



**2002 PROGRESS REPORT
&
PUBLIC HEALTH
ASSESSMENT STUDY**



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Executive Summary

- Clean Air Hamilton is a Hamilton community initiative focused on improving air quality in the City. Clean Air Hamilton receives financial support from and reports annually to Council and advises Council on current air quality issues.
- Clean Air Hamilton developed out of the VISION 2020 process and addresses air quality issues identified, in part, by that process. Clean Air Hamilton initiatives aim to address the following two goals of VISION 2020 related to air quality:
 - To ensure the City has the best air quality of any major urban area in Ontario
 - To reduce greenhouse gas emissions 20% from 1990 levels.
- Clean Air Hamilton programs address the following VISION 2020 theme areas:
 - Natural Areas and Corridors
 - Reducing and Managing Waste
 - Consuming Less Energy
 - Changing Our Modes of Transportation
 - Land Use Issues in Urban Areas
 - Personal Health and Well-being
- Citizens benefit directly from the actions and activities of Clean Air Hamilton.
- A new assessment of human health impacts of air pollution in Hamilton is included in this report. This assessment, based on the most recent science and Hamilton air quality data, confirms that each year about 100 people in Hamilton die prematurely and about 620 people are admitted to hospitals due to respiratory and cardiovascular problems associated with exposure to air pollutants. Clean Air Hamilton views exposures to elevated levels of air pollutants as a public health issue and continues to develop programs to improve Hamilton's air quality.
- Clean Air Hamilton sponsored the second biannual *Upwind Downwind Conference* in February, 2002; as a result of exposure from the conference and the web site, inquiries continue to be received from municipalities throughout southern Ontario, Canada and U.S. related to Clean Air Hamilton initiatives and activities.
- Clean Air Hamilton is viewed as a success at the federal, provincial, and municipal levels. Funding from Council is an integral part of Clean Air

Hamilton's progress as it is substantially leveraged by in-kind support from stakeholders.

- Together with VISION 2020, Clean Air Hamilton's community process in local air quality improvement earned the City of Hamilton the prestigious 2000 Dubai International Award for Best Practices in Improving the Living Environment.

Significant improvements in air quality will require moving Clean Air Hamilton into a new phase that supplements voluntary contributions with committed funding from key stakeholders, including the City of Hamilton, local industries, academic institutions and various levels of government.

1.0 Introduction

Clean Air Hamilton presents the 2002 Progress Report on Air Quality to City Council.

This report presents the activities that have taken place in 2002 to help improve air quality in the City of Hamilton through the activities of Clean Air Hamilton. The report gives an update on new initiatives that were begun in 2002 and others that have continued from previous years. Many positive achievements have been realized in the five years since the publication of the Hamilton Air Quality Initiative (HAQI) reports in October 1997.

- Appendix A summarizes Clean Air Hamilton's numerous programs and activities to achieve air quality improvements in Hamilton.
- Appendix B presents ten-year trends (including 2002) for nine key air quality parameters.
- Appendix C is a summary of the biannual conference called *Upwind Downwind: A Practical Conference on Improving Air Quality*, held in February 2002 and hosted by Clean Air Hamilton and the City of Hamilton.
- Appendix D is a Health Impacts Assessment report; this report is a timely and up-to-date evaluation and used the most current scientific literature to assess the impacts of air pollution on the health of Hamilton residents.

1.1 Background

The former Regional Council endorsed the establishment of Clean Air Hamilton (then called the Hamilton-Wentworth Air Quality Improvement Committee or HAQIC) in 1998 following the publication of a series of reports in October 1997, entitled *The Hamilton-Wentworth Air Quality Initiative* (HAQI).

HAQI began in 1995 as a cooperative initiative between all levels of government, the community-at-large, government and non-government organizations, and academia to assess the social, environmental, human health, and economic impacts of air pollution in the City. The reports concluded with 25 recommendations for community action on air quality, including suggestions and strategies for governments, corporations, and individuals.

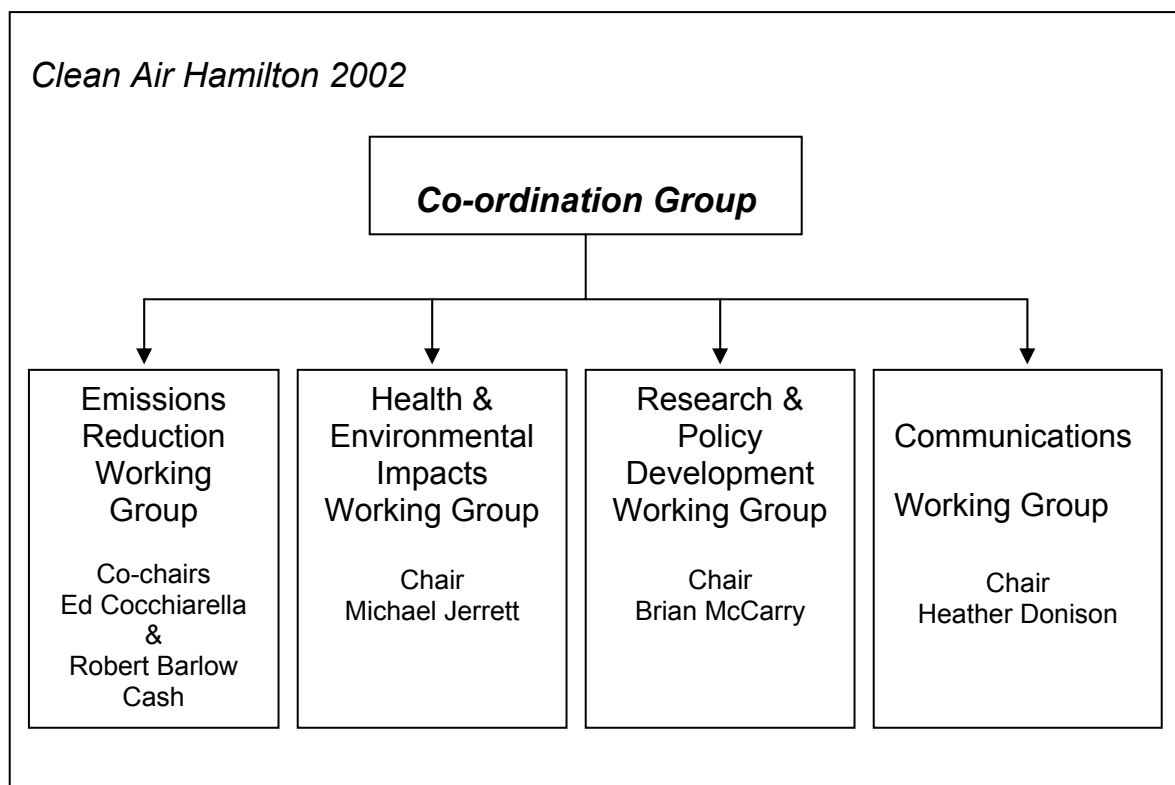
1.2 Profile of Clean Air Hamilton

Clean Air Hamilton has received attention regionally, nationally, and internationally for its outstanding commitment to improving local air quality. Many innovative

initiatives have emerged, directly and indirectly, from this program. However, due to an ever increasing work-load and the range of projects undertaken, the current membership has felt over-worked. Although the yearly budget for Clean Air Hamilton is \$98,000, it has been estimated that in-kind contributions (valued at \$400,000) provide a substantial amount of the expertise and energy through the efforts of volunteers. While members of Clean Air Hamilton are committed and give generously of their time and resources, such a heavy reliance on their benevolence cannot be expected to continue indefinitely.

As a result of this dynamic, most of the programs running in 2002 were continuations of programs initiated in previous years; two new initiatives were begun in 2002. It is clear that if Clean Air Hamilton is to make additional progress toward achieving the targets of the recommendations in the original HAQI reports, more funding will have to be committed to Clean Air Hamilton projects in coming years. Clean Air Hamilton will continue to seek external sources of funding but committed sources of funding will be needed for future success.

Figure 1: Organizational Structure of Clean Air Hamilton



Co-ordination Group Members

Dr. Brian McCarry, McMaster University, Chair
Ed Cocchiarella, Dofasco
Robert Barlow Cash, Arthur Daniels Midland
Dr. Michael Jerrett, McMaster University
Heather Donison, Green Venture
Bill Janssen, City of Hamilton
Sharon Mattiuz, Stelco
Brent Bullough, City of Hamilton
Linda Harvey, City of Hamilton
Elisabeth Nebesny, Citizen
Mark Nazar, City of Hamilton
Esther Bobet, Environment Canada
Carl Slater, Ministry of the Environment

2.0 Program Funding

2.1 Current Programs

Clean Air Hamilton received \$98,000 in funding from the City of Hamilton in 2002. Most of these funds were spent on existing programs. Funding from the City of Hamilton for Clean Air Hamilton was committed to the following on-going programs:

- Homeowner Tree Subsidy
- Northeast Gateway Study
- Trees Plantings for Award Winners and Conference Speakers
- Upwind Downwind Conference
- Commuter Challenge
- Climate Protection Campaign
- Anti-idling Campaign
- Smog Plan

Detailed descriptions of the current programs, progress to date, and short-term and long-term plans for each program can be found in Appendix A.

2.2 New Programs

Two new activities that were initiated in 2002 are discussed in detail below. The first activity involved work to establish the Hamilton Air Monitoring Network while the second is a comprehensive human health impacts study. In 2002, it was also decided that Clean Air Hamilton would need to secure additional funding from key stakeholders in

order to make additional progress toward air quality improvements. A funding proposal was developed and work on this proposal was continuing at the end of 2002.

2.2.1 Hamilton Air Monitoring Network

In December 2001, Clean Air Hamilton was approached by the MOE's West Central Region Office to act as a facilitator and participant in the formation of a new air monitoring network for the industrial area of Hamilton. The Province of Ontario (through the MOE) informed local industries that the cost of monitoring air quality parameters near all industrial sites would be borne by the industries responsible for those emissions rather than by the taxpayers. The MOE contacted many companies in Hamilton and encouraged them to participate in the establishment of an industry-operated air monitoring network that would collect and report air quality data from the industrial area to the MOE on a regular basis.

The West Central Region Office of the MOE agreed that this consortium could have access to all of the industrial air monitoring sites currently operated by the MOE in Hamilton and the air monitoring equipment at these sites. The costs of operating and upgrading the network would be borne by the members of this consortium. The MOE will continue to operate the three Air Quality Index (AQI) sites in Hamilton and will make this data available to the industrial partners in this consortium. A group of lead companies agreed to participate in the establishment of this new network and to set up a Steering Committee (chaired by the Chair of Clean Air Hamilton) to see the process of setting up the network through to completion.

Considerable effort was required on the part of Clean Air Hamilton and the Steering Committee members to ensure that this new network was established. The good will and strong commitment to local process that was the hallmark of the HAQI process several years ago was evident throughout this complex and difficult process. Negotiations and discussions to establish this network continued throughout 2002 and into 2003. The new network will supply air quality monitoring reports to the MOE on a regular basis.

[An administrator and a contractor were identified in the spring of 2003 through separate competitive bidding processes based on comprehensive requests for proposals. The Hamilton Air Monitoring Network officially took over operation of all Hamilton air quality monitoring stations, except the three AQI stations, on May 1, 2003.]

2.2.2 Health Impacts of Air Pollution Assessment Report

Clean Air Hamilton wished to conduct a reassessment of the health effects impacts of air pollution using current levels of pollution in Hamilton and the latest methods used in health-air pollution science. Dr. Michael Jerrett and Talar Sahsuvaroglu (School of

Geography and Geology, McMaster University, with funding from Clean Air Hamilton) agreed to undertake this study, a copy of which constitutes Appendix D.

