AN ANALYSIS OF AIR-POLLUTION TRENDS IN SOUTHERN ONTARIO

BY

ERIC UNRAU

A Research Paper

Submitted to the Department of Geography

in Fulfilment of the Requirements

of Geography 4C6

McMaster University

April 1990

Abstract

Concentrations of seven pollutants, carbon monoxide, nitric oxide, nitrogen dioxide, total nitrogen oxides, ozone, particulates and sulphur dioxide are evaluated to identify trends since 1971 when the Canadian Clean Air Act became law. Data is analyzed from monitoring stations located in four cities in southern Ontario. Decreases are observed in the nitrogen oxides, carbon monoxide and sulphur dioxide giving some indication of the effects of the act.

Acknowledgments

Special thanks are extended to my advisor Dr. John A. Davies for suggestions and advice in the evolution of this paper, the Ministry of Ontario, particularly Phil Kiely and Frank Dobroff who provided the data and to Ric Hamilton who provided production advice and assistance.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

In 1971 the Canadian Clean Air Act became law. This law was created to satisfy three main objectives; first, to protect the public from the dangers of air pollution, second, to instate and enforce industrial guidelines for pollutant emissions and third, to allow for the maintenance and expansion of a permanent and ongoing monitoring program across Canada (Environment Canada, 1987). The effects of this act on air quality were studied by Ricci et al. (1978). Their paper illustrated a significant decline in air pollution across Canada in the four years following the inception of the act. They studied six pollutants, sulphur dioxide, carbon monoxide, ozone, oxides of nitrogen, suspended particulate matter and hydrocarbons, across Canada, over a four year period by analyzing the monthly means using simple statistical analysis. In view of their findings, this study was undertaken to provide a longer term evaluation of air pollution indices in Southern Ontario.

Analysis of air pollution trends is an important means of monitoring and making predictions about the quality of the air that we breath. Recent controversial studies have linked high airborne pollutant levels with increased mortality rates and higher hospital admissions. Bates and Sizto (1987) found significant links between summer sulphate and ozone concentrations and respiratory admissions in hospitals across

Ontario. In a similar study, significant correlation was found between mortality rates and carbon monoxide, hydrocarbons and suspended particulate matter trends over a ten year period in Los Angeles (Shumway et al., 1988).

In 1982 two papers were published which studied the significance of particulate aerosols in the attenuation of solar radiation. The particles of aerosols which constitute haze act to scatter incoming solar radiation resulting in a decrease in solar irradiance, the amount of solar radiation received at the surface.

Ball and Robinson (1982) used a semi-empirical haze model to estimate the effects of haze on solar irradiation throughout the year at locations in central United States. Their model estimated attenuation coefficients by modelling the vertical distribution of aerosols and parameterizing haze effects. Estimates made by this model were validated by comparisons with physical data which gave good correlation. A major finding of this paper was that aerosol attenuation reduces solar irradiance at the surface by approximately 7.5% in the central regions of the United States. Reductions of this magnitude could have important impacts on agriculture.

In 1982 Davies and McCay assessed the performance of several versions of three models which estimate solar irradiance. In examining error estimates for each model it

was found that aerosol effects are significant and their inclusion in models is an important factor in estimating solar irradiance in Toronto and Montreal. Direct beam solar irradiance in these cities is over estimated by 14-19% when aerosol effects are not included.

In 1971 regulations were passed by the federal government under the Motor Vehicle Safety Act to control emissions from all new automobiles. These regulations are quite significant to this report since Environment Canada estimates that 75% of carbon monoxide emissions and 25% of nitrogen oxide emissions are due to automobile use (Environment Canada, 1974).

Trends in carbon monoxide, nitrogen oxides, ozone, suspended particulate matter and sulphur dioxide are presented in this report. The trends of these gases are considered in four cities, Windsor, London, Hamilton and Etobicoke for a period whose length was determined by the availability of data.

Carbon monoxide (CO) is a colourless odourless gas produced by the incomplete combustion of fossil fuels. Automobiles are the primary source of this gas while fuel burning in industry also contributes to the problem. Carbon monoxide is dangerous to humans because it impairs the blood's ability to transport oxygen.

Nitric oxide (NO), nitrogen dioxide (NO_2) and total

oxides of nitrogen (NO_x) are all considered in this report. These oxides are all formed as a result of high temperature combustion which allows atmospheric nitrogen and oxygen to react, resulting in the formation of NO. The high temperatures of internal combustion engines make these the predominant sources. NO is released directly to the atmosphere during combustion where some of the gas is oxidized to NO_2. Eye and respiratory tract irritation result with exposure to nitrogen oxides.

Ozone (O_3), a respiratory irritant, is an oxidant produced at the surface by a photochemical reaction between nitrogen oxides and hydrocarbons, primarily produced by automobiles, in the presence of sunlight. Nitric oxide acts as a catalyst in this reaction but it also behaves as an ozone scavenger reducing ozone to oxygen, decreasing ozone concentrations where nitric oxide pollution is high.

The concentration of particulates ranging in size from less than one micrometer to ten micrometers is expressed as the soiling index which is measured in coefficient of haze units per 1000 feet (COH/1000 ft). The sources of these particulates are mainly road and construction dust, the visible smoke from industry and automobiles and sulphate particles formed in the atmosphere from sulphur dioxide emissions.

Sulphur dioxide (SO_2) is a colourless gas which is

odourless in low concentrations. When fossil fuels are burned the sulphur they contain is converted into SO_2. The principal sources of sulphur dioxide are industrial, including copper and nickel production, iron ore processing and in the refining of petroleum and natural gas. The dangers of SO_2 pollution include the formation of acid rain as well as its ability to irritate and destroy respiratory tissue.

2.0 Methodology

The Ontario Ministry of the Environment maintains an air pollution monitoring network in Ontario of 103 stations. The Ministry's sampling techniques and instrument use (OME, 1978) is outlined below:

2.1 Carbon Monoxide

Carbon monoxide is monitored by the Bendix 8501-5BA. This instrument calculates CO concentration by measuring infra-red energy in a sample and comparing it to the known infra-red absorption spectrum of carbon monoxide.

