A First-approximation Urban-air-quality Indicator

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ABSTRACT.—Development of the first-approximation-urban-air-quality indicator was reported by the Economic Council of Canada. The indicator takes account of ambient concentrations of five pollutants: sulfur dioxide, particulate matter, oxides of nitrogen, carbon monoxide, and total oxidants. Epidemiological evidence indicating the potential impact of these pollutants on human health is also reported. Values of the indicator are calculated for the years 1971-74 for a number of Canadian cities: the overall trend appears to be toward cleaner air, though concentrations of oxidants and nitrogen oxides have increased.

THE CHARACTER OF URBAN CENTERS

DESPITE THE HUMAN TENDENCY to build urban islands of man-made physical environments, our cities are highly dependent upon their interaction with natural ecosystems. In days gone by, cities have always tended to be built in the most productive areas within natural ecosystems. By replacing plant and animal life with asphalt and concrete, houses and factories, and the products and residuals of production and consumption, man has created deserts in which there is minimal natural energy production and maximum human energy use. To fill this gap in net energy requirements, the city spreads its tentacles throughout the ecosystem.

The interaction between the energy-deficient man-made environment and the energy-surplus natural environment is dynamic, and the interface (the "urban confrontation") is often abrupt. The flow of energy and natural resources into the man-made centers and the outflow of man-made products, services, and residuals is continuous, causing a shift in costs and benefits across the interfaces. However, this area of urban confrontation is sufficiently distinct to describe the walls that encase the "fragile bubble-world" referred to by Mowat:

> "When, and if, man comes to regard himself as being in effect an alien entity in the ancient world that formed him, then he will have become the ultimate egomaniac, imprisoned in an infinitely fragile bubble-world of his own contriving — and unquestionably doomed."
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> Farley Mowat, *Tundra*, McClelland and Stewart, Ltd., Toronto, 1973, p. 13.

Unfortunately, the degree to which human activity affects the remaining elements of the natural environment that exist within cities is still difficult to define and, therefore, to include in the derivation of an urban environmental quality indicator.

The human population itself is exposed, at least to some extent, to pollutants that it generates; and if we assume that urban populations are (statistically) normally distributed with respect to susceptibility to environmental contaminants, we can see that the population potentially at risk serves as a convenient common weighting factor for aggregating the social impacts of environmental pollutants across urban areas (even though we are aware that air quality can differ greatly from point to point within each area). Because contaminated water can be avoided or rendered safe before use and because North Americans are protected against pollutants that may affect their food (by way of public controls and the availability of a great variety of food stuffs and food sources), the element of environmental pollution most critical to human health is the quality of air that urban populations must breathe. For these reasons the Economic Council of Canada developed its first environmental quality indicator in consideration of urban air quality.

DIMENSIONS OF AIR QUALITY

The popular perception of air pollution is that, if you can see it or smell it, it's "bad." This is, of course, a gross oversimplification: some pollutants, such as carbon monoxide or lead, may be completely undetected by the human senses at typical ambient concentrations. On the other hand, preoccupation with the multitude of elements and compounds that may pose a threat to human life in isolated instances may obscure general trends in air quality.

In constructing our first-approximation-air-quality indicator, the choice of which pollutants to include was largely pragmatic. That is, we included all the pollutants that are measured on a roughly consistent basis in most large urban areas in Canada. These are sulfur dioxide, nitrogen oxides, total oxidants, particulate matter, and carbon monoxide. A sixth pollutant group, total hydrocarbons, was rejected because of imprecise measurement and the absence of generally accepted criteria of safe ambient concentrations.

To provide guidance in our choice of pollutants to be included in the indicator, and also to confirm the choice of pollutant weights (relative severity factors), we undertook a statistical analysis of the relationship between air pollution and health. Weekly average ambient concentrations of the six pollutants mentioned above were related to hospital admissions among the most sensitive members of the population (those under 15 or over 45) for five categories of respiratory disease. In addition, a temperature variable was used to control for seasonal variations. Data were available for the last 41 weeks of 1972 for the cities of Windsor, Ontario, and Edmonton, Alberta.

Hypothesizing a simple linear relationship, we fitted regression equations for each category of respiratory disease by the technique of ordinary least squares. The coefficients, t-statistics, and coefficients of multiple determination (R^{-2}) for selected equations are shown in table 1.