One of the most important innovations of the 1997 HAQI Reports was the assessment of air quality impacts on the health of the citizens of Hamilton. Such an assessment of human health effects impacts had never been done previously at a community level. At the time of the preparation of the HAQI Reports only a handful of research papers had linked air pollution to health effects in the general population. The methodology used in the HAQI reports was used in subsequent air quality assessments by the City of Toronto and the Ontario Medical Association.

Since the publication of the HAQI Reports, over 200 publications dealing with the health effects impacts from exposure to atmospheric pollutants have appeared in the scientific and health literature. A great deal has been learned with respect to short-term effects of exposures to air pollution as well as chronic health effects impacts, two important questions that could not be answered in 1997.

At the time of the writing of the HAQI Reports there was a particular focus on the impacts of inhalable air particulate material or PM₁₀ (or particulate material of less than 10 microns in diameter) on human health. Recently, a consensus has emerged that implicates a range of contaminants, nitrogen dioxide (NO₂), sulphur dioxide (SO₂), ozone (O₃), and carbon monoxide (CO) with the health effects impacts associated with air pollution. Nitrogen dioxide, a major contributor to the health effects impacts of smog, is directly correlated with vehicular emissions.

The new study provides estimates of (a) the number of non-traumatic deaths, (b) the number of respiratory admissions to hospital and (c) the number of cardiovascular admissions to hospital as a result of exposures to the five key atmospheric pollutants listed above.

2.2.2.1 Major Findings of Study

The total number of non-traumatic deaths attributable to the five air pollutants is estimated to be about 96 per year; the numbers of hospital admissions due to respiratory problems and cardiovascular problems are estimated to be about 139 and about 479, respectively. The estimates for non-traumatic deaths and hospital admissions for respiratory ailments are similar to the 1997 estimates, while the estimate for hospital admissions for cardiovascular conditions are about double the previous value. These estimates are very conservative values and should be viewed as the minimum numbers of deaths and hospital admissions associated with air pollution exposures in Hamilton.

The principal conclusion of the report is that air pollution remains a major contributor to overall mortality and hospital admissions in Hamilton; the human health impacts of air

pollution represent a significant burden (through direct costs and use of resources) to the health care system for this City (and for any urban area around the world).

While this study did not identify the health impact burdens associated with specific sources, we know from other Clean Air Hamilton research that local vehicular emissions (particularly nitrogen dioxide) and airborne pollutants from outside the Hamilton area (e.g., ozone in the summer months) are major contributors to the pollutant burden in the residential areas of Hamilton. Nearer the industrial areas of the City, there is an increased pollutant burden (particularly due to increased levels of PM₁₀, sulphur dioxide, and benzene) from industrial activities and the associated heavy vehicle traffic.

2.2.2.2 Trends in Air Pollutant Levels – Relationship to Health Study

Trends for eight pollutants over the past ten years (presented in Appendix B) show that, overall, there are improvements in the levels of most air pollutants. Significant improvements are the results of specific pollution abatement actions (e.g., benzene and benzo[a]pyrene). Many of the figures in Appendix B provide comparisons between pollutant levels in the industrial and residential areas of Hamilton; pollutant levels in residential areas are usually lower than levels near industrial areas.

2.2.2.3 Nitrogen Dioxide Levels and Health Impacts

One pollutant whose levels have not decreased over the past decade is nitrogen dioxide, a pollutant related primarily to vehicle emissions; this pollutant alone is responsible for about one-third of all non-traumatic deaths and hospital admissions due to air pollution. The levels of this pollutant in the industrial and residential areas of the City are essentially identical, reflecting the broad-scale impacts of vehicle emissions across the whole City.

2.2.2.4 Ground-level Ozone Levels and Health Impacts

Ground-level ozone levels in Hamilton are not the result of local emissions but rather are the result of long-range transport of this pollutant from urban areas to the southwest of Hamilton, primarily from the Ohio Valley region. Ground-level ozone levels are rather variable but have not decreased over the past decade. As with nitrogen dioxide, the health effects impacts of exposure to ground-level ozone are significant; about one-third of all premature deaths and hospital admissions due to air pollution can be attributed to this contaminant alone.

2.2.2.5 Summary

In summary, nitrogen dioxide and ground-level ozone, contaminants that are the result of combustion emissions (from cars, trucks, heating, coal-fired power plants, etc.), account for two-thirds of all non-traumatic deaths and hospital admissions attributable to air pollution in Hamilton. Clean Air Hamilton views the health effects impacts of

combustion emissions, including vehicle emissions, as an important public health issue. All efforts that reduce combustion emissions will also reduce levels of all five pollutants examined in this health study; reductions in pollutant levels (in particular the levels of nitrogen dioxide and ground-level ozone) will have positive impacts on the health of citizens, both in Hamilton and in communities downwind of Hamilton. For this reason, a number of Clean Air Hamilton's major initiatives (e.g., NuVehicle program, fleet greening, Commuter Challenge, anti-idling campaign, smog plan development) have been spearheaded to address the issue of reducing vehicle emissions. Federal, provincial, and municipal programs that are designed to achieve Kyoto Protocol reductions in combustion emissions will clearly have direct human health benefits.

3.0 Project Status

The 1997 HAQI report contained many recommendations (see Appendix A for a list of all recommendations). New and continuing projects address these recommendations in various ways. The following is a summary of projects that were in progress in 2002.

3.1 Reducing the number of single-occupancy auto trips

Commuter Challenge

Commuter Challenge is a week-long national event in which participants utilize alternative modes of transportation in an attempt to reduce single-occupancy auto trips. Participants are encouraged to walk, cycle, jog, bus, carpool, rollerblade, or use any other creative mode of transportation – anything but drive alone – to get to work or to school.

This year's Commuter Challenge showed increased participation. Hamilton placed 13th out of 34 participating communities across Canada. City-wide, Hamiltonians kept 54,671 kilograms of pollutants out of the air during the week of the Commuter Challenge. Congratulations and thank you to all participants in this year's challenge.

3.2 Greening of Fleets

Normal Use Vehicle (NuVehicle) Partnership

As part of its commitment to reduce emissions from City owned vehicles, the City of Hamilton purchased 10 Toyota Prius gas-electric hybrid vehicles to replace older vehicles in its fleet.

3.3 Reduction of Trans-boundary Air Pollution

Upwind Downwind: A Practical Conference on Improving Air Quality

Clean Air Hamilton and the City of Hamilton hosted the second bi-annual conference on air quality on the 25th and 26th of February 2002. Once again, the conference was a great success. The goal of the conference is to bring together municipalities, government agencies, corporations, ENGOs, and citizens that have a stake in the well-being of our (and their) airshed. The theme for the 2002 was *A Practical Conference on Improving Air Quality*.

3.4 Development and/or enhancement of tree projects

Homeowner Tree Subsidy Program

This program, in partnership with Green Venture and the Hamilton Industrial Environmental Association, continued in 2002 and resulted in 274 native trees being planted. Homeowners are entitled to up to two native trees to be planted on their property at a subsidized rate of \$29.99 for each tree. Although the number of trees planted this year was less than the year before, all of the objectives identified in the 2002 proposal were met. For instance, a comprehensive web site was launched that provides detailed information on the program. The site can be accessed at www.greenventure.on.ca/tp.asp. Also, there was an increase in participation from residents in the central and northern parts of the City. And, finally, a valuable survey of past participants in the program was completed and will be used to improve the program in the future.

VISION 2020 Award Tree Planting

Each year, as an expression of gratitude to those in the community who work to support the goals of VISION 2020 and Clean Air Hamilton, trees are planted in the name of winners of the VISION 2020 Sustainable Community Awards. Two awards are presented for efforts to improve air quality. This year's recipients were the McMaster Solar Car Project and Re-cycle Cycles.

3.5 Development of a Community Smog Plan

Corporate Smog Response Plan

Whenever the Ontario Ministry of the Environment issues a smog advisory for the City of Hamilton, the City enacts its Corporate Smog Response Plan. In so doing, the City modifies its activities and thereby reduces emissions of smog forming pollutants, which would otherwise contribute to the problem.

Departmental leads train employees on departmental policies that come into effect on smog days.

In 2002, the City of Hamilton had 20 days during which a smog advisory was in effect. While departmental compliance during these days was the norm, there were instances when staff made inquiries to the Clean Air Hamilton co-ordinator regarding the impact the Corporate Response Plan would have on their work. More work needs to be done to train employees as to the benefits of such a plan and how they can continue to do an effective job on smog days while at the same time helping to improve air quality.

Anti-idling Campaign

Due to restructuring and staffing changes at the City, the anti-idling campaign did not move forward to the extent intended. However, much of the work has been done (a draft internal policy has been developed along with a draft City-wide by-law; and, signs have been developed and locations for posting the signs have been identified). Newly re-assigned staff in Fleet, which is where the campaign resides at present, will have to be updated on the history and status of this initiative before we can move forward.

3.6 Promotion of Public Awareness through Social Marketing

Clean Air Hamilton Communications

The use of a newsletter continued this year with the release of two issues. This year also saw three members of Clean Air Hamilton participate as panel members on the July 7 episode of CHTV's *Straight Talk* with Heather Hiscox. Dr. Brian McCarry, Dr. Michael Jerrett, and Dr. Denis Corr comprised an expert panel on air quality issues.

Clean Air Awards

The Clean Air Hamilton Air Quality Awards are given out as part of the VISION 2020 Sustainable Community Recognition Awards. Two Air Quality Awards were presented to two organizations in 2002. One winner was the McMaster Solar Car Project. This team had representatives from several different faculties at McMaster University. They worked together to build a solar car, which is now used as an educational tool throughout the City.

The other award was earned by Recycle Cycles. This project involved the restoration of old bicycles, which are then sold at a moderate price to people with moderate incomes.

Both winners are to be commended for their excellent work.

3.7 Funding Proposal

The goal of this proposal was to secure three years of committed funding from key stakeholders. Three million dollars over three years was the desired goal of this initiative. It was felt that this amount would enable Clean Air Hamilton to move beyond its current capabilities, which are heavily dependent upon in-kind contributions (valued at about \$400,000), to specific, large-scale management initiatives. As 2002 came to an end, no new funding had been secured.

4 Progress Indicators

In past Progress Reports, air quality data was available only for the previous year. In other words, the 2001 Progress Report contained data on air quality for the year 2000. For the 2002 Progress Report, we are able to report trends in air quality over the past decade, including recently released 2002 data (see Appendix B). However, because this data is so timely, it has not been verified yet by the MOE. Any changes that may be applied to the 2002 data through review will not affect the overall trends presented in Appendix B.

5 Recommendations

Clean Air Hamilton continues to make an important contribution to improved air quality in the City of Hamilton. It is suggested that additional sources of funding continue to be sought. New monies will likely be available from other levels of government, especially the Federal level, with respect to Kyoto commitments; Clean Air Hamilton should be ready with proposals to secure some of this funding.

The new Health Study supports past findings that people continue to die prematurely and to be admitted to hospital due to poor air quality in the City. The Health Study also suggests that future improvements to air quality can be realized most effectively through land use planning and transportation planning. Many of the pollutants we deal with locally are the results of transportation choices and land use decisions made locally and in areas distant from Hamilton. Provincial decisions notwithstanding, the City has many choices to make with respect to how it develops land and, in turn, how it's inhabitants, visitors, and workers move about.

This report also point out that many improvements have been made by industries to reduce emissions, as evidenced by general improvements in local air quality in Hamilton, particularly in the areas impacted by industry-related emissions. Clean Air Hamilton will continue to provide practicable advice on how we can better move Hamiltonians around while protecting air quality.