2.2 Nitrogen Oxides

To determine the concentrations of nitrogen oxides, the TECO 14D instrument is used. Concentrations of nitric oxide and total oxides of nitrogen are measured directly by measuring the chemiluminescence produced by the reaction of the oxides with ozone. Nitrogen dioxide is then calculated as the difference between the two.

2.3 Ozone

Determination of ozone concentration is similar to that of nitrogen oxides. The Bendix 8002 instrument is used which measures the chemiluminescence resulting from a reaction between ethylene and ozone.

2.4 Particulates (Soiling Index)

Sub-micron to 10 micron sized particles are measured by coefficient of haze (COH) tape samplers. These samplers draw screened air through filter paper continuously at a specific rate over a one or two hour period. The optical density of the filter is then determined in COH units and compared to unexposed filter paper. Soiling index is then expressed as the number of COH units per 1000 feet of air.

2.5 Sulphur Dioxide

The instrument used to measure sulphur dioxide is the Beckman 906A. Concentration is determined in a detection cell by continuous coulometric titration. The gas reacts with bromine resulting in an electro-chemical imbalance measured by an electrode.

For this report four stations were chosen to represent southern Ontario (see Figure 1). Ricci's (1978) study used data from stations in Windsor, Kitchener, Hamilton and Metropolitan Toronto. This example was followed with one exception. Use of the Kitchener station was decided against since its questionable location beside a freeway has resulted in unrepresentative measurements. London was chosen as its replacement since it is isolated from heavy industry and data for a satisfactory period was available.

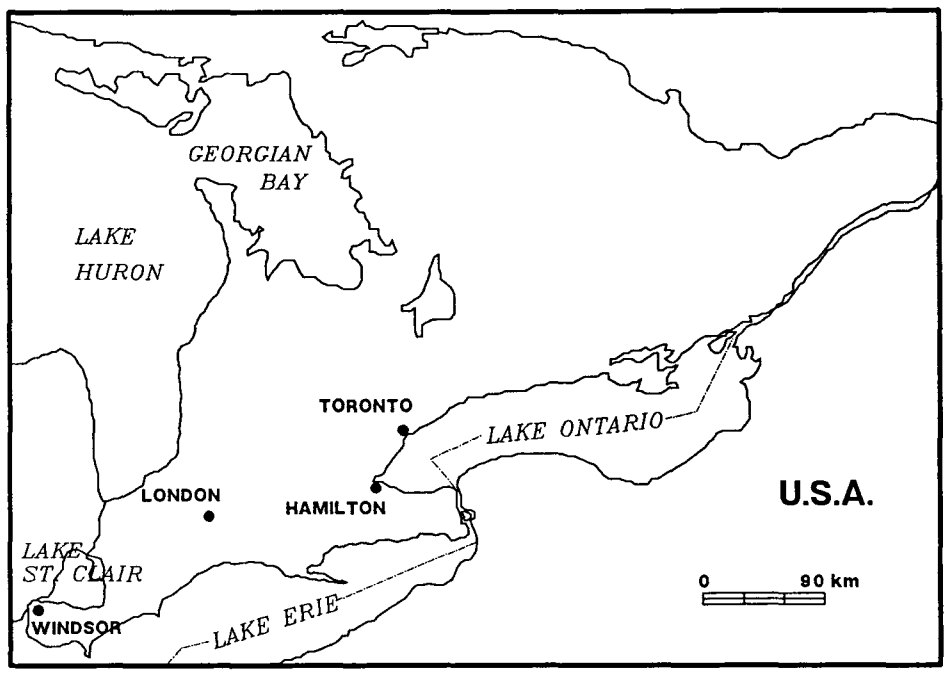

Figure 1. Location of Windsor, London, Etobicoke and Hamilton.

The monitoring station in Windsor (no. 12008), located at 467 University Ave West (see Figure 2), was chosen for this study because it has been monitoring continuously between 1969 and the present. This the only station in the city with data for the years 1969 through 1975. London's station (no. 15001) is located on the western fairgrounds at the intersection of King and Rectory streets (see Figure 3). This station has the longest record of pollution monitoring in London beginning in 1970. The station chosen for Hamilton (no. 29025) is located at Barton and Sanford (see Figure 4). The station is situated between the city's core and the industrial area and has been in use since 1969. The Etobicoke station (no. 35033) located

at Evans and Arnold Avenue active since 1969 was chosen to represent the metropolitan Toronto area (see Figure 5).

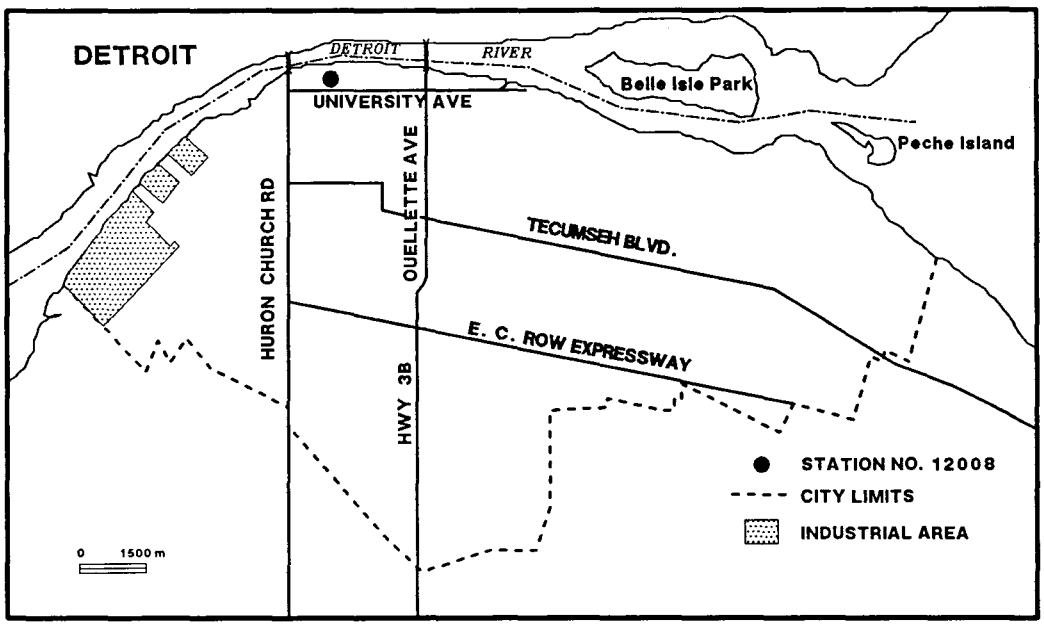

Figure 2. Map indicating location of pollution monitoring station in Windsor Ontario.