The results, in summary, imply that, indeed, oxidants at levels found in ambient air in several Canadian cities are significant contributors to hospitalization for, in particular, upper respiratory ailments but other categories of respiratory ailments as well; this despite the general Canadian perception that conditions such as those found in Los Angeles are far removed from Canadian circumstances. Likewise, for Windsor, nitrogen oxides and, to some extent, sulfur dioxide air pollutants have some significant bearing on the respiratory well-being of individuals. And the results from our investigation of hospitalization in a third city, Sudbury, Ontario,

Table 1.—Selected regression results

Item	Independent Variables							
	SO_2	COH	NO_x	TOX	HC	CO	TEMP	R^2
WINDSOR, ONT.:								
Upper respiratory Infections	.2 (.2)	—.5 (—.4)	1.6 (1.4)	2.3 (1.1)	— .3 (— .9)	—2.2 (—2.0)	— .2 (—1.2)	.42
			2.6 (2.5)	4.0 (2.4)			— .3 (4.3)	.39
Pneumonia	1.6 (2.2)	—.1 (—.1)	1.2 (1.1)	1.7 (.8)	— .4 (—1.3)	—1.7 (—1.6)	— .1 (— .5)	.37
			2.2 (2.1)	3.4 (2.0)			— .2 (—2.9)	.24
EDMONTON, ALTA.:								
Upper respiratory Infections		12.6 (.7)	40.5 (.5)	8.3 (3.4)		—4.0 (— .9)	— .1 (—1.3)	.22
				8.9 (3.9)			— .1 (—1.7)	.26

Values in brackets are T-statistics.

Table 2.—Correlation coefficients, Windsor, 1972

Item	SO_2	COH	NO_x	TOX	HC	CO	Temp
SO_2	1.0	—	—	—	—	—	—
COH	.42	1.0	—	—	—	—	—
NO_x	— .01	.05	1.0	—	—	—	—
TOX	— .17	.00	.13	1.0	—	—	—
HC	.23	.39	— .40	— .51	1.0	—	—
CO	— .11	— .30	— .11	.38	.01	1.0	—
TEMP	— .39	— .55	— .01	— .10	— .34	.80	1.0

indicate that sulfur dioxide and particulate matter, alone or combined, do not provide a sufficient proxy indicator for all airborne pollutants in that hospitalization for respiratory ailments are not significantly explained by the occurrences of these pollutants. In all, this epidemiological examination lends support to the contention that the traditional concern (sulfur dioxide and particulate matter) must be extended to a wider array of pollutants; an indicator based on several pollutants is not a sufficient proxy for the general quality of urban air. Since, moreover, there are many costs to air pollution other than hospitalization for respiratory ailments, we also reject an air-quality proxy indicator based merely on oxidants, nitrogen oxides, and sulfur dioxide.

Simple correlation coefficients among pollutants (table 2) provide further statistical evidence that the five pollutants included in the indicator cannot be reduced further by using one variable as a proxy for one or more others: only one of these coefficients is as high as 0.5 (although two related to the correlation between pollutants and temperature are also higher than 0.5).

In addition, the literature on the health effects of air pollution provides numerous references to the increased impacts (synergism) that can be expected when two or more air pollutants occur simultaneously; there are, in addition, a few references to decreased impacts. The most notable evidence suggests that particulate matter (particularly small, respirable-sized particles), together with sulfur dioxide, may have an impact greater than the combined impact of both pollutant groups considered separately. Similarly, some experts treat ozone (oxidants) as a synergistic effect of the presence of nitrogen oxides and hydrocarbons together with sunlight; we have included ozone (oxidants) as a pollutant in its own right although we realize that emissions of the two precursors provide the only policy options for control purposes.

RELATIVE SEVERITY FACTORS

From medical evidence, and from our own epidemiological study, it is clear that, at the same concentration, different pollutants give rise to impacts of differing severity. To take account of this rather obvious fact, the concentration of each pollutant is weighted by a "relative-severity factor."

The relative-severity factor for each pollutant is based on the 24-hour average criterion established by the Ontario Ministry of the Environment, this criterion being the only common time base for which criteria are stated for all five pollutants.

The severity factors are in inverse proportion to the 24-hour criteria; hence total oxidants have the lowest acceptable concentration — 0.03 parts per million — and therefore have the highest relative severity factor —267. Table 3 shows the Ontario criteria and the severity factor for the five pollutants. Note that the scale of the factors is set by arbitrarily denoting the factor for carbon monoxide as equal to one. Finally, since the criteria indicate that one COH has eight times the impact of one part per million of carbon monoxide, the severity factor was determined accordingly without regard for the difference in units of measurement.

