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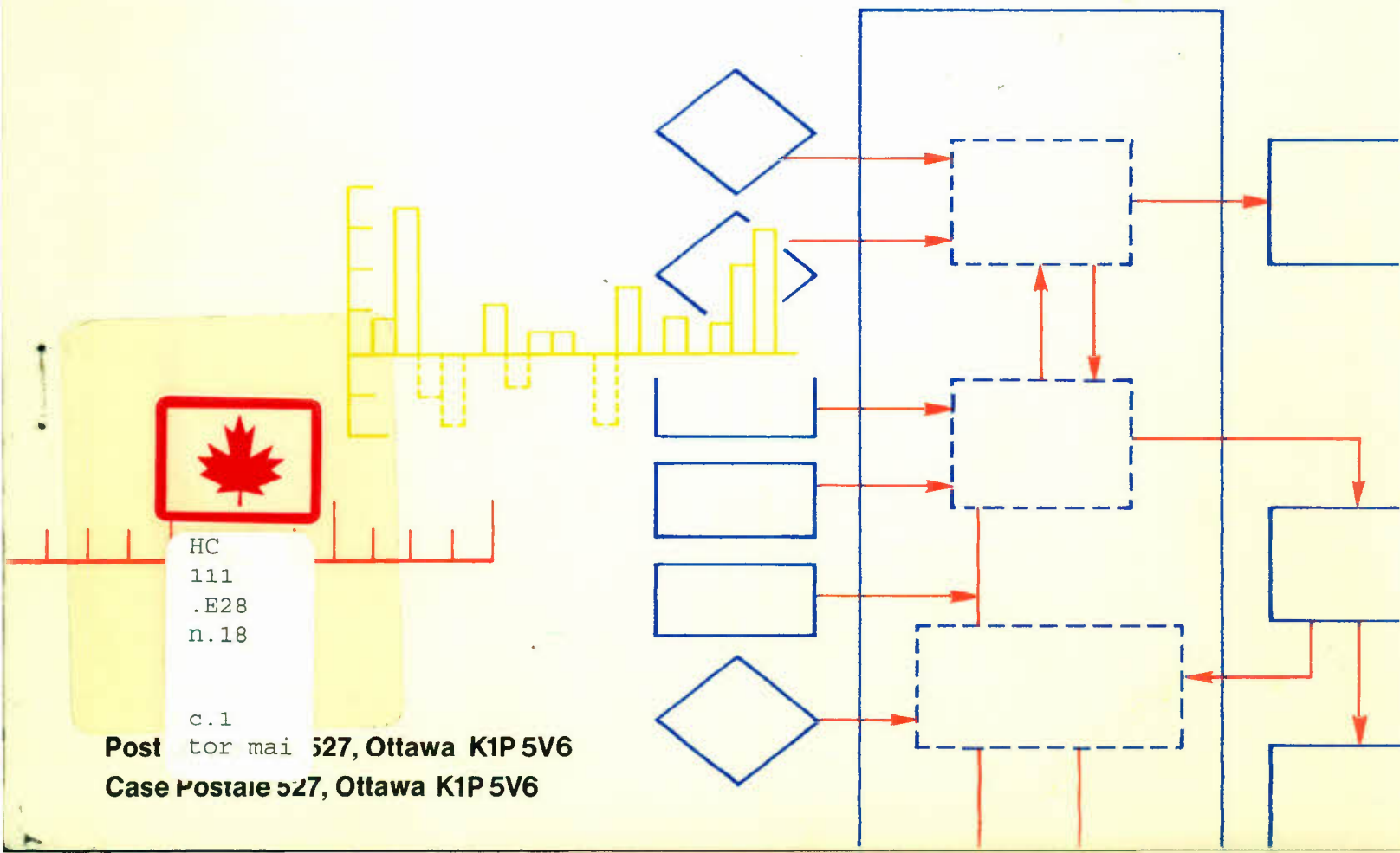

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DISCUSSION PAPER NO. 18

Air Quality in Canadian Urban Areas

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and Julian R. Walker

December 1974

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RÉSUMÉ

Dans ce document de travail, nous présentons un résumé de la recherche engagée dans la détermination d'un indicateur de première approximation de la qualité de l'air urbain, tel que présenté dans le *Onzième Exposé annuel* du Conseil économique du Canada. L'indicateur proposé et l'analyse des sources et des effets de la pollution de l'air présentés dans ce document visent à faire plus de lumière sur les facteurs à l'oeuvre dans ce domaine d'intérêt.

Étant donné que les mesures relatives à la concentration de l'un ou l'autre polluant de l'air ne peuvent servir de façon satisfaisante à indiquer le degré de contamination de l'air pour l'ensemble des polluants, il faut donc un indicateur qui cumule les effets d'un certain nombre de polluants. L'indicateur calculé de la qualité de l'air urbain exprime l'impact possible combiné de plusieurs polluants, pondéré de façon à tenir compte de leurs effets distincts et conjoints sur l'environnement.

L'indicateur de la qualité de l'air urbain présenté dans ce document porte sur 11 villes canadiennes représentant environ 60 % de la population des centres urbains de 10,000 habitants ou plus, et il est calculé sur une période de trois ans (1971-1973). Les valeurs de l'indicateur laissent voir que dans l'ensemble, la qualité de l'air dans ces centres urbains s'est améliorée durant cette période. Les mesures utilisées pour établir l'indicateur agrégé permettent des comparaisons entre les villes et entre les impacts relatifs des divers groupes de polluants. Au cours de cette période, la qualité de l'air s'est améliorée dans le cas de quatre des cinq groupes de polluants, et de dix des onze villes étudiées.

Dans l'établissement d'objectifs en vue de l'amélioration de la qualité de l'air, les décisionnaires doivent tenir compte des coûts et des avantages découlant de la réduction d'un polluant parmi plusieurs. Ce document souligne les effets potentiels des polluants de l'air sur la santé, mais indique aussi la nécessité de recherches beaucoup plus poussées sur les effets globaux de la pollution de l'air, afin d'aider à l'établissement d'objectifs, en particulier quant aux polluants les plus dangereux.

Les programmes et politiques visant à réaliser les objectifs énoncés quant à la qualité de l'air, doivent porter sur la génération des polluants et leur émission dans l'atmosphère. Dans ce document, nous étudions les niveaux d'émission et les tendances, ainsi que les principaux facteurs qui y contribuent. Le document renferme également une brève description des variables pouvant aider à établir le lien entre les émissions et la qualité de l'air ambiant.

Il ressort de ce document quelques idées générales quant à l'orientation que pourrait prendre de nouvelles recherches concernant la qualité de l'air urbain.

ABSTRACT

This discussion paper presents a summary of the research involved in the determination of a first-approximation urban air quality indicator, as presented in the *Eleventh Annual Review* of the Economic Council of Canada. The proposed indicator and the associated discussion of the sources and effects of air pollution presented in this paper are intended to provide some insight into the factors at work within this area of concern.

Since the measures related to the concentration of any single airborne pollutant do not adequately serve as a proxy for the presence in ambient air of all pollutants, an indicator which aggregates the effects of a number of pollutants is required. The calculated urban air quality indicator expresses the combined potential impact of the several pollutants, weighted so that their separate and joint effects on the environment are taken into account.

The urban air quality indicator presented in this paper covers 11 Canadian cities representing about 60 per cent of the population in urban centres of 10,000 or more, and is calculated for three years (1971-73). The values of the indicator suggest that the quality of air of these urban centres has improved overall during this period. The measures that are used to derive the aggregate indicator permit comparisons between cities and between the relative impacts of the various pollutant groups. Over this period, the quality of the air improved for four of the five pollutant groups, and for ten of the eleven cities studied.

To set objectives for improvement in air quality, policy-makers must consider the costs and benefits associated with the reduction in any one of several pollutants. This paper emphasizes the potential effects of air pollutants on human health, but it also suggests the need for much more research on these and other effects of air pollution to aid the setting of objectives, particularly with respect to the potentially most dangerous pollutants.

Programs and policies designed to achieve the benefits expressed by stated objectives with respect to air quality must relate to the generation of pollutants and their emission into the atmosphere. This paper considers emission levels and trends, and the major factors which affect them. It also describes briefly those variables that may be instrumental in establishing the linkage between emissions and ambient air quality.

Some general directions that further research on urban air quality might take are suggested throughout this paper.

ACKNOWLEDGEMENTS

Essentially, we do not consider ourselves as experts in the field of environmental studies. We have had to rely on experts involved in the sciences directly related to the study of the generation of pollutants, the atmospheric environment and the effects of pollutants on humans, plants and animals and physical structures and formations. In general, we made a great deal of effort to communicate our requirements to these experts and they, in turn, responded to our enquiries in a manner which we could understand.

The following list of institutions and organizations does not exhaust the full range of experts with whom we dealt; this list does include the sections of these institutions which were most helpful in providing guidance and/or information. To the individuals who so generously helped us, we express our appreciation; however, they are in no way responsible for any misrepresentations that we may have made in our summation of the issues at hand.

Alberta

-- Department of the Environment

Air Quality Control Branch
Environmental Protection Services
Pollution Control Division

-- Department of Health

Statistics and Research Division
Hospital Insurance Commission

Saskatchewan

-- Department of the Environment

Air Pollution Control Branch

Ontario

-- Ministry of the Environment

Air Quality and Meteorology Section

-- Ministry of Health

Research and Analysis Division

Quebec

-- Services de protection de l'environnement

Montreal

-- Communauté Urbaine de Montréal

Service de l'assainissement de l'air et
de l'inspection des aliments

Federal Government

-- Energy, Mines and Resources

Fuels Research Centre
Canadian Combustion Research Laboratory

-- Environment Canada

Abatement and Compliance Branch
Atmospheric Environment Services

-- Health and Welfare Canada

Bureau of Health Hazards (Air and Water)
Environmental Health Directorate
Planning and Evaluation Directorate

-- National Research Council

Other

-- The Canadian Manufacturers' Association

Environmental Quality Committee

The authors also extend their thanks to David Henderson for his editorial assistance and to Suzanne Dorion for typing and proof-reading these pages.

Dennis M. Paproski
and Julian R. Walker
December 1974

Chapter 1

BACKGROUND

A. Introduction

Objective and Scope

Although much of Chapter 1 of this discussion paper applies to the examination of any environmental condition, the short-term objective of the research into first approximations of *principal environmental indicators* has been to derive measures of urban *air* quality that describe major components affecting this quality, and provide a basis from which to consider some of the factors at work in this particular subsystem.

We approach the examination of this subsystem with due reservation. It would be quite straightforward to examine any subsystem of the entire array of social, economic, and environmental areas of concern *if* a comprehensive social research framework existed, one which explicitly incorporated direct and indirect relationships between all areas or subsystems. Such a framework does not exist. However, in pursuing our research, subsystem by subsystem, the lines of interconnection may be revealed and through successive approximation, a total framework may evolve and revised "second-approximation" indicators for each subsystem may be derived within a "total reality" perspective.

We have defined our enquiry very narrowly in that we have not explicitly examined the linkages between all parts of the environmental subsystem. For instance, we

know that air pollution can lead to soil and water pollution since many airborne pollutants eventually return to the surface in one form or other. Likewise we have not examined how these three forms of pollution may combine to induce a disutility in some target population. As an example of this complexity one may well consider the case in which human activity generates residuals that are initially found in the air. Over time, many of these residuals will fall out and contribute to the levels of residuals in the water and soil environments. It may be, therefore, that a population could be affected by the residual in question by breathing polluted air, drinking polluted water, or eating food that contains the pollutant as a result of its deposition directly on plant life or its absorption by plants from soil upon which it has been deposited. In an indirect way, given that man is at the end of the food chain, air, water, and soil pollution that affects plant and animal populations may eventually return to affect man himself.

Although we attempt to keep these complex factors in mind throughout our investigations, we have only examined, in an explicit way, some of the *direct* aspects of air quality with particular emphasis on the relationship between air quality and the human population. Thus the scope of our research was limited by numerous factors not the least of which was a time and data constraint.

Social Indicators[1]

Social indicators are considered to be the operative parameters in the model of a particular socio-economic subsystem or specific aspects of this subsystem. In this *quantitative* dimension, the designated outputs of the subsystem and the inputs that have a bearing on the outputs are combined to permit something of an understanding of the functioning of the subsystem, and to do so in such a way that trends over time are apparent. In this quantitative orientation, social indicators are not fundamentally normative in that direct value judgments as to whether conditions or changes are necessarily "good" or "bad", "too much" or "too little", are not inherent in the values of the indicators. Thus, our first-approximation indicators are quantitative, relative and non-normative.

Since our present investigations relate to one aspect of the environmental subsystem, the atmosphere, it is best to avoid the normative conclusions that are so often drawn on the basis of a partial view of reality. If, for instance, the concentration of airborne pollutants is reduced as a result of, say, the strict imposition of certain regulations on industry, it is impossible to say whether this is a good thing or not; we would have to know the benefits arising from the reduction in the negative effects caused by these

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[1]D. W. Henderson, *Social Indicators: A Rationale and Research Framework*, Economic Council of Canada (Information Canada: Ottawa, 1974). This work provides the general conceptual basis for our investigations into environmental, as well as other, indicators.

same pollutants *and* the cost to individuals and the society of factors such as any reduction in profitability or the shutdown of marginal plants (along with any associated impact on investment, employment, and income), before any statement as to the net total effects could be made.

We seek, therefore, to make statements, though our derived indicators, of how air quality conditons have changed from the viewpoint of the possible *direct* environmental effect on populations potentially affected by such changes. In the context of the example discussed above, a reduction in the concentration of airborne pollutants for a given population will make the indicator of "pollution" fall, regardless of whether other socio-economic indicators show improvement or not.

As suggested by the above comments, environmental indicator statistics, by themselves, can only be of certain help to those who set goals and objectives and select policies and programs for society, since these measures represent only one aspect of the many that should be taken into consideration. However, the usefulness of any economic, social, or environmental indicator can be increased by supplementing it with a description and explanation of some of the factors which influence changes in the indicator. This paper and the material derived from this research which is included in the *Eleventh Annual Review* of the Economic Council of Canada therefore examine some of the effects of air pollution, the environmental conditions which give rise to these effects, and

the human activities which contribute to these conditions. The intent of the investigation is to provide some assistance to those who set objectives related to effects and to those who set policies or strategies (related to sources of residuals) designed to achieve these objectives. This paper reports on the research undertaken over an eight-month period and presents our findings in terms of an urban air quality indicator and several sub-indicators which are consistent with the definition of social indicators stated above.

Background

Canada is a vast country. As others have suggested, if the residuals of human activity in Canada were or could be distributed over the land, water and air expanses below the Artic and sub-Artic areas, there is little doubt that "pollution", in any real sense, would be relatively unimportant. Nature has a capacity to assimilate or adapt to at least small concentrations of most elements and compounds. Of the problems that may exist, most are the result of the scale of residual generation in *local* or *regional* contexts. Large urban centres and/or large-scale, geographically concentrated industrial activity centres are of particular concern in our investigations. These are the centres of both massive residual generation and of human populations potentially "at risk". We recognize that environmental damage may occur within a nonurban context as well, particularly in cases where the residuals are slow to degrade by reason of their chemical

natures (pesticides for example) or because the local environment is not capable of rapid assimilation of residuals of most sorts (as in the Arctic and sub-Arctic areas of the country). In *any* context, whenever the capacity of the environment to assimilate residuals is exceeded by the deposition of residuals into the environment, the conditions for "pollution" exist. There are conditions in which an excess of residuals may have no discernible effects on man, plants, or animals (e.g., gravel deposits, and sanitary land fill matter) and, as such, these would not fall into our definition of pollution.

We thus perceive "pollution" to describe conditions wherein residuals of human activity are in excess of the environmental assimilative capacity at any moment in time *and*, wherein this excess, by itself or in conjunction with other natural and human conditions, has a significant potential to affect humans adversely and/or to cause damage to plant and animal life. This definition permits us to talk about "acceptable" levels of pollution. In other words, it seems realistic to admit that a series of trade-offs exist within the range from zero pollution generation to a high degree of pollution, trade-offs that describe real-world situations where the costs of "pollution" are weighed against the benefits derived from human activities that lead to residual generation.

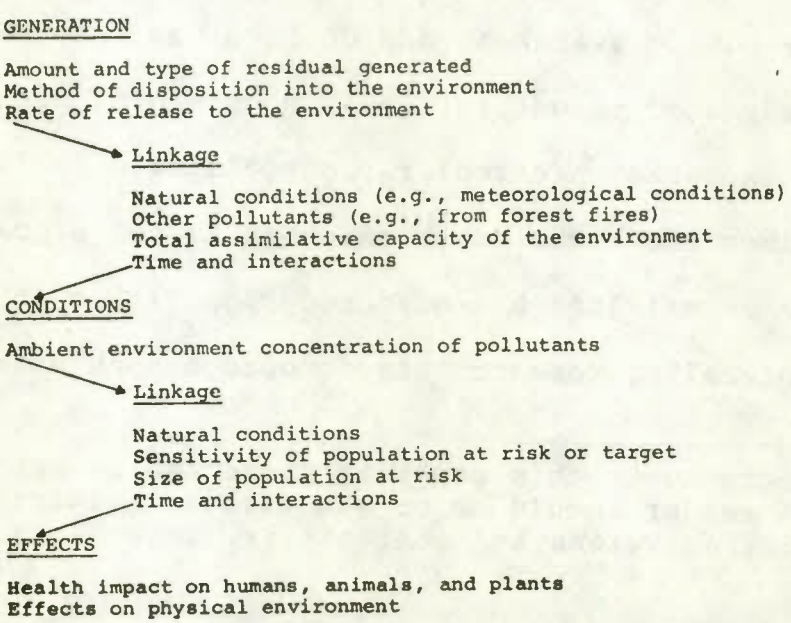
Attention is drawn to the implication that there are three segments to this conception of the environmental

system; human generation of residuals (from production and consumption), the resulting conditions of the ambient air into which these residuals are passed, and the effects or impacts of these conditions caused by any excess of residuals left after assimilation, dispersion, and other factors have acted on the generated residuals. There is, therefore, a time dimension to be considered as well. For instance, an excess of a residual in the ambient environment may exist for only a moment, or it may persist for some time. This excessive residual (which we label a "pollutant") may dissipate quickly or it may accumulate in the environment over time.

It should be obvious, because of these time considerations alone, that the linkages between residual generation, environmental conditions, and the impacts of pollutants are extremely complex. The linkages which are probably the most important are listed in Figure 1.

Figure 1

AN ENVIRONMENTAL SYSTEM STRUCTURE



Because we perceive pollution to have some negative effects, it seems logical to ascertain just what effects (if any) may have arisen in conjunction with excesses of residuals in the environment.

B. The Effects of Pollution

Direct Effects

A considerable body of research related to the effects of pollutants on human populations, plant and animal life, and the physical environment already exists.[2] This research indicates that the effects of pollutants are related both to the duration and level of exposure on the one hand, and the susceptibility of the "target" to single and groups of pollutants on the other. When a single target is exposed to a number of pollutants, it appears that the effects of the pollutants within a particular array can be additive, synergistic, or neutralizing, depending on the pollutants.

In respect of the concentration consideration, much of the public awareness and concern has related to acute exposures of targets; that is short-term, high concentration exposures particularly associated with "disasters" at which times the human death rate has jumped significantly or plant or animal life has suffered significant physical damage. Generally, research has focused on one and sometimes

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[2]The bibliography to this paper is presented by subject matter to aid the reader should he or she wish to examine: emissions, ambient air, emissions and ambient air, impacts, and general.

two pollutants; an association has been found between peaks of pollutant concentrations of these select pollutants and the damage suffered by a target, and conclusions have been drawn as to cause and effect. On the other hand, research into the possible effects of low-level, long-term exposure to pollutants is less well developed, although cross-sectional analysis, which may pick up an association between some result and generally prevailing environmental conditions, has been undertaken by a substantial number of authorities. In all, there has been a tendency to omit a number of pollutants from equations designed to explain the observed changes or differences in certain characteristics of the target population over time or from place to place. In addition, there has been too little recognition, outside the field of epidemiology, of the fact that pollution may either *cause* a reaction or *aggravate* a pre-existing condition in the target population. If, as is the case in most epidemiological studies, a pollutant or several pollutants aggravate a pre-existing condition or susceptibility, all the factors that bear on the total body burden must be known if we are to understand why such aggravation occurs. For example, smoking habits probably play a major role in the susceptibility of certain individuals to the ill effects of some ambient air pollutants. An alternative way to identify the various effects is to expose sample populations to pollutants in a laboratory setting where all other factors can be controlled. Some such work has been carried out with plant and animal targets being exposed to one or two pollutants

for various times and at various concentrations; one cannot work so freely with human subjects at extreme exposure levels.

Still, experience derived from medical examinations of patients (or cadavers) who have been exposed to high concentrations of pollutants by accident or at work allows experts to generalize as to possible community effects based on the specific reaction of these victims.[3] To a considerable extent, critical reaction has occurred at exposure (time and concentration considered) levels far in excess of ambient (community) conditions. At the levels of pollution to which members of the community are exposed or expose themselves (as in swimming in a stream or lake known to be polluted), human reaction seems to vary from minor (perhaps best illustrated by skin rashes or eye irritation) to moderate (hospitalization for a pollution-related cause). Deaths associated with community-wide pollution generated by human activity have not been documented in Canada to date (to the authors' knowledge), with the rare exception of certain typhoid and paratyphoid deaths connected with accidental pollution of drinking water. A recent examination, on a cross-section basis, of morbidity in a number of Canadian cities revealed no significant role for two air pollutants;

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[3]Numerous incidents of isolated acute exposures that warn of the possible effects of community exposure to very high levels of particular pollutants can be found in the literature. For example, Harry Heimann, "Status of Air Pollution Health Research, 1966", *Archives of Environmental Health*, Vol. 14, March 1967 (pp. 488-503) provides a summary of such incidents related to a number of highly toxic pollutants; arsenic compounds, mercury, beryllium, lead and others.

lead and particulates.[4] This, of course, does not rule out any yet undetermined effects on morbidity or mortality of longer-term exposure to low or medium levels of other pollutants.

Our definition of pollution states that disutility arises from an excess of residuals in the environment. A complete examination of pollution-related effects on human beings, animals, plants, and/or the physical environment, through direct and indirect channels, would seem to be required to understand the full impact of pollution. This reaches far beyond the scope of our present work. Given the scarcity of research results to do with the effects of ambient pollution within a Canadian context, we have undertaken an examination of the human response (in terms of hospitalization for respiratory conditions) to ambient air pollutant concentrations for three cities (see Chapter 3). The objective of this examination was to provide some indication of the relative importance of several airborne pollutants generally found and measured in a number of urban centres. One of our observations is that pollution of ambient urban air in Canadian cities has only some *direct* impact on the respiratory tracts of the segments of the population most susceptible to hospitalization for these categories of health conditions.