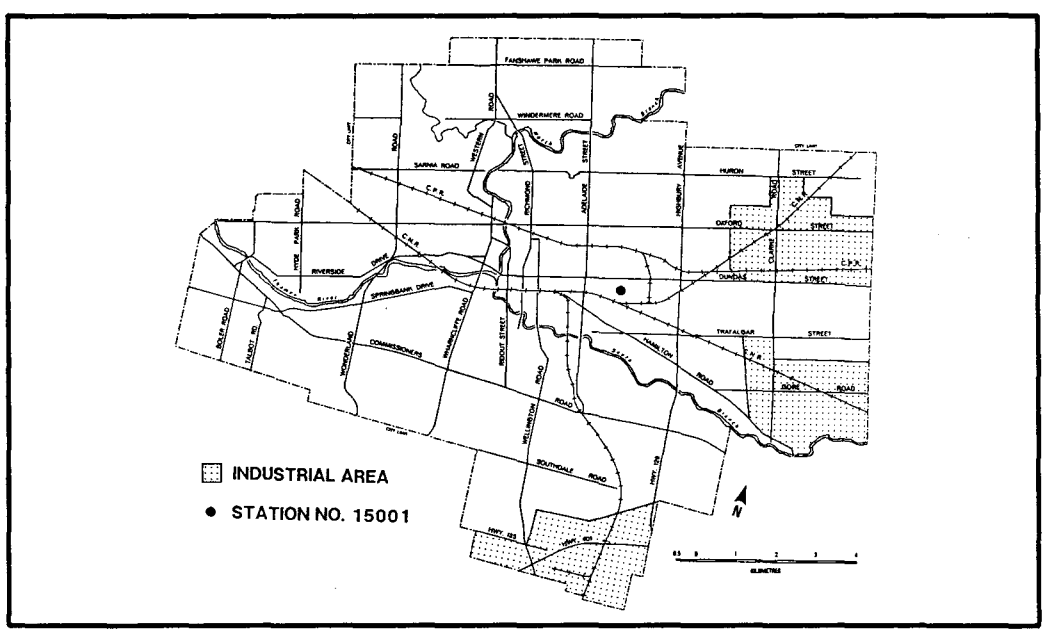

Figure 3. Map indicating location of pollution monitoring station in London Ontario.

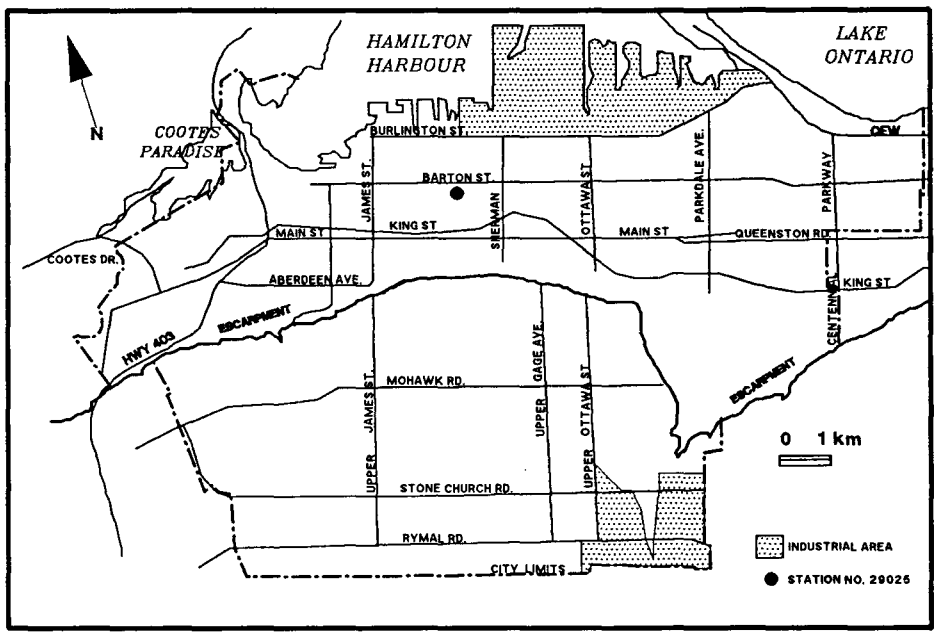

Figure 4. Map indicating location of pollution monitoring station in Hamilton Ontario.