CALCULATING THE INDICATOR

The air-quality indicator for any one urban area is a weighted sum of the annual average 24-hour concentrations of the five pollutants and a synergism factor (to be discussed shortly). The annual mean concentration is multiplied by the relevant severity factor; the products are labelled "impact units per capita," and they can be added to yield a "city-pollution index." These calculations are depicted schematically in figure 1.

The synergistic impact of sulfur dioxide and particulate matter is assumed to be limited by the lesser occurrence of either one or the other pollutant. Consequently, as shown in figure 1, this factor enters the calculation of the city-pollution index (CPI) as the lesser of the value of the impact units per capita for these two pollutants; it is not directly calculated from any ambient air concentration data.

The CPIs are roughly comparable from city to city and provide relative, not absolute, descriptions of urban air quality between cities and over time in any one city. For public policy purposes, the latter time series is very useful not only because it gives a gross picture of air-quality changes, but because it reflects, from its component parts, the possible impacts of air pollution on the population; clearly, such information will suggest control priorities that might provide substantial benefits

Table 3.—Relative severity factors

Pollutant	Units	Ontario 24-hour criteria	Relative-severity factor
Carbon monoxide	ppm	8.00	1
Nitrogen oxides	ppm	.10	80
Oxidants	ppm	.03	267
Sulfur dioxide	ppm	.10	80
Particulates	coefficient of haze per 1,000 ft. of air	1.00	8

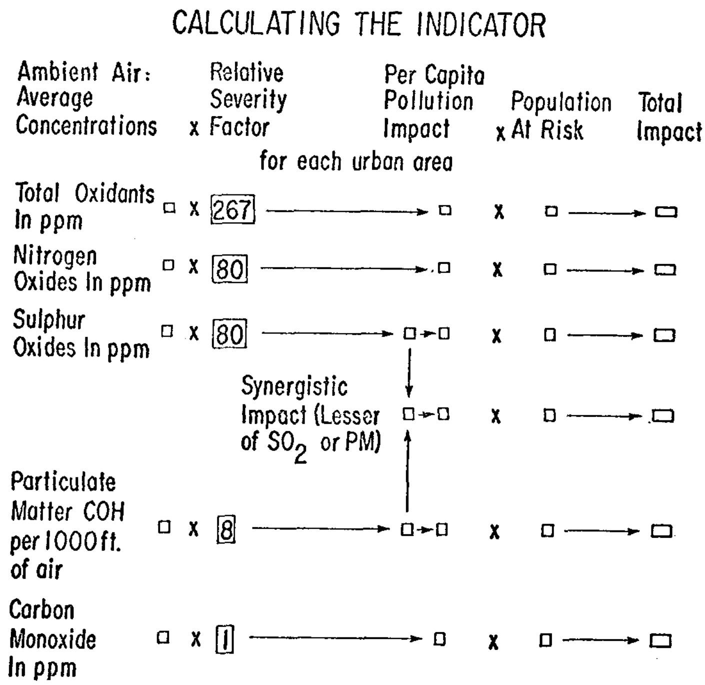

Figure 1.—Calculating the indicator.

—not merely a nebulous statement about the weight or volume of different pollutants in ambient air.

The impact units per capita for each pollutant and synergism are multiplied by the population potentially at risk to yield what we call "impact units." These products are added, by pollutant, for all cities in the sample to yield an "urban pollutant sub-indicator" which provides a comparison, over all cities combined, of the *relative* importance of each pollutant, in any one year, and, when measured over several years, of the emerging or diminishing importance of each pollutant group in respect of all citizens living in all urban areas considered in the compilation of the indicator.

The sum of the urban pollutant Sub-indicators, including synergism, is defined as the "urban air-quality indicator."

The first-approximation-air-quality indicators are, in fact, *social* indicators in that, if all the pollutants had the same annual average concentration in 1975 as in 1974 (and given the constant relative severity factors) and at the same time the population of the cities increased, all urban pollutant subindicators would increase in 1975, implying a fall in the quality of life, in respect to the air environment. In other words, the quality of life (at least in respect to this one aspect of reality) is improved if individuals move from areas of high air pollution to areas of relatively low air pollution, and the converse would also hold; not an unreasonable assumption in our estimation.

Of course, the purpose of improving the quality of life could be more effectively, and probably more economically, achieved by reducing the emissions and thereby the concentration of airborne pollutants. One might note also that dispersion of emissions (by high stack and/or escape-velocity management) could also lower the pollutant subindicators, provided that the pollutants do not merely fall out on some other urban area included in the indicator. This, at one time, implies that dispersion can provide a means to improve urban living standards and yet, that it can only be seen as a partial solution; ideally the compilation of the indicator will be extended to all urban areas (and to rural population where the risk is high). Likewise, as the implications of the impact of air pollution on the nonhuman elements of the environment are incorporated into the relative-severity factors, the inclusion of air-pollution data from rural areas may render the strategy of dispersal less effective in lowering the value of the pollutant subindicators.