Appendix A

Clean Air Hamilton Activities

The following is a list of activities that have resulted from direct actions of Clean Air Hamilton or from recommendations contained in the 1997 Hamilton Air Quality Initiative (HAQI) reports. Responsibility for the activities stemmed from Clean Air Hamilton and one or more of its working groups but partnerships with other organizations has led to the success of most of the activities. Many other projects that address air quality issues are in progress across the City, but only programs that can be traced back to Clean Air Hamilton are listed below.

Recommendations	Responsibility		Progress to Date	Short Term Plans (1 year)	Long Term Plans (5 years)
	CAH	Partners			
Reduce Industrial Sources					
Implement Code of Best Practice Guidelines {HAQI Recommendation 1}					
Develop Best Available Control Technology and Practices for Major Sources {HAQI Recommendation 2}	ERWG	MOE Industries	<ul style="list-style-type: none">Developed website registry for companies and their fine particulate reduction projects	<ul style="list-style-type: none">Promote and utilize emissions reduction registry	<ul style="list-style-type: none">Reward companies for the air pollution reduction projects through a series of local Clean Air Awards
Implement Strategic Options Process (SOP) Recommendations	ERWG	EnvCan MOE Stelco Dofasco VFT. Ltd.	<ul style="list-style-type: none">A review on the effectiveness of the SOP was planned for 1999		<ul style="list-style-type: none">Monitor progress on implementation

Recommendations	Responsibility		Progress to Date	Short Term Plans (1 year)	Long Term Plans (5 years)
{HAQI Recommendation 3}	CAH	Partners Columbian Chemicals Other Industries			
Continue Permitting Programs {HAQI Recommendation 4}	ERWG	MOE Dofasco Stelco	<ul style="list-style-type: none"> Stelco with commitment to meet the terms of the Strategic Options Process or better, plans to refurbish or shut down coke oven with high emissions Voluntary Agreement with Dofasco 		<ul style="list-style-type: none"> As the MOE continues to develop and enforce air quality/source performance standards, the team will comment on the programs as required.
Establish Industry-Local Resident Liaison Committee {HAQI Recommendation 5}	CG ERWG RPDWG HEIWG CWG	HIEA	<ul style="list-style-type: none"> The Hamilton Industrial Environmental Association (HIEA) has established a Community Advisory Panel 		
Reduce Emissions from Private Vehicles					
Reduce the Number of Single-Occupancy Auto Trips <ul style="list-style-type: none"> Enhance HSR Bus Services Design Accessible Urban Development Promote Cycling Promote Walking Discourage 	ERWG	Green Venture City of Hamilton EnvCan HIEA	<ul style="list-style-type: none"> Staff Transportation Alternatives Plan presented to Council, referred to City with recommendation for joint action. City Council has referred it to staff for a report Free Regional staff parking ended as benefit on grandfathered basis Hamilton Commuter Challenge successful in June 2000, 2001, and 2002 	<ul style="list-style-type: none"> Commuter Challenge in Spring 2003 	<ul style="list-style-type: none"> Support for Commuter Challenge to continue each year

Recommendations	Responsibility		Progress to Date	Short Term Plans (1 year)	Long Term Plans (5 years)
CAH		Partners	<ul style="list-style-type: none"> HSR Campaign to show transit use a “green” alternative to the private automobile, especially during Smog Advisory Days Travel Options Workshop hosted by the City in 2000 for local organizations City of Hamilton Bikeways System – Waterfront Trail 		
Parking Downtown {HAQI Recommendation 6} Minimize the Emissions of Private Vehicle Use <ul style="list-style-type: none"> Promote Carpooling Offer Discounts on Vehicle Tune-Ups Minimize Discretionary Trips {HAQI Recommendation 7}	ERWG	City of Hamilton Green Venture	<ul style="list-style-type: none"> Hamilton Commuter Challenge successful in June 2000, 2001, and 2002 Staff Carpooling Registry established on City’s internal (intranet) web site. 		
Establish Standards for Vehicle Emissions and Implement Vehicle Emissions Testing {HAQI	ERWG	MOE Drive Clean Office EnvCan	<ul style="list-style-type: none"> Ongoing support to the Ontario Drive Clean program, implemented in Hamilton in 1999 Ongoing support to the Drive Clean pilot program for heavy duty vehicles introduced in 		

Recommendations	Responsibility		Progress to Date	Short Term Plans (1 year)	Long Term Plans (5 years)
	CAH	Partners			
Recommendation 8}			1999 <ul style="list-style-type: none"> Ongoing support to the fuel economy tax MOE Smog Rover monitors tailpipe emissions of cars and light duty trucks in Hamilton and the Greater Toronto Area 		
Anti-idling By-Laws {HAQI Recommendation 9}	RPDWG ERWG CWG	City of Hamilton	<ul style="list-style-type: none"> Anti-idling By-law drafted and on hold Anti-idling signage designed for railway crossings, industrial properties, and City-owned works yards Research and Educational Packages for anti-idling campaign complete 		<ul style="list-style-type: none"> Expand anti-idling signage campaign
Reduce Emissions from Commercial/Fleet Vehicles					
Enact Commercial Vehicle Maintenance Standards {HAQI Recommendation 10}					
Achieve more Efficient Commercial Vehicle Flow {HAQI					

Recommendations	Responsibility		Progress to Date	Short Term Plans (1 year)	Long Term Plans (5 years)
Recommendation 11}	CAH	Partners			
Greening of Fleets <ul style="list-style-type: none"> Schedule Off Peak Trucking Shipments Replace Old Trucks Alter Fleet Technology Specify Trucks that meet Standards in Purchase Contracts Switch to Rail {HAQI Recommendation 12}	ERWG	City of Hamilton MOE EnvCan Hamilton Hydro	<ul style="list-style-type: none"> Workshop was held in 1999 with 13 fleet managers in attendance, where a commitment to further meetings and information sharing was made Literature review initiative, focused on greening, strategies of other fleet replacement alternatives for retired vehicles NuVehicle considerations ongoing: MOE, City of Hamilton, and Hamilton Hydro have altogether purchased three Honda Insight hybrid vehicles and one Toyota Prius in 2000 Evaluation of local hybrid vehicle performance complete City of Hamilton replaced 10 fleet vehicles with hybrid vehicles in 2002 		<ul style="list-style-type: none"> Partners will purchase additional hybrid vehicles as they become available, and as they are evaluated
Reduce Overall Community Emissions					
Control Fugitive Dust <ul style="list-style-type: none"> Establish Paving Bylaws Establish Fugitive Dust Control 	RPDWG ERWG	City of Hamilton	<ul style="list-style-type: none"> Street Sweeping Study is complete. Enhanced street sweeping and monitoring in the north end to continue until December 2000 (on hold) Major industries continue their 		

Recommendations	Responsibility		Progress to Date	Short Term Plans (1 year)	Long Term Plans (5 years)
CAH	Partners				
Bylaws <ul style="list-style-type: none"> Establish Operating Standards for Trucks Use Best Available Control Technology {HAQI Recommendation 13}			internal programs to control fugitive dust through paving, street sweeping and green belting		
Reduce Transboundary Pollution {HAQI Recommendation 14}	HEIWG	City of Hamilton SO CAN I members	<ul style="list-style-type: none"> Two <i>Upwind Downwind: A Practical Conference on Improving Air Quality</i> events have been held. September 30 to October 1, 1999, and February 25 to 26, 2002. Southern Ontario Clean Airshed Network Initiative (SO CAN I) was established in January 2000 City of Hamilton chaired SO CAN I in 2002 	<ul style="list-style-type: none"> Next <i>Upwind Downwind</i> conference will be held in early 2004. 	<ul style="list-style-type: none"> Air Quality Conference to address transboundary air pollution to be held biennially
Develop and Implement Energy Conservation Measures <ul style="list-style-type: none"> Municipal Energy Reduction Programs Industrial Energy 	RPDWG	City of Hamilton Green Venture	<ul style="list-style-type: none"> City to promote EnerGuide program in buildings approval process District Energy Project Energy Management Program City a Member of Partners for Climate Protection Campaign; developing action plan to 		<ul style="list-style-type: none"> City to develop and implement energy reduction action plan to reduce greenhouse gas emissions and air pollutants

Recommendations	Responsibility		Progress to Date	Short Term Plans (1 year)	Long Term Plans (5 years)
CAH	Partners				
Reduction Programs <ul style="list-style-type: none"> • Alternative Energy Pilot Program • Subsidies for Energy Audits • District Heating and Co-generation {HAQI Recommendation 15}			reduce energy consumption		
Develop and/or Enhance Community Tree Projects {Council Recommendation}	ERWG	City of Hamilton Green Venture HIEA	<ul style="list-style-type: none"> • The City of Hamilton Tree Planting Program supported partnerships with non-profit groups to plant trees on school grounds and near industries (completed) • Green Venture, in partnership with the City and HIEA, offers subsidized trees homeowners • HIEA, in consultation with the citizens, are devoting \$50,000 to tree planting in the north end of Hamilton on industrial sites • Trees planted on behalf of VISION 2020 award recipients 	<ul style="list-style-type: none"> • Review, evaluate and continue tree planting programs underway 	
Develop a Community Smog	ERWG CWG	City of Hamilton	<ul style="list-style-type: none"> • Provincial Anti-Smog Action Plan 		<ul style="list-style-type: none"> • City of Hamilton Smog Management Plan

Recommendations	Responsibility		Progress to Date	Short Term Plans (1 year)	Long Term Plans (5 years)
Plan {Council Recommendation}	CAH	Green Venture Partners	<ul style="list-style-type: none"> City of Hamilton Corporate Smog Response Plan (continuing) Community Anti-Smog Campaign Corporate Smog Plan Policies at two local organizations 		<ul style="list-style-type: none"> Corporate Smog Plan Policies at five local organizations
Public Awareness					
Promote Public Awareness through Social Marketing <ul style="list-style-type: none"> Videos Pamphlets Updates in Print Media Combine with High Profile Municipal Initiatives Website {HAQI Recommendation 16}	ERWG HEIWG RPD WG CWG	City of Hamilton Green Venture	<ul style="list-style-type: none"> Research results are publicized and explained through verbal presentations and visual displays Reports are linked to the Clean Air Hamilton website Smog brochures, fact sheets and posters produced for the City's Corporate Smog Response Plan Promotional materials produced by Green Venture and the City of annual Commuter Challenge ERWG Work Plan has been incorporated into the Clean Air Hamilton website www.airquality.hamilton.on.ca Received 2000 Dubai International Award for Best Practices in Improving the Living Environment Logo designed, Website 	<ul style="list-style-type: none"> Promote results of research Finalize communications plan and prepare public information kit 	<ul style="list-style-type: none"> Continue promotion of research and developed policies Activities to be incorporated into a Clean Air Hamilton newsletter and video Use Dubai Award to create a monument that celebrates Hamilton's commitment to air quality and sustainability.