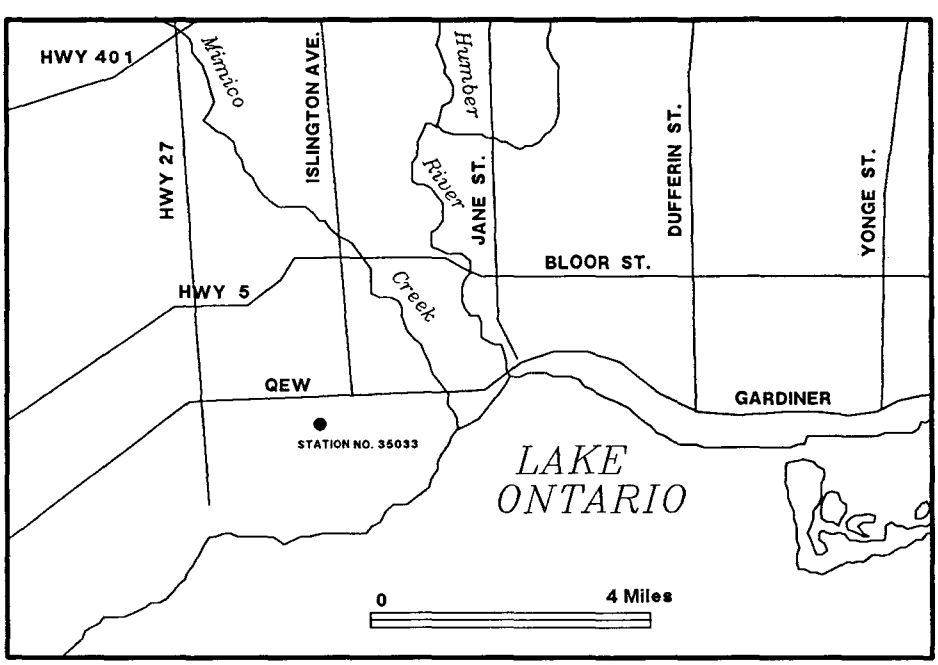

Figure 5. Map indicating location of pollution monitoring station in Etobicoke Ontario.

Data for each of the stations was obtained through the Air Resources Branch of the Ontario Ministry of the Environment. The data was received on floppy disks containing monthly averaged concentrations of the hourly measured pollutants. From this data, yearly arithmetic means were calculated for each pollutant at each station. The yearly means were then plotted against time so that the concentration trends could be viewed. Trend was evaluated subjectively and then statistically using the one sided Cox-Stuart Test for Trend (Bradley, 1968). This test is a simple sign test that expresses the significance of trend in temporal data.

3.0 Results and Discussion

In analyzing the trends in the following pollutants, results from the Cox-Stuart one-sided test for trend (Bradley, 1968) which are printed in Table 1 were used.

Table 1. Results from performing a one-tailed Cox and Stuart's test for trend on the yearly averaged data. These α values signify the probability of a trend not existing within the set. All data was tested for decreasing trend except for bracketed values where increasing trend was tested.

	Windsor	London	Etobicoke	Hamilton
Carbon Monoxide	.005	.025	.025	.005
Nitric Oxide	.005	.01	.05	.25
Nitrogen Dioxide	.05	.25	.05	.25
Oxides of Nitrogen	.05	.05	.01	.25
Ozone	.50	(.25)	(.50)	.50
Particulates	.25	(.25)	.50	.50
Sulphur Dioxide	.005	.25	.025	.005

3.1 Carbon Monoxide (CO)

Figure 6 shows the trends in yearly averaged CO concentrations for the four stations in Windsor, London, Hamilton and Etobicoke. Large decreases in CO were experienced between 1971 and 1977 in Hamilton, Etobicoke and Windsor. These decreases reflect the control of auto

emissions which began in 1971 (Environment Canada, 1974). In the years following 1977 Windsor continues to fall while little or no trend can be seen at Etobicoke or Hamilton. Etobicoke experienced the highest levels during this period probably due to its close proximity to the Queen Elizabeth Way (see Figure 5). London began monitoring CO in 1974, a decline was experienced between 1976 and 1979 after which the concentrations remained low and stable. Trends at all four station were found to be significant with 97% confidence.

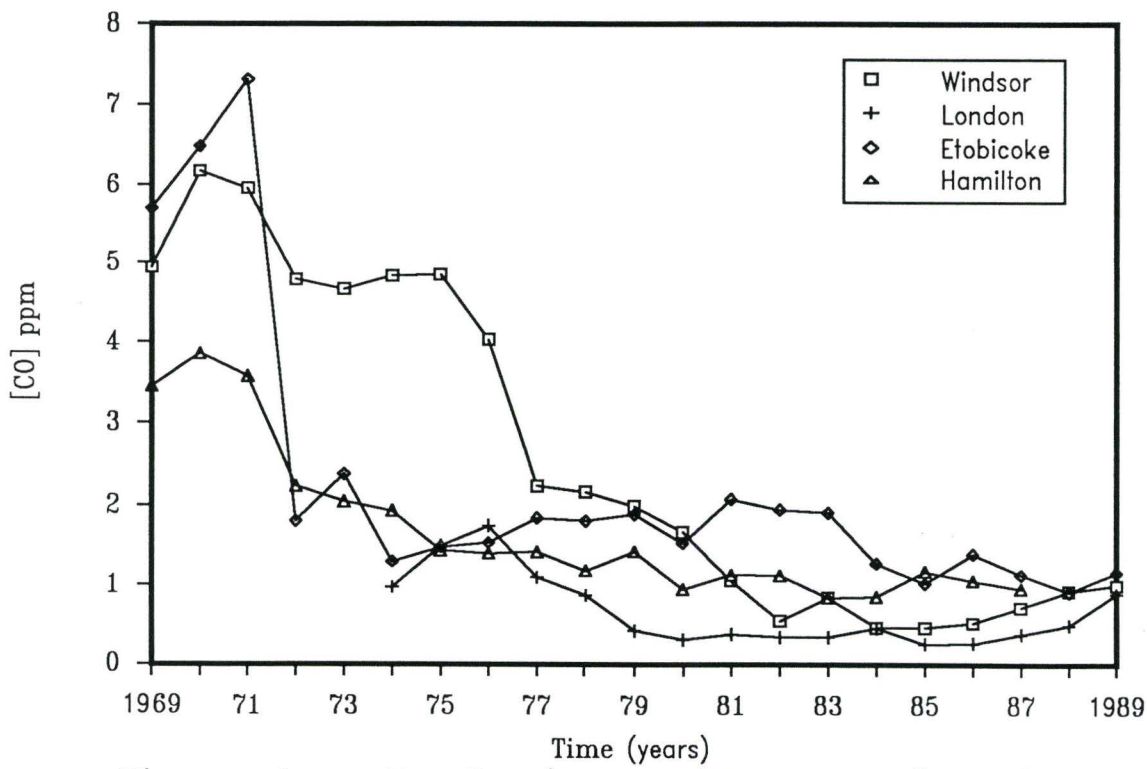

Figure 6. Trends in yearly averaged carbon monoxide concentrations between 1969 and 1989 for Windsor, London, Etobicoke and Hamilton.