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[4]Joel Diena, "Have the Health Effects of Air Pollution Been Oversold? - The Canadian Experience", *Proceedings of the Specialty Session*, 67th Annual Air Pollution Control Association Meetings, June 1974, Denver, Colorado, pp. 23-27. Mr. Diena's examination of morbidity related to respiratory conditions considered lead and particulates only.

However, from what we have stated before, our investigations do not imply that airborne pollutants are correspondingly limited in their full impact. Obviously, long-term, low-level exposure could be contributing to a wide variety of health problems, including those that are not sufficiently severe to warrant hospitalization. Because our indicators are not "qualitative" and thus do not incorporate consideration of perceptual disutilities, there may be many direct effects, real or perceived, besides contributions to respiratory ailments. As well, we have not carried out any analysis of damage to plants, animals, and the physical environment.

Indirect Effects

Because man is perceived to be a part of the ecological system, consideration of pollution damage to the nonhuman environment must be incorporated into any comprehensive calculation of the effect of single pollutants or groups of pollutants. These indirect effects on the human population are even less well understood than the direct effects. This situation calls for scientifically based development of "ecological impact indicators" particularly since the species affected within even a very small area are numerous and, therefore, the magnitude of required sampling, in terms of individual plants and/or animals, would be extremely large. Briefly, these indicators would "measure certain variables that indicate the presence or conditions of phenomena that cannot be measured directly".[5] Some species

[5]Norman E. Cooke, "Some Practical Details About Environmental Impact Assessment", *Proceedings: Environmental Impact Assessment Seminar*, sponsored by the Canadian Manufacturers' Association, Toronto, October 16, 1973, p. 42.

could be described by certain indicator groups consistent with biological classifications such that, given food chain, predator-prey, or other relationships, a change in any section of the groups should bring about some deviation from the normal in the sample indicators. Such a system of indicators would be able to pick up changes due not only to destruction of one part of the biological chain but also those due to any enforced migration to or from the environment being monitored.

As man is part of the biological network, the linkages between the direct effects on plants and animals of pollutants created by human activity, and the eventual (indirect) impact on man himself must be examined most carefully in the future. These linkages, at present, are not specifically defined.

Summing the Effects

Given that the effects of pollution are many and complex, it was necessary for us to rely on the evaluation of impacts made by the scientifically oriented experts in the field. In order to compile aggregate measures or indicators of the potential impact of pollution on a target population, it is necessary to find a common denominator for all the pollutants. The base which we have chosen is the relative severity of impact of each pollutant at a given

level of concentration.[6] In addition, it is necessary to incorporate consideration of the fact, derived in laboratory tests,[7] that two or more pollutants jointly may have a greater impact than merely the sum of the separate effects of the two or more pollutants. In Chapter 2, the calculations of relative severity factors and synergistic effects are presented.

C. The Condition of the Environment

Earlier we defined pollutants as those excess residuals in the environment that have a significant potential to cause negative effects on living organisms and the physical environment. The condition of the environment

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[6]The concentration considered for the gaseous pollutants is with respect to parts per million in air. The solids which are measured as a coefficient of haze, the light blocking characteristics of particulate matter suspended in air, is converted to an equivalent value by assuming that, at the criteria for desirable ambient air conditions, the relative severity of sulphur oxides times the concentration (in ppm) at criteria is equal to the relative severity of particulate matter (in coefficient of haze terms) times the relevant reading at criteria. This ratio, in the case of two published criteria, implies that 10 coefficient of haze units approximate 1 part per million of sulphur dioxide. The San Francisco criteria (see Lyndon R. Babcock, Jr., *A Combined Pollution Index for Measurement of Total Air Pollution*, a paper presented at the 63rd Annual Meeting of the Air Pollution Control Association, St. Louis, June 1970, p. 12), and the Province of Ontario criteria (see *Air Quality Monitoring Report, Ontario, 1972, Volume 1*, Ministry of the Environment, Ontario, Toronto, 1974, p. 10) both support this relative severity criteria ranking.

[7]For instance, 12 volumes of laboratory results on the effects of various combinations of sulphur-based compounds and/or particulates on animals have been published by the Hazleton Laboratories, Inc., Vienna, Virginia. The tests represented by these reports were carried out over the years 1969 through 1973 and were financed by the Electric Research Council of the United States.

that we would hope to have represented by an indicator is the concentration and the duration of concentration of these pollutants in local settings. As we mentioned in the introduction, our major concern has been directed to centres of population (consumption) where the probability of widespread direct effects on the human population is greatest and where ambient environmental conditions are scientifically monitored.

In our air quality studies, data in respect of the quantity (concentration) and duration of pollutants in ambient air was available, on a more or less consistent basis, for only three years (1971-73) and eleven cities. Although certain measures of sulphur oxides and particulate matter are available for over 30 cities, other pollutants were measured only in a limited number of urban areas over the period 1971-73. This explicit concern with these two pollutant groups stems from the fact that they may be perceived by the human senses, visually or by odour. Also, they have been associated with pollution disasters noted earlier and they may well have been the most important pollutants before the conversion of space heating and locomotive power from coal to natural gas, oil, and diesel fuel, before the sharp rise in automobile use, and before the increasing concentration of population and industrial activity. The main sources of pollution generation and, therefore, the main residuals and by-products of residuals (in consideration of the direct effects on human health) have undoubtedly changed over time. The measurement of these other pollutants has not been widespread in Canada.

From our examination of the effects of ambient air pollutants it appears that oxidants and nitrogen oxides may be more dangerous to human health than has previously been generally recognized. That is to say, at prevailing concentrations, this group of pollutants is significantly associated with hospitalization for respiratory ailments as will be discussed in Chapter 3. But measurement of this group has been intermittent for most urban areas and somewhat inconsistent from one area to another because of differing measurement techniques. Since the preconditions required for the formation of ozone (the major component of oxidants) include sunlight, certain nitrogen oxides, and hydrocarbons, one must also look at the conditions governing the presence of the relevant man-made residuals; after all, the "controllable pollutants" are the only ones for which policies and programs can be devised.

Ozone occurs naturally in the upper atmosphere where it provides a protective layer against excessive exposure to ultraviolet rays at the earth's surface. Small amounts of nitrogen dioxide formed from the two most abundant elements of air (nitrogen and oxygen), together with hydrocarbons emitted by vegetation may also lead to ozone formation at high altitudes on the earth's surface, providing there is abundant sunshine. There is little man can do, or should want to do to affect such instances of natural ozone generation. In centres where automobile use is high, however, this vehicle generates both nitrogen oxides and hydrocarbons and therefore, should sunlight also be prevalent, the preconditions for photochemical production of ozone exist.

Add to the automobile those activities that involve high temperature combustion (thermal electric plants, diesel engines, etc.) and the potential for nitrogen oxide emissions to the ambient air increases considerably. Measurement of nitrogen oxides and hydrocarbons in ambient air would thus seem to be warranted in all relatively large urban centres in Canada. Because the pollutant category "hydrocarbons" is composed of a wide array of compounds with a few distinctly related to cancer formation, some related to photochemical reactions, and some not being related to any specific effects in the short-run, existing measures of total hydrocarbons are rather inadequate for describing the condition of urban air. In other words, it is not because hydrocarbons have little or no impact on the human condition in the long run that we have decided to leave this category of pollutant out of the calculations of air quality, it is because we are uncertain as to the degree to which the measures are meaningful. It should be noted also that, because of these considerations, no criteria of "acceptable concentrations" have been presented by any provincial or federal environmental protection agency.

Another group of pollutants, one which, like hydrocarbons, tends also to be highly heterogeneous, is the particulate matter category. Dust particles may vary a great deal in size, shape, colour, and chemical composition within any one sample and, obviously, from place to place. In the last several years, detailed analysis of the chemical composition of particulate matter has been undertaken by means of high volume samplers which collect dust over some period

of time; this dust is subsequently analysed for its chemical properties. It should be obvious that dust with a high lead content will lead to somewhat different reactions in target populations than dust with high iron or asbestos concentrations. High volume samples of particulate matter, although not providing a continuous monitoring system, should eventually provide a better measure of airborne solids than the presently widely utilized measure termed the "coefficient of haze". This measure is essentially a continuous measure of the light blocking character of airborne dust. At any one sample site the correlation between this coefficient of haze and total particulate matter measured by high volume samplers may be quite high but this relationship will vary from centre to centre depending on prevalent sources of these particulates. Since, however, the coefficient of haze statistic is collected in most urban centres on a consistent basis and since criteria for the acceptable levels of particulate matter so measured have been expressed by the Province of Ontario, the coefficient of haze has been incorporated in the indicator of urban air quality.

There are, likewise, a number of reservations concerning the measurements of carbon monoxide in ambient air; these reservations are those related to the use of data generated at certain points as proxies for conditions prevailing at all other points in an urban centre. Obviously the implied (from point data) quality of the entire mass of air over the metropolitan region will depend on the number and location of monitoring stations within the area. The

registered concentration will vary greatly in both the horizontal and vertical dimensions from the point of measurement. This is true, of course, of all pollutants, but it is particularly true for carbon monoxide, the readings for which vary more than for other pollutants over short distances. It is therefore necessary to assume that monitoring stations are located so that representative measures of any pollutant, and particularly carbon monoxide, are made for the entire urban air mass.

With this matter in mind, we can make the following summary. Sulphur dioxide and coefficient of haze measurements are most representative of area-wide conditions because they are monitored at a number of sites in almost every urban centre. Nitrogen oxides and oxidants, although measured at only a limited number of sites in most of our sample cities, are generally representative of urban air concentrations of these pollutants, while carbon monoxide measures are most site specific of the pollutants that are, in fact, monitored. The assumption we are obliged to make at this point in time is that the average concentration for more than one monitoring site, or the data for a single monitoring station, serve as adequate proxies for the average air quality which the entire metropolitan population breathes.

Earlier it was stated that the impact of pollutants is a function of the duration of exposure and their concentration. Obviously, the criteria for acceptable air quality for short periods of time are expressed in terms of higher

concentrations than the acceptable criteria for longer time periods. Longer-term averages may not always be sufficient measures of the possible impact of air pollution since the longer the period over which the average concentration of air pollutants is measured the more likely it is that acute exposures (short-duration, high-concentration) will be obscured in the average figure. Included in Chapter 2 are 1973 data showing the proportion of days for which the 24-hour criteria were exceeded for each of several pollutants in each city. However, our investigations concerning average daily and weekly hospital admissions for certain respiratory problems and their relationship to average hourly concentrations of pollutants over the same length of time (lagged by one day) indicate some significant association for certain pollutants even if the 24-hour criteria were not exceeded at any time. Likewise, it does not necessarily follow that hospital admissions are highly correlated with frequent occasions, in some cities, during which the criteria for some pollutants (particularly sulphur dioxide and particulate matter) are exceeded. For this reason, the average concentration of a pollutant may be a better measure of the impact on the environment over a year than measures concerned with the percentage of time the criterion for this pollutant was exceeded.

The condition of the environment is not necessarily fully described by the pollutants which are measured. Our indicator has explicitly included only five of them, and, in using them, we have had to assume that:

(a) the measures reflect the average community air quality;

(b) the measures capture the potential effect of short- to long-term and low- to high-level exposures; and

(c) the measures themselves are reasonable descriptions of the pollutant when the composition of the pollutant is varied (e.g., particulate matter).

D. The Sources and Assimilation of Pollutants

The residuals in the atmosphere come from two sources -- from human-directed activities and from the natural generation of airborne gases, solids and liquids. The concentration of these residuals is, in part, a function of the degree to which the natural cleansing activities are overburdened with respect to the *total* load on the natural assimilative capacity. In general, the man-made element of pollution is the only controllable parameter, and thus the importance of human activity should be viewed from the perspective of the assimilative capacity less the background natural occurrence of any potential pollutant.

A second factor to be considered is the way in which the natural assimilative capacity of the environment can be utilized to absorb residuals without damage to the environment. It is possible to control river flow to minimize the effect of effluents of human activity, to design solid waste disposal facilities that do little damage to the ecology, and to arrange disposal of residual emissions to the atmosphere

such that plume contact with the surface is as wide and diluted as possible. In the shorter term, these types of approaches may indeed meet the objective of reducing the local concentrations of and damage from pollutants. At some point, however, the control of pollutant generation itself becomes necessary, assuming a finite natural assimilative capacity.

The obvious way of curbing pollution of the environment is to reduce the quantity of pollutants allowed to "escape" to the environment. The residual-creating activity may be controlled via input substitution or process improvement, or the residual may be captured or treated to render it assimilable or recyclable. For example, sewage treatment may be used to effectively minimize undesirable liquid effluents, and potential airborne pollutants, some of which can be recycled, may be captured or converted in the chimneys or exhausts of industrial or combustion equipment.

In consideration of human activity which has led to pollution of the ambient environment, it must be restated that the concentration of pollutants in the air (as measured in our sample urban areas) are in fact measures which describe the *net* result of pollution generation, pollution control, assimilative capacity, and atmospheric conditions as affected by wind, vertical air movement, humidity, temperature and other natural phenomena. The "background level" of any pollutants is also part of each reading (in fact, it may be difficult to separate man-made from background contributions). While we explicitly

consider the general sources of pollutants in Chapter 4 of this paper, the sources of pollutants are not directly incorporated into the indicator. In Chapter 4 we investigate the major sources of air pollutants and consider the linkages between the sources and the air quality indicator, the calculations of which follow in Chapter 2.

Chapter 2

A FIRST-APPROXIMATION AIR QUALITY INDICATOR

A. Introduction

The quality of the air environment was considered the most crucial aspect of environmental quality since, unlike water pollution and soil pollution, the opportunity to avoid being subjected to this form of pollution is quite limited. One can avoid polluted water by not partaking in aquatic recreational activities in such water. Further, most Canadians are served by drinking water systems which effectively remove all water-borne bacteriological risks to human health. We are presently investigating the role of trace metals and other chemical aspects of drinking water to ascertain whether non-biological agents are contributing to the health conditions of Canadians; drinking water may not be as "pure" as we have thought it to be, but the presence of man-made pollutants in drinking water is a relatively minor problem.

In addition, the affluence of the Canadian consumer generally allows him or her the opportunity (given the necessary information) to avoid reliance on any one foodstuff or any one source of any foodstuff whereby a regular consumption of food tainted by man-made pollutants could lead to negative effects on human health. There also exist several public authorities which are supposed to have the expertise and power to prevent the marketing of highly polluted foodstuffs.

Air is different. Avoidance of polluted air can only be achieved by choosing one's place of residence away from areas of highest concentrations and durations of exposure, an option which is hardly practical for the largest part of the population. The involuntary nature of the population's subjection to air pollution in general leads us to choose this aspect of the environment for our investigations leading to the compilation of an environmental quality indicator.

In our first-approximation indicator, we incorporate three factors: measures of pollutants in the air, the relative severity of the several pollutants per unit of concentration, and the population at risk from exposure to these pollutants. Since, as was pointed out previously, the measures of pollutant concentrations in ambient air implicitly reflect the net amount of residuals (i.e., pollution generation plus or minus the effects of in-atmospheric changes), the indicator will implicitly take account of some aspects of pollution sources and generation. Thus, directly or indirectly the indicator incorporates consideration of the air environment "system" -- the generation of pollutants, ambient air quality conditions, and the impact or effects of these conditions.

B. Ambient Air Conditions

The mean hourly concentration (over the year) of each pollutant in each urban area has been chosen as the

measure most relevant to the description of ambient air conditions. We readily admit that this is not an ideal measure. Public concern regarding pollutants must relate to short-term, high-level exposure, as well as to longer-term, lower-level exposures. Use of this measure cannot capture precisely the shorter-term, higher-level dimensions of the condition which we are examining. As an example, a person may be exposed to a variety of concentrations of carbon monoxide over a certain period of time. On the average the concentration may be quite low and appear relatively safe; however, short instances of acute and dangerous exposure may have occurred during this period.

Exposure should thus be viewed in two ways for each pollutant; the instantaneous impact of high exposure, and the continuous and sometimes cumulative effect of various lower levels of exposure. The impact of the level of exposure during a particular interval of time is affected by the level of exposure in previous and subsequent intervals. If one could assume that the impact of exposure to one or more pollutants is linear over the entire actual range of concentrations and time periods, the mean concentration is probably the preferred statistic to capture the essence of urban ambient air quality. For our purposes, we had to assume linearity over the full range of actual pollutant concentrations even though there is a great deal of uncertainty in our minds as to the realism of such an assumption.

To illustrate the reason for this uncertainty, assume that the average concentration of pollutant *X* over one hour is 2 parts per million (ppm); we do not know if 4 ppm over one hour is less than twice, twice, or more than twice as important. Likewise, we do not know the exact "duration of exposure" relationships over time. For instance, is 4 hours' exposure at, say, 2 ppm exactly twice as critical as 2 hours' exposure at 2 ppm? Authorities who have the responsibility of setting criteria for desirable ambient air quality have stated criteria points (from which our "relative safety factors" are derived in the following section) but a continuous relationship between these points has not yet been derived. One attempt at weighting a moving hourly average to take into account the cumulative effect of exposure and the recuperative period provided by reduction of pollutant concentrations to zero yielded a variable which did not marginally improve the explanatory power of the same variable expressed as a weekly average in our respiratory ailment equations (see Chapter 3). Therefore, despite the reservations regarding the use of the mean annual hourly concentration of a pollutant, this appears to be the best measure to employ at present. The assumption that we have had to make is that the mean measures represent the true value of any airborne pollutant, with respect to the potential impact of air pollution on a population.

The annual hourly mean measures are derived from data provided by provincial authorities with the exception of the data provided by the Montreal Urban Community.

Some of the data from the provinces were generated solely by their own monitoring stations and other data were the result of joint monitoring programs involving both Environment Canada and the provinces.

Oxidants: Measurement and Effects

The pollutant group referred to as oxidants or total oxidants generally includes 80 to 90 per cent ozone. Our epidemiological investigations (see Chapter 3) indicated that oxidants are, at a given concentration, the most significant of all pollutants examined in explaining hospitalization for respiratory ailments. All air quality criteria known to the authors also attribute relatively high effects to oxidant pollution compared to an equal concentration of other pollutants. The measurement of this group of pollutants, however, is not undertaken in many urban areas, and it is not monitored as extensively in either a geographic or a time perspective as are most other pollutants. Further, there are several monitoring techniques which do not necessarily yield precisely comparative measurements. Many authorities appear to be moving towards the measurement of ozone directly by the relatively precise chemiluminescence technique. It is believed that this approach will give a more accurate picture of air quality with respect to this pollutant group. Nonetheless, "total oxidants" measurements still predominate in monitoring activity. "The entire class of contaminants which release iodine from a potassium iodide solution are referred to as total oxidants."[1] By and large it is agreed that these

[1] *Air Quality Monitoring Report, Ontario, 1972, Volume 1*, Ministry of the Environment, Ontario (Toronto, 1974), p. 5.

measures generally understate the presence of oxidants in the air and thus, if anything, the subindicator for this pollutant is rather conservative. Since, both historically and geographically, oxidants have been measured as "total oxidants", ozone readings in this paper are transformed (assuming ozone represents 85 per cent of total oxidants) to estimate the total oxidant level where this group is not measured directly. Table 1 presents the annual averages provided by the monitoring authority or estimated from sample readings, data from other years or statistics relating to ozone. The footnotes specify the estimation technique used where applicable.

Two final comments with respect to measurement must be made at this point. First, as ozone (O_3) is mainly a secondary contaminant formed by reactions between organic substances (mainly unsaturated hydrocarbons) and nitrogen oxides, in the presence of sunlight, ozone readings during night hours and in winter months are low. The annual hourly mean, therefore, is not as accurate a measure of long-term exposure as for the other pollutants; however, it is employed in order to maintain a consistant basis vis-à-vis the other pollutants. Secondly, as we discussed earlier, the number of stations monitoring any parameter of total oxidants are few. The fewer the monitoring stations, within one urban area, the less confident one can be that any reading truly represents community-wide air quality.

Table 1

TOTAL OXIDANTS
AVERAGE ANNUAL CONCENTRATION
ELEVEN CANADIAN CITIES

(Parts per million)

(Cities are ranked according to three-year average)

	1971	1972	1973	Average
Calgary	.006	.006	.008	.007
Toronto	.010	.008	.011	.010
Sudbury	.021	.011[2]	.004	.012
Edmonton	.021	.009	.007	.012
London	.023	.018	.016	.019
Montreal	.020[1]	.020[1]	.020[1]	.020
Ottawa-Hull	.019	.031	.017	.022
Windsor	.028	.021	.019	.023
Sarnia	.033	.028	.026	.026
Cornwall	.032	.046	.015	.031
Hamilton	.042	.031	.030	.034

[1]Based on ozone readings over the period July-December 1973.

[2]Based on the ratio of oxidants to hydrocarbons and nitrogen oxides in 1971 and 1973 applied to readings of hydrocarbons and nitrogen oxides in 1972; both sets of ratios yield the same estimate.

Source: Alberta Department of the Environment; Gouvernement du Québec, Services de protection de l'environnement; Ontario Ministry of the Environment; and estimates by the authors.

Plant damage caused by air pollution is often considered to be a forewarning of potential damage to animal and human life. Oxidants, and particularly ozone, are known to cause "leaf markings" on leaves and grass and other damage to plants. However, the ability to distinguish such damage from that caused by insects, other biological factors, or

other pollutants is limited.[2] Thus, plant damage cannot be considered an accurate "lead indicator" of the effects of airborne pollutants in general, or oxidants in particular.

Other biological effects of ozone include dryness of mucous membranes of the mouth, nose and throat, changes in visual acuity, headaches, functional disturbance of the lungs, pulmonary congestion, and edema.[3] Human response (and that of all other animals) varies widely with the level of ozone concentration, the duration of exposure, the susceptibility of the target, and temperature (toxicity increases with temperature).

From medical examinations it is concluded that ozone brings out latent respiratory infections as a result of either continuing moderate concentrations or short-term acute exposure.[4] The results of our epidemiological study support this specific medical finding. Other medical studies indicated, moreover, that damage from exposure to ozone is not restricted to the respiratory system. In addition, the oxidizing effects of ozone are important in the aging processes of plants and animals and the erosion of the physical environment.