Recommendations	Responsibility		Progress to Date	Short Term Plans (1 year)	Long Term Plans (5 years)
	CAH	Partners	revamped and electronic newsletter prepared in 2001		
Monitoring, Research and Development					
Expand Capability for Inhalable/Respirable Particulate Monitoring {HAQI Recommendation 17}	HEIWG	MOE	<ul style="list-style-type: none"> MOE maintains monitoring network in Hamilton MOE began monitoring for PM_{2.5} in 2002 		<ul style="list-style-type: none"> Facilitate a partnership in industrial self monitoring.
Maintain Current Monitoring System {HAQI Recommendation 18}	HEIWG	MOE	<ul style="list-style-type: none"> Provincial monitoring network in Hamilton Discussions were held to hand over operation of the air monitoring network to HAMN, the Hamilton Air Monitoring Network (a new industry-led organization), in 2003 	<ul style="list-style-type: none"> HAMN to begin operation of most of the air monitoring network in 2003 	
Expand Mobile/Portable Monitoring Capabilities {HAQI Recommendation 19}	HEIWG	MOE	<ul style="list-style-type: none"> MOE looking for partners to strengthen the monitoring network MOE has enhanced the telemetry network 		
Maintain Government Scientific/Laboratory Capabilities	HEIWG	MOE	<ul style="list-style-type: none"> MOE has requested lab allocations for air quality in 2000 MOE is working on a self 	<ul style="list-style-type: none"> HAMN to begin monitoring their own emissions; MOE to act as auditor 	

Recommendations	Responsibility		Progress to Date	Short Term Plans (1 year)	Long Term Plans (5 years)
CAH	Partners				
{HAQI Recommendation 20}			<ul style="list-style-type: none"> monitoring program for industry Formation of the HAMN began in 2002 		
Research about the Origins, Characteristics and Health Impacts of Particulates {HAQI Recommendation 21}	HEIWG RPDWG	McMaster University City of Hamilton	<ul style="list-style-type: none"> Discussion with McMaster University to create a research chair in Air Quality has begun Canada-Wide Standards Sub-Agreement committees to the development of national standards for ozone and fine particulate. The process for developing the standards is on target 	<ul style="list-style-type: none"> Health Impacts Study to be completed in 2003 	
Analyze and Model Transportation Emissions {HAQI Recommendation 22}	RPDWG	EnvCan City of Hamilton McMaster University	<ul style="list-style-type: none"> Truck Emissions Modeling complete Support reductions in sulphur content of fuels and diesel fuel regulations 	<ul style="list-style-type: none"> Conduct a truck industry survey to determine truck travel patterns and come up with policy recommendations for reducing transportation emissions 	<ul style="list-style-type: none"> Implement policy recommendations from the Truck Emissions Modeling project
Research on the Impact of Air Toxins on Ecosystems {HAQI Recommendation 23}	RPDWG	City of Hamilton McMaster University	<ul style="list-style-type: none"> Research on the impacts of air toxins ongoing at McMaster University 	<ul style="list-style-type: none"> Chemical Analysis of pollutants to be completed 	
Develop an Emissions Inventory	ERWG RPDWG	RWDI Ltd.	<ul style="list-style-type: none"> MOE is establishing a mandatory emissions reporting 		

Recommendations	Responsibility		Progress to Date	Short Term Plans (1 year)	Long Term Plans (5 years)
and Carry out Atmospheric Modeling {HAQI Recommendation 24}	CAH	MOE Partners	<ul style="list-style-type: none"> program (Regulation 127) ERWG is following the stages of mandatory reporting Large industry has reported emissions (pre Reg. 127) since 2001 Smaller industry reporting began in 2002 Hamilton data sets can eventually be extracted for RWDI airshed modeling 		
Review and Continued Refining of Environmental Priorities {HAQI Recommendation 25}	HEIWG	City of Hamilton McMaster University McMaster Institute of Environment and Health	<ul style="list-style-type: none"> 1997 Air Quality Initiative used to identify priority pollutants, sources and management strategies Protocol development for Human Health Risk Assessment underway 		<ul style="list-style-type: none"> Environmental Priorities will be introduced through the results of the Health Assessment
Land Use/Transportation Air Quality Issues {HAQI Recommendation 26}	ERWG	City of Hamilton	<ul style="list-style-type: none"> Initial issues identified for City-wide planning and case studies addressed electronic database established on land use/transportation/air quality references ACTION 2020 Task Force on 	<ul style="list-style-type: none"> monitor secondary planning studies and development of City official plan and provide comments where appropriate 	<ul style="list-style-type: none"> monitor secondary planning studies and development of City official plan and provide comments where appropriate full implementation of

Recommendations	Responsibility		Progress to Date	Short Term Plans (1 year)	Long Term Plans (5 years)
	CAH	Partners			
			<p>Air Quality; development of action plan to improve air quality indicators (discontinued)</p> <ul style="list-style-type: none"> • Building a Strong Foundation, Growth Related Integrated Development Strategy, and VISION 2020 Renewal all began in 2002 		Task Force on Air Quality Action Plan

CWG – Communications Working Group
EnvCan – Environment Canada
ERWG – Emissions Reduction Working Group
HAMN – Hamilton Air Monitoring Network
HAQI – Hamilton-Wentworth Air Quality Initiative Co-ordination Group
HEIWG – Health and Environmental Impacts Working Group
HIEA – Hamilton Industrial Environmental Association
Mac – McMaster University
MOE – Ontario Ministry of the Environment
RPDWG – Research and Policy Development Working Group
SO CAN I – Southern Ontario Clean Airshed Network Initiative

Appendix B

Progress Indicators

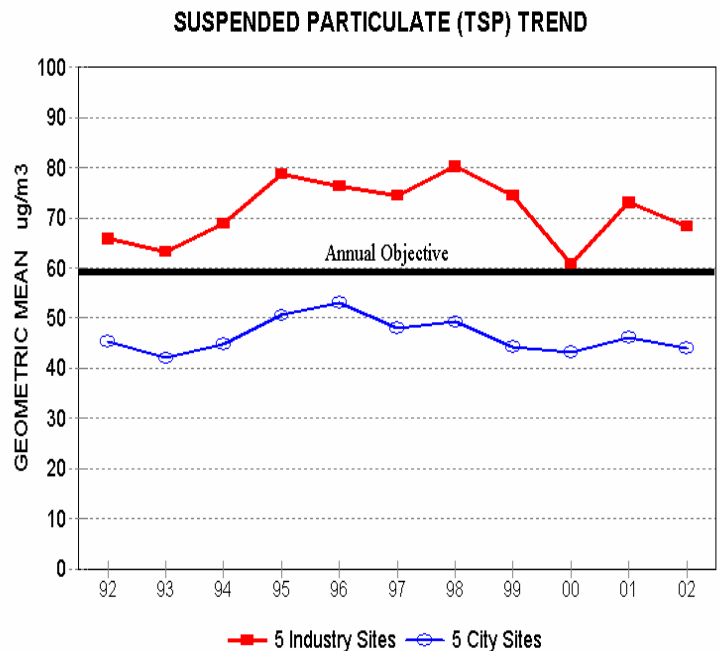
Summaries of Air Quality Data over the Past Ten years

The following graphs illustrate trends in key air quality parameters in Hamilton. The data presented only covers the period of the past ten years; more comprehensive data covering the past 30 years can be found in the 1997 HAQI reports. Dramatic reductions in all parameters were observed between 1970 and 1990 because many major industrial sources were outfitted with pollution abatement equipment. Since 1990 improvements have been less dramatic; however, pollution abatement technologies and strategies continue to be implemented and are having measurable impacts on air quality improvement. Clean Air Hamilton strongly recommends that all stakeholders install the most efficient and non-polluting technologies and identify the best available pollution abatement technologies when constructing new facilities or when retrofitting existing facilities.

On most of the graphs below one line shows the average of data from two or more air quality stations that are indicative of exposures in residential areas (City Sites) while the other line shows the average of data from two or more air quality stations that are indicative of exposures close to industrial areas (Industry Sites). Two graphs include lines indicating “annual objectives,” these objectives are values set by the Ontario Ministry of the Environment.

a. Total Suspended Particulate

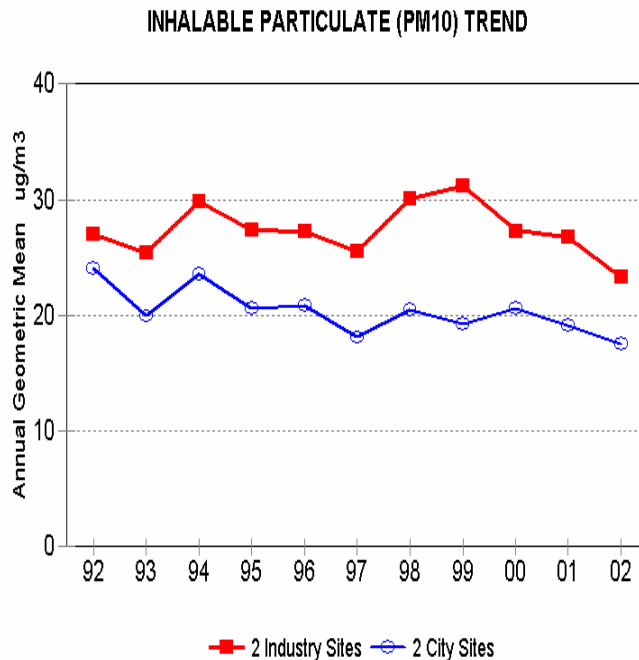
Total suspended particulate (TSP) levels in Hamilton have not changed significantly since the early 1990s. TSP includes all particulate material below about 45 μm (45 micrometres or 45 microns). The largest TSP particles have diameters similar to a human hair (25 to 50 μm) and are thus just barely visible to the eye. A substantial portion of TSP is related to industrial activities, road dust, agricultural dusts and other sources of airborne soils.



b. Inhalable Particulate Material (PM₁₀)

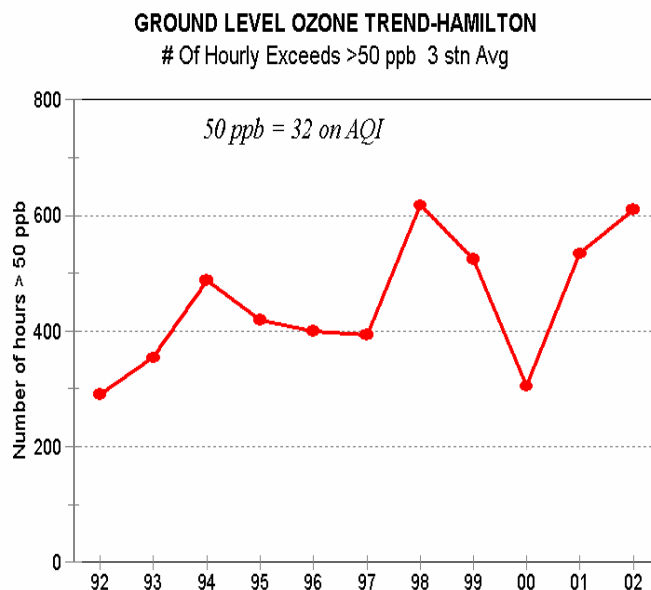
Inhalable particulate material (PM₁₀) levels have decreased by about 20% in most areas of the City since the early 1990's. There has been a steady downward trend in PM₁₀ levels over the past four years. PM₁₀ stands for particulate material with a mean aerodynamic diameter less than 10 µm. PM₁₀ is a subset of the total suspended particulate (TSP) and constitutes about 40% to 45% of TSP.

The interest in PM₁₀ levels is related to the health effects impacts associated with exposures to these small particles. The Province of Ontario has recently begun to monitor an even finer fraction of particulate material, PM_{2.5}, particulate material with a mean aerodynamic diameter of 2.5 µm or less; this fine particulate is a subset of PM₁₀ and total suspended particulate (TSP) and constitutes about 40% to 45% of PM₁₀. The health effects impacts of particulate exposure are now recognized as being associated primarily with exposure to fine particulate (PM_{2.5}).