Imposing urban-generated costs on the rural portion of the same or other ecosystems of which the city is merely a part, can, and eventually must, reduce the benefits the city and its population must obtain from the countryside.

Finally, like the gross indicators of economic activity (gross national product, price indices, unemployment rates, etc.), the generality of the urban-air-quality indicator provides little more than a glimpse of reality; like its counterparts, however, it can provide comparisons with previous time periods and therefore can generate public and political interest in delving deeper into its component parts and distributional aspects.

SOME RESULTS

The urban-air-quality indicator has been calculated for the years 1971-74 and is plotted on the upper portion of

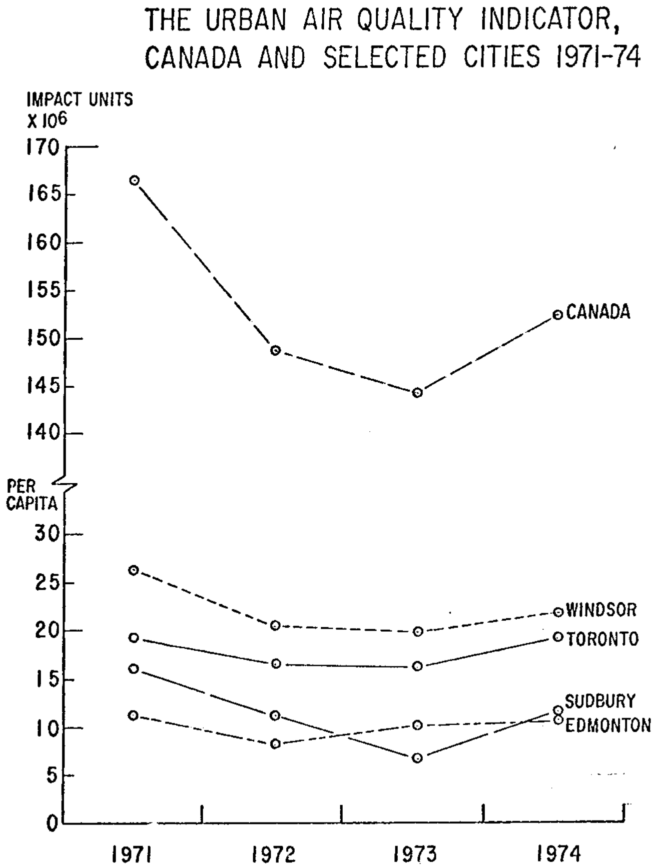

Figure 2.—The urban air-quality indicator, Canada and selected cities, 1971-74.

figure 2. As the graph shows, the indicator fell substantially between 1971 and 1973, reflecting improved air quality. In 1974, however, the indicator rose again, but remained below the 1971 level. In the absence of large population movements over this period, these trends can be attributed directly to changes in ambient concentrations of the pollutants measured.

City pollution indices for four representative urban areas are plotted on the lower portion of figure 2 (the indicator includes data from 11 Canadian cities). With the exception of Edmonton, these cities reflect the national trend of improved air quality through 1973, worsening by various degrees in 1974, the most dramatic reversal taking place in Sudbury.

Further disaggregation, by pollutant, reveals the nature of the decline in air quality in 1974. Figure 3 compares the 1971 and 1974 levels of the pollutant sub-indicators, totalled across the 11 cities. Reflecting traditional concern for air quality in terms of the popular pollutants, and the resulting decline in ambient levels by abatement and dispersion, the indicators for carbon monoxide, sulfur dioxide, and particulate matter have all declined substantially over the 4-year period. The new pollutants, oxidants and oxides of nitrogen, on the other hand, have increased considerably. Since oxidants are formed by photochemical reactions in the atmosphere, for which nitrogen oxides are a necessary input, the increase in ambient concentrations of these two pollutants can probably be explained in terms of emissions of the latter alone.

Nitrogen oxides are one of the products of fuel combustion: if the flame temperature is high enough, atmospheric nitrogen is oxidized. A nationwide inventory of pollutant emissions compiled by the Federal Department of the Environment for 1970 reveals that motor vehicles accounted for some 58 percent of total NO_x emissions, and that stationary combustion such as power generation and incineration accounted for most of the remainder (34 percent of the total).

