(11) Chestnut, L G, *Human Health Benefits from Sulphate Reductions under Title IV of the 1990 Clean Air Act Amendments: Final Report*, Environmental Protection Agency, Office of Atmospheric Programs, Acid Rain Division, 1995; Lang *et al.*, *Environmental and Health Benefits of Cleaner Vehicles and Fuels: Supplemental Reports 2, 3 and 4*, 1995; CCME, Cleaner Vehicles and Fuels Task Group, *Benefits Study Results and Uncertainty Analysis*; The Acidifying Emissions Task Group, *Towards a National Acid Rain Strategy*, presentation to the NAICC, 1997; British Columbia, Department of the Environment, Lands and Parks, *Clean Vehicles and Fuels for British Columbia*.

such as chronic bronchitis. There would also be benefits in terms of effects on natural resources and property. Most studies did not predict that monetary benefits would be as great as direct health benefits in quantitative terms.

The studies emphasize the numerous possible sources of error in research of this type: responses to rates of pollutant concentration; estimating the monetary value of effects on health; changes in ambient pollutant concentrations; the populations studied; and environmental and monetary factors not known or not taken into account. The authors of the studies therefore suggest that the quantitative estimates may well underestimate the benefits that could be achieved.