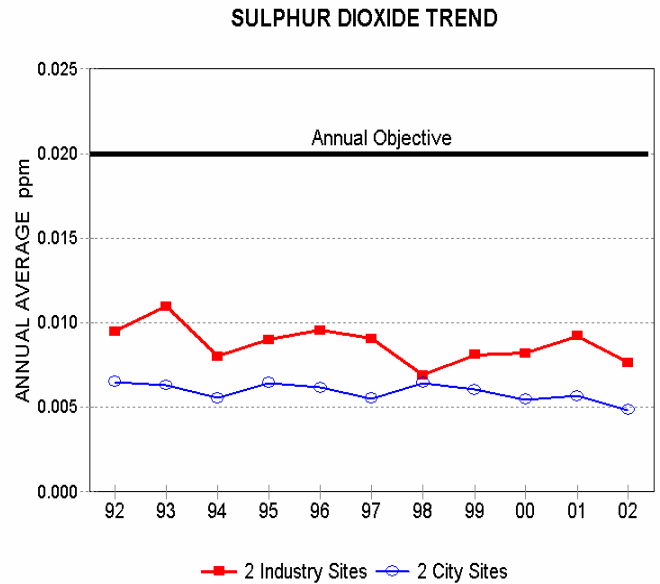
c. Ground Level Ozone

Ground level ozone is formed as a secondary chemical by-product due to the action of sunlight on the atmospheric chemicals that constitute smog. Summertime ground level ozone levels are due primarily to long-range transport of airborne contaminants from distant pollution sources, particularly urban emissions from the Ohio Valley region in the USA. Ozone levels been variable over the last 10 years and are not related to any local emission sources. The impacts of ozone precursors released in the Hamilton area would not be observed in Hamilton but in regions downwind of Hamilton.



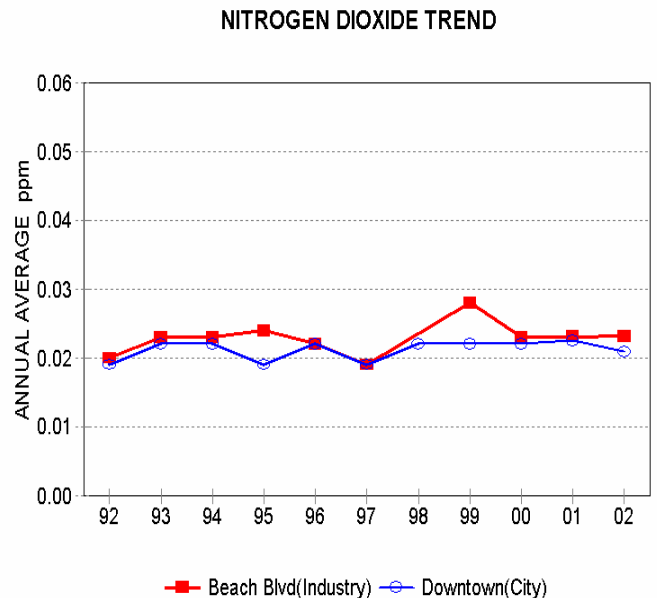
d. Sulphur Dioxide

Sulphur dioxide levels have decreased by over 20% since 1990 across the City and remain well below the MOE's annual objective. The primary sources of sulphur dioxide are the combustion of sulphur-containing fuels, particularly diesel fuel, and the coking operations at the steel mills. The reductions in sulphur dioxide levels reflects lower levels of sulphur in diesel fuels and improvements to emissions controls at the coke oven batteries.



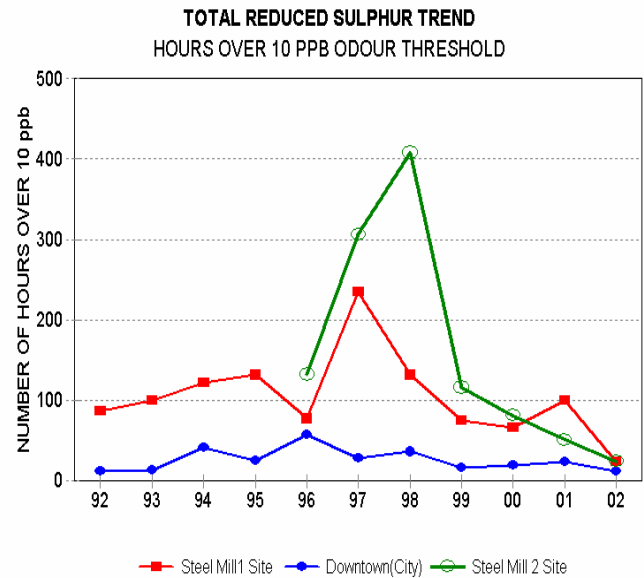
e. Nitrogen Dioxide

Nitrogen dioxide levels have remained constant over the past decade. The primary source of nitrogen dioxide is the combustion of fuels (gasoline, diesel, wood, coal, etc.). There is a direct link between the number of vehicles, the number of miles the vehicles are driven and the nitrogen dioxide levels. These data show that there has been no improvement in the overall impacts of car and truck traffic emissions over the past decade. A number of other major urban centres have seen increases in the nitrogen dioxide levels in those cities over the same period.



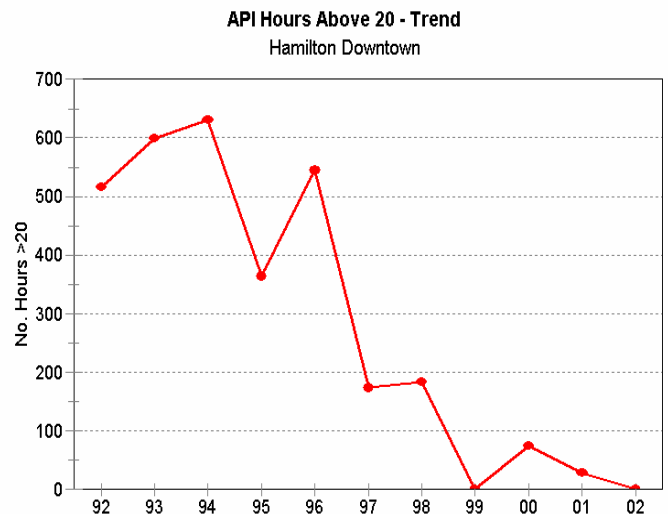
f. Total Reduced Sulphur (TRS)

Total Reduced Sulphur (TRS) is a measure of the sulphur-containing compounds that are the basis of many of the odour complaints related to steel mill operations, particularly coke oven and blast furnace releases. At 10 parts per billion (ppb) TRS many people can detect an odour related to rotten eggs. In recent years there has been a decrease between 70% and 90% in the number of hours that the TRS levels exceeded 10 ppb. Significant improvements in the management and operations of the coke ovens and the blast furnaces have resulted in these substantial improvements.



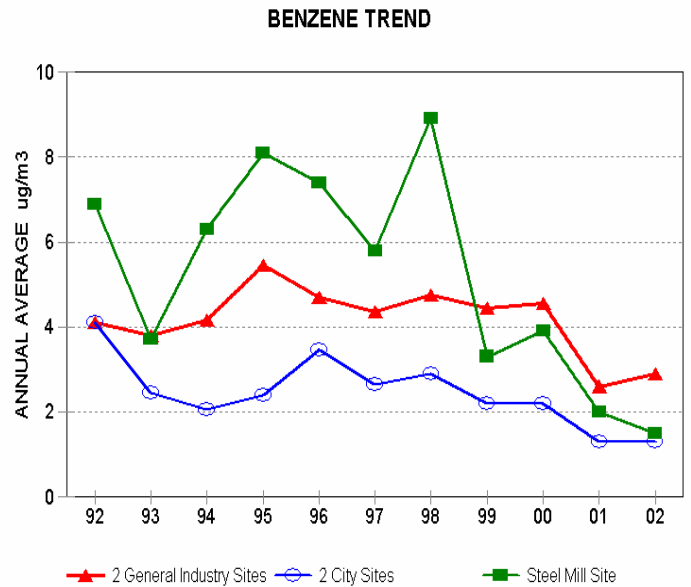
g. Air Pollution Index

The Air Pollution Index (API) has not reached the advisory level of 32 at any of the API stations since June 1996, and thus no requests for voluntary cutbacks by local industries have been necessary. These were the first years that this has occurred in Hamilton API history. The figure adjacent shows that the API now rarely exceeds 20.



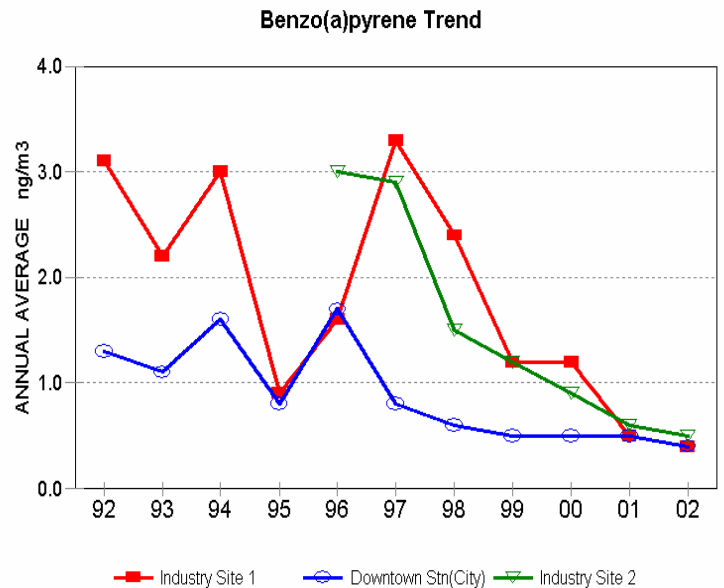
h. Benzene

Benzene emissions arise primarily from the coke ovens and the associated by-products plants in the steel industry. Improvements in the control of benzene vapours at the by-products plants has resulted in large reductions (60-80%) at a monitoring site near the steel mills over the past five years. There have also been improvements in the benzene levels in the industrial area and residential areas.



i. Benzo[a]pyrene

Benzo[a]pyrene (BaP) is a known carcinogen which is produced by the combustion of carbonaceous fuels (gasoline, diesel fuel, wood, coal, etc.) and tobacco. The principal sources of BaP in Hamilton are vehicle emissions and coke oven emissions. Improvements made to the coke oven operations have led to dramatic reductions (65-85% since the mid 1990s) in the ambient BaP levels near and away from the industries.



Appendix C

2002 Upwind Downwind Conference Summary

On February 25 and 26, 2002, Clean Air Hamilton and the City of Hamilton hosted the second biennial *Upwind Downwind Conference*. The first *Upwind Downwind Conference*, held in 1999, was the result of a recognized need to address the issue of transboundary air pollution.

The theme of the 2002 conference, *A Practical Conference on Improving Air Quality*, drew 216 delegates. Environmental managers, planners, non-profit project managers and citizens participated and helped maintain momentum for initiatives that emerged from the 1999 conference and dedication was renewed to sharing information on air quality issues.

By all accounts, the 2002 conference was success. According to response sheets, participants were extremely satisfied with the overall Conference. On a scale from one to five, with five being most satisfied, delegates, on average, rated the conference a four.

Revenues of \$42 368 covered the \$36 311 cost of the conference. Revenues were the result of sponsorship (\$22 500), participant registration (\$19 568), and booth fees (\$300).

Conference Flyer

Upwind Downwind: A Practical Conference on Improving Air Quality

February 25 and 26, 2002

Hamilton, Ontario

Upwind Downwind explores the relationships between health, policy, urban planning, building design, local improvement strategies, public-private partnerships and air quality. This conference will introduce interesting approaches to reduce emissions in the community with emphasis on transportation and urban sources.

Keynote Speakers

Russell Perry, Building Designs for Sustainability

Russell Perry is a managing partner with William McDonough and Partners, Architecture and Community Design, a firm that believes in maximizing design effectiveness by incorporating the elegance of natural systems. William McDonough, the author of *The Hannover Principles/ Design for Sustainability* leads the firm. The regeneration of Ford's historic River Rouge plant in Dearborn, Michigan; a mixed-use project and a residential development in Banff, Alberta; a private school master plan in Toronto, Ontario are but a few of the firm's current projects.