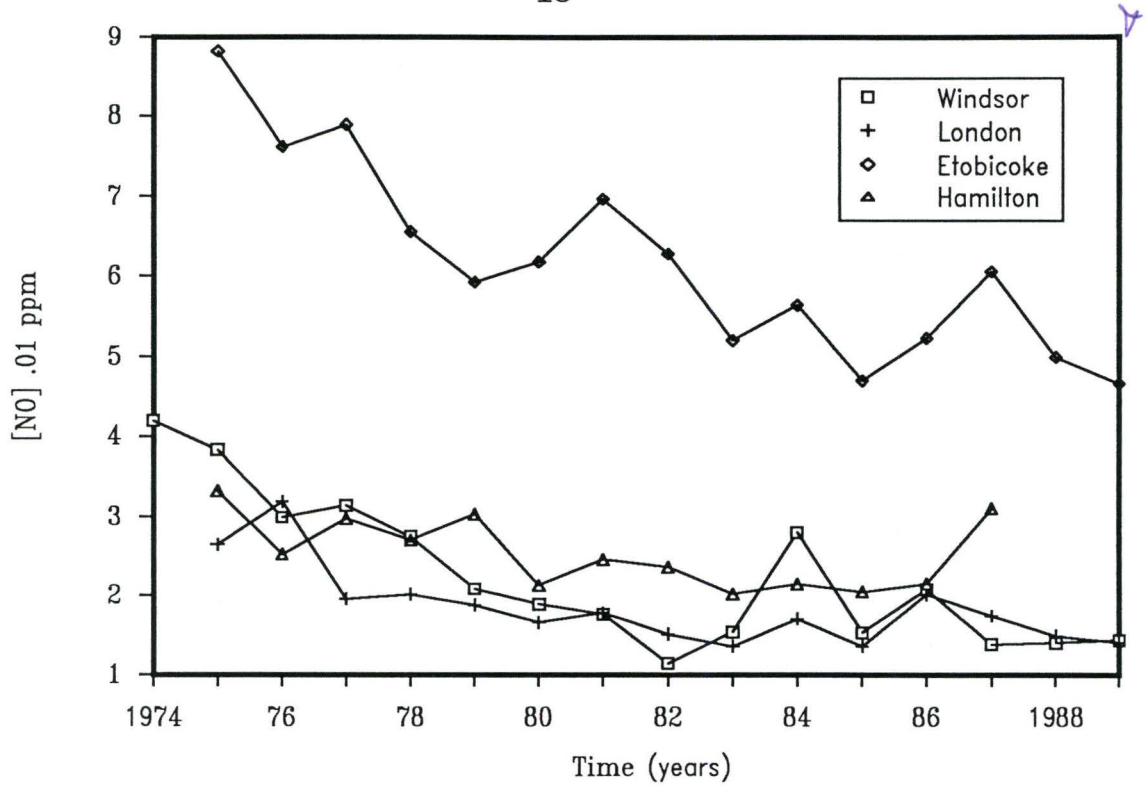

Figure 7. Trends in yearly averaged nitric oxide concentrations between 1974 and 1989 for Windsor, London, Etobicoke and Hamilton.

3.2 Nitric Oxide (NO)

NO monitoring began in 1974 in Windsor and in 1975 in the other cities. Visual inspection of Figure 7 reveals an apparent overall decrease at each station. Etobicoke's trend is obviously downward, a strong decline is noted between 1975 and 1979 after which the trend is slightly less noticeable. Etobicoke's high concentrations of NO may be a result of its location near the QEW or merely the higher concentration of automobiles within the city. From 1974 until 1980 Windsor and London decline quite strongly with