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[2]C. Stafford Brandt and Walter W. Heck, "Effects of Air Pollutants on Vegetation", *Air Pollution, Vol. 1: Air Pollution and Its Effects*, 2nd Edition, Arthur C. Stern, ed. (New York: Academic Press, 1968), pp. 401-443.

[3]Herbert E. Stokinger and David L. Coffin, "Biologic Effects of Air Pollutants", *Air Pollution, Vol. 1: Air Pollution and Its Effects*, 2nd Edition, Arthur C. Stern, ed. (New York: Academic Press, 1968), p. 447.

[4]*Ibid.*, p. 452.

Given this short summary of the potential damage that ozone pollution can create, and given the general prevalence of this pollutant in urban air, we conclude that ozone should rate a relatively high severity weighting. Although a precise weighting is impossible, given the lack of information on the actual or potential cost of damage per unit of concentration of this pollutant, the *relative* importance (in relation to other common air pollutants) is assumed to be high.

Nitrogen Oxides: Measurement and Effects

Of the compounds included in this pollutant group, nitrogen dioxide (NO_2) is the most serious in the context of ambient air considerations (as opposed to generation and emission considerations).[5] NO_2 plays an important role in photochemical formation of oxidants and, in its own right, is a relatively toxic compound. Given that NO_2 is the main component of nitrogen oxides (NO_x), in respect of both quantity and potential impact, it would seem reasonable to suggest that this compound be monitored separately. In fact, since September 1972, the Province of Ontario shifted its monitoring program from NO_x to direct measurement of NO_2 in many locations.

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[5]Other nitrogen oxides include nitric oxide, nitrogen trioxide, and nitrogen tetraoxide. These all react in air to produce NO_2 which is, therefore, the principal compound of this group found in ambient air.

Three techniques have been employed to measure the NO_x group and, separately, the NO_2 concentrations; this has led to a somewhat confusing array of data, not all of which are necessarily directly comparable. To obtain the best estimates of NO_x, it has thus been necessary in certain cases to use data on both NO_x and NO_2, and the ratio between them in one year, to estimate the concentration of NO_x in a subsequent year for which we have only NO_2 data. Table 2 presents the annual average hourly mean concentration and the footnotes explain the method of estimation where applicable.

Table 2

NITROGEN OXIDES
AVERAGE ANNUAL CONCENTRATION
ELEVEN CANADIAN CITIES
(Parts per million)

(Cities are ranked according to three-year average)

	1971	1972	1973	Average
Montreal	.014*	.014*	.022*	.017
Sudbury	.018	.023	.010[1]	.017
Cornwall	.025	.017	.012[1]	.018
Sarnia	.025	.018	.017[1]	.020
London	.033	.026	.026[1]	.028
Windsor	.048	.022	.034[1]	.035
Ottawa-Hull	.035	.037	.037[1]	.036
Edmonton	.028	.032	.064	.041
Calgary	.050	.038	.053	.047
Hamilton	.051	.048	.045[1]	.048
Toronto	.062	.063	.058[1]	.061

*Nitrogen dioxides readings only; i.e., not transformed to NO_x.

[1]Based on ratio of NO_2 to NO_x in 1972 applied to NO_2 in 1973.

Source: Alberta Department of the Environment; Ontario Ministry of the Environment; Montreal Urban Community; and estimates by the authors.

Acute injury to plant life by NO_2 resembles that caused by sulphur dioxide fumigation; it often shows as lesions on broad-leafed plants. As with ozone effects, it is difficult to distinguish the effects of NO_2 exposure from other non-pollution related causes of plant damage.

In addition to the unpleasant odour associated with NO_2, the effect of exposure on human beings (and presumably on other animals) includes nose and eye irritation, pulmonary congestion and edema, and obliterative bronchiolitis and pneumonia.[6] One might therefore expect nitrogen dioxide to be a significant explanatory variable in equations designed to ascertain the causes of hospitalization for bronchitis and emphysema as well as other pulmonary conditions. Three considerations must be kept in mind however; the apparent rapid recovery from the effects of NO_2 when concentrations fall to low levels, the possibility of a threshold level below which effects are not sufficiently serious to warrant hospitalization and above which the seriousness of impact increases at some rate which is not linearly described by increases in concentration, and the possible neutralizing effects of other components in the atmosphere on NO_2. Nonetheless, the significant association between the concentrations of NO_x and the hospitalization rate for some respiratory ailments in one of

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[6]Stokinger and Coffin, *op. cit.*, pp. 461-72.

the cities considered in Chapter 3 justifies a relatively high weighting for this pollutant. There is some support for such a relative weighting to be found in other studies.[7]

Sulphur Oxides: Measurement and Effects

Although a number of stations within the National Air Pollution Surveillance Program, a co-operative venture of the federal and provincial governments, monitor the sulphation rate (expressed as SO_3 per 100 cm^2 per day), the most complete and continuous measurement of this pollutant group pertains to airborne concentrations of sulphur dioxide (SO_2). Over 20 cities are covered in this program and, including provincial stations operating outside the program, the total number of municipalities in which SO_2 is monitored is about 50, with well over 100 stations, in total, being located in these centres.[8] Generally speaking, SO_2 is monitored in residential, commercial and industrial areas within cities where sources of this pollutant are known to be large or numerous; for instance, there are some 14 stations in the Sudbury district alone. The data produced by this monitoring system, which operates continuously, can be transmitted directly to central computer facilities (as in Ontario's network) to provide hour-by-hour

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[7]See, for instance, the summaries of air quality criteria in Lyndon R. Babcock, Jr., *A Combined Pollution Index for Measurement of Total Air Pollution*, a paper presented at the 63rd Annual Meeting of the Air Pollution Control Association, St. Louis, June 1970, p. 12.

[8]The Environment Canada publication, *National Air Pollution Surveillance*, provides a summary of data on ambient concentrations of the several pollutants measured in the network. The measurement techniques are also explained. The provinces likewise publish annual reports on pollutant concentrations in urban centres.

information on airborne concentrations of this pollutant. For these reasons, we believe that the annual mean concentration statistics represent a rather complete picture of total urban air quality in respect of this pollutant. These data are presented in Table 3.

Table 3

SULPHUR DIOXIDE
AVERAGE ANNUAL CONCENTRATION
ELEVEN CANADIAN CITIES

(Parts per million)

(Cities are ranked according to three-year average)

	1971	1972	1973	Average
Edmonton	.002[1]	.002	.002[1]	.002
Calgary	.004[1]	.004	.004[1]	.004
London	.015	.006	.005	.009
Ottawa-Hull	.010	.026	.010	.015
Hamilton	.021	.014	.015	.017
Toronto	.027	.019	.015	.020
Sarnia	.026	.020	.018	.021
Cornwall	.041	.021	.013	.025
Windsor	.029	.031	.027	.029
Montreal	.035	.034	.027	.032
Sudbury	.050	.034	.023	.036

[1]Based on 1972 average, derived from Environment Canada, Monthly Summaries, *National Air Pollution Surveillance.*

Source: Alberta Department of the Environment; Ontario Ministry of the Environment; Environment Canada; Montreal Urban Community; and estimates by the authors.

From laboratory test results on animals, it would seem that sulphur dioxide -- in concentrations normally found in urban air -- may not seriously affect animals.[9] Further, low- to medium-level exposure to SO_2, *alone*, does not seem to cause or seriously aggravate undesirable human health conditions.[10] It may be, therefore, that a more appropriate measure of air concentrations, in the sense that they represent a threat to health, would relate to the frequency with which this pollutant exceeds stated air quality criteria. Table 4 presents the statistics related to the percentage of days, in 1973, that air quality criteria were exceeded for each of the pollutants studied in each of our sample cities.

For Sudbury, where the criteria for SO_2 are exceeded most often (but only 4 per cent of the days in 1973), our investigation of hospitalization for respiratory conditions did not reveal a significant correlation between these conditions and acute exposure (see Chapter 3). In other words, it would seem that humans, like animals tested in laboratory situations, are not seriously affected by short-term acute exposures to concentrations of SO_2 such as recorded in Canadian centres in recent years. We have therefore assumed that the annual mean concentration statistic, besides being derived from a rather complete, continuous monitoring system, represents the most appropriate measure of air quality and its effects, in respect of SO_2.

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[9]See footnote 7, Chapter 1, p. 14.

[10]Stokinger and Coffin, *op. cit.*, p. 477.

Table 4

PERCENTAGE OF DAYS AIR QUALITY CRITERIA EXCEEDED BY CITY AND POLLUTANT, 1973[1]

City	Pollutant				
	Total Oxidants	Nitrogen Oxides	Carbon Monoxide	Sulphur Dioxide	Particulate Matter
Edmonton	*	11	*	*	*
Calgary	*	19	4	*	2
Ottawa-Hull	12	*[3]	*[3]	*	*
London	7	*	*[2]	*	*
Sudbury	*	*	*[3]	4	*
Toronto	37[4]	7[3]	10	*	2
Cornwall	7	1	*[3]	*	*
Sarnia	23	*	*	*	*
Montreal	33[4]	*	2	3	10
Hamilton	34	*[3]	*	*	6
Windsor	11	*	2	2	2

*Less than 1 per cent.

[1]Using the Ontario Ministry of the Environment 24-hour criteria.

[2]Data for 1971.

[3]Data for 1972.

[4]Based on the measurement of ozone by chemiluminescence (a more precise technique).

Source: Alberta Department of the Environment; Gouvernement du Québec, Services de protection de l'environnement; Ontario Ministry of the Environment; Montreal Urban Community; and estimates by the authors.

The precise effects of chronic, moderate concentrations of SO_2 on animals and man are difficult to assess. Nonetheless, relatively small problems (compared to hospitalization or chronic health impairment) appear to be associated with SO_2 exposure. The pungent, suffocating condition of the air which arises from the presence of SO_2 is, of course, highly noticeable -- and therefore the cause of much concern. But at concentrations which are found in the urban areas studied, the effects on the general public, when noticeable

(despite a wide range in individual tolerance *and* hypersensitivity), tend to be associated with irritation of the upper respiratory tract insufficiently serious to warrant hospitalization. There may also be more serious chronic effects (which were beyond our epidemiological examination) such as coughing, shortness of breath and other respiratory distress. In addition, although there is no evidence of similar circumstances having occurred in Canada, sharp increases in the mortality rate, particularly among the hypersensitive subpopulations such as the old and sick, have occurred in a number of places at times when SO_2 levels were known to be extremely high.[11]

Plant life, as with ozone and nitrogen dioxide, appears to be particularly sensitive to sulphur dioxide. Blotches on broad leaves exposed to SO_2 indicate cellular damage, streaks may be visible on grass leaves indicating similar damage, and needle tip damage on conifers is also noted in association with exposure to SO_2.[12] Such occurrences have been noted in many parts of Canada and, in quite a few instances, the cause can be related directly to sources of industrial activity, even though natural damage (as opposed to damage arising out of human activity), in some instances, can closely resemble the effects of SO_2 (winter kill, high temperature scorching, white spot and blight effects, to give some examples).

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[11] A summary of air pollution disasters associated with extremely high sulphur dioxide concentrations in ambient air is presented in Harry Heimann, *op. cit.*, pp. 488-503.

[12] *Man, Materials and Environment* (Washington: National Academy of Sciences/Engineering, 1973), pp. 79-80.

Since sulphur oxides inhaled as an aerosol or as an appendage to particulate matter are thought to have more dramatic effects than SO_2 by itself, consideration of this aspect is more suitably covered separate from that of SO_2 alone. This matter is discussed under the subtitle of "synergism".

Because of the widespread, if only moderate, disutility arising from SO_2 pollution, we (and others) have assumed that the relative severity of SO_2, by itself at a given level of concentration, might be of the same order as that attributable to NO_x, although the latter has a greater potential, it would seem, to cause acute distress at high levels of concentration.[13]

Particulate Matter: Measurement and Effects

Although particulate matter is a grouping of a wide array of airborne solids, with various shapes, sizes, and chemical properties, one possible way of aggregating these heterogeneous qualities is to devise a common denominator. One common measure of total particulate matter, the coefficient of haze (COH), involves the collection of particles on a filter with a subsequent optical evaluation of their collective light-blocking characteristics. This measure does not specify the chemical or all of the physical properties of airborne solids. Since the tape samplers generally collect particles in the size range of 0.1 microns to 10.0 microns, the measures of COH correspond to the concentration in ambient

[13]For other relative weightings see Babcock, *op. cit.*

air of respirable particles of 0.5 to 5.0 microns, this being the range of particle size which is retained by the lungs.[14] Without a detailed breakdown of the chemical and physical properties of particulate matter, we assume that COH captures at least one significant aspect of air quality; the likelihood of airborne solids lodging in the lungs, and therefore having the potential to impact negatively on human health.

Thus, the coefficient of haze is not a measure of the concentration per unit volume of ambient air as are data related to other pollutants. Table 5 presents mean levels of COH concentrations in gross (COH) terms; these figures can be converted to SO_2 ppm equivalents by dividing by 10 if the time-base period for the criteria for these pollutants is 24 hours (see Table 7). If the time base were one year, the factor would be 22.5.

This broad category of pollutants may obviously have a wide range of potential effects and, therefore, the overall effect is difficult to determine. If there is a high proportion of lead in the particulate matter, the effects are much different from those associated with particulate matter containing low lead levels but high levels of, for example, iron, or cadmium, or asbestos. Likewise, there is some medical evidence that the shape of the particles may be a partial determinant of the effect.

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[14] *Air Quality Monitoring Report, Ontario, 1972, Volume 1,* p. 5.

Table 5

PARTICULATE MATTER
AVERAGE ANNUAL CONCENTRATION
ELEVEN CANADIAN CITIES

(Coefficient of haze per 1,000 feet of air)

(Cities are ranked according to three-year average)

	1971	1972	1973	Average
Sudbury	.24	.12	.09	.15
Edmonton	.19	.19	.13	.17
London	.24	.17	.15	.19
Calgary	.23	.16	.18	.19
Cornwall	.26	.24	.22	.24
Ottawa-Hull	.27	.27	.19	.24
Toronto	.34	.33	.32	.33
Sarnia	.34	.37	.28	.33
Hamilton	.40	.45	.40	.42
Windsor	.56	.41	.39	.45
Montreal	.77	.73	.62	.71

Source: Alberta Department of the Environment; Ontario Ministry of the Environment; Environment Canada; Montreal Urban Community; and estimates by the authors.

In general, particulate matter can injure plant life through obstruction of stoma or through the effect of the chemical properties of the particles on the plant. For example, the harmful impact on plant life in the vicinity of cement plants (essentially a result of blockage of stoma) and near aluminum smelters (a result of the fluoride component of the particulate matter) is well known.

Likewise, particulates can adversely affect the health of animals either through direct inhalation or from

their ingesting forage on which the particulate matter has settled. Fluorides, for instance, can cause short- and long-term damage to forage animals although many animals refuse acutely toxic feed.[15]

With respect to humans, "it is known that inhalation and retention of particles in general induce a physiological response reflected in the slowing of the ciliary beat and mucous flow in the bronchial tree."[16] In addition, small particles penetrate deeply beyond the natural protection mechanisms of the nose and throat into the respiratory system where irritation caused by the physical properties alone may be critical. Of course the toxic properties of the particles are also important once penetration is achieved.

We have emphasized the physical rather than chemical properties of particulate matter in our considerations of its relative effect on the environment because the measure of this pollutant group (COH) relates to the former rather than the latter properties. On the basis of these physical properties alone it is probably reasonable to assume a relative severity factor with respect to the effect of particulate matter on the environment (particularly on humans, animals, and plants) somewhat below those for total oxidants, NO_2, or SO_2. This assumption is explicit in the criteria for desirable air quality with respect to particulate matter set by the

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[15] *Man, Materials and Environment*, *op. cit.*, pp. 77-9.

[16] Stokinger and Coffin, *op. cit.*, p. 492.

responsible authorities, one of these criteria (that of Ontario's Ministry of the Environment) being employed in this paper. However, if one were to make allowances for the potential harmful effects known to be associated with the chemical properties *sometimes* found in this pollutant group, the total effect may well be considerably greater.

Synergism: Measurement and Effects

Laboratory tests on animals and *ex post* examination of critical pollution incidents indicate that sulphur oxides in conjunction with particulate matter of respirable size can cause harmful effects greater than those which would be expected from the sum of the effects of sulphur oxides and particulate matter in isolation from one another. This additional effect is referred to as *synergism*. SO_2 has a demonstrated affinity for particulate matter. Further, sulphur trioxide (SO_3), a small but significant component of the sulphur oxides, is transformed into sulpheric acid mist upon contact with moisture in ambient air. We do not have direct measures of sulphuric acid mist, but one might note that, if the precondition of moisture in the air exists, the impact of sulphur oxide pollutants may be greater than the effect of SO_2 alone. Since high humidity, sulphur oxide concentrations, and particulate matter concentrations are not necessarily significantly correlated, it may be that the potential for harmful effects is greatest only when all these conditions exist in unison. For the purposes of constructing an air quality indicator, it seems reasonable to represent the potential effect of this combination through the mean

sulphur dioxide concentration (one expects SO_2 and SO_4 to be highly correlated) and the mean concentration of particulate matter (measured in COH units) -- both of which have been discussed -- plus a measure of synergism which defines the potential interaction between the sulphur oxides and particulate matter.

It has been assumed elsewhere,[17] and we accept this assumption, that the lower of the concentrations of SO_2 or particulate matter sets the upper limit for the added or synergistic effect. Thus, no matter how great the concentration of, say, particulate matter, the amount of SO_2 carried into the lung by the particulate matter will be limited by the amount of SO_2 concentration, should it be the lower of the two (on an equivalent concentration (ppm) basis). The reverse situation, where the SO_2 concentration exceeds particulate matter, is logically limited by the concentration of particulate matter. The impact of pollutants on the environment is a function of their concentration and their relative severity. The synergism factor in our indicator is thus equivalent to whichever impact is the smaller between that of SO_2 and that of particulate matter.

Carbon Monoxide: Measurement and Effects

As indicated in Chapter 1, the concentration of carbon monoxide (CO) in the air varies a great deal over short distances.[18] In general, also, CO is present in high

[17]Babcock, *op. cit.*, p. 12.

[18]The standard monitoring technique employs infrared analysis of the carbon monoxide content of air samples which are collected on a continuous basis.

concentrations during the morning and evening rush hours since the automobile is the predominant source of CO emissions.

Unlike ozone, however, dissipation of carbon monoxide during the night is not complete. CO is a heavy gas which settles in the air at street level and, therefore, surface air movement is necessary to provide dilution. Although carbon monoxide concentrations just above ground level along busy streets may be sufficiently high during peak hours to affect sensory perception (and thus driving capability), community exposure in general is probably represented as well by a 24-hour average as by any other measure. Thus the annual mean 24-hour exposure is used as a proxy for community air quality in respect of CO.

When we mentioned earlier that it is necessary to consider all exposures to pollutants in attempting to ascertain the potential negative effects of air pollution, one aspect of predisposition to negative impacts on human health that was in the back of our minds was that of "voluntary pollution" through smoking. Besides the tar and nicotine of which smokers have been warned, there are other pollutants in the smoke which is inhaled, a major component of which is CO. Thus the individual who smokes is likely to be affected to a greater extent by ambient CO concentrations than a nonsmoker would be, but it is difficult to separate involuntary and voluntary exposure or to ascertain precisely the source of each contribution to total body burden.

However, given that there may be negative effects of relatively low-level, ambient-air CO exposure (apart from that attributable to smoking) the annual mean concentration of CO would seem an appropriate statistic to describe this air quality condition; Table 6 presents these statistics for 1971-73 for the 11 cities covered by this paper.

Table 6

CARBON MONOXIDE
AVERAGE ANNUAL CONCENTRATION
ELEVEN CANADIAN CITIES

(Parts per million)

(Cities are ranked according to three-year average)

	1971	1972	1973	Average
Cornwall	1.6	1.0	0.8[1]	1.1
Ottawa-Hull	1.6	1.1	1.4[1]	1.4
Sudbury	1.2	1.8	1.6[1]	1.5
Edmonton	1.6	1.4	1.8	1.6
London	1.6	1.9[1]	2.0[1]	1.8
Hamilton	3.5	2.3	2.1	2.6
Sarnia	3.5	2.6	2.8[1]	3.0
Calgary	3.7[2]	2.7	4.1	3.5
Toronto	4.6	3.6	3.6	3.9
Windsor	6.0	4.8	4.7	5.2
Montreal	7.0	5.0	6.0	6.0

[1]Based on ratio of CO:HC in previous years applied to 1973.

[2]Based on ratio of CO:NO_x in subsequent years applied to 1971 NO_x average.

Source: Alberta Department of the Environment; Ontario Ministry of the Environment; Montreal Urban Community; and estimates by the authors.

As a result of the not too unusual occurrence of death from accidental exposure to extreme levels of carbon monoxide (CO), a wide public concern regarding this pollutant has developed. In addition, "no other gaseous air pollutant with such a toxic potential as CO exists at such high concentrations in urban atmospheres".[19] To derive a measure of relative severity, however, one must consider the effects of an average unit of exposure within the range of concentration of the pollutant normally found in ambient air. Thus we are not trying to estimate the marginal effect of an additional unit of a pollutant.

At concentrations of carbon monoxide generally found in urban air, there would appear to be a potential negative impact on individuals who, by reason of their occupational location (e.g., at street level near busy thoroughfares), health status (e.g., those with cardiovascular or cardio-respiratory problems), or smoking habits, are least able to tolerate additional exposure to this pollutant. From a review of studies concerning this pollutant and its effects it is clear that the average level of concentration has a relatively small impact on health; however, because the generation of CO is so great (mainly from the automobile), and the concentration in ambient urban air is so high and prolonged, the total impact of this pollutant is, nonetheless, considerable, even though the relative impact of this pollutant, at a given concentration, is the lowest of the pollutants studied here.

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[19]Stokinger and Coffin, *op. cit.*, p. 480.

Two final points should be made with regard to the effects of this pollutant on man and on animals. First, recovery from exposure is very rapid given a reduction in the level of concentration, and, secondly, there is a defence mechanism incorporated in the human metabolism which enables the body to adapt to generally prevailing background levels of CO, with essentially minor loss in the body's ability to take up, transport, and utilize oxygen.

C. Criteria for Desirable Air Quality

A number of public authorities have specified criteria for desirable air quality. We have chosen those set by the Ontario Ministry of the Environment since they refer to all the pollutants that are incorporated in our calculations. The criteria are set so that, for a given time period, the ambient air concentration of each pollutant is expressed as a limit above which concentrations would be considered undesirable. To the greatest extent possible, the potential effects on various aspects of the environment are taken into consideration in setting these criteria. Table 7 sets out the Ontario criteria.