Perry, with over twenty years of professional management and design experience with complex architectural projects, has been recognized with numerous awards, including a national American Institute of Architects design award in 2000 and a Federal Design Achievement Award in 1995. Perry will speak on "eco-effective" design principles and their applications in products, buildings, communities and cities, in particular, Chicago, Illinois.

Reid Ewing, Best Planning Practices for Air Quality

Reid Ewing is the author of *Best Development Practices*, the American Planning Association's top selling book for three consecutive years; *Traffic Calming State-of-the-Practice*, the Institute of Transportation Engineers' projected top selling book based on first-year sales; *Pedestrian and Transit-Friendly Design* (Florida Department of Transportation), and *Context-Sensitive Design Standards for Main Streets* (New Jersey Department of Transportation). He has written numerous articles on growth management, community design, and traffic management, and speaks and consults widely on these subjects.

Ewing, a former Arizona state legislator and former Congressional staff director, is a Research Professor at Rutgers University and a Research Director of the Surface Transportation Policy Project in Washington, D.C., the recognized U.S. leader in transportation reform. Ewing is also Acting Director of the Alan M. Voorhees Transportation Center at Rutgers University, and oversees the National Transit Institute and Transportation Policy Institute. Ewing holds Master Degrees in Engineering and City Planning from Harvard University and a Ph.D. in Transportation Systems and Urban Planning from Massachusetts Institute of Technology.

Conference Highlights

Human Health Perspectives

A focus on recent research and strategies to identify and evaluate information about health and environmental effects, sources of pollutants and projections of future trends in emissions. Hear the latest on air quality related health issues and how they influence public policies, planning practices and local improvement initiatives.

Speakers: Barry Jessiman, Health Canada; Dr. David Pengelly, McMaster Institute of Environment and Health; Dr. Brian McCarry, McMaster University; and Barry Boyer, Buffalo-Niagara Institute for Local Governance and Regional Growth.

Urban Planning for Healthy Cities

The quality of air can be impacted significantly by the way in which land is used and developed. The effects of urban sprawl provide evidence of this through rising traffic counts and subsequent increases in emissions. Hear how planners have introduced new sustainable strategies to address air quality in transportation and land use planning. See how an airshed modeling exercise can help plan for healthier cities.

Speakers: Reid Ewing, Rutgers University; Sue Zielinski, Moving the Economy; Christopher Morgan, City of Toronto; and Mike Lepage, Rowan Williams Davies & Irwin Inc.

Green Building Design

A look at big picture concepts of energy usage by medium and large-sized buildings. Find out how employing green building principles can reduce energy usage and emissions to air.

Speakers: Russell Perry, William McDonough and Partners; Joanne McCallum, McCallum Sather Architects Inc.; and a representative from Keen Engineering Inc (invited).

Community Partnerships

Improve air quality beyond individual commitments. Learn how communities have benefited from coalitions and networking.

Speakers: A representative from the State and Territorial Air Pollution Program Administrators and Association of Local Air Pollution Control Officers (invited); Sonya Kapusin, City of Hamilton; Jack Gibbons, Ontario Clean Air Alliance; and Keith Stewart, Toronto Environmental Alliance.

Tools and Best Practices

Find out how the Ontario government is implementing its new vision for managing the environment.

Discover innovative pilot projects to improve energy efficiency and reduce air emissions, such as Wind Farms, Eco-Efficient Homes and District Energy.

Hear about trends in cleaner fuels, the growing "alternative fuel vehicles" industry in the US and Ontario's vehicle emissions testing program results.

Speakers: Daniel Cayen, Ontario Ministry of Environment; Fred Eisenberger, Green Venture; Murray Paterson, Ontario Power Generation; Bryan Young, Toronto Renewable Energy Co-op; Don Marsales, Hamilton Community Energy; a representative from the California Bureau of Automotive Repair (invited); Denis Corr and Ed Gill, Ontario Ministry of Environment; and Isabell Berger, Erie County Department of Environment and Planning.

Registration

Registration Fee (GST Registration #889323218RT0001)

\$190 plus GST - corporate, academic and government,

\$50 plus GST - students, community groups and non-profit organizations

For more information, contact the City of Hamilton at 905-643-1262, extension 272, or email us: hagic@city.hamilton.on.ca. Web site: <http://www.airquality.hamilton.on.ca>

Upwind Downwind is hosted by the City of Hamilton and Clean Air Hamilton in partnership with Environment Canada, Ontario Ministry of Environment, McMaster University, McMaster Institute of Environment and Health, McKibbin Wakefield Inc. and Air and Waste Management Association.



Environment
Canada

Environnement
Canada



McKibbin Wakefield Inc.



Appendix D
Public Health Assessment

McMaster Institute of Environment and Health

**A Public Health Assessment of
Mortality and Hospital Admissions
Attributable to Air Pollution in Hamilton**

Prepared by:

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and

Michael Jerrett, PhD

Assistant Professor

School of Geography and Geology

and

McMaster Institute of Environment and Health

May, 2003

Acknowledgements

We thank Dr. Tom Abernathy, Central West Health Planning Information Network, for supplying the mortality and morbidity data. Mr. Frank Dobroff, Ontario Ministry of the Environment, assisted with the air pollution data. We acknowledge helpful comments from Dr. Susan Elliott, Ms. Sonya Kapusin, Mr. Norm Finkelstein, and Mr. Chris Giovis. Ms. April Eby and Ms. Monica Anderson helped administer the project. Mr. Pat DeLuca helped prepare the figures. The Toxic Substances Research Initiative of Health Canada supplied financial assistance with the literature review. Finally, we acknowledge the City of Hamilton for funding this research.

EXECUTIVE SUMMARY

Background

Health risks from ambient air pollution exposure have emerged as a major public health issue. In this report, we estimate mortality and hospital admissions associated with ambient air pollution exposure in Hamilton. Currently, Hamilton exceeds government objectives by about 20 days per year and has some of the highest ambient air pollution in Canada. Ambient pollution exposures result from a combination of pollution from outside the region, industrial emissions, transportation sources, and local meteorology and topography. All of these factors elevate ambient air pollution exposures and make the issue of health effects particularly important in Hamilton.

Numerous epidemiological studies have found a significant association between air pollution and health effects. In 1997, Pengelly and colleagues estimated that air pollution was associated annually with a midpoint estimate of 214 non-traumatic mortalities in Hamilton. Since 1997, much has been learned about the short-term and chronic health effects of air pollution. The past six years have also seen changing ambient air pollutant levels throughout Hamilton. The combination of new research findings and changing pollution levels has created a need to update and expand on earlier work. Information from this new assessment can help local decision-makers understand the magnitude of health effects from air pollution and in taking action that protects and improves population health in Hamilton.

Methods

To estimate mortality and hospital admissions associated with ambient air pollution in Hamilton, we derived dose-response relationships based on local estimates published in the scientific literature. These estimates were applied to recent data on air pollution and health outcomes available through government sources.

Many of the acute studies pooled here used generalized additive models in their statistical analysis. A recent statistical discovery revealed a programming limitation in the statistical software used, leaving the findings from these studies in question. Reanalyses of data indicate that risk estimates may have been overestimated by as much as 42%. Adjustments were applied to study data to account for the 42% overestimation.

In accordance with past studies, health effect estimates are compared to a zero pollution level, considered by many to be practically unattainable. We thus calculated estimates using a baseline of the lowest quintile of measured pollution values. Local estimates derived from Hamilton-specific models were also conducted. Additional sensitivity analyses were based on pooled random effects models and from chronic studies from other jurisdictions.

We compared these results to earlier studies to assess how estimates of health effects have changed since the last assessment.

Results

Our results revealed a wide range in estimates of mortality and morbidity attributable to air pollution. Using the 1997 study as baseline, estimates conducted using similar methods as the initial HAQI report, resulted in an increase of 76 deaths (298 to 374), due to larger dose-response relationships in the literature and slightly higher ambient pollution levels (Table 1). Respiratory admissions increased by 463 (144 to 607), while cardiovascular admissions increased by 1743 (257 to 2000). The 42% adjustment estimated 217 deaths, 352 respiratory admissions and 1120 cardiovascular admissions. The most conservative estimate involved combining both the 42% adjustment and the 20% baseline models. Using this new methodology, mortality and morbidity estimates decreased to 96 deaths, 139 respiratory and 479 cardiovascular admissions - an average decrease of 76% from our initial estimates.

Table 1. Summary of Mortality and Morbidity Counts Using Average Dose-Response Calculations, Based on 1997 Hamilton Pollution Values.

Pollutant	NT mortality (average incidences/year) average of estimates					Respiratory admissions (incidences/year) average of estimates					CV admissions (incidences/year) average of estimates				
	P1997	CAH	Adj	M-min	M-min adj	P1997	CAH	Adj	M-min	M-min adj	P1997	CAH	Adj	M-Min	M-Min adj
PM ₁₀	97	73	43	24	14	48	144	83	46	27	112	280	157	84	49
SO ₂	16	53	31	27	16	28	69	40	35	20		56	31	45	26
NO ₂	81	134	78	46	27	20	244	142	83	48	125	888	497	303	176
CO	3	10	6	6	3						20	118	66	65	38
O ₃	102	105	61	62	36	48	150	87	75	44		659	369	329	191
Total	298	374	217	119	96	144	607	352	239	139	257	2000	1120	826	479

P1997 = HAQI report, Pengelly 1997

CAH = Current reanalysis for City of Hamilton

Adj = Adjusted value of CAH, for overestimate of 42%

M-min = Estimate calculated for pollution values of mean – min (lower quintile) for 1997

M-min adj = Application of adjusted value to M-min calculation

Interpretation

A cautionary note is required with respect to the totals given above. They should be interpreted as general aids to decision-making rather than as exact counts of death and illness. The totals may be influenced by uncontrolled confounding of co-pollutants. This may have resulted in an overestimate of mortality and hospital admission totals.

We have excluded other serious health effects. These include the development and exacerbation of asthma, reproductive abnormalities, elevated cancer rates, and less serious respiratory conditions such as infectious respiratory diseases. Thus, our mortality and admission estimates may, in fact, underestimate the total burden of illness associated with air pollution in Hamilton.

Conclusions

In this report, we have identified air pollution as a major source of mortality and hospital admissions in Hamilton. We have not linked the health estimates to specific sources, but this represents an important area for future research. It appears that gaseous pollutants most closely associated with transportation emissions have increased over the five-year study period (1995-99). The scientific evidence on the health effects of these pollutants has also advanced. The combination of increasing pollution and growing scientific knowledge leads to the conclusion that these sources should be the focus of concerted policy efforts in the realm of land use and transportation planning. Both these areas fall within the jurisdiction of the city. Future research combining the methods used in this report with source apportionment could supply more definitive guidance for priority setting in local decision-making.

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1. OBJECTIVES AND BACKGROUND

1.1 Objectives

The primary objective of this report is to estimate mortality and hospital admissions attributable to ambient air pollution in Hamilton, based on the most recent research and data available. A secondary objective is to compare recent findings with those reported by Pengelly et al. (1997) and other recent reports that use similar methods (Pengelly et al., 2000).

1.2 Background

Hamilton experiences some of the highest ambient air pollution exposures in Canada, exceeding government objectives by about 20 days per year. The reasons for these high exposures include the following: (1) proximity to the Ohio River Valley, where coal-fired generating stations emit pollutants that travel hundreds of kilometers to Hamilton; (2) the Nanticoke coal-fired generating station located on the northern shore of Lake Erie, which also contributes considerably to local pollution; (3) increasing transportation emissions that result from automobile and truck traffic in and around the city; (4) local point source emissions from one of the largest industrial areas in Canada; and (5) topographic and meteorological conditions that often keep the pollution close to ground level. All of these factors elevate ambient air pollution exposures and make the issue of health effects particularly important in Hamilton.