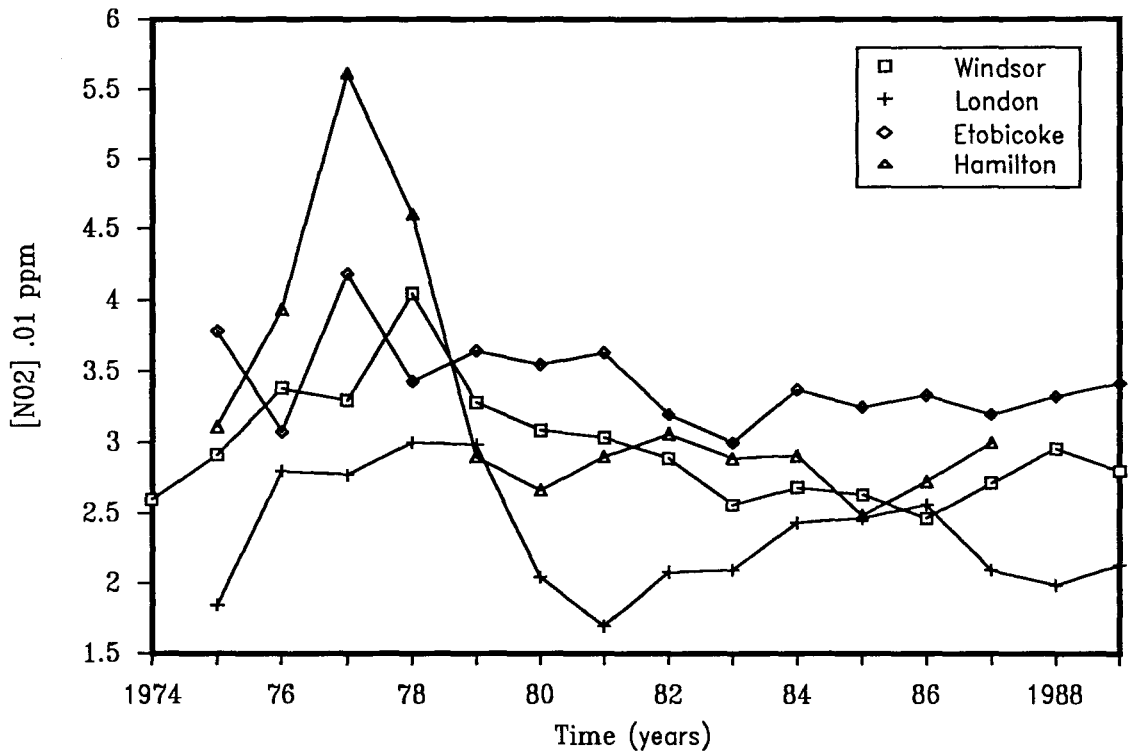

Figure 8. Trends in yearly averaged nitrogen dioxide concentrations between 1974 and 1989 for Windsor, London, Etobicoke and Hamilton.

concentrations levelling off in subsequent years. A trend in the Hamilton data is less easy to detect although it does appear to be slightly negative. Downward trends for Windsor, Etobicoke and London were found significant at 95% confidence while Hamilton's was not.

3.3 Nitrogen Dioxide (NO_2)

For NO_2 (Figure 8) there do not appear to be any strong long term trends in the data although concentrations in the 1970's were higher than in the 1980's. Since NO_2 is

formed by the oxidation of NO in the atmosphere it is expected concentrations of NO_2 would echo those of NO. This may be true to a certain extent considering the slight downward trend, but the differences in magnitude are not seen between Etobicoke and the other cities. For NO_2 only Windsor and Etobicoke showed significant decreases with 95% confidence.

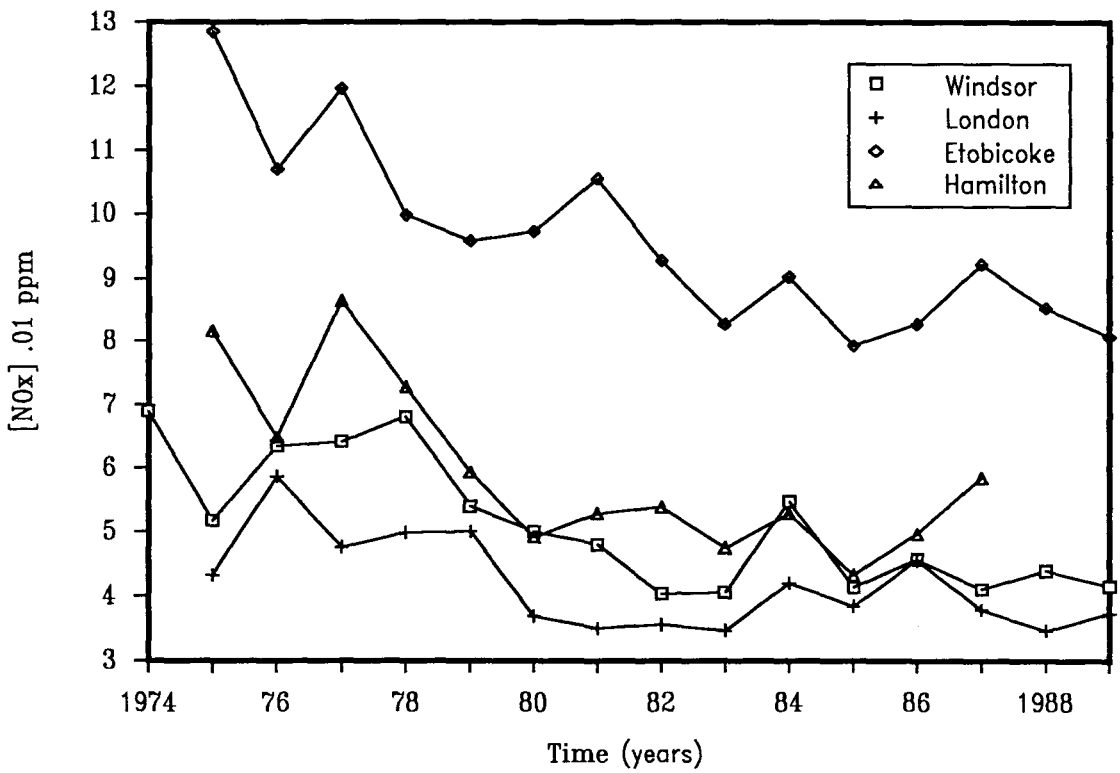

Figure 9. Trends in yearly averaged total oxides of nitrogen concentrations between 1974 and 1989 for Windsor, London, Etobicoke and Hamilton.

3.4 Total Oxides of Nitrogen (NO_x)

Since NO_x is essentially the sum of NO and NO_2 its trends should behave similarly. Strong decreases are seen (Figure 9) in each of the cities between 1977 and 1980 with slight decreases occurring after that. These trends are quite similar to those of nitric oxide which is sensible since they are both measured within the same instrument by the same process. NO_2 which is not measured but is the difference between NO_x and NO behaves erratically since wherever NO_x and NO move in opposite directions a peak or a low will occur. As with NO, decreasing NO_x trends are significant with 95% confidence for Windsor, London and Etobicoke.

3.5 Ozone (O_3)

Trends in ozone are virtually nonexistent (Figure 10) and in the London's case appear to be slightly upward. This is confirmed by the one-sided Cox-Stuart test (Table 1) which indicates the probability of trends for Windsor, Hamilton and Etobicoke are only 50% while London's upward trend is only 75% probable. Therefore the hypothesis of trend can be rejected for each city with 97% confidence.