It will be noted that there is only one set of criteria covering every pollutant on a common average time -- the set applicable to a 24-hour concentration. For this reason in part, the relative severity factors are derived from this set.

Table 7

PROVINCE OF ONTARIO CRITERIA
FOR DESIRABLE AMBIENT AIR QUALITY

Name of Contaminant	Units of Measure	Averaging Time	Concentration at Criterion
Sulphur Dioxide	Parts per million	1 hour	0.25
		24 hours	0.10
		1 year	0.02
Total Oxidants	Parts per million	1 hour	0.10
		24 hours	0.03
Nitrogen Oxides	Parts per million	1 hour	0.20
		24 hours	0.10
Carbon Monoxide	Parts per million	1 hour	40.00
		8 hours	15.00
		24 hours	8.00
Suspended Particulate Matter (Soiling Index)	Coefficient of Haze per 1,000 feet of air	24 hours	1.00
		1 year	0.45

Source: *Air Quality Monitoring Report, Ontario, 1972, Volume 1* Ontario Ministry of the Environment, Table 2, 1972.

D. Relative Severity Factor

Carbon monoxide has the highest concentration at criterion (Table 7). The relative severity factor of each pollutant is taken to be the factor by which each concentration at criterion must be multiplied to equal the concentration at criterion of carbon monoxide. For the 24-hour criteria, this factor is 1 for carbon monoxide (by definition), 267 for total oxidants, and so on. The relative severity factor for each pollutant is presented in Table 8.

Table 8

THE RELATIVE SEVERITY FACTORS

Pollutant	Units of Measure	Time Period Base for Criteria	Concentration[1] at Criterion	Relative Severity Factor
Carbon Monoxide	Parts per million (volume)[2]	24 hours	8.00	1
Nitrogen Oxides	Parts per million (volume)[2]	24 hours	0.10	80
Total Oxidants	Parts per million (volume)[2]	24 hours	0.03	267
Sulphur Dioxide	Parts per million (volume)[2]	24 hours	0.10	80
Particulate Matter	Coefficient of Haze per 1,000 feet of air	24 hours	1.00	8

[1] *Air Quality Monitoring Report, Ontario, 1972, Volume 1*, Ontario Ministry of the Environment, Table 2, 1972.

[2] The concentration of the pollutant is measured by its proportional volume in air. For instance, 1 ppm carbon monoxide represents one volume of carbon monoxide for every million volumes of ambient air.

Source: Ontario Ministry of the Environment, and estimates by the authors.

As noted earlier, the ratio of COH to SO_2 at criteria for the two pollutant groups (1.0 COH and 0.1 ppm, respectively) was assumed to indicate equal severity and, therefore, the COH readings divided by 10 were assumed to be equal in severity to SO_2 readings in ppm. Thus, the relative severity factor for particulate matter is stated in terms of the SO_2 factor divided by 10 (i.e., $80 \div 10 = 8$). Each relativity factor applies, therefore, to the observed concentrations of pollutants expressed in normal measurement terms; parts per million for the gaseous pollutants and COH (per 1,000 feet of air) for suspended particulates.

The relative severity factor is an average measure and, therefore, it is implicitly assumed that, over the range of concentration of pollutants found in ambient air

above Canadian cities, the impact of a particular pollutant on the environment as a whole is linear. This impact for each of these pollutants equals the concentration times the relative severity factor, and increases directly with increasing concentration.

E. The Population at Risk

Although not every citizen of an urban area is equally exposed to community air pollution or equally susceptible to the ill effects of pollution exposure, we have assumed that the air monitoring system readings of the concentration of pollutants is reflective of total community air quality. It follows, therefore, that, under normal circumstances of air movement -- vertically and horizontally -- the entire population is potentially at risk to exposure and damage. More detailed air quality monitoring and intra-urban examination of effects will probably be possible in the future but, at this point in time, such an examination is clearly impossible over a wide range of cities; the data are simply not available.

In order to aggregate across cities the air quality impact units per capita that are derived for each city from the summation of the products of pollutant concentration data and the relevant relative severity factors, it is necessary to consider the potential population at risk in each city and the total for all the cities in our sample. In other words, the severity of impact on the total population is some function of

the degree to which the citizens of each city are at risk. It is obtained by multiplying the impact of each pollutant (relative severity factor times concentration) by the population at risk, for each city, and summing across cities.

Even if air pollution levels remained constant over time, increasing urbanization (by natural growth, rural to urban population shifts, or immigration) would cause the urban air quality indicator for all 11 cities in the sample to rise when the population at risk is taken into account, or the quality of life for all Canadians to fall with respect to this one measure of social well-being. A shift of population from less polluted to more polluted areas, in any social sense, implies a negative effect on the quality of life.

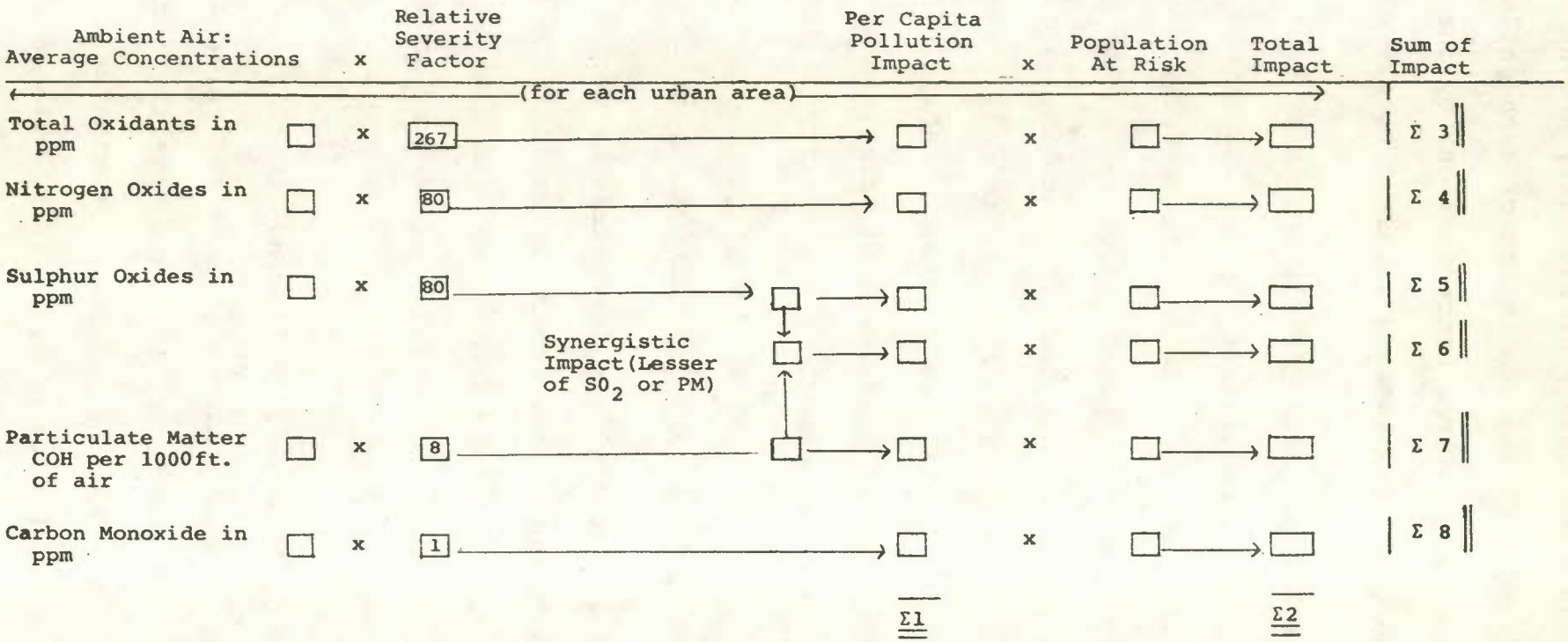
F. Calculation of the Air Quality Indicator

Figure 2 pictorially illustrates the methodology we have employed to derive the urban air quality indicator, its component urban pollutant indicators, and a city pollution index for each of the 11 urban centres covered in this work.

Tables 9, 10 and 11, following Figure 2, bring together the mean annual pollutant concentration data given in Tables 1, 2, 3, 5 and 6, the relative severity factors (shown by pollutant), and the population estimates for the urban regions for which data on all five pollutants in the indicator are collected.

Figure 2

METHODOLOGY EMPLOYED IN CALCULATING THE URBAN AIR QUALITY INDICATOR, ITS COMPONENT URBAN POLLUTANT SUBINDICATORS, AND THE CITY POLLUTION INDEX FOR A GIVEN URBAN AREA



Σ1: for each urban area, provides the City Pollution Index (impact units per capita).

Σ2: for each urban area, provides that urban area's contribution to the Urban Air Quality Indicator (impact units). The sum of Σ2 across all cities in the sample provides the Urban Air Quality Indicator.

Σ3 to Σ8: for each urban area, provides that urban area's contribution to each of the six Urban Pollutant Sub-Indicators (impact units). The sum of Σ3 across all cities provides the Urban Pollutant Subindicator for total oxidants; similarly, the sums of Σ4, Σ5, Σ6, Σ7 and Σ8, respectively, give the Urban Pollutant Subindicators for the other pollutants. Thus, the Urban Air Quality Indicator is:

$$\sum_{i=1}^{11} (\Sigma 2)_i = \sum_{i=1}^{11} \left| (\Sigma 3)_i + (\Sigma 4)_i + (\Sigma 5)_i + (\Sigma 6)_i + (\Sigma 7)_i + (\Sigma 8)_i \right| .$$

Table 9

URBAN AIR QUALITY INDICATOR, 1971

City	Population	Impact Units[1]						Total Impact Units by City	City Pollution Index	Urban Rank
		Total Oxidants	Nitrogen Oxides	Carbon Monoxide	Sulphur Dioxide[2]	Particulate Matter	Synergism[3]			
	(Thousands)	(Thousands)							(Impact units per capita)	(1=Best 11=Worst)
Relative Severity Factor		267	80	1	80	8	--	--	--	--
Edmonton	495.70	2,779	1,110	793	79	753	79	5,593	11.3	1
Calgary	403.32	646	1,613	1,492	129	742	129	4,751	11.8	2
Ottawa-Hull	602.51	3,057	1,687	964	482	1,301	482	7,973	13.2	3
London	286.01	1,756	755	458	343	549	343	4,204	14.7	4
Sudbury	155.42	871	224	187	622	298	298	2,500	16.1	5
Toronto	2,628.04	7,017	13,035	12,089	5,677	7,148	5,677	50,643	19.3	6
Cornwall	47.12	403	94	75	155	98	98	923	19.6	7
Sarnia	57.64	508	115	202	120	157	120	1,222	21.2	8
Montreal	2,743.21	14,649	3,072	19,202	7,681	16,898	7,681	69,183	25.2	9
Hamilton	498.52	5,590	2,034	1,745	838	1,595	838	12,640	25.4	10
Windsor	258.64	1,934	993	1,552	600	1,159	600	6,838	26.4	11
Total	8,176.13	39,210	24,732	38,759	16,726	30,698	16,345	166,470		
Urban Pollutant Subindicators (millions of impact units)		39.2	24.7	38.8	16.7	30.7	16.3			
Urban Air Quality Indicator (millions of impact units)					166.5					
Per Capita Urban Air Quality Indicator (impact units per capita)					20.4					

(1) Impact units are defined as (relative severity factor) x (pollutant concentration in ppm) x (population).

(2) Sulphur oxides are converted to sulphur dioxide equivalents.

(3) The impact of synergism is considered equivalent to the lower of the impacts for sulphur dioxide and particulate matter.

Source: Alberta Department of the Environment; Gouvernement du Québec, Services de protection de l'environnement; Ontario Ministry of the Environment; Montreal Urban Community; Statistics Canada; and estimates by the authors.

Table 10

URBAN AIR QUALITY INDICATOR, 1972[1]

City	Population	Impact Units: Total Oxidants	Nitrogen Oxides	Carbon Monoxide	Sulphur Dioxide	Particulate Matter	Synergism	Total Impact Units by City	City Pollution Index	Urban Rank
	(Thousands)				(Thousands)				(Impact units per capita)	(1=Best 11=Worst)
Relative Severity Factor		267	80	1	80	8	--	--	--	--
Edmonton	507.00	1,218	1,298	710	81	771	81	4,159	8.2	1
Calgary	417.00	668	1,268	1,126	133	534	133	3,862	9.3	2
Ottawa-Hull	613.00	5,074	1,814	674	1,275	1,324	1,275	11,436	18.7	7
London	290.00	1,394	603	551	139	394	139	3,220	11.1	3
Sudbury	157.00	461	289	283	427	151	151	1,762	11.2	4
Toronto	2,672.00	5,707	13,467	9,619	4,061	7,054	4,061	43,969	16.5	5
Cornwall	47.81	587	65	48	80	92	80	952	19.9	8
Sarnia	58.45	437	84	152	94	173	94	1,034	17.7	6
Montreal	2,761.00	14,744	3,092	13,805	7,510	16,124	7,510	62,785	22.7	11
Hamilton	505.00	4,180	1,939	1,162	566	1,818	566	10,231	20.3	9
Windsor	262.00	1,469	461	1,258	650	859	650	5,347	20.4	10
Total	8,290.26	35,939	24,380	29,388	15,016	29,294	14,740	148,757		
Urban Pollutant Subindicators (millions of impact units)		35.9	24.4	29.4	15.0	29.3	14.7			
Urban Air Quality Indicator (millions of impact units)					148.8					
Per Capita Urban Air Quality Indicator (impact units per capita)					17.9					

[1] See notes and source for Table 9.

Table 11

URBAN AIR QUALITY INDICATOR, 1973[1]

City	Population	Impact Units: Total Oxidants	Nitrogen Oxides	Carbon Monoxide	Sulphur Dioxide	Particulate Matter	Synergism	Total Impact Units by City	City Pollution Index	Urban Rank
	(Thousands)				(Thousands)				(Impact units per capita)	(1=Best 11=Worst)
Relative Severity Factor		267	80	1	80	8	--	--	--	--
Edmonton	518.00	968	2,652	932	83	539	83	5,257	10.1	3
Calgary	431.00	921	1,827	1,767	138	621	138	5,412	12.6	6
Ottawa-Hull	619.00	2,810	1,832	867	495	941	495	7,440	12.0	5
London	293.00	1,252	609	586	117	352	117	3,033	10.4	4
Sudbury	155.00	166	124	248	285	112	112	1,047	6.7	1
Toronto	2,692.00	7,906	12,491	9,691	3,230	6,892	3,230	43,440	16.1	7
Cornwall	48.51	194	47	39	50	85	50	465	9.6	2
Sarnia	59.27	411	81	166	85	133	85	961	16.2	8
Montreal	2,775.00	14,819	4,884	16,650	5,994	13,764	5,994	62,105	22.4	11
Hamilton	513.00	4,109	1,847	1,077	616	1,642	616	9,907	19.3	9
Windsor	264.00	1,339	718	1,241	570	824	570	5,262	19.9	10
Total	8,367.78	34,895	27,112	33,264	11,663	25,905	11,490	144,329		
Urban Pollutant Subindicators (millions of impact units)		34.9	27.1	33.3	11.7	25.9	11.5			
Urban Air Quality Indicator (millions of impact units)					144.3					
Per Capita Urban Air Quality Indicator (impact units per capita)					17.2					

[1] See notes and source for Table 9.

The city pollution index for a particular city is the sum for all pollutants of the mean annual concentration of each pollutant times its relative severity factor. In other words, the comparison relates to air quality and not to the population at risk; the urban ranking is based on this index.

There is an urban pollutant subindicator for each pollutant; it is the sum across all 11 urban areas of the product of the mean annual pollutant concentration for a particular urban centre and pollutant, the relative severity factor for that pollutant, and the population of that urban area. As such, these subindicators reflect how the importance of the various pollutants that make up the urban air quality indicator have changed over time, and, therefore, suggest emerging or receding problem areas for the urban centres as a whole.

As with any macro indicator, the urban air quality indicator, whether in gross terms (the sum of the urban pollutant subindicators) or in per capita terms, provides only the broadest of indications of relative changes in one parameter among many in the entire environmental system.

Some observations are warranted at this point. Based on the city pollution indexes and the change in the index for each city over the period 1971 to 1973, all but one urban area have experienced an improvement in air quality, but the rate of improvement varies considerably from city to city. Since there are complex factors that determine the

level and changes in the level of pollution, one is not justified in saying that abatement of pollutants, *at source*, is alone responsible for the indicated improvement in air quality. In any one year, climatic conditions and natural background pollution levels (for example, forest fire generation of particulates) can result in substantial changes in the registered levels of airborne concentrations of certain pollutants even though the level of human activity may remain the same. However, the level of economic activity will determine, to some extent, the quality of urban air. Nonetheless, the means of abating pollution generation are such that it is presently possible to reduce the total generation of pollutants and to improve the quality of urban air at the same time as production increases. For instance, over the period 1971-73, gross domestic production increased by 11.3* per cent for the country as a whole while the pollution indicator fell by 13.3 per cent in gross terms (despite the increase in population in these cities) and by 15.7 per cent in per capita terms for our 11 sample cities. One might note, however, that the improvement over the period 1972-73 was smaller than that over the period 1971-72.

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*This statistic is derived from gross domestic product data divided by the price deflator (for gross national product) to approximate the percentage increase in real (constant value) rather than current value terms.

Table 12 presents a summary of the changes in the city pollution index, for each city and for each of the three years covered by the indicator.

Table 12

CITY POLLUTION INDEX, ELEVEN CITIES, 1971-1973[1]

(impact units per capita)

	1971	1972	1973	Average 1971-73	Per cent change 1971-73
Edmonton	11.3	8.2	10.1	9.9	-10.6
Calgary	11.8	9.3	12.6	11.2	+ 6.8
Ottawa-Hull	13.2	18.7	12.0	14.6	- 9.1
London	14.7	11.1	10.4	12.1	-29.3
Sudbury	16.1	11.2	6.7	11.4	-58.4
Toronto	19.3	16.5	16.1	17.3	-16.6
Cornwall	19.6	19.9	9.6	16.4	-51.0
Sarnia	21.2	17.7	16.2	18.4	-23.6
Montreal	25.2	22.7	22.4	23.4	-11.1
Hamilton	25.4	20.3	19.3	21.6	-24.0
Windsor	26.4	20.4	19.9	22.3	-24.6

[1]The formulation of these indices is shown in Tables 9, 10, and 11.

Source: Alberta Department of the Environment; Gouvernement du Québec, Services de protection de l'environnement; Ontario Ministry of the Environment; Montreal Urban Community; and estimates by the authors.

On average, Edmonton, Calgary, Sudbury (despite the much-publicized occurrences of sulphur dioxide in that area), and London had the least polluted air, as defined by the product of annual concentrations of pollutants multiplied by the relevant severity factors. Montreal, Windsor and Hamilton were clearly the most polluted areas in respect of our measurement definition. Table 12 indicates as well the degree of improvement in 10 of the cities and the degree of deterioration in Calgary. The changes in the index are quite obviously different from city to city over time and, therefore, the rankings shown in Tables 9 through 11 shift somewhat from year to year.

Since the rankings, the indicies and the indicators are all relative measures, in a time and geographic sense, these statistics beg the question as to precisely what component pollutants have caused these data to move and what sources of air pollution have contributed to these changes.

In comparing Tables 9 and 11, we note that, although the total oxidant urban pollutant subindicator for 1973 is lower than for 1971 because of lower concentrations of this pollutant in most cities, there was a significant increase in Calgary and Toronto over the same time period. With respect to nitrogen oxides, the urban pollutant subindicator increased and this was the result of increases in four of the eleven cities, again comparing 1973 to 1971. Over these same years, the urban pollutant subindicator for carbon monoxide decreased, with seven of the cities registering an improvement, and four registering some deterioration.

The greatest improvement in air quality was noted with respect to sulphur dioxide, with the minor increases observed in the pollutant subindicator for Edmonton, Calgary and Ottawa-Hull associated with increases in population. In other words, the annual average concentrations remained constant at low levels in these three centres, and actually decreased in each of the other eight centres between 1971 and 1973. Roughly the same trend can be noted in the synergism component of the indicator due largely to its close relation to the value of the sulphur dioxide component. The other component which determines the value of the synergism factor, particulate matter, declined in importance in all the cities

except Hamilton where the annual average concentration remained the same but where increasing population caused this statistic to inch forward.

As one might expect, the urban pollutant sub-indicators and the urban air quality indicator are substantially affected by the population distribution among the cities. A small change in the concentration of a pollutant in Montreal or Toronto may have a significant effect on these summary statistics whereas a large change in the concentrations of one or more pollutants in Cornwall or Sarnia may have only an insignificant effect. This is in keeping with the underlying social concern of this first-approximation indicator. Obviously, if ambient air quality was extremely severe in any one relatively small centre, there would be justification for taking this matter into account, although such a recognition of the higher social costs at very high severity (for example, mortality versus morbidity) should be incorporated in the relative severity factor. As it is, airborne pollutants are probably not sufficiently severe in any of the centres to warrant such differential weightings; therefore, the implicit assumption remains that all individuals at risk to the potential danger of a similar set of air pollutants have an equal weight in the measurement of impact. Table 13 summarizes the way in which the air quality indicator and the pollutant subindicators have moved over the period 1971-73, for all cities combined.

Table 13

URBAN AIR QUALITY INDICATOR AND URBAN POLLUTANT SUBINDICATORS 1971-73

Year	Urban Pollutant Subindicators[1] (millions of impact units)						Urban Air Quality Indicator (millions of impact units)[3]	Per Capita Urban Air Quality Indicator (impact units per capita)
	Total Oxidants[2]	Nitrogen Oxides	Carbon Monoxide	Sulphur Dioxide	Particulate Matter	Synergism		
1971	39.2	24.7	38.8	16.7	30.7	16.3	166.5	20.4
1972	35.9	24.4	29.4	15.0	29.3	14.7	148.8	17.9
1973	34.9	27.1	33.3	11.7	25.9	11.5	144.3	17.2
% change 1971-1973	-11.0	+ 9.7	-14.2	-29.9	-15.6	-29.4	-13.3	-15.7

[1]Summed across the eleven cities for each pollutant; see Tables 9, 10, and 11. The impact units for each pollutant in each city are calculated as follows: (severity factor) x (pollutant concentration (ppm)) x (population of city).