One can speculate, therefore, that the increase in the subindicators for oxidants and nitrogen oxides reflect the

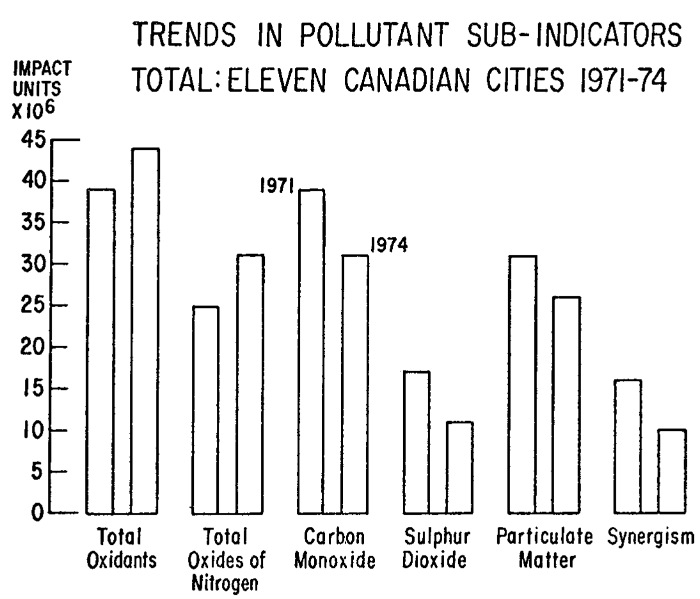

Figure 3.—Trends in pollutant subindicators, eleven Canadian cities 1971-74.

increase in the urban automobile population and the relative lack of control of NO_x by new-car emission standards, at least prior to 1973. The effect of exhaust gas recirculation, first used on some 1973 models, will not significantly reduce NO_x concentrations until these cars make up a significant portion of the automobile age structure.

As a final note on the analytical utility of the indicator, we should point out its "first-approximation" nature. The indicator will be subject to continual modification and improvement as more and better data become available. Specifically, for 1975 and beyond, the indicator will be reformulated, if possible, to consider ozone (as opposed to total oxidants), nitrogen dioxide (versus total oxides of nitrogen), and specific size and chemical descriptions of particulate matter (replacing the coefficient of haze measurements). Finally, the more accurate chemiluminescence technique is coming into wider use for measuring ozone and nitrogen oxide, imparting greater precision to the indicator.

OBJECTIVE OF SOCIAL AND ENVIRONMENTAL INDICATORS

Why have an indicator of air quality in urban centres at all? To repeat some points raised earlier:

- The urban confrontation with the natural environment tends to be abrupt to the point that the air environment is something different from the natural environment in which mankind developed over thousands of years;
- This different environment may have adverse effects on the population that resides in the urban bubbles, and this population represents the bulk of the total population;
- And therefore, if our interest is the maintenance or improvement of the quality of human life, we should have some general information on how this one aspect of the total reality is changing, information that is easily understood by the society and its political leaders.

If the indicator is changing, we (individuals, society, and the decision-makers) will want to know what *controllable* factors are influencing the change and what the distributional aspects of these changes are. This the indicator and its sub-indicators can do. The simplicity of the indicator is "on purpose;" its lack of precision and sophistication makes it meaningful to the *public*, and yet it does not preclude more detailed analysis — it may even encourage it. Finally, one may be critical of the fact that it is a relative measure of air quality rather than a statement of absolute quality — that is, it does not say that at a value of, say, "X" things are "bad," that at "X-Y" things are "good," and that at "X+Y" things are "terrible." Why do we not venture into the debate of absolute air quality? Precisely because air quality is but one part of environmental quality as a whole, and environmental quality is but one aspect of the quality of life as a whole.

Let us emphasize one point. Since the materials that enter production and consumption must equal, in terms of mass, the material content of the products we manufacture and the residuals we generate (less that portion that is recycled), we should be aware that the residuals that are removed from waste gases may simply be reflected in an increase in residuals that we release into the water and land resources of the planet. Quite obviously the net environmental impact of such a transformation may be greater than, equal to, or less than that associated with the equivalent mass of air pollution. Let us ask then, "Which of us can say, *a priori*, that a reduction in air pollutant exposure is automatically a good thing in the wider context of environmental quality and the quality of human life?"

An urban air-quality indicator describes one aspect of the fragile bubble world of the urban scene, but it should be sufficient evidence that man creates unnatural microenvironments. We must all be prepared to examine the viability of this human milieu lest the bubble burst.