Numerous epidemiological studies have found a significant association between air pollution and health effects (see Section 4 and Appendix 1 for details). In 1997, Pengelly et al. (1997) estimated that air pollution was associated annually with a mid-point estimate of 214 non-traumatic mortalities in Hamilton. Since 1997, much has been learned about the short-term and chronic health effects of air pollution. The past six years have also seen changing ambient air pollution levels throughout Hamilton. The combination of new research findings and pollution levels has created a need to update and expand on the earlier work. Quantitative information from this new assessment can help local decision-makers to understand the size of the health effects from air pollution and to take action to improve population health in Hamilton.

2. METHODS

2.1 Overview

The methodology used in this report followed seven steps:

1. Identification of pollutants of interest,
2. Literature review to identify risk coefficients for specific pollutants and conversion into comparable values,
3. Identification and acquisition of relevant air quality data,
4. Acquisition of health outcome data,
5. Estimation of the burden of illness due to air pollution in Hamilton using available data,
6. Sensitivity analysis using Pengelly models, data specifically derived from Hamilton studies, and adjusted estimates, and
7. Analysis of the findings.

2.2 Identification of Pollutants of Interest

Based on consultations with the Health and Environmental Impacts Working Group for Clean Air Hamilton, we utilized the criteria pollutants that were indicated in the Hamilton-Wentworth Air Quality Initiative (HAQI) report in 1997, with the exception of the “air toxics.” Specifically, we included particulate matter (PM₁₀), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO), and ozone (O₃). Pengelly et al. (1997) also applied this methodology to Toronto data in 2000 (i.e., using the same pollutants except for the air toxics). In addition, we estimated the mortality attributable to fine particles (i.e., PM_{2.5}) because these have received increasing attention in the scholarly literature as particularly harmful to pulmonary function.

2.3 Literature Review

We conducted our literature review with the Medline and PubMed search engines. We searched combinations of the words “air pollution” with the following keywords – mortality, morbidity, health effects, time-series – for articles dated 1997 and onwards, until the beginning of October, 2001. Using Medline, 2067 related articles were identified, while the search in PubMed revealed about 6900 articles.

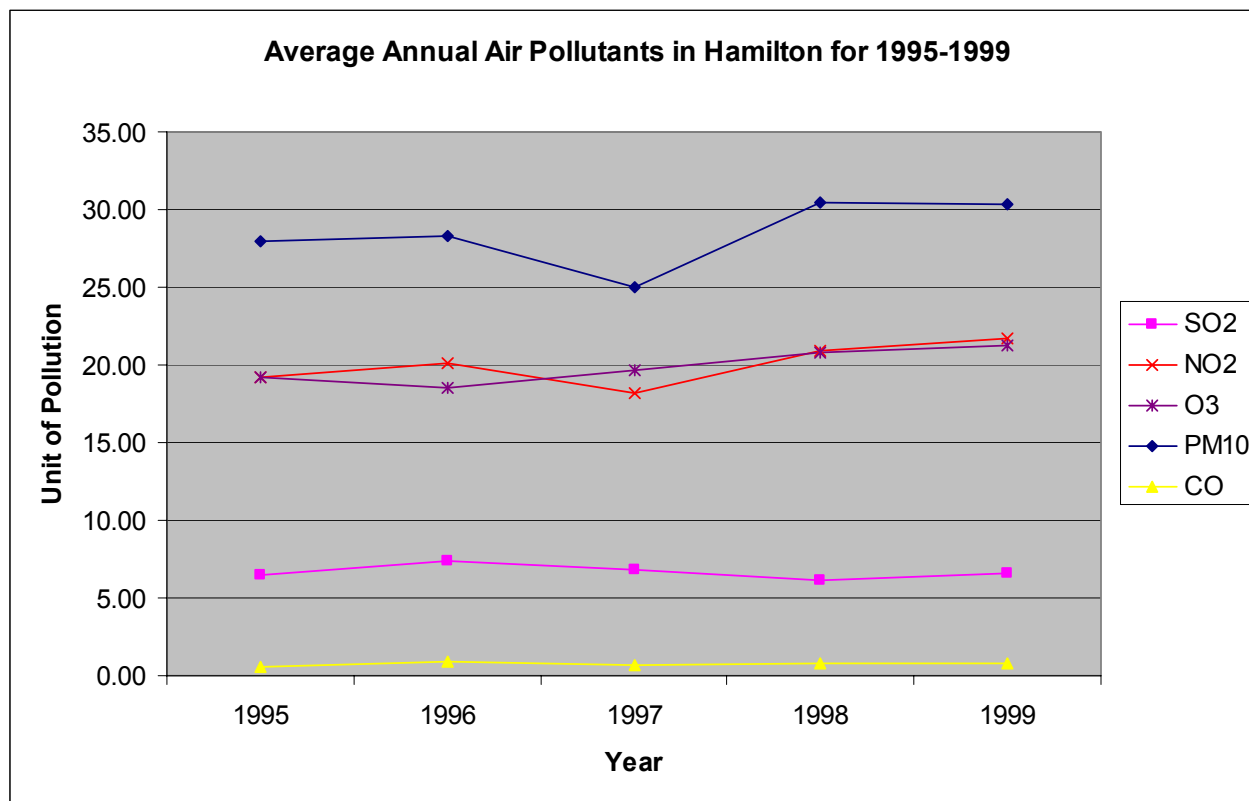
Subsequent review and selection of the articles was based on relevance, suitability of outcome measure, and significance of findings. We excluded articles that were not related to mortality or hospital admissions; those that focused on indoor air pollutants and tobacco smoke; those in languages other than English or French; and articles that specifically identified elderly or infants as study groups. Articles that made use of multipollutant models were given priority to provide maximum control for co-pollutants. While findings from single pollutant models and significant associations with the elderly population were present in the review tables, they were not included in the calculated averages. Studies including random effects and meta-analysis of previous studies as a comparative metric were selected. Research that used Hamilton estimates in particular was emphasized.

Chronic studies were included in this analysis. Based on the limited number available, this literature review included a search as far back until 1993 when the earlier chronic effect literature was published. Recent reanalyses of these articles was also included in the literature review.

2.4 Air Quality Data

Annual averages for the identified pollutants were available for multiple locations in Hamilton, courtesy of the Ministry of Environment’s monitoring network. Regional arithmetic averages from all the available stations were calculated to derive the city-wide average. Figure 1 illustrates the general trends in ambient pollution for the period 1995-99. The average pollutant values for the study period can be found in Appendix 1 in tabular format.

Figure 1. Change of Average Annual Air Pollutants in Hamilton, 1995-1999



Note: SO₂, NO₂, and O₃ expressed in parts per billion (ppb), CO expressed in parts per million (ppm) and PM₁₀ expressed in µg/m³

2.5 Health Outcome Data

Annual morbidity and mortality data for Hamilton were supplied by the Central West Health Planning Information Network. The data were extracted from the Ontario “data warehouse,” available through the Government of Ontario Network (GONET). The ICD-9 codes used were those indicated by the Pengelly studies, covering the area of the New City of Hamilton. Mortality data were only available for 1995 to 1997, while hospital admissions data were available for a longer period (i.e., 1995 to 1999). These tables can be found in Appendix 2.

We observed a marked increase in the number of hospital admissions, especially for cardiovascular (CV) admissions, between 1995 and 1996. We checked the acquired data for internal errors, but the difference seems to be due to other factors not reported by the Ministry of Health.

2.6 Estimating the Mortality and Hospital Admissions Associated with Air Pollution

Following the methodology set by the Pengelly et al. 1997 and 2000 reports, we computed the relationship to estimate health outcomes as follows:

$$HO = B * \Delta H\% * P$$

where:

HO = annual health outcome

B = base number of outcomes per year

$\Delta H\%$ = percent change in health outcome per unit increase of pollutant

P = annual pollution average

2.6.1 Sample Calculation

The following data were utilized to calculate the premature mortality attributable to particulates (PM₁₀) for the year 1995:

- Total non-traumatic deaths in Hamilton for 1995 = 3730 deaths per year
- Percent increase in non-traumatic mortality for PM₁₀, averaged from literature values, per unit increase = 0.076 increase in deaths per 1 µg/m³ increase in PM₁₀ * 1/100
- Annual average of PM₁₀ for Hamilton for 1995 = 27.9 µg/m³

$$HO = 3730 \frac{\text{deaths}}{\text{year}} \times 0.076 \frac{\text{deaths}}{\mu\text{g}/\text{m}^3} \text{ per } 100 \text{ deaths} \times 27.9 \mu\text{g}/\text{m}^3 = 79.09 \frac{\text{deaths}}{\text{year}}$$

The sample equation shows that the units cancel each other out to leave deaths per year as the final unit. Thus, following normal rounding rules, 79 premature deaths are associated with PM₁₀ exposure in Hamilton for the year 1995.

2.7 Estimate Adjustments

Two adjustments were conducted on the original estimates. The first involves a recent discovery of a statistical limitation in one of the software packages used in time-series analyses. The second adjustment pertains to an achievable baseline pollution estimate.

The time-series studies summarized in this report typically have used generalized additive models (GAM) in their statistical analysis, as these models allow for control of time-varying factors through the incorporation of non-parametric smoothers of weather and other confounders. However, in light of recent findings of a programming limitation in the statistical software used in these analyses, the findings from these studies are now in question (Ramsey et al., 2003). The statistical software provided biased risk estimates because it did not assure convergence of its iterative estimation procedure. A reanalysis of National Morbidity, Mortality and Air Pollution Study (NMMAPS) data, one of the largest pooled data sets in the U.S., has revealed that the risk estimates have been overestimated by 36 - 42% (Dominici et al., 2002). The reanalysis showed that positive associations still exist, although in some cases the associations become insignificant.

All the reported findings in these types of studies now have to be reconsidered before use in policy analysis. This major statistical discovery has left scientists and policymakers wondering about the magnitude of associations between acute exposures to air pollution and health.

Adjustments were made on the summarized findings of the average dose-response estimates in this report. The values were adjusted to account for the maximum overestimation of 42%. This model is referred to as the “adjusted” model.

The second adjustment considers that in calculating risk estimates, pollution estimates are calculated in terms of comparison to a zero pollution level. The zero pollution level can be considered to be unattainable and overly idealistic. A more achievable estimate, though arbitrarily chosen, was considered to be at a baseline of 20% of pollution concentrations. Thus a separate estimate was calculated using annual pollution values of the mean minus the lower quintile, based on daily averages. These were calculated for 1997 to provide a comparison estimate. This adjustment is referred to as “baseline 20% model”.

2.8 Hamilton-specific Estimates

We also calculated estimates of studies conducted in Hamilton, using the research of Burnett et al. (1998a) for gaseous air pollutants and Jerrett et al. (2001) for the particulate measure, measured with the coefficient of haze (CoH). For these estimates, multipollutant models were used for the gaseous air pollutants, while single pollutant models were available for the particulate measures. The percent risks at the mean value for relevant years were computed. Because the Poisson regression takes a log-linear form, we computed the risk estimates for each criteria pollutant as follows:

$$e^{(\beta \bar{x})}$$

where:

e is the exponential function,

β is the regression coefficient estimating the average increase in mortality associated with a unit increase in pollution, and

\bar{x} is the average of the air pollutant.

3. RESULTS

3.1 Results of the Literature Review

The detailed tables containing the literature review results are contained in Appendix 3. The tables show the study location, the modeled pollutants, and the key results in a standardized format. A commentary on our findings from the literature search is presented below.