[2]The figures for total oxidants are probably underestimated because of the analytical techniques used in most cities.

[3]The sum of the urban pollutant subindicators.

Source: Statistics Canada; Alberta Department of the Environment; Gouvernement du Québec, Services de protection de l'environnement; Ontario Ministry of the Environment; Montreal Urban Community; and estimates by the authors.

We leave the question of what changes in man-made sources (emissions) of pollutants have affected these sub-indicators and the urban air quality indicator to Chapter 4. This paper now turns to an elaboration of the observations that the authors have concerning some of the fundamental aspects underlying the calculation of the indicies subindicators and the urban air quality indicator presented above.

G. Reservations

Since the urban air quality indicator presented here is a first-approximation indicator, one might rightly expect a number of reservations to be attached to its content and formulation. Certain of these are noted below. To begin with there are appropriate reservations with respect to the quality of pollutant concentration data -- the way pollutants are measured, the places in which monitoring stations are located, and the continuity of measurement. The largest area of ignorance, however, is related to the overall impact of

pollutants on the ecology (including man) and the physical environment. Our reservations are greatest, therefore, with respect to the exactitude of the relative severity factors, and with respect to the importance of pollutants not included in the indicator. In what follows, there is an outline of some of the complicating factors that may affect the accuracy or completeness of the measures of air quality presented here and/or blur an understanding of the linkages between the effects of air pollution and ambient air quality. The linkages between the sources or generation of pollutants and the ensuing ambient air conditions are also complex; more will be said on the topic of these latter linkages in Chapter 4.

Pollutants Not Specifically Considered

Earlier we mentioned that the chemical properties of particulate matter are not captured in the statistics which are employed in this research. A chemical analysis of particulates would indicate that, at certain times and places, the public is exposed to a wide array of elements and compounds through this pollutant group and these have a negative impact potential quite distinct from the physical nature of the particulate itself. Specific examination of the harmful effects on the ecology, and particularly on human health, have been undertaken with respect to lead, fluorides, mercury, beryllium, asbestos, arsenic, cadmium and other substances embodied in particulate matter. The indications are that in at least some instances, these substances consitute an actual or potential threat to health. For this reason, more complete coverage of their occurrence through an extensive network "high-volume samplers" which collect suspended

particulates for analytical purposes is being developed. The present lack of consistent, widespread analysis makes the inclusion of these parameters of air quality impossible at this point in time.

It was also noted earlier that the pollutant group normally referred to as "total hydrocarbons" has been excluded from our indicator primarily because this group is very heterogeneous and because there are no standards or criteria expressing desirable or undesirable concentration levels in ambient air. A relative severity factor for this pollutant group is therefore difficult to determine.

> "The main interest in hydrocarbons is their role in secondary reactions in the atmosphere to produce photochemical smog. This class of reactive hydrocarbons, olefins from car exhausts and terpenes from vegetation are not measured specifically by the samplers used and until instrumentation for this class is available — no criteria can be set which would be meaningful."[20]

In addition to their role in the photochemical reaction which leads to ozone formation, a number of organic vapours may be highly irritating to the mucous membranes of the eyes, nose and throat (for example, formaldehyde and its homologs) and, at sufficiently acute exposures, some may cause severe lung damage. A number of studies have also implicated benzo(a)pyrene, a fairly prevalent hydrocarbon, as a carcinogenic agent.

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[20] *Air Quality Monitoring Report, Ontario, 1972, Volume 1, op. cit.*, p. 6.

As more complete analyses of the physical and chemical properties of the atmosphere are completed, other pollutants, some of which we may not even now suspect, may be brought to light. Organic and inorganic mists may be important pollutants -- compounds on which we have only limited amounts of information. In addition, human activities generate large quantities of carbon dioxide and water vapour which, although not perceived to be pollutants in a direct sense (i.e., no direct negative impact), may be seen to have effects on the ecological balance and thus may be perceived to be pollutants in an indirect sense. Waste heat may also be considered in a similar fashion.

In-Atmosphere Mixtures

We have dealt at some length with oxidants, and particularly ozone, and explained that this pollutant group is not generally to be considered to be generated *directly* by human activity. This pollutant group is formed largely by photochemical reactions in the atmosphere, and is thought to be the most important example of in-atmosphere creation of pollutant groups.

Besides the in-atmosphere chemical reactions which lead to new pollutants (and, sometimes, to neutralization of pre-existing pollutants), one must consider the ways in which combinations of pollutants, without chemical reaction, can have effects greater than the sum of those attributed to each pollutant separately. We have specifically incorporated consideration of the synergistic impact of sulphur dioxide

and particulate matter into our indicator. There are other examples of synergism and its opposite, neutralization.

As an example of neutralization, sulphur oxides and oxidants acting together, may bring about less damage than is implied by adding their separate effects. The same may be true for ozone and nitrogen dioxide. Combinations of gases, gases and mists, and gases and particulates are generally complex in their joint effects so that one is not justified, in a precise sense, in assuming that the effects are necessarily additive, synergistic or neutralizing.

One final combination that should be noted, but about which little is now known, is the interaction of airborne pollutants and microbiological agents. As an example, some "air pollutants have been shown to encourage the establishment of bacterial pneumonias and to enhance mortality from such conditions."[21]

Differing Effects and Severity of Impact on Target Populations

When considering the effects of pollutants on a target population, both in the acute sense and the more difficult to ascertain chronic sense, one must appreciate, as noted earlier, that air pollution can be either a cause of a condition or an aggravation of a condition. In other words, air pollution is but one of the many factors, internal or external to the target, that determine a particular condition. In many cases it is difficult to determine the precise role of air pollution with respect to the condition.

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[21] Stokinger and Coffin, *op. cit.*, p. 510.

Our occupational and domestic exposure to pollutants, whether or not we smoke, the food we eat and the water we drink, and our pre-existing mental and physical health are all important factors in determining the likely or possible impact of an additional unit of air pollution. Proof of the cause of a condition and the way in which it is caused is, therefore, not easy to come by outside of strictly controlled laboratory experiments.

It may be appropriate if and when authorities begin to specify pollution abatement objectives on the basis of target population health goals (including those for humans, plants, and animals) to consider the most sensitive groups. These groups would have to be fairly large since, at the extreme end of any normal distribution of a population even very low background levels of airborne pollutants may harm certain individuals in the population. In setting such objectives, it must be recognized that zero levels of pollution are clearly impossible.

As the above comments imply, it is difficult at this point in time to be precise about the effects of particular air pollutants or their relative seriousness mainly because of the lack of knowledge about all other factors contributing to the condition of the ecological components being subjected to air pollution.

A Summary of Other Dilemmas

The determination of the effects of air pollution on a target population is complicated by several other factors which we present in point form:

(i) Mixes of any given set of pollutants may have effects which vary non-systematically with changing proportions of the component pollutants.

(ii) Cumulative effects of one or several pollutants are hard to assess, partly because of varying automatic or deliberate responses of the target to environmental conditions in the short term.

(iii) Several pollutants may have virtually the same effect on the target, making the role of any one pollutant difficult to determine.

(iv) In some cases, it is difficult to determine whether a given pollutant's effect arises from exposure to it in air, or in some other media (e.g., water or food); the effects through other media make it difficult to pin down the original source of pollution and, therefore, the point at which control may be exercised.

* * * * * * * * *

The foregoing discussion of the reservations that we have with regard particularly to the existing relative severity factors points out the need for an extensive effort to investigate the linkage between environmental conditions and the effects of these conditions. This information is necessary, but not sufficient, for the setting of objectives for air pollution control. In order to design programs to achieve these objectives, the scientific determination of the linkage between the generation of pollutants and ambient air concentrations of these pollutants will also be necessary.

Chapter 3 presents our findings with respect to the association between airborne pollutants and hospitalization for respiratory ailments. Chapter 4 presents an overview examination of the sources of pollutants generally found in the urban ambient air in Canada and discusses some aspects of the linkages between emissions and ambient air quality; it does not, however, go into plume dispersion, mixing depths, air movement, and other considerations of the relationship between the generation of pollutants and ambient air quality.

Chapter 3

AIR POLLUTION AND HEALTH

A. Introduction

As noted earlier, there are two dimensions to the possible negative health effects of air pollution. First, it is argued that a population which is exposed to relatively low levels of air pollution over a long period of time will exhibit a higher incidence of certain types of disease than will a population exposed to essentially unpolluted air. Second, there is reason to believe that variations in the incidence of respiratory diseases for a given population may be attributed, at least in part, to concurrent variations in the quality of air (extreme examples of this are the effects of certain episodes of high pollution, such as those in Donora, Pennsylvania (1948) and London, England (1952)).

In this chapter, an analysis emphasizing the second dimension is undertaken using data for three Canadian cities in 1972. The main purpose of this analysis was to provide empirical justification for the relative severity factors assigned the pollutants in our urban air quality index; in other words, although clinical evidence of negative physiological effects of a pollutant may exist, we sought to determine whether effects can be detected in a population exposed to low average but variable ambient air concentrations of this pollutant. Also, synergistic or neutralizing effects not detected or fully determined clinically may occur when several pollutants, individually believed to be harmful, mix together in the air

we breathe. Finally, although this was not borne out by our analysis, it is possible that one pollutant, or at least a small subset of pollutants may be used as a proxy for overall air quality. An example of this approach is Ontario's use of an air pollution index which uses only the concentrations of sulphur dioxide and particulate matter.

B. The Model

The hypothesis under consideration here is that the incidence of respiratory disease in a population is at least partly the result of variations in ambient air quality. If it is assumed that other causes of respiratory disease are unrelated to air quality, this hypothesis can be stated in general terms as:

$$IRD = f(AAQ) \qquad (1)$$

where

IRD: incidence of respiratory disease

AAQ: ambient air quality.

Incidence of respiratory disease is measured by hospital admissions among the most sensitive elements of the population -- those aged under 15 or over 45 -- for five categories of respiratory disease. These five categories, and the mnemonics used to represent hospital admission over a particular time period for each of these categories are:[1]

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[1]Correspondence between these categories and ICDA classification is given in Appendix A.

(1) asthma (ASTHMA),

(2) upper respiratory infections (UPRESP),

(3) pneumonia (PNEUMØ),

(4) bronchitis (BRØNCH),

(5) other respiratory disease (ØTHRES).

Ambient air quality is measured by averaging hourly readings on a number of pollutants over a particular time period. The pollutants considered, and the mnemonics representing their concentrations, are:

(1) sulphur dioxide (SO_2),

(2) particulate matter (COH),

(3) nitrogen oxides (NO_x),

(4) total oxidants (TOX),

(5) hydrocarbons (HC),

(6) carbon monoxide (CO).

In addition to the above, a temperature variable (TEMP) was used to capture the effect of weather and season on health.

With the aid of two additional assumptions, equation (1) can now be expressed in an operational form. These assumptions are:

(1) The relationship between ambient air quality and incidence of respiratory disease is linear over the relevant range.

(2) The six pollutants, and temperature, are not multi-collinear.

Equation (1) can now be written as:

$$IRD = \beta_0 + \beta_1(SO_2) + \beta_2(COH) + \beta_3(NO_x) + \beta_4(TOX) + \beta_5(HC) + \beta_6(CO) + \beta_7(TEMP). \quad (2)$$

This equation really represents five equations since IRD is measured in five ways -- by the number of hospital admissions over a particular time period for the five categories of disease mentioned above.

If the usual assumptions are made about random errors, the coefficients of equation (2) can be estimated using ordinary least squares. It was anticipated that the coefficients of the pollution variables would be positive, and that of the temperature variable negative -- at least for diagnostic categories known to be affected by temperature, such as pneumonia. In fact, however, our empirical results only partly justified these expectations.

Finally, it should be pointed out that in models of this kind, the nature of the dependent variable is such that standard statistical tests of significance of the coefficients and of the regression hyperplane are strictly invalid. The problem is that the dependent variable, number of admissions, is constrained logically to be a positive integer. As a result, random errors cannot reasonably be assumed to follow a normal distribution, and use of the "t" and "F" distributions for significance tests is not truly appropriate. Notwithstanding this problem, t and F ratios are reported for the

equations fitted, and the reader may judge for himself or herself the importance to be attached to these statistics.

C. The Data

The model described above was tested using data for 1972 for three cities -- Windsor, Sudbury, and Edmonton. The choice of these cities was determined entirely by availability of data. We had originally hoped to use data for other cities in Ontario but it proved impossible to obtain a continuous series on the pollution variables. This choice can be rationalized *ex post* by noting that Windsor ranked second only to Montreal on a three-year average of the Council's first-approximation air pollution indicator, that the air pollution problem in Sudbury has been widely publicized, and that Edmonton appears to have a somewhat different mix of airborne pollutants in that levels of oxidants are relatively high, while sulphur dioxide levels are very low.

(1) Windsor: The source data for the dependent variables were records of individual admissions to hospitals. A frequency count was obtained for each day of 1972 for each diagnostic category for residents of Windsor under 15 or over 45 years of age. These daily frequency counts could then be combined to obtain any observation period desired. A more sensitive, and hence, more desirable measure of morbidity would be a frequency count of visits to doctors, but these data are not available. Similarly, it would have

been desirable to include only individuals with a history of respiratory disease, but again, the data were not available.[2] Finally, it was discovered that many records did not contain a date of admission, and that this resulted in a frequency count that appeared to be too variable for the first 11 weeks of 1972 and, consequently, these weeks were dropped from the sample.

Source data for the independent variables consisted of hourly readings from the continuous monitoring station at 471 University Avenue for the pollution variables, and daily average temperatures for the city (TEMP) as recorded at the airport. Implicit in the use of these pollutant data is the assumption that these point source measurements fairly measure the ambient air quality over the same geographical area as that from which hospital admissions are drawn. This assumption is necessary because the University Avenue station is the only one which monitors all six pollutants.

The hourly pollution readings were combined into daily arithmetic means for the six pollutants. As a result, missing hourly observations, which are more frequent for some pollutants than others, are "submerged" at the daily level. The daily means were then combined into an appropriate observation period.

(2) Sudbury: The dependent variables were derived in the same way as for Windsor, and the same problem was encountered with missing admission dates.

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[2]The reader might examine the study by Levy, D., Gent, M., and Newhouse, M., *The Relationship Between the Air Pollution Index and Hospital Admissions for Acute Respiratory Illness in Hamilton*, paper presented to the Air Pollution Control Association of Ontario Annual Meeting, Toronto, 1973.

The independent variables were obtained from hourly data recorded at the Ash Street water tank. This station was chosen because, as in Windsor, it was the only one which measured all six pollutants. Unfortunately, however, missing data were so extensive that a reliable daily or weekly series could only be obtained for sulphur dioxide and particulate matter.

(3) Edmonton: Data for the dependent variables were available directly in the form of frequency counts per day by age group and diagnosis. Since there was no diagnostic category corresponding to Ontario's "other respiratory disease" this variable was dropped.

Daily mean readings of temperature, total oxidants, particulate matter, carbon monoxide, and nitrogen dioxide were taken directly from computer printouts.

D. Results

The equations discussed in section B above were fitted to the data for the three cities using the technique of ordinary least squares. Observation periods of one day, three days (using moving averages) and one week were tried, but weekly observations consistently produced much better fits. Consequently, the shorter periods were discarded.

The determination of the appropriate time lag between the dependent and independent variables was not so easily resolved. There are three possible reasons for lagging the

dependent variable: first, there may be an institutional lag between the time an individual expresses a wish to enter hospital, and the actual recording of his admission; second, the effects of pollutants on the individual may not manifest themselves immediately; and third, people are sometimes reluctant to enter hospital through fear or apprehension. However, preliminary fits using three different lag periods (no lag, one day, and one week) did not indicate the superiority of any one lag period. Consequently, a one day lag was used since this seemed reasonable in light of the three reasons mentioned above.

The results are presented separately for each of the three cities, in the form of correlation matrices and regression coefficients; t- and F-statistics are reported, but as noted above, they should be interpreted with caution.

(1) Windsor

Correlation coefficients among all the variables used in the Windsor equations are presented in Table 14. It will be noted that several variables in this table were not defined in Section B above. These four variables, SØK, API, SUBTØTAL, and TØTAL, were added in an attempt to improve the fits of some equations. They are defined as follows:

SØK -- this is an eight-hour distributed-lag function which was fitted to the hourly sulphur dioxide data in an attempt to capture the effect of duration as well as level of exposure. However, when averaged into weekly observations, there was a negligible difference between the figures for sulphur dioxide and SØK.

API -- the Ontario Ministry of the Environment's air pollution index was calculated from sulphur dioxide and particulate matter data. The formula for Windsor was as follows:[3]

$API = 0.78 [156.7 SO_2 + 18.26 COH] 1.06.$

SUBTØTAL and TØTAL -- aggregates used to determine the extent to which one can generalize about respiratory disease. They are defined as:

SUBTØTAL = UPRESP + PNEUMØ + BRØNCH

TØTAL = ASTHMA + ØTHRES + SUBTØTAL.

Table 14

CORRELATION MATRIX, WINDSOR, 1972

	SØK	COH	NO_x	TOX	HC	CO	TEMP	API	SO_2
Independent Variables:									
SØK	1.00								
COH	.41	1.00							
NO_x	- .02	.05	1.00						
TOX	- .19	.00	.13	1.00					
HC	.23	.39	- .40	- .51	1.00				
CO	- .15	- .30	- .11	.38	.01	1.00			
TEMP	- .39	- .55	- .01	.58	- .34	.80	1.00		
API	--	--	.02	- .10	.39	- .27	- .57	1.00	
SO_2	--	.42	- .01	- .17	.23	- .11	- .39	--	1.00
Dependent Variables:									
ASTHMA	- .15	- .21	.20	.03	.01	.09	.18	--	- .13
UPRESP	.10	.22	.38	.04	- .32	- .57	- .45	.19	.10
PNEUMØ	.34	.23	.36	.10	- .34	- .43	- .31	.33	.32
BRØNCH	.18	.17	.20	.46	- .19	.20	.23	.21	.24
ØTHRES	.08	.01	.21	- .11	- .12	- .31	- .29	--	.08
SUBTØTAL	.28	.28	.45	.21	- .40	- .48	- .33	.33	--
TØTAL	.22	.21	.47	.20	- .37	- .42	- .27	.25	--

[3]For details of the derivation of this formula, see *Ontario's Air Pollution Index*, 2nd Revision (Toronto: Ontario Ministry of the Environment, September 1973).

The upper portion of Table 14 contains simple correlation coefficients among the components of ambient air quality. The absolute value of these coefficients provide little justification for the use of any subset of these variables as a proxy for the complete set. In addition, in some cases the signs are "wrong" -- that is, if one pollutant is to be used as a proxy for one or more others, then it should have a relatively high positive coefficient, but this is not the case. To provide a more rigorous means of judging the significance of these correlations, the hypothesis that the population correlation coefficient between any two variables is zero was tested. The critical value of the sample correlation coefficient (corresponding to a level of confidence of 95 per cent) is F.31.[4] By this criterion only 12 of the 26 coefficients (counting either those for sulphur dioxide or those for SØK, but not both) are significantly non-zero (absolute value ≥ .31), and in the light of our theoretical expectations, two of these have the "wrong" sign.

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[4]The usual statistic for this test is:

$$t = \sqrt{\frac{r}{\frac{1 - r^2}{n - 2}}}$$

where r is the sample correlation coefficient from a sample size n, and t has a t-distribution with n-2 degrees of freedom. Rearranging this in terms of t;

$$r_c = t_{\alpha/2} \sqrt{\frac{1}{(n-2) + (t_{\alpha/2})^2}}$$

where $t_{\alpha/2}$ is the t-value with n-2 degrees of freedom at a level of significance of α, and r_c is the desired critical value.

The lower half of Table 14 contains correlation coefficients between dependent variables and independent variables. Applying the same criterion as above, only 20 of 54 coefficients are significantly non-zero, and of these, nine have the "wrong" sign. However, it is interesting to note that all these significantly "wrong" signs involve carbon monoxide or hydrocarbons. As will be noted below, this perverse result was also reflected in the regression analysis.

Table 15 presents seven regression equations. Of these, four equations are quite encouraging, as judged by the $\bar{R}^2$ statistic, but the ASTHMA and ØTHRES equations are clearly very poor fits. This judgment is reinforced by the F-statistic: at a level of significance of 95 per cent, the critical F-value is 2.32. This value is exceeded for the UPRESP, PNEUMØ, SUBTØTAL, and TØTAL equations, and is approximately achieved by the BRØNCH equation.

Table 15

REGRESSION EQUATIONS, WINDSOR, 1972

Dependent Variables	Independent Variables								$\bar{R}^2$	F	Degrees of Freedom
	Intercept	SO_2	COH	NO_x	TOX	CO	HC	TEMP			
ASTHMA	-2.99 (-.48)	-.06 (-.11)	-.91 (-1.11)	1.42 (1.88)	1.15 (.78)	-.29 (-.39)	.29 (1.53)	.01 (.12)	-.03	.85	7,31
UPRESP	31.32 (3.37)	.18 (.23)	-.52 (-.43)	1.59 (1.41)	2.34 (1.08)	-2.20 (-1.98)	-.25 (-.88)	-.15 (-1.21)	.42	4.99	7,31
PNEUMØ	23.58 (2.64)	1.60 (2.21)	-.06 (-.05)	1.23 (1.14)	1.70 (.82)	-1.73 (-1.62)	-.35 (-1.31)	-.05 (-.46)	.37	4.16	7,31
BRØNCH	-5.53 (-.93)	.90 (1.86)	.38 (.48)	.72 (1.00)	2.34 (1.68)	.04 (.06)	.003 (.02)	.04 (.46)	.19	2.31	7,31
ØTHRES	11.84 (2.29)	.03 (.07)	-.12 (-.18)	.41 (.65)	-.23 (-.19)	-.25 (-.41)	-.08 (-.48)	-.04 (-.61)	-.04	.78	7,31
SUBTØTAL	47.20 (.04)	2.38 (2.04)	.50 (.30)	3.73 (2.05)	6.28 (1.67)	-3.54 (-1.60)	-.69 (-1.54)	-.16 (-.65)	.54	7.40	7,31
TØTAL	44.77 (.03)	2.26 (1.57)	-.48 (-.23)	5.15 (2.30)	7.53 (1.63)	-3.73 (-1.38)	-.40 (-.72)	-.16 (-.55)	.41	4.77	7,31

Note: (1) SUBTØTAL = UPRESP + PNEUMØ + BRØNCH
TØTAL = SUBTØTAL + ASTHMA + ØTHRES.

(2) Values in brackets are t-statistics.