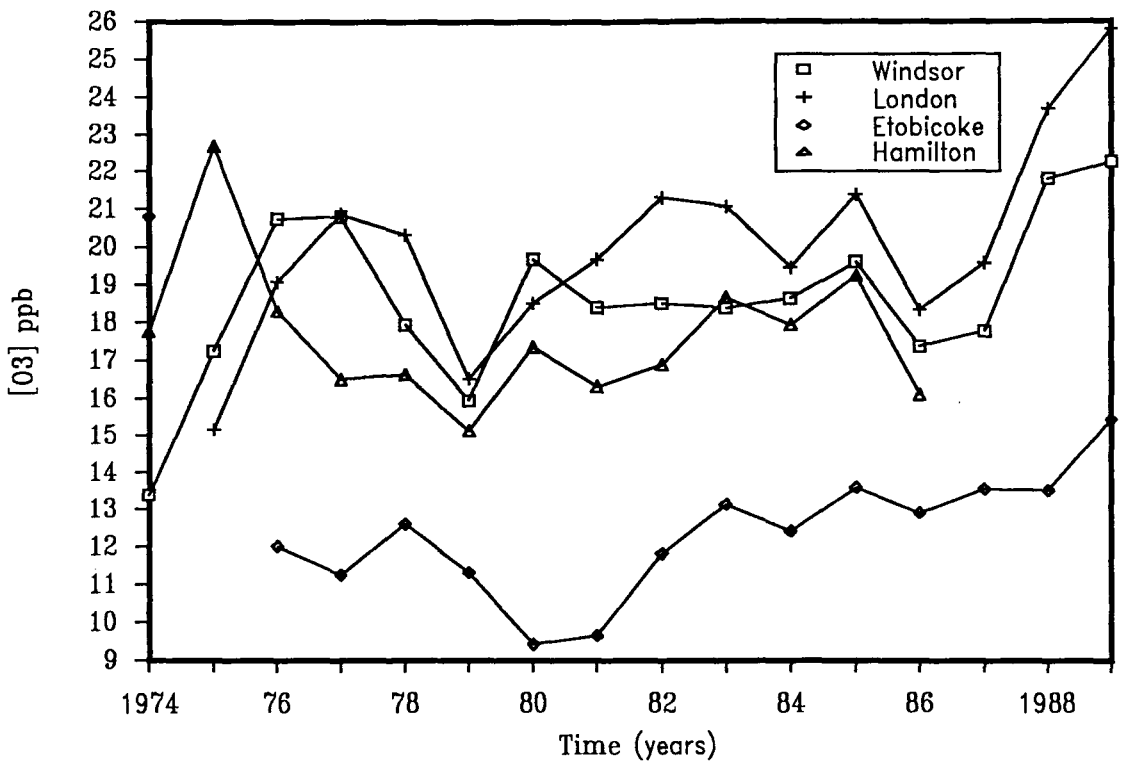

Figure 10. Trends in yearly averaged ozone concentrations between 1974 and 1989 for Windsor, London, Etobicoke and Hamilton.

3.6 Particulates

The soiling index has remained relatively constant throughout the last twenty years. Figure 11 shows that Windsor, Etobicoke and Hamilton's index display no observable trend, while London with a lower overall index shows a slight increase. Results from the one-sided Cox-Stuart Test indicate with 97% confidence that no trend exists.

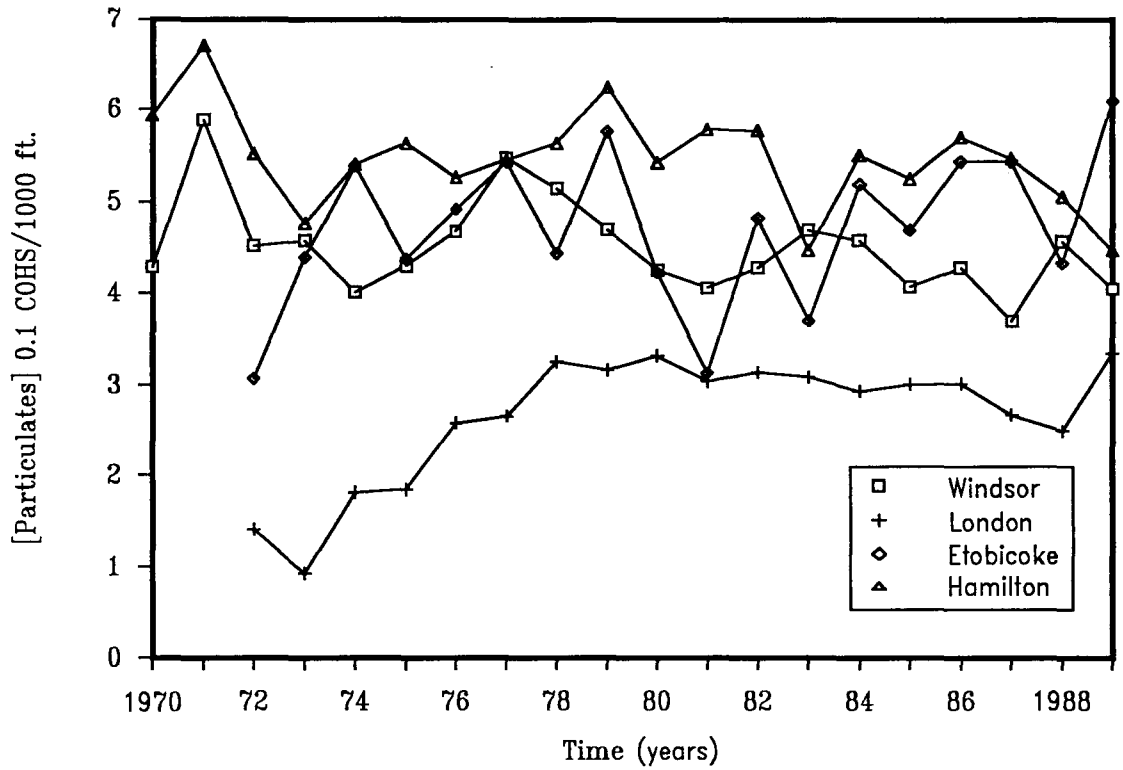

Figure 11. Trends in yearly averaged particulate concentrations, measured by soiling index in coefficient of haze units, between 1970 and 1989 for Windsor, London, Etobicoke and Hamilton.