A possible explanation for the poor fit in the ØTHRES equation may be that the category "other respiratory disease" is too heterogeneous to be correlated with air quality. In the case of ASTHMA, it may be that pollen or dust are the critical factors, and not the measures used here. In any event, these two categories were not included in further work. It should also be noted that the SUBTØTAL equation fitted the data better than did TØTAL, and the latter category includes ASTHMA and ØTHRES.

Turning now to the independent variables, carbon monoxide and hydrocarbons, as noted in the correlation matrix, exhibited positive coefficients only in the BRØNCH equation but were not significant in this case. In the case of carbon monoxide, the medical effects one would expect relate primarily to the circulatory rather than the respiratory system (i.e., the oxygen carrying capacity of the blood). Even in respect of the circulatory system, recovering from carbon monoxide exposure is very rapid when exposure is reduced. This factor plus the known high spatial variance in the concentration of this pollutant[5] may be the important reasons why the carbon monoxide coefficients yielded in the tested equations are negative or of low significance. Further, in this particular analysis, carbon monoxide concentrations were highly correlated with TEMP (r = .80) which in turn was negatively correlated with all diagnostic categories except ASTHMA and BRØNCH. The poor performance of hydrocarbons, on the other hand, may be due to the previously

[5]Carbon monoxide levels increase exponentially as one approaches major roads, and very high levels are found in parking garages and subways.

noted heterogeneity of this pollutant group. Whatever the cause, these two variables persistently produced perverse results, and consequently were dropped from subsequent equations.

On a more positive note, the coefficients for sulphur dioxide, the nitrogen oxides, and total oxidants exhibited the "correct" sign in all but two cases. The t-statistics provide a guide to the confidence one has in these results, bearing in mind of course our earlier caveat about the strict validity of t- and F-tests. The t-value corresponding to a level of significance of 95 per cent is ±2.03 and by this criterion, sulphur dioxide is significant in the PNEUMØ and SUBTØTAL equations, and nitrogen oxides are significant in the SUBTØTAL and TØTAL equations.

The particulate matter variable, COH, performed poorly: in five of the seven equations it entered with a negative sign, and was insignificant in all seven. This may be because, as we noted earlier, the "coefficient of haze" measurement does not record the chemical composition or the size of airborne particles and hence, this variable is very heterogeneous. However, an attempt was made to obtain a significant coefficient by computing the Ontario air pollution index (API) which combines sulphur dioxide and particulate matter, and fitting equations with this new variable.

The upper part of Table 16 shows the coefficients and t-statistics for three equations including API with the

other pollutants which showed some promise. The F-statistic indicates that these regressions are all statistically significant: the critical F-value is 2.65. However, API enters with a negative sign in the UPRESP equation, and is significant and positive only in the PNEUMØ regression. The other two pollutants, total oxidants and nitrogen oxides, consistently enter with the correct sign.

The lower part of Table 16 shows three regression equations without API. Here, total oxidants and nitrogen oxides enter with positive signs and are significant in all three equations. In the two equations which are directly comparable (those involving UPRESP and PNEUMØ), the removal of API causes only a negligible drop in $\bar{R}^2$. Thus, clearly the critical pollutants from a predictive point of view are total oxidants and nitrogen oxides.

Table 16

REGRESSION EQUATIONS, WINDSOR, 1972

Dependent Variables	Independent Variables					$\bar{R}^2$	F	Degrees of Freedom
	API	TOX	NO_x	TEMP	Intercept			
UPRESP	-.45 (-1.61)	4.90 (2.88)	2.51 (2.50)	-.37 (-4.41)	22.26 (3.76)	.42	7.81	4,34
BRØNCH	.19 (.63)	3.02 (1.68)	2.25 (2.13)	-.17 (-1.87)	10.46 (1.67)	.23	3.81	4,34
PNEUMØ	.38 (2.20)	1.79 (1.71)	.68 (1.10)	.063 (1.22)	-5.21 (-1.43)	.25	4.12	4,34
UPRESP		3.97 (2.43)	2.59 (2.53)	-.29 (-4.27)	14.89 (3.88)	.39	9.14	3,35
SUBTØTAL		9.94 (3.50)	5.42 (3.06)	-.49 (-4.26)	29.38 (4.42)	.45	11.23	3,35
PNEUMØ		3.40 (2.03)	2.22 (2.12)	-.20 (-2.92)	13.52 (3.44)	.24	5.03	3,35

(2) Sudbury

Table 17 presents the results for six regression equations fitted to data for Sudbury. As noted earlier, complete series were only available for sulphur dioxide and particulate matter, but these limited data do reinforce, in a negative sense, the results of the Windsor study. That is, these two pollutants cannot, by themselves, explain hospital admissions for respiratory ailments. In fact, in five of the six equations, SØK and particulate matter enter with a negative sign, and none of the coefficients are significant (as judged by the t-statistics).

Table 17

REGRESSION EQUATIONS, SUDBURY, 1972

Dependent Variables	Independent Variables				$\bar{R}^2$	F	Degrees of Freedom
	Intercept	TEMP	COH	SØK			
ASTHMA	.84 (.98)	.011 (.91)	-.38 (-.70)	.20 (1.84)	.14	2.01	3,38
UPRESP	10.75 (5.32)	-.042 (-1.44)	.43 (.34)	-.29 (-1.13)	.12	1.68	3,38
PNEUMØ	5.32 (3.91)	-.021 (-1.06)	-.039 (-.05)	-.19 (-1.11)	.07	.98	3,38
BRØNCH	5.16 (4.19)	-.009 (-.48)	-1.54 (-2.00)	-.08 (-.49)	.12	1.65	3,38
SUBTØTAL	22.07 (7.16)	-.061 (-1.35)	-1.53 (-.80)	-.36 (-.92)	.08	1.05	3,38
TØTAL	23.82 (7.22)	-.056 (-1.17)	-1.45 (-.70)	-.36 (-.87)	.06	.84	3,38

(3) Edmonton

Table 18 gives simple correlation coefficients between all pairs of variables for which data was available for Edmonton. Using the criterion derived from the t-statistic (±.31) in our discussion of the Windsor results, Table 18 indicates significant negative correlations between TEMP and the concentrations of particulate matter (COH), the nitrogen oxides (NO_x), and carbon monoxide (CO), and significant positive correlations between NO_x and COH, between COH and CO and between CO and NO_x. This suggests the possibility, at least in Edmonton, that one of these pollutants may act as a proxy for the other two.

Table 18

CORRELATION MATRIX, EDMONTON, 1972

	TEMP	TOX	COH	NO_x	CO
Independent Variables:					
TEMP	1.00				
TOX	.11	1.00			
COH	- .47	- .00	1.00		
NO_x	- .62	- .11	.56	1.00	
CO	- .59	- .20	.70	.74	1.00
Dependent Variables:					
ASTHMA	.31	.09	- .09	- .24	- .30
UPRESP	- .17	.50	.14	.11	- .02
PNEUMØ	- .31	- .22	.24	- .02	.12
BRØNCH	- .07	.07	.06	.05	.09
SUBTØTAL	- .33	.08	.26	.05	--
TØTAL	- .23	.10	.23	- .02	.02

Note: SUBTØTAL = UPRESP + PNEUMØ + BRØNCH
TØTAL = SUBTØTAL + ASTHMA.

-- Correlation not tested.

The lower part of Table 18 offers little hope of good regression results; using the same criterion (±.31) only 4 of the 29 coefficients are significantly non-zero, and only one of these involves a pollution variable.

Regression results are presented in Table 19. Only the UPRESP equation contains a significant, positive pollution coefficient (that for the total oxidant variable). $\bar{R}^2$ also indicates that this equation is the best fit, and, in fact, the other equations represent unquestionably poor fits (the PNEUMØ equation seems almost as good as UPRESP but three of the four pollution variables enter with a negative sign).

Table 19

REGRESSION EQUATIONS, EDMONTON, 1972

Dependent Variables	Independent Variables						$\bar{R}^2$	F	Degrees of Freedom
	Intercept	TOX	NO_X	COH	CO	TEMP			
ASTHMA	11.47 (.05)	- .11 (- .06)	8.26 (.14)	15.79 (1.22)	-4.08 (-1.34)	.06 (1.20)	.04	1.32	5,36
UPRESP	29.45 (.09)	8.27 (3.39)	40.51 (.49)	12.60 (.71)	-3.96 (- .94)	- .08 (-1.28)	.22	3.35	5,36
PNEUMØ	69.40 (.13)	-6.95 (-1.68)	-272.7 (-1.96)	55.05 (1.83)	-4.17 (- .59)	- .28 (-2.53)	.18	2.85	5,36
BRØNCH	13.43 (.05)	1.11 (.57)	-16.81 (- .26)	- 2.43 (-.17)	1.72 (.52)	- .01 (- .25)	-.11	.14	5,36
TØTAL	123.75 (.12)	2.32 (.38)	-240.78 (-1.17)	81.01 (1.82)	-10.48 (- .99)	- .32 (-1.95)	.07	1.65	5,36

To emphasize that total oxidants are the only pollutant group with a significant effect on hospital admissions, an equation was fitted with just the total oxidants variable and TEMP. The equation is:

$$\underset{}{\text{UPRESP}} = \underset{}{27.31} + \underset{(3.87)}{8.86}(\text{TOX}) - \underset{(-1.70)}{.08}(\text{TEMP}) \quad \bar{R}^2 = .26$$

where the figures in brackets below the equations are t-statistics. This equation exhibits a higher $\bar{R}^2$ than the corresponding equation in Table 19: taking account of other pollutants does not improve the fit.

E. Summary

In summarizing the results presented in this chapter, it must be emphasized that the fits obtained, and the number of insignificant or perverse coefficients observed, lead us to be hesitant in drawing strong conclusions. However, the Windsor data do suggest that sulphur dioxide, total oxidants, and nitrogen dioxide, all have measurable negative effects on human health (as indicated by hospitalization for respiratory problems). The Sudbury data suggest that sulphur dioxide and particulate matter alone are inadequate measures of ambient air quality if human health, and hospital admissions for respiratory diseases in particular, are the criterion. Finally, the Edmonton data indicate again that total oxidants have a measurable impact on hospitalization, at least for upper respiratory infections. We conclude, therefore, that an index of ambient air quality must include measurements of oxidants, sulphur dioxide, and nitrogen dioxide that are weighted more heavily (i.e., have a higher relative severity factor) than the other pollutants.

Chapter 4

RESIDUAL EMISSIONS

A. Introduction

Measures of ambient air quality such as our first-approximation air quality indicator are, by themselves, of only limited helpfulness to those who wish to control levels of air pollutants: indicators merely describe situations. It is incumbent upon those who build such indicators to also explain these situations. In this chapter, we begin the explanatory function by considering what is known of the linkage between the pollutant burden in ambient air and waste emissions, and then turning our attention to the sources of the emissions.

Precise evaluation of each source of airborne pollutants is clearly beyond our capacity, and any efforts to compile data on emissions would merely duplicate the efforts being made by others in this respect. Our tendency is to rely on information compiled by the responsible organizations. In this respect, the published reports of government bodies and interviews with senior industrial management responsible for environmental programs have provided the information on which this part of the study is based.

A rather complete overview of pollutant emissions for Canada and the provinces, by source, is given in the publication *A Nationwide Inventory of Air Pollutant Emissions 1970.*[1] An updated version of this publication (in respect of the year 1972) should be published in 1975. Some of the provinces also compile detailed data on emissions specific to industrial sources and general area-wide emissions with respect to transportation and heating sources. Summaries of such emission details are published, by urban area, from time to time and are available through the appropriate provincial Department or Ministry.

B. Emissions -- Air Quality Linkage

At the outset of this paper we emphasized that it is because the population is centred about many major fixed sources of pollutant generation, and the activities of this population also result in the considerable generation of pollutants, that our interest has been directed towards urban agglomerations. However, no political boundaries can prohibit the flow of air pollutants. Thus there is reason to believe that the pollutant concentrations in any one urban area are a function both of local and external sources. The air over Windsor reflects to some extent the pollution generated in Detroit; it is known that a large part of the sulphur dioxide content of the air over Hamilton is generated by the Hearn thermal electric power plant in Mississauga under certain weather conditions; and the Montreal Urban Community may be

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[1] *A Nationwide Inventory of Air Pollutant Emissions 1970*, Environment Canada, Technical Appraisal Report EPS 3-AP-73-2 (January 1973).

affected by pollutants generated in the industrial complexes in basically upwind centres such as Beauharnois and Valleyfield. In designing air quality control programs, therefore, it is necessary to have a complete understanding of *regional* sources of pollutants. When high dispersal stacks are used to reduce the concentration of pollutants in the local vicinity, the results may be increases in the level of pollutants outside that area. The plume of gases emitted in Sudbury has been photographed by satellite over Georgian Bay and over Ottawa-Hull, and sulphuric acid "rain" in Scandinavia has been attributed to the emission of sulphur oxides in the Midlands of England. Quite obviously, all these factors must be considered in any program designed to improve local air quality. As evidence that ambient air pollutant concentrations are not a simple proportional function of local pollutant emissions one might cite the observed ratios of sulphur dioxide in three Ontario cities. The sulphur oxide emissions for Sudbury, Toronto, and Hamilton were roughly in the ratio of 50 to 7 to 1 in 1973,[2] and yet the ratio of annual mean concentrations in ambient air was about 1.6 to 1.1 to 1.0 respectively.

There are a number of reasons why the linkage between emissions and ambient air quality, in a local context, is also relatively complex. The height and velocity at which pollutants are injected into the atmosphere, the

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[2]Albert E. Boyer and Keith C. Heidorn, *Urban Planning Utilizing a Regional Atmospheric Simulation Model*, a paper presented at the Eighth Annual Congress, Canadian Meteorological Society, North York, May 1974, p. 8. The ambient air ratios are derived from mean values at the four decimal level rather than the rounded data presented in Table 4.

physical properties of the pollutant (density, or size and shape), the chemical properties, and the weather conditions (air movement and mixing depth) all determine the pattern of concentration for each pollutant. The pattern changes from day to day and even hourly. And in the long term, the activities which generate pollutants may also alter the weather conditions that prevail within a micro-environment. A city, for example, modifies the temperature and wind patterns that prevail in the surrounding countryside.

These various local and external linkages are being examined by certain responsible organizations at this time, and in the relatively near future the prospects for an improved understanding of the relationship between local air quality conditions and the local, regional, and extraregional sources of pollutants, are promising.

With this improved level of understanding, objective and effective air pollution controls become possible. Air pollution indexes, by pollutant groups, can be designed to provide control guidelines and, using meteorological forecasts, potentially dangerous concentrations may be avoided by reducing certain pollutant generating activities. The Ontario "air pollution index"[3] is such a guideline for the sulphur dioxide-particulate matter-synergism complex of air quality. Given that this guideline can be enforced by an authority that spans many regions, control can be effectively implemented by requiring

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[3]The introductory volume to the annual *Air Quality Monitoring Report, Ontario, 1972, Volume 1*, provides an overview of the determination of the air pollution index, the manner in which it is updated hourly, and its use in providing criteria upon which government orders to curtail emissions are determined.

sources of pollutants to reduce, or even cease, operations which generate the offending pollutants. An extension of this methodology to curtail the generation of nitrogen oxides, carbon monoxide and possibly hydrocarbons (when measured precisely enough to permit the determination of quality criteria in respect to the component pollutants of this group) seems desirable. Excesses of ozone concentrations can only be controlled through the reduction of nitrogen oxide and/or hydrocarbon emissions.

C. Nationwide Emissions

To briefly illustrate the generation of airborne residuals, Table 20, derived directly from Environment Canada's inventory for 1970, is presented below.

Table 20

NATIONWIDE POLLUTANT EMISSIONS, 1970 PERCENTAGE DISTRIBUTIONS, BY SOURCE*

Source	Particulate Matter	Sulphur Oxides	Nitrogen Oxides	Hydro-carbons	Carbon Monoxide
1. Industrial:[1]	59.0	75.5	1.1	3.6	4.4
Primary iron and steel production	6.5	--	--	--	0.3
Other iron and steel mills	0.4	--	--	--	0.1
Nonferrous metals	4.7	63.3	--	--	--
Petroleum refining	0.1	0.5	0.3	2.1	2.7
Natural gas processing	--	8.2	--	--	--
Nonmetallic minerals (excluding cement)	22.5	--	--	--	--
Cement	10.5	--	--	--	--
Pulp mills	3.6	2.2	--	--	1.3
Other	10.7	1.3	0.8	1.5	0.0
2. Combustion in Stationary Sources:	20.3	22.1	33.7	4.9	4.3
Utilities	9.3	6.6	12.9	0.1	0.0
Industrial	5.6	12.4	15.4	1.3	0.2
Private	1.6	3.0	3.5	0.8	0.4
Incineration	3.8	0.1	1.9	2.7	3.7
3. Transportation:	2.7	2.4	61.6	76.7	82.9
Motor vehicles -- gasoline	1.5	0.3	50.7	75.2	82.3
Motor vehicles -- diesel	0.2	0.1	7.6	0.3	0.4
Air, marine, and rail	1.0	2.0	3.3	1.2	0.2
4. Miscellaneous:	18.0	--	3.6	14.8	8.4
Forest fires	15.0	--	3.1	8.2	7.3
Other (surface coating, slash burning, etc.)	3.0	--	0.5	6.6	1.1
	100.0	100.0	100.0	100.0	100.0
Total weight of emissions (tons)	2371	7210	1359	3074	17,312

*The emissions are measured by weight.

[1]Includes only emissions directly from industrial processes. Combustion sources, by industry, are not provided; however, a total for all industries is presented under "combustion in stationary sources".

Source: Environment Canada, *A Nationwide Inventory of Air Pollutant Emissions 1970* (Ottawa, 1973).

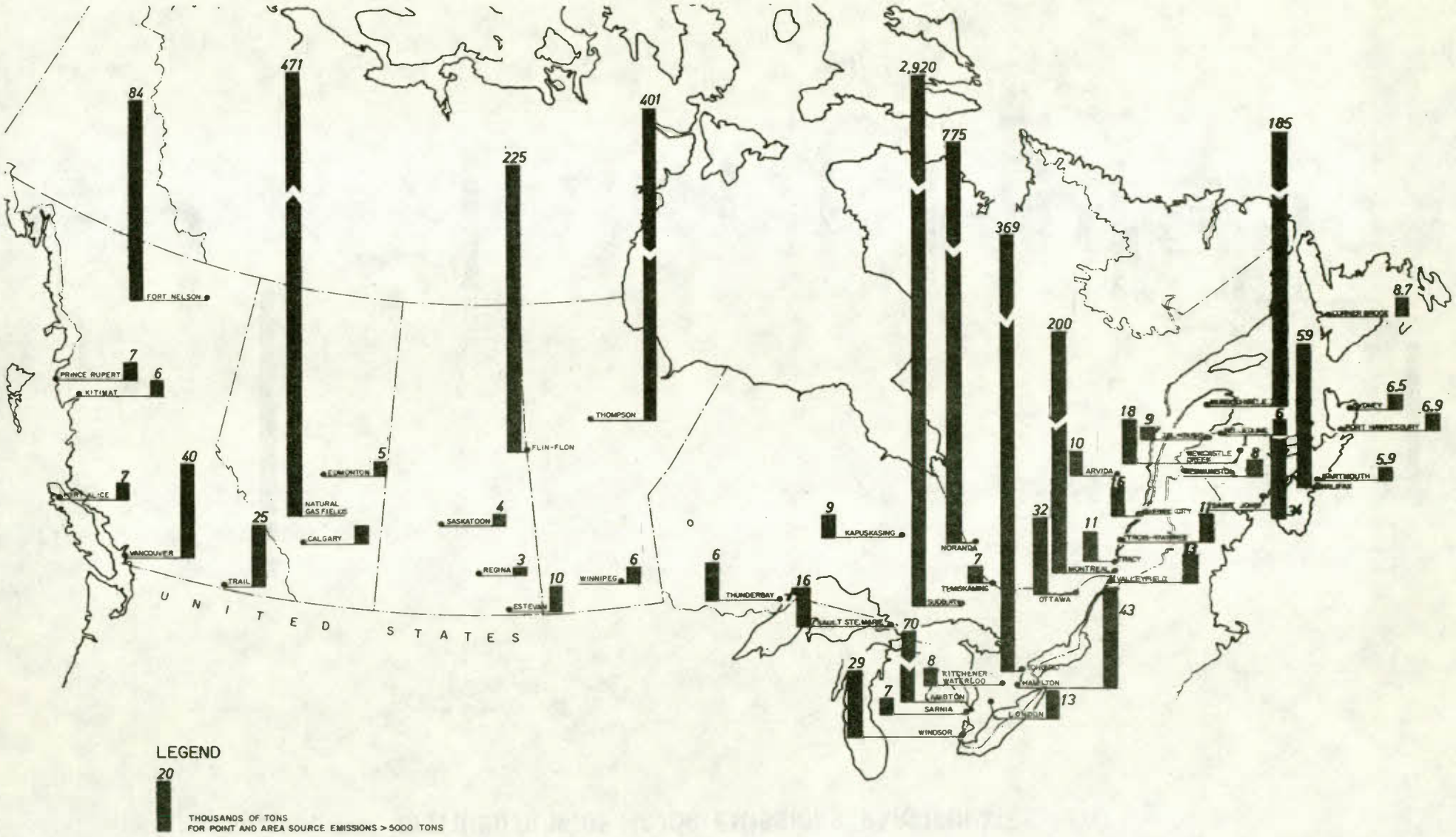
To illustrate the concentration of emission generation, Figures 3 and 4 depict emission points or areas for sulphur oxides and particulates respectively, for 1970 only. The nationwide inventory, at least with respect to the two pollutants depicted in Figures 3 and 4, points out the amounts generated at the various locations shown on the maps. The amounts are often the result of emissions from several different point sources, and sometimes largely from one source. For example, the huge emissions of sulphur oxides shown in Figure 3 for Sudbury are generated by the copper-nickel smelting industry in that area, while the generation of large tonnages of particulates at Wahamum, Alberta (Figure 4) is associated with the Calgary Power coal-fired, thermal-electric power plant.

This single inventory of emissions *does not* imply a stable state in reality; the updated inventory for 1972 will indicate the advances in abatement control (for example, the emission of much-reduced tonnages of sulphur oxides from natural gas processing) as well as sources which have become, in absolute and relative terms, more serious. It should be pointed out that the emissions data do not register improvement in dispersal; on the other hand, installations of tall dispersal stacks do not imply that actual emissions have decreased.

In the following subsections, emissions of particulate matter, sulphur oxides, nitrogen oxides, hydrocarbons, and carbon monoxide are discussed.

Figure 3

DISTRIBUTION OF MAJOR EMISSIONS, OXIDES OF SULPHUR, 1970



LEGEND

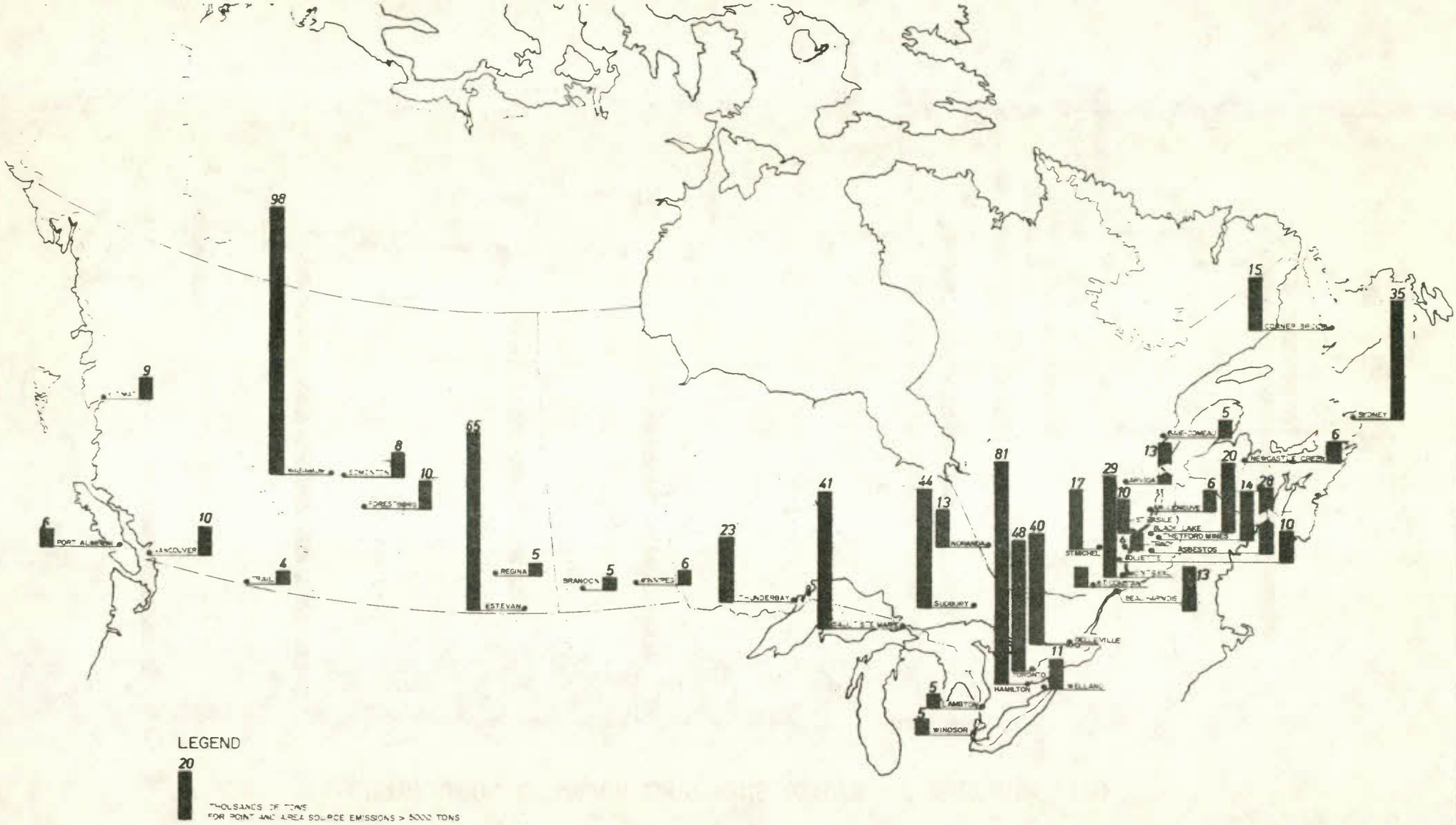
20

THOUSANDS OF TONS
FOR POINT AND AREA SOURCE EMISSIONS > 5000 TONS

Source: A Nationwide Inventory of Air Pollutant Emissions (Environment Canada, January 1973).

Figure 4

DISTRIBUTION OF MAJOR EMISSIONS, PARTICULATES, 1970



Source: A Nationwide Inventory of Air Pollutant Emissions (Environment Canada, January 1973).

a) Particulate Matter

In 1970, 59 per cent of particulate matter emissions were attributable to direct emissions from industrial processes, with 33 per cent of the total particulate emissions arising from the production of nonmetallic minerals. This group includes the cement, lime, asbestos, stone, and sand and gravel industries, but since the cement industry alone was responsible for more than 10 per cent of total particulate emissions, and this industry is to some extent typical of the whole group, it is on this industry that we will centre our comments.

The materials which go into the production of cement are quarried, finely ground, and mixed. Quarrying generates dust, much of which is heavy and, therefore, represents an occupational rather than a community pollutant. Smaller particles, however, may be dispersed over a larger area. The same situation prevails in the quarrying (mining) of lime, asbestos, stone, and sand and gravel deposits.

The quarried product is either milled at site or transported to milling (grinding) facilities. To the extent that the transport routes are through urban areas, the dust blown from the transportation mode can affect the community along the route. The milling/grinding/sorting processes, wherever located, also create dust, the fineness of which determines its tendency to be blown over the surrounding countryside.

In the case of cement and lime, the milled materials are processed in kilns to form a solid product (in lumps or clinkers) and there tend to be substantial emissions from this process. Further milling then takes place, generating yet more dust. Packaging and transportation of the final material also leads to dust emissions.

In respect of all the noted industries, the dust created by processing and handling varies in physical *and* chemical properties, and as we have repeated several times, the danger of particulate matter varies with these properties. Thus, although the asbestos industry is not a major polluter in a nationwide context (in terms of emissions being measured by weight), there are suggestions that the particulate matter which it generates may have disproportionate impacts on populations exposed to it, relative to other particulate matter.

The technology required to greatly reduce these types of emissions (bag houses, gravel bed filters, and electrostatic precipitators -- used at different process points) is available now. For cement flue gas pollutant control, electrostatic precipitators have a lifetime efficiency ranging from 99.5 to 99.995 per cent. While production in the cement industry is projected to increase by over 60 per

cent from 1970 to 1975,[4] the availability of abatement equipment, and existing and proposed legislation (and industrial compliance therewith), indicate that total emissions will probably be sharply curtailed, perhaps by as much as 90 per cent. Forecasts of emissions based on a constant (1970) ratio of pollutant generation to output would be about 30 times as high as the probable level in 1975. This serves as an example of the unreliability of basing pollutant emission forecasts on projected output levels and constant pollution emission ratios.

Much of the technology mentioned above can be employed by all the industries in this category. The use of the available abatement equipment and covered transport containers could well lead to a dramatic fall in pollutant emissions for this group. As an *urban* source of pollution generation, this category may well become much less important. In addition to the above, rising value of urban land may force some of these industrial activities away from urban locations, thus reinforcing the trend towards reduced urban emissions from these sources. At present, only about 40 per cent of the 26 cement plants could be considered to have a potential impact on urban air quality.

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[4] In 1970, Canadian cement production was about eight million short tons. Estimates for 1975 in D. H. Stonehouse, *Cement in Canada* (Department of Energy, Mines and Resources, Ottawa, 1973), p. 92, are for an increase, 1975 over 1970, of about 35 per cent; however, actual figures for 1972 indicate a 30 per cent increase by that time and the industry appears to be approaching full capacity at this time (1974). On the basis of the industry's estimate, production at about 13 million tons in 1975 seems likely.

Among other sources of particulate matter, the primary metals industry was the most important in 1970, accounting for about 11 per cent of total emissions. However, this figure underestimates the importance of this industry as a source of this pollutant group since most of the plants are located in large urban areas. Primary iron and steel production, involving the reduction of iron ore in blast furnaces, and steel production in open hearth, basic oxygen, and electric arc furnaces, accounted for 6.5 per cent of total emissions in 1970, and of this, 72 per cent was in Ontario and 22 per cent in Nova Scotia (mainly Hamilton and Sydney, respectively).

Primary nonferrous metal production and, in particular, the production of aluminum and the smelting of nickel, zinc, copper, and lead, was responsible for 4.7 per cent of particulate emissions in 1970. In many cases local concentrations have since been lowered by the use of tall stacks to disperse pollutants. It should be noted, however, that particulates emitted from primary metals production are known to contain small concentrations of highly dangerous elements and compounds -- in particular, beryllium, cadmium, zinc, lead, mercury, and fluorides -- and consequently pollution control in these industries must continue to be given a high priority.

Combustion in stationary sources, including thermal electric power generation, industrial and private space heating, and incineration of solid wastes, accounted for about 20 per cent of particulate emissions in 1970. In the

past, substitution of "cleaner" fuels has resulted in reduced emissions from these sources, but cost and supply considerations are likely to shift the emphasis to combustion technology and smoke dispersal through high stacks as a means of reducing the impact of this pollutant group. In the case of electric power generation, the massive James Bay Hydro-electric Project and the more modest nuclear program in Ontario will provide "cleaner" electricity in the future, though, of course, in a total environmental sense the net impact of this substitution has not been measured.

Finally, forest fires, which consumed an average of 2.5 million acres of forest annually from 1958 to 1968, contributed about 15 per cent of particulate emissions in 1970. However, these fires are generally confined to relatively sparsely settled areas so that the population affected is small, and, in any case, our ability to control this source of emissions is somewhat limited.

(b) Sulphur Oxides

Industrial sources accounted for more than three-quarters of emissions of oxides of sulphur in 1970. Nonferrous metal production, for which the raw material is mostly low-grade sulphide ore, contributes by far the largest share (63 per cent of the total, of which the largest part -- about 61 per cent -- comes from primary copper and nickel production). From the perspective of urban air quality, only the smelters at Sudbury pose a constant problem, but four other areas, Flin Flon and Thompson in Manitoba and Noranda

and Murdockville in Quebec, may experience high ambient levels of sulphur dioxide under certain weather conditions as a result of relative proximity to copper and/or nickel operations.

At the present time dispersal through tall stacks is the main means used to control ambient concentrations, and this is not likely to change. In fact, the capital costs it would take to abate the largest part of the sulphur dioxide emissions in the Sudbury region are estimated to be in excess of one-quarter of a billion dollars, and although this would result in enormous recovery of sulphur, and production of sulphuric acid, the market for these is unlikely to justify expenditure on this scale.

There are two other industrial sources of sulphur dioxide emissions that are worthy of mention. Natural gas processing accounted for about 8.2 per cent of total emissions in 1970, but this industry is restricted to areas of very low population density, in northeastern British Columbia and Alberta. Pulp and paper mills accounted for only about 2 per cent of total emissions, but contribute to a highly noticeable pollution problem in some urban areas. However, in both these industries newer plants have greatly reduced the level of emissions per unit of output.

Fuel combustion in stationary sources was responsible for 22 per cent of sulphur oxide emissions in 1970 with the emission rate being a direct function of the sulphur content of the fuel consumed. As was mentioned earlier

with respect to particulate emission, substitution of low-sulphur fuel will become progressively more expensive as markets for energy sources become tighter in the future.

Overall, in the face of huge abatement costs and minimal economic incentives for recovery, dispersal will remain the main means of control of sulphur oxide emissions, at least in the medium term.

(c) Nitrogen Oxides

Nitrogen oxide emissions are almost exclusively the by-product of fuel combustion. More specifically, nitrogen in the air, and, to a lesser extent, nitrogen in fuel, is oxidized at typical combustion temperatures. Consequently, the most important sources of emissions of oxides of nitrogen are combustion in stationary sources (33.7 per cent of the total in 1970) and motor vehicles (58.3 per cent). Emissions can be controlled to some extent in the former source by controlling the amount of air in the air-fuel mixture and by using lower combustion temperatures. Because of the importance of motor vehicles as the source of the largest share of hydrocarbons and carbon monoxide, as well as nitrogen oxides, this source will be discussed separately below.

(d) Hydrocarbons

Hydrocarbon emissions result primarily from fuel combustion, with gasoline-powered motor vehicles responsible for the largest share (75.2 per cent of the total in 1970),

and the only other sizable source being forest fires. A secondary and numerically small source is evaporation in the refining of oil and handling of gasoline and during the application of paints and other surface finishes. As mentioned above, motor vehicles will be discussed separately.

(e) Carbon Monoxide

Carbon monoxide emissions are primarily the result of incomplete oxidation of hydrocarbons during combustion. Once again, gasoline-powered motor vehicles are by far the most important source, accounting for 82 per cent of total emissions in 1970. Of the remainder, 3.7 per cent was emitted as a by-product of solid waste incineration (mainly the combustion of sawdust in Wigwam burners) and 2.7 per cent was emitted during the catalytic cracking process of petroleum refining. Finally, forest fires accounted for about 7 per cent of the total emissions, but again, this source is to a considerable degree beyond systematic control.

D. Provincial and Local Emissions

Although the nationwide survey is presented in provincially disaggregated terms, many emission sources are calculated in terms of a nationwide (and often based on American) coefficient, relating emissions to output in a single firm. Obviously no single firm describes an industry. The estimates of the nationwide inventory may, therefore, be considerably overstated or understated with respect to any one plant in any one area.

Provincial governments have also developed inventories of emissions often determined by actual observation of plant emissions. In Ontario, for a number of urban areas, industrial emission inventories, by plant and even by process, are compiled each month for virtually all industrial manufacturing operations. In several other provinces inventories are also compiled although standard emission coefficients are often employed. Quite obviously, the same detailed inventory compilation for transportation and space-heating sources is impractical. Whereas large commercial and public complexes may be specifically examined for space-heating emissions, transportation and small space-heating sources are generally evaluated within a transportation corridor or a grid system context, respectively. Nonetheless, the provincial inventory has a large element of point-specific analysis. As more geographically disaggregated ambient air quality monitoring comes into use, intra-urban emission control programs can be developed. As an example of such a control program one can imagine programs designed to keep air in the vicinity of hospitals, where the population at risk is particularly susceptible to ill effects from air pollution, considerably less polluted than the air for the urban community in general.

Not all provincial and urban emission inventories are as finely determined as are those in certain Ontario cities. In fact, emission factors based on fuel consumed provide a rough and ready estimate of the majority of emissions, and this may

be sufficient in smaller urban areas, in areas where industrial activity is not too prominent, and/or in areas where the wind patterns and mixing depths are generally sufficient to dilute pollutant concentrations rapidly. On the other hand, however, detailed analysis might be warranted on the basis that, in any urban area, one should be able to plan to avoid the consequences of any undesirable air pollution conditions to the extent possible.

Unfortunately, the approaches to emission inventory compilation are not standard throughout Canada. This leads to the situation in which the experience of the more sophisticated monitoring and control authorities cannot be readily transferred to other centres. Perhaps of less importance, this also means that inter-urban comparison of emission sources is somewhat difficult. Without such comparisons, the role of the regional and national governments -- in respect of aid and the standardization of control regulations -- is difficult to determine and optimize.

To illustrate, in a summary fashion, the type of emission inventory which is regularly updated, the emission summaries for Metropolitan Toronto, over a five-year period, are presented in Table 21.

This table indicates the effect over time of a number of abatement programs, changes in government policy, fuel substitutions, and changes in production technology and operations. The effects of abatement equipment on the generation of particulates and sulphur dioxide from thermal

generating plants is apparent, the reduction in the sulphur content in heating fuels is also notable, and the impact of exhaust controls on automobiles from the 1973 and later models is noted as carbon monoxide and hydrocarbon emissions fall and nitrogen oxides rise in the last year depicted. Hamilton is the only other urban area for which regularly updated inventories have been published (to our knowledge), and the emission data for this city confirm some of the trends one can note in the Toronto summary. Parallel changes in data in respect to emissions and ambient air concentrations lend credibility to the emission data.

Table 21

EMISSION INVENTORY SUMMARIES BY SOURCE AND POLLUTANT
METROPOLITAN TORONTO, 1969-74

(Thousands of Tons)

Source Type	Year	Sulphur Dioxide	Particulate Matter	Nitrogen Oxides	Carbon Monoxide	Hydro-carbons
Thermal Generating Stations	1969-70	246.2	10.8	63.8	1.6	0.6
	1970-71	246.2	10.8	63.8	1.6	0.6
	1971-72	191.4	3.3	53.3	1.2	0.5
	1972-73	190.7	3.7	43.8	2.1	1.4
	1973-74	190.7	3.7	43.8	2.1	1.4
Motor vehicles[1]	1969-70	1.8	2.4	22.3	427.4	64.8
	1970-71	1.8	2.4	22.1	418.7	64.0
	1971-72	2.0	2.6	24.6	462.8	71.1
	1972-73	2.0	2.6	24.6	462.8	71.1
	1973-74	2.0	2.6	36.1	370.3	53.0
Other Transportation	1969-70	0.8	1.4	1.8	1.5	6.1
	1970-71	0.8	1.3	2.0	1.5	6.1
	1971-72	0.8	1.3	2.0	1.5	6.1
	1972-73	0.8	1.3	2.0	1.5	6.1
	1973-74	0.8	1.3	2.0	1.5	6.1
Heating	1969-70	40.1	6.9	18.6	3.4	1.2
	1970-71	25.3	3.6	11.0	1.1	0.7
	1971-72	24.4	4.2	12.3	1.7	0.8
	1972-73	23.2	4.2	12.3	1.7	0.8
	1973-74	21.0	4.3	12.2	1.2	1.1
Other Industry and Utilities	1969-70	31.8	17.6	13.5	2.9	21.5
	1970-71	19.3	14.5	10.4	4.8	21.4
	1971-72	11.7	10.9	10.9	4.6	23.3
	1972-73	10.3	10.8	10.3	4.7	22.9
	1973-74	10.8	9.5	12.0	4.1	22.2
Total	1969-70	320.7	39.1	120.0	436.8	94.2
	1970-71	293.4	32.6	109.3	427.7	92.8
	1971-72	230.3	22.3	103.1	471.8	101.8
	1972-73	227.0	22.6	93.0	472.8	102.3
	1973-74	225.3	21.4	106.1	379.2	83.8

Note: Actual years are October 1969-September 1970; year ending August 1971; year ending December 1972; year ending March 1973; and year ending March 1974.

[1]Automobile emissions likely account for well over 95 per cent of the emissions attributed to motor vehicles.

Source: Based on data from the Ontario Ministry of the Environment.

For other urban areas, only a single year's emission inventory is available. Summaries of these inventories are depicted in Appendix B. As we stated earlier, not all of these inventories are as precisely measured as those for the several Ontario cities; in most cases, emission factors derived elsewhere are employed to estimate, rather than measure, probable emissions. When one analyses the data for the various cities (say, for example, to determine the emission of any one pollutant per registered automobile in a given city) an extremely wide range in emission factors emerges. Likewise, wide ranges in these factors can be noted for space heating per household, for similar industries, and for aviation per take-off or landing. Additionally, the approach to estimation differs substantially from province to province. One would expect emissions to vary with average temperature, prevalence of the use of block heaters, age of automobiles, scale of production, and the like, but these factors alone do not explain the full variation noted in comparing the existing data.

It would appear advisable, therefore, to standardize estimation procedures and direct-measuring methodology across the country. Such an approach may also reduce the cost of initial and subsequent emission inventory-taking. The following quote provides an example of the possible economies of shared experience:

> "Some 10,000 man-hours were required to obtain an (initial) inventory of five pollutants for Toronto. ... the Hamilton (initial) inventory was completed with less than 3,000 man-hours, in part because there were fewer sources, in part because the experience gained in the Toronto inventory made possible a more efficient use of resources."[5]

While present inventories are not directly comparable from city to city (and there are some changes in source definition and measuring/estimation techniques year-to-year in the Toronto inventory), the reader may obtain some idea of the predominant sources of air pollutants in each of the urban areas represented in Appendix B.

E. The Motor Vehicle and Its Role as a Source of Carbon Monoxide, Hydrocarbons, and Nitrogen Oxides

The motor vehicle accounts for almost one-fifth of our total energy consumption while emitting, by weight, the greatest amount of pollutants of any source.[6] Implicit in the data underlying this general statement is the contention that the automobile is a wasteful user of energy. Particularly since 1968, the average emissions of pollutants from new automobiles have been reduced in several steps. At the same time, net horsepower output per engine size has been reduced while engine sizes have been increased to provide equal or additional gross horsepower. Reductions in compression ratios,

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[5]L. Shenfeld and A. E. Boyer, *The Utilization of an Urban Air Pollution Model in Air Management* (Environment Ontario, July 1972), pp. 1-2.

[6]A.C.S. Hayden, *Energy Conversion and Conservation* (Canada, Department of Energy, Mines and Resources, Mines Branch, Fuels Research Centre, April 1973), p. 7.

particularly to accommodate pollution abatement equipment, have led to reduced gas mileage and, given ever-growing vehicle miles, increased consumption of energy by this mode of transportation. It seems somewhat ironic that we should have to resort to less efficient and basically greater pollutant-generating engines in order to utilize abatement equipment to effect an overall reduction in emissions.

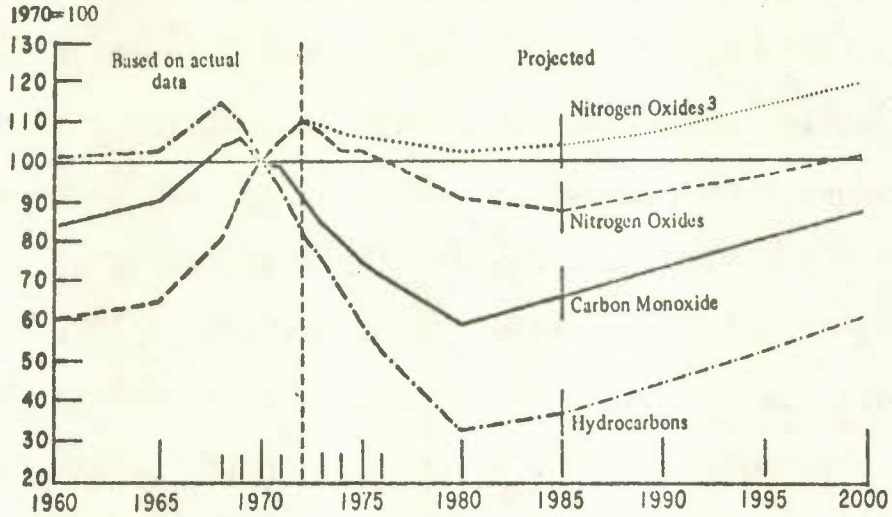
The modifications made to North American automobile models from 1968 to the present have eliminated blow-by hydrocarbon emissions altogether, and reduced hydrocarbon emission rates from fuel evaporation by 95 per cent per vehicle and exhaust emission rates of carbon monoxide and hydrocarbons by 70 and 80 per cent per vehicle, respectively, *for new cars*. However, it takes a considerable period of time before older models are entirely replaced and, over time, pollution abatement equipment loses some of its effectiveness if proper maintenance is not practiced. As a net result of these and other factors, average hydrocarbon emission rates per vehicle for the stock of automobiles on Canadian roads in 1974, is expected to be about 47 per cent as high as in 1968; in respect of the average emission rates of carbon monoxide, the corresponding reduction over the same period is expected to be 62 per cent. Without further modifications, the average emission rates for hydrocarbons and carbon monoxide are expected to fall until 1985 while total emissions are expected to fall only to 1980 at which time the growth in total vehicle miles will more than offset the reduction in emission rates.