3.7 Sulphur Dioxide (SO_2)

Figure 12 shows trends in SO_2 concentrations. Hamilton's SO_2 concentrations dropped substantially between 1969 and 1972 levelling off for a period of five years until 1977 from which they decreased until 1981 since when they have varied around the same level. Concentrations decreased from 1971 to 1985 at both Windsor and Etobicoke. London began monitoring SO_2 in 1972 and since 1977 has been experiencing a slight downward trend. Over the entire sampling period Hamilton, Etobicoke and Windsor experienced

downward trends significant with 95% confidence while London's trend was found to be not significant.

In determining the absolute effects of pollution control policies on southern Ontario's air quality there are problems which this paper does not consider. The proximity of the region to the United States is one which could have a significant impact on air quality.

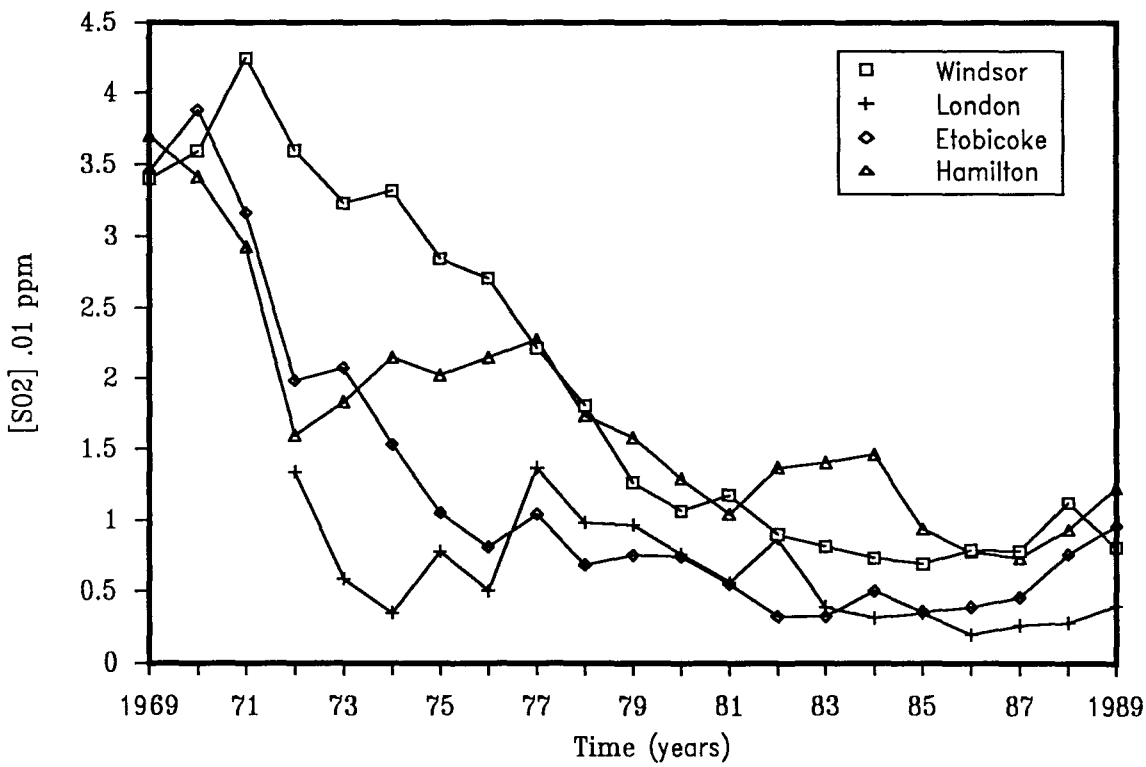

Figure 12. Trends in yearly averaged sulphur dioxide concentrations between 1969 and 1989 for Windsor, London, Etobicoke and Hamilton.

4.0 Summary and Conclusions

This report is one of a few studies including Ricci's (1978) which consider the effects of the Canadian Clean Air Act on Canada's air quality. Significant decreases have been observed in the concentrations of carbon monoxide, the nitrogen oxides and sulphur dioxide at Windsor and Etobicoke. London has experienced decreases in carbon monoxide, nitric oxide and total oxides of nitrogen while decreases at Hamilton have only occurred in carbon monoxide and sulphur dioxide. These decreases in gaseous pollutants since 1971 appear to be correlated to the inception of Canadian Clean Air Act although causation cannot be assumed.

References

Ball, R.J. and G.D. Robinson. 1982: The Origin of Haze in the Central United States and Its Effect on Solar Irradiation. Journal of Applied Meteorology, **21**, 171-188.

Bates, D.V. and R. Sizto. 1987: Air Pollution and Hospital Admissions in Southern Ontario: The Acid Summer Haze Effect. Environmental Research, **43**, 317-331.

Bradley, J.V. 1968: Distribution-Free Statistical Tests. Prentice-Hall, 388 pp.

Canada, Environment Canada. 1984: National Urban Air Quality Trends 1974-1981. Ottawa, 53 pp.

Canada, Environment Canada. 1987: The Clean Air Act Report. Ottawa, 43 pp.

Canada, Environment Canada. 1974: Canada's Motor Vehicle Pollution Control Program. Ottawa, 35 pp.

Davies, J.A. and D.C. McCay. 1982: Estimating Solar Irradiance and Components. Solar Energy, **29**, 55-64.

Ontario, Ministry of the Environment, Technical Support Section. 1978: Air Quality Hamilton 1970-1977. Toronto, 44 pp.

Ontario, Ministry of the Environment, Technical Support Section. 1989: 1978 Hamilton-Wentworth Air Quality. Toronto, 91 pp.

Ricci, P., H. Inhaber and M. Pinchuk. 1978: Canadian Urban Air Quality, 1971-1975. Atmospheric Environment, **12**, 2369-2375.

Shumway, R.H., Y. Pawitan and A.S. Azari. 1988: Modelling Mortality Fluctuations in Los Angeles As Functions of Pollution and Weather Effects. Environmental Research, **45**, 224-241