Some elaboration of the probable emission rate of nitrogen oxides from motor vehicles is required in light of the trends suggested in Figure 5 and the apparent contradiction in Table 21; the latter indicates an increase in total automotive emissions of nitrogen oxides (NO_x) in Toronto in 1973-74 while the trends in Figure 5 indicate an overall reduction (the Environment Canada estimate) or, alternatively, a levelling-off of NO_x emissions (our estimate). The issue at hand revolves around the engineering requirement that compression ratio reductions are necessary if pollutant abatement equipment (for hydrocarbons and carbon monoxide only) is to be effective. Fuel economy and emissions of nitrogen oxides are thought to vary directly with compression ratios and inversely with engine displacement and horsepower. It may be that the expected reduction in NO_x emissions associated with reduced compression ratios was too optimistic in the first place or that compression ratio reductions have been offset by increases in engine displacement and/or horsepower. For our part, we have assumed an average emission rate for NO_x somewhat greater than that assumed by Environment Canada, yet somewhat below the rate attributed to new cars in the 1968 through 1972 model years. We have assumed that control proposals for nitrogen oxides (originally intended for 1976 models) will be postponed possibly to 1978; emission standards at that time may be less severe than those originally proposed for 1976.

Figure 5

INDEX OF AUTOMOBILE EMISSIONS:[1]
CARBON MONOXIDE, HYDROCARBONS AND NITROGEN OXIDES[2]
CANADA

(1970 = 100)



[1]Automobiles account for about 83 per cent of total intercity passenger miles and almost 98 per cent of urban travel. Automobile emissions are therefore indicative of total motor vehicle emissions. See reference below, page 3.

[2]Based on 1973 emission standards.

[3]Estimate by the authors assuming relatively higher compression ratios.

Source: Environment Canada, *Automobile Emission Trends in Canada, 1960-1985* (Ottawa: Information Canada, 1973); and estimates by the authors.

The question of resource (fuel) conservation on the one hand, and pollution abatement on the other, should not be thought to involve only the abatement equipment and modifications necessary to achieve its performance capability. Fuel economy and a reduction in emissions can also be achieved through a reduction in the weight of automobiles, a higher ratio of standard to automatic transmissions, higher taxes on air conditioning in automobiles and, perhaps, the wider use of "unconventional" engines -- e.g., the Wankel and stratified charge systems. Other modifications that might allow an engine to run at maximum fuel efficiency over the

entire range of operation would also improve fuel economy and burning efficiency. Even driver education could improve fuel economy and reduce pollutant emissions in general; the use of block heaters in winter, proper use of the (manual) choke, and some reduction in the speeds at which vehicles are driven on highways or thoroughfares could be helpful in this regard. Given the often rapid deterioration of pollution control devices when improperly used, frequent servicing would be an important factor in keeping emissions down. Of course, proper tuning will improve the fuel and pollutant control performances of all motor vehicles. We might pursue this discussion in many directions but to do so would only add marginally to our depiction of the general trends of emissions (see Figure 5) likely to be associated with motor vehicle usage.

We have seen in Table 20 that the motor vehicle is the primary source of carbon monoxide emissions, emissions that lead to rather high ambient air concentrations of this compound. No other source is so important and widespread. The abatement of emissions and the resultant improvement in air quality, in respect of this pollutant, will result in the main from the presence of the 1973 emission control equipment in an increasing percentage of the automobiles on the road. The reduction of urban air concentrations of carbon monoxide is expected to be over 50 per cent by 1980 (compared to 1970). Likewise, this abatement equipment will drastically reduce hydrocarbon emissions in urban areas, by perhaps as much as 70 per cent over the same period of time. Nitrogen

oxide emissions, given our assumption of postponement of abatement controls, will remain roughly at current levels from this source alone; increasing emissions from other sources, given this high base load, may cause total emissions to increase and, therefore, ambient air concentrations to increase. The present debate concerning the role of the automobile in our economy and society is clearly more complex than the issue of pollution generation. Property damage, public safety, energy consumption, and land use are all involved. The use of public transit in urban centres is a viable alternative in these perspectives to the private automobile. In rural settings the motor vehicle contributes relatively less to the degradation of the atmosphere and, therefore, to human and ecological disutility.

F. Future Outlook

What about the future? We have seen that there is a considerable potential to reduce emissions of pollutants given current levels of technology. We also know that abatement costs at the margin increase very rapidly as emissions are reduced. Near-total abatement, therefore, appears unrealistic.

Nonetheless, as noted earlier, urban air in 1980 should contain much less carbon monoxide and hydrocarbons as a result of motor vehicle emission abatement (1973 standards), and considerably less (in weight or volume terms) particulate matter due to the widespread installation of precipitator equipment in the

chimneys or stacks of electrical utilities, industrial and commercial combustion sources, and industrial process complexes. Sulphur oxides could be reduced through some fuel high-grading[7] in the residential market, the at-refinery removal of sulphur from fuels used in the furnaces of industry and commerce, and the thermal-electric power stations' use of stack scrubbers to remove this pollutant. In the long run, however, the basic trend is towards more use of energy per capita and if this energy is to be produced by fossil fuels, the total trend in emissions of hydrocarbons, carbon monoxide, sulphur oxides, and particulate matter will *eventually* turn upward assuming existing technology. In the short run, total nitrogen oxides may even increase despite some reductions in the output of these compounds by the electrical generation industry.

What should also be noted is that energy consumption not only produces residuals that may be air pollutants, it also depletes available energy resources. Wider use of coal is seen as a means of extending known reserves of higher grade fuels; this would lead to an increase in the generation of certain pollutants. Growing affluence makes demands on all resources and, as the world turns to solutions such as recycling, one may witness the reduction in certain categories of pollutants *but* an increased demand for energy. Thus, air

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[7]By "high-grading" it is inferred that higher quality fuels are substituted for those of lesser quality. Natural gas which is "clean", relatively easy to pipe into homes and other buildings, and easily adaptable to simple, efficient furnaces, is considered a higher grade fuel than heating oil. Substituting natural gas for oil would be considered "high-grading".

quality objectives can be seen to be directly involved with all the wider aspects of environmental management. If, as we expect, urban air quality improves in general in respect of each man-made pollutant, except perhaps nitrogen oxides, over the next five to ten years, part of this improvement may have been purchased at the price of a depletion of high-grade fuels.

Improved emission abatement will not be universal; some cities and towns may not share in general reductions in pollutant generation, and many sources will, against the general trend, generate as much or more of certain pollutants. While certain emission standards can be proposed, for industry or other sources on a nationwide basis, most programs and projects will have to be examined in local or regional contexts, keeping in mind the sources of pollutants, the concentration of these pollutants in ambient air, and the effects on people, plants and animals, and the physical environment.

Chapter 5

CONCLUSIONS

The generation of pollutants is directly associated with industrial production and is also linked to total consumption. As national output grows, as population increases, and as the per capita consumption of energy and other goods grows, there is a basic upward force exerted on the trends in residual emissions. Given a particular level of applied technology, constant tastes, particular emission controls, and an unchanging geographical pattern of production and consumption, the quality of air can only get poorer.[1]

There are, however, currently available technologies that enable this nation to greatly reduce the generation of pollutants and/or their emissions. In other words, what must be considered at this point is the application of available technology to reduce pollutant generation/emission.

Tastes also change. As the proportion of services consumed increases relative to the consumption of goods, a reduction of pollution generation may result, compared to a growth in consumption with a fixed proportion of goods to services. Perhaps the substitution of new goods for traditional goods can also lead to lower levels of pollution generation by both consumption and production activities.

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[1]As an example of the basic forces leading to increased pollutant emissions from fuel combustion, the reader is referred to F. D. Friedrich and E. R. Mitchell, *Air Pollution in Canada from Fuel Combustion -- 1st Addendum to Air Pollution: Causes and Control* (Ottawa: Energy, Mines and Resources, Canadian Combustion Laboratory, 1970).

Likewise, services may be substituted, for other services, or for private goods, reducing overall emissions (for instance, in the latter case, public transit for private automobiles).

There is also the possibility that production and consumption patterns can be geographically relocated in such a manner that high concentrations of emissions can be avoided.

Of course, other factors may arise that result in an increase in pollution. New technologies may give rise to a smaller quantity or volume of emissions but to emissions of more critical pollutants, many of which may not even enter the air quality indicators now. Additionally, a different mix of production and consumption at a given level of technological development may lead to the emission of a different proportion of the same pollutants. Further, present urban areas may continue to grow at the expense of outlying areas, resulting in potentially greater ambient air concentrations of pollutants over these urban areas. Even recycling can lead to sharp increases in energy consumption, and the net effect on the air environment is difficult to assess.

But, as we have seen in Chapter 4, there is a distinct possibility that, in respect of most of the pollutants now measured, by 1980 air quality in Canada will have improved as the result of the application of presently available technology. Nonetheless, it is essential to monitor the emissions of pollutants through emission inventories and to measure the occurrence of the several pollutants in ambient urban air across all urban regions, so as to be

able to evaluate trends that will indicate the effectiveness of pollution abatement programs and point out emerging problems. Since it may well be that the cities not included in the present indicators are as affected by air pollution as those included, the extension of comprehensive monitoring is obviously desirable.

In the context of the entire array of social, economic, and environmental objectives, it is not possible, at this point, to draw hard and fast conclusions as to the resources that should be devoted to the reduction of air pollution. Basically, the reasons that we would wish to reduce air pollution involve the avoidance of the costs associated with it. Much more research into the *effects* of air pollution is needed before a full cost-benefit assessment can be made of the benefits (costs avoided) of abatement above and beyond that now contemplated. Even if we assumed that the benefits would exceed the costs the question would still arise, "by how much?". Expenditures on air pollution abatement must be justified in relation to the cost-benefit position of other expenditures designed to meet alternative objectives, given limited total resources.

Even with improved information on the effects of air pollution, it will still be necessary to clarify the linkage between the generation/emission of pollutants and the ambient air pollution with which we are concerned. Only in this broader context (see Figure 1) can effective, efficient, and equitable control programs be devised.

Governments, industry and the public at large all have a role to play in any thrust towards a cleaner environment. After all, human activities are the major cause of pollution. Given that all Canadians have an interest in improving the environment that they jointly share, there is obviously a legitimate interest on the part of each level of government, and all governments in concert. It is for this reason and because there are possibly great economies in the exchange of information on methodology and programs (if this information is in compatible form), that a standard nationwide approach to research, emission and ambient air monitoring, and impact evaluation be developed. As noted in the *Eleventh Annual Review*, the Canadian Council of Resource and Environmental Ministers may be an appropriate authority to bring about such an approach. Further, the federal and provincial governments have the appropriate experts needed to fill in the additional information required to achieve a standard, effective approach to the improvement of Canadian air quality. Non-government institutions, the private sector, and citizens' groups can provide the necessary complements to the efforts of the public sector.

Besides the countrywide concertation that appears necessary, much concern must be focused on regional and local air pollution problems. Air pollution has both common and unique aspects from place to place and from industry to industry.

With a better understanding of the air environment and its linkage to the quality of human life, and with indexes and indicators to monitor human activity and the quality of air in Canada, achievement of various objectives in this sub-sector can be objectively planned.

Our research is a preliminary step in improving the collective understanding of urban air quality in Canada. The results of our investigations note that, over the period 1971 through 1973, ambient urban air quality has improved in general. But there is evidence also that ambient concentrations of oxides of nitrogen are increasing and that total oxidants, which are formed in the atmosphere partly as a result of the presence of oxides of nitrogen, continue to exceed expressed criteria on many occasions. It would seem, therefore, that reductions in the concentrations of these pollutants require greater regulation of the sources (emissions) of nitrogen oxides. The value of an indicator that takes into consideration most of the commonly measured airborne pollutants is that it can put each pollutant into an overall perspective and suggest action on the major and emerging problems without downgrading the importance that other pollutants may assume in individual urban areas. The intent and, we believe, the achievement of this paper has been to highlight the changing quality of air, particularly from an urban viewpoint, but also, to some extent, from a nationwide perspective.

Appendix A

CORRESPONDENCE BETWEEN DIAGNOSTIC CATEGORIES AND ICDA EIGHTH REVISION CODES

Asthma:

ICDA	
493	Asthma

Upper Respiratory:

ICDA	
460	Acute Nasopharyngitis (Common Cold)
461	Acute Sinusitis
462	Acute Pharyngitis
463	Acute Tonsillitis
464	Acute Laryngitis and Tracheitis
465	Acute Upper Respiratory Infection of Multiple or Unspecified Sites
466	Acute Bronchitis and Bronchiolitis
470	Influenza, unqualified
471	Influenza with Pneumonia
472	Influenza with other Respiratory Manifestations
473	Influenza with Digestive Manifestations
474	Influenza with Nervous Manifestations

Pneumonia:

ICDA	
480	Viral Pneumonia
481	Pneumococcal Pneumonia
482	Other Bacterial Pneumonia
483	Pneumonia due to other Specified Organism
484	Acute Interstitial Pneumonia
485	Bronchopneumonia, unspecified
486	Pneumonia, unspecified

Bronchitis:

ICDA	
490	Bronchitis, unqualified
491	Chronic Bronchitis
492	Emphysema

Other Respiratory Diseases:

ICDA	
501	Peritonsillar Abscess
502	Chronic Pharyngitis and Nasopharyngitis
503	Chronic Sinusitis
504	Deflected Nasal Septum
505	Nasal Polyp
506	Chronic Laryngitis
507	Hay Fever

508	Other diseases of upper respiratory tract
510	Empyema
511	Pleurisy
512	Spontaneous Pneumothorax
513	Abscess of Lung
514	Pulmonary Congestion and Hypostasis
515	Pneumoconiosis due to Silica and Silicates
516	Other pneumoconioses and related diseases
517	Other Chronic Interstitial Pneumonia
518	Bronchiectasis
519	Other diseases of respiratory system

Appendix B

SUPPLEMENTARY TABLES

Table A

SUMMARY OF EMISSIONS INVENTORY
BY POLLUTANT AND SOURCE
VANCOUVER, 1973

(Thousands of tons per year)

	Particulate Matter	Sulphur Oxides	Nitrogen Oxides	Hydro-Carbons	Carbon Monoxide	Percent City Total
Automobiles	2.1	1.6	20.6	78.0	453.0	69.6
Other Transportation	1.1	.3	2.7	22.0	13.8	5.0
Space Heating	4.0	16.3	13.7	.9	3.0	4.7
Thermal Power	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Other Industries and Utilities	34.7	6.2	6.7	24.2	92.4	20.6
TOTAL	42.9	24.4	43.7	125.1	562.2	100.0

Source: *Environmental Pollution Studies, Air Quality in British Columbia*, B. C. Research (1970) and Appendix Report (1972); *Environmental Quality in Greater Vancouver*, Greater Vancouver Regional District (1973); *A Nationwide Inventory of Air Pollutant Emissions 1970*, Environment Canada (1973); and estimates by the authors.

Table B

SUMMARY OF EMISSIONS INVENTORY
BY POLLUTANT AND SOURCE
EDMONTON, 1971

(Thousands of tons per year)

	Particulate Matter	Sulphur Oxides	Nitrogen Oxides	Hydro-Carbons	Carbon Monoxide	Percent City Total
Automobiles	.4	.2	9.0	21.3	147.6	47.8
Other Transportation	.2	.3	3.3	1.2	2.4	2.0
Space Heating	.5	--	2.9	.8	.4	1.3
Thermal Power	.2	--	13.1	.6	--	3.7
Other Industries and Utilities	3.4	22.2	.4	73.0	69.7	45.2
TOTAL	4.7	22.7	28.7	96.9	220.1	100.0

Source: *Inventory of Air Pollution Sources and Emissions in the City of Edmonton, 1971*, Alberta Environment, 1973; *A Nationwide Inventory of Air Pollutant Emissions 1970*, Environment Canada (1973); and estimates by the authors.

Table C

SUMMARY OF EMISSIONS INVENTORY
BY POLLUTANT AND SOURCE
CALGARY, 1971

(Thousands of tons per year)

	Particulate Matter	Sulphur Oxides	Nitrogen Oxides	Hydro-Carbons	Carbon Monoxide	Percent City Total
Automobiles	.4	.2	7.7	17.6	121.4	83.2
Other Transportation	.2	.4	3.5	1.6	2.6	4.7
Space Heating	1.1	--	2.5	.6	.4	2.6
Thermal Power	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Other Industries and Utilities	2.8	4.9	2.3	5.7	.2	9.4
TOTAL	4.6	5.5	16.0	25.6	124.6	100.0

Source: *Inventory of Air Pollution Sources and Emissions in the City of Calgary, 1971*, Alberta Environment (1973); *A Nationwide Inventory of Air Pollutant Emissions 1970*, Environment Canada (1973); and estimates by the authors.

Table D

SUMMARY OF EMISSIONS INVENTORY
BY POLLUTANT AND SOURCE
REGINA, 1971

(Thousands of tons per year)

	Particulate Matter	Sulphur Oxides	Nitrogen Oxides	Hydro-Carbons	Carbon Monoxide	Percent City Total
Automobiles	.1	.1	1.3	2.4	27.9	61.4
Other Transportation	.3	.1	.5	2.1	1.9	9.5
Space Heating	.2	.5	1.6	--	--	4.4
Thermal Power	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Other Industries and Utilities	3.2	.9	1.1	1.1	6.5	24.7
TOTAL	3.8	1.6	4.5	5.6	36.3	100.0

Source: *An Emission Inventory of Air Pollutants for the City of Regina*, Saskatchewan Department of Public Health (1972); *A Nationwide Inventory of Air Pollutant Emissions 1970*, Environment Canada (1973); and estimates by the authors.

Table E

SUMMARY OF EMISSIONS INVENTORY
BY POLLUTANT AND SOURCE
SASKATOON, 1972

(Thousands of tons per year)

	Particulate Matter	Sulphur Oxides	Nitrogen Oxides	Hydro-Carbons	Carbon Monoxide	Percent City Total
Automobiles	.2	.1	1.7	3.1	35.5	65.5
Other Transportation	.3	.1	.8	2.8	2.7	10.8
Space Heating	.2	.4	1.0	--	--	2.6
Thermal Power	2.7	1.8	3.7	--	--	13.2
Other Industries and Utilities	2.5	.3	.1	1.5	.5	7.9
TOTAL	5.9	2.7	7.3	7.4	38.7	100.0

Source: *City of Saskatoon, Inventory of Emissions*, Environment Saskatchewan (1974); *A Nationwide Inventory of Air Pollutant Emissions 1970*, Environment Canada (1973); and estimates by the authors.

Table F

SUMMARY OF EMISSIONS INVENTORY
BY POLLUTANT AND SOURCE
HAMILTON, 1973-74

(Thousands of tons per year)

	Particulate Matter	Sulphur Oxides	Nitrogen Oxides	Hydro-Carbons	Carbon Monoxide	Percent City Total
Automobiles	.3	.2	4.3	6.9	53.3	34.7
Other Transportation	.3	1.5	.6	.2	.1	1.4
Space Heating	.7	3.0	1.4	.1	.1	2.8
Thermal Power	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Other Industries and Utilities	22.2	28.3	48.6	11.5	3.5	61.0
TOTAL	23.5	33.0	54.9	18.7	57.0	100.0

Source: Environment Ontario.

Table G

SUMMARY OF EMISSIONS INVENTORY
BY POLLUTANT AND SOURCE
TORONTO, 1973-74

(Thousands of tons per year)

	Particulate Matter	Sulphur Oxides	Nitrogen Oxides	Hydro-Carbons	Carbon Monoxide	Percent City Total
Automobiles	2.6	2.0	36.1	53.0	270.3	44.6
Other Transportation	1.3	.8	2.0	6.1	1.5	1.5
Space Heating	4.4	21.0	12.2	1.1	1.2	4.9
Thermal Power	3.7	190.7	43.8	1.4	2.1	29.6
Other Industries and Utilities	9.4	10.8	11.9	22.2	104.3	19.4
TOTAL	21.4	225.3	106.1	83.8	379.4	100.0

Source: Environment Ontario.

Table H

SUMMARY OF EMISSIONS INVENTORY
BY POLLUTANT AND SOURCE
MONTREAL, 1970-71

(Thousands of tons per year)

	Particulate Matter	Sulphur Oxides	Nitrogen Oxides	Hydro-Carbons	Carbon Monoxide	Percent City Total
Automobiles	3.5	2.6	32.8	69.4	668.0	60.9
Other Transportation	11.0	3.5	22.2	49.1	9.9	7.5
Space Heating	9.9	100.3	27.7	1.4	1.4	11.0
Thermal Power	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Other Industries and Utilities	22.8	64.7	12.4	162.2	.9	20.6
TOTAL	47.2	171.1	95.1	282.1	680.2	100.0

Source: *Assainissement de l'air, Rapport des progrès réalisés, 1972*, Communauté urbaine de Montréal; *A Nationwide Inventory of Air Pollutant Emissions 1970*, Environment Canada (1973); and estimates by the authors.

Other Urban Areas for which Partial Emission Data were Collected from Municipal and Provincial Authorities

Chicoutimi

Société d'Aménagement Industriel du Chicoutimi Métropolitain Inc.

Kingston

Kingston Industrial Commission

London

City of London

Moncton

City of Moncton

Niagara Falls

City of Niagara Falls

St. John's

St. John's Metropolitan Area Board

Winnipeg

City of Winnipeg

Manitoba Hydro

Winnipeg Hydro

Greater Winnipeg Gas Company

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