3.1.1 Carbon Monoxide (CO)

Non-traumatic mortality

Three studies have found significant associations between CO and non-traumatic mortality since the HAQI study in 1997. Burnett et al. (1998a, 1998b) and Gywnn et al. (2000) found an increase of 4.7%, 2.0%, and 4.13% per 1ppm increase, respectively. The studies all used multipollutant models.

Respiratory hospital admissions

None of the literature reported significant associations between respiratory hospital admissions and CO.

Cardiac hospital admissions

CO was related to cardiac hospital admissions, specifically for hospitalization for congestive heart failure. Schwartz (1997) examined data for Tucson, US, and reported an increase of 1.4% in admissions per 1 ppm increase. Burnett et al. (1997) calculated congestive heart failure admissions specifically for Hamilton and reported a 2.5% increase. Interestingly, the Toronto-specific estimate by the same researchers was comparatively higher at 6%.

3.1.2 Sulfur Dioxide (SO₂)

Non-traumatic mortality

Recent research shows a range of dose-response estimates for sulfur dioxide and total non-traumatic mortality. Garcia-Aymerich et al. (2000) found that in Barcelona, Spain, a 10 ppb increase in SO₂ led to a 4.2% increase in total mortality. Saez et al. (2001) found a 1.1% increase for three Spanish cities using a multipollutant model. In Madrid, Spain, Diaz et al. (1999) found a 2.1% increase in non-traumatic mortality with a single pollutant model. Taking 12 European countries into account, Katsouyanni et al. (1997) found an increase of 1.1%. Kelsall et al. (1997) considered a multipollutant model for Philadelphia, US, and found a 0.84% relative increase to the 10 ppm increase. Burnett et al. (1998a) studied SO₂ effects for 11 cities in Canada, using multipollutant models, and obtained a 3.89% increase in non-traumatic mortality for Hamilton.

Respiratory hospital admissions

Gywnn et al. (2001) associated an increase of 3.7% per 10 ppb increase in SO₂ in terms of respiratory hospital admissions. No other studies investigated this association.

3.1.3 Nitrogen Dioxide (NO₂)

Non-traumatic mortality

NO₂ has recently been significantly associated with non-traumatic mortality in a number of studies. In Rome, Italy, Michelozzi et al. (1998) found a 1.54% increase in a 10 ppb increase, while in Barcelona, Spain, Garcia-Aymerich et al. (2000) reported a 2.9% increase. Morgan (1998) in Sydney, Australia indicated the value was closer to 1.5%. However, the latter study did not take multipollutant modeling into account. Burnett et al. (1998) revealed a 1.5% increase

in non-traumatic mortality associated with a 10 ppb increase in NO₂, specifically for Hamilton, while a 2.3% increase was estimated for Toronto.

Respiratory hospital admissions:

Burnett et al. (1997a) found a 4.87% increase in respiratory admissions for Hamilton for a 10 ppb increase in NO₂.

Cardiac hospital admissions:

Three studies found significant associations between NO₂ and cardiac hospital admissions. Burnett et al. (1997a) found an 8.7% increase for the 10 ppb increase in NO₂. Morgan et al. (1998) found a lower value of 4.4%. However, a multipollutant model was not taken into account for this study. Moolgavkar (2000), in Los Angeles County, US, found a 1.7% increase, with a two-pollutant model (i.e., SO₂ and NO₂).

3.1.4 Ozone (O₃)

Non-traumatic mortality

There has been an increasing amount of research in ozone-related mortality. Recent studies showed significant associations between O₃ and non-traumatic mortality. Garcia-Aymerich et al. (2000) in Barcelona, Spain, estimated a 0.95% increase in non-traumatic mortality, while Gouveia et al. (2000) in Sao Paulo, Brazil, identified a 0.43% increase. In Philadelphia, US, Kelsall et al. (1997) found the relative risk to be at 0.94%, while in Santa Clara County, California, US, Fairley (1999) estimated a much higher risk at 2.47%. Thurston and Ito (2001) calculated this value at 0.56% in a meta-analysis study based on 12 published estimates.

Respiratory hospital admissions:

Moolgavkar et al. (1997) found a 4% increase in respiratory hospital admissions associated with a 10 ppb increase of ozone, while using a multipollutant model. Burnett et al. (1997b) found an increase of 1.5%; however, in his 1998 article (Burnett et al., 1998), this value was estimated to be 4.9%. Gywnn et al. (2000) found this value closer to 2.0%.

Cardiac hospital admissions:

Only one study, Burnett et al. (1997b) tested the ozone-admission association. They reported a 4.5% increase for cardiac hospital admissions. As this is the only study to find significant associations at such high values, this estimate should be considered preliminary.

3.1.5 Particulates

Non-traumatic mortality:

Numerous studies have calculated the percent increase in daily mortality per 10µg/m³ increase in particulate matter, in the form of TSP, PM₁₀, PM_{2.5}, and SO₄²⁻.

TSP:

Alberdi Odriozola et al. (1998) and Diaz et al. (1999) conducted studies in Madrid, Spain, and found a 0.6% and 0.72% increase, respectively. In Rome, Italy, Michelozzi et al. (1998) calculated a comparable 0.66% increase. Neas et al. (1999) found a 0.56% increase in

Philadelphia using a single pollutant study. Goldberg et al. (2001) calculated increases in non-traumatic mortality in Montreal and reported a value of 0.65% for a 10 $\mu\text{g}/\text{m}^3$ in TSP in single pollutant analysis. Kelsall et al. (1997) found a 0.3% increase in Philadelphia using a multipollutant model.

PM₁₀:

Burnett et al. (1998b) estimated a 0.7% increase in non-traumatic deaths in Hamilton taking into account other pollutants, while in Montreal, Goldberg et al. (2001) calculated an increase of 0.69% in a single pollutant analysis.

In a meta-analysis, Daniels et al. (2000) found a 0.54% increase in non-traumatic deaths in 20 US cities. Samet et al. (2000) reported a 0.51% increase for 20 US cities considered. In their reanalysis of Schwartz et al. (1996) article on particulates in six US cities, Klemm et al. (2000) found a 0.8% increase associated with PM₁₀. Katsouyanni et al. (1997) reported non-traumatic mortality for PM₁₀ increases equal 0.4% for the 12 European countries studied.

Primarily in European research, black smoke (BS) values were used as approximations to PM₁₀ values. Saez et al. (2001) calculated a 0.64% increase for the three Spanish cities in the study, while Garcia-Aymerich et al. (2000) found this value closer to 1.1% in their single-pollutant analysis.

PM_{2.5}:

Goldberg et al. (2001) found a 1.96% increase in non-traumatic mortality related to the increase in PM_{2.5} in Montreal. Fairley (1999) calculated a 4.46% in Santa Clara County, US. Klemm et al. (2000) estimated this increase as 1.3% in a study of six US cities. In Mexico City, Mexico, Borja-Aburto et al. (1998) recorded a 1.68% in non-traumatic mortality associated with the fine particulates. Burnett (1998) reported a 2.5% increase in Hamilton.

Respiratory hospital admissions:

PM₁₀:

Moolgavkar et al. (1997) found a 1.7% increase in respiratory hospital admissions in Los Angeles County, US. Burnett et al. (1997) calculated the relative risk at 2.1% in Hamilton, while Gywnn et al. (2000) found this value to be closer to 2.2% in New York, US.

PM_{2.5}:

There were no studies found to report significant associations

SO₄²⁻:

Gywnn et al. (2000) estimated this to be 0.5% in New York, while Burnett et al. (1997) reported 2.7% for Hamilton.

Cardiac hospital admissions:

PM₁₀:

Burnett et al. (1999) found a 0.5% increase in cardiac admissions in Toronto, Canada, while Morgan et al. (1998) found this value closer to 0.76% in Sydney, Australia.

PM_{2.5}:

Burnett et al. (1999) calculated a 0.75% increase. Again, this was the only study that found significance, and it should be considered preliminary.

3.2 Results of Estimated and Adjusted Calculations

To calculate the final averages of the risk estimates from the literature, only multipollutant models were used. A simple averaging method for correlation studies was used to compute the overall effect from the literature (see Wolf, 1986). As well, the low and high ends of the findings are noted, as there are considerable differences in estimates of dose-response. Adjusted values were applied to the mean values. Recent pooled random effect estimates (Stieb et al., 2003) and estimates from chronic studies (Pope et al., 2002) were also included.

Notation in the following tables includes 'P1997' as the original HAQI report, Pengelly et al. (1997); 'P2000' as the City of Toronto report, Pengelly et al. (2000); 'CAH' as the current reanalysis of HAQI conducted for Clean Air Hamilton; 'Adjusted' as the current results with adjustment of 42% overestimate; 'M-min' (mean minus minimum 20%) represents the baseline 20% model; and 'M-min adj' indicates the baseline model adjusted for the 42% overestimate.

Relatively wide ranges can be observed within the estimated percent changes from increases in pollutants. For an increase of 10 µg/m³ in PM₁₀, there was an increase ranging from 0.43% to 1.07% in non-traumatic deaths; 0.7-3.5% for respiratory admissions; and 0.5-2.3% in cardiovascular admissions. In the case of SO₂, the increase per 10ppb resulted in a range of 0.84-3.89% increase in mortality; 1.3-6.1% for respiratory admissions; and 0.2-2.1% in cardiovascular admissions. The other pollutants follow similar ranges, with the higher ranges existing for morbidity results and lower ranges in mortality estimates. Adjusted mean values were slightly higher than the low end of the estimates, except for the association between O₃ and non-traumatic mortality.

Table 1. Summary of Percent Changes per 10 Units of Pollutant: Low, Mean, High, and 42% Adjusted Mean Estimates of Calculated Values

Pollutant	NT mortality ^a (change per 10 units pollutant) range of estimates				Respiratory admissions ^b (change per 10 units pollutant) range of estimates				CV admissions ^b (change per 10 units pollutant) range of estimates			
	low	mean	high	adj mean	low	mean	high	adj mean	low	mean	high	adj mean
PM ₁₀ (µg/m ³)	0.43	0.76	1.07	0.44	0.7	2.1	3.5	1.22	0.5	1.4	2.3	0.8
PM _{2.5} (µ/m ³)	1.68	2.88	4.46	1.67								
SO ₂ (ppb)	0.84	2	3.89	1.16	1.3	3.7	6.1	2.15	0.2	1.1	2.1	0.6
NO ₂ (ppb)	1.5	1.9	2.3	1.10	1	4.9	9	2.84	4.4	6.55	8.7	3.8
CO (1 ppm)	2	3.68	4.95	2.13					0.4	1.95	2.5	1.1
O ₃ (ppb)	0.94	1.38	1.7	0.80	1.5	2.8	4.9	1.62	1.6	4.5	7.5	2.6

NT= Non-traumatic; CV = cardiovascular;

^a = Mortality values were calculated on the basis of 2 or 3 estimates

^b = Morbidity values were calculated on the basis of 1 or 2 estimates; in the case of one estimate, 95% confidence intervals were used as the low and high range of estimates

adj mean = Mean estimate adjusted for 42% overestimate

Note: Because the ranges of data vary among pollutants, the 10-unit change is not directly comparable as a metric of severity in effects. For pollutants with a smaller range such as CO, a 10-unit change is proportionately larger than for PM₁₀, which has a larger range.

Table 2 compares the average values for the risk estimates found in the literature after 1997 with the literature findings from the two previous studies and the adjusted values. This identifies the trends in literature values for the estimates. Current estimates were consistently higher than the 1997 estimates, except for PM₁₀ estimates for non-traumatic mortality and CO estimates for cardiovascular admissions. Adjusted values were lower than initial estimates for PM₁₀ and O₃, but higher for SO₂, NO₂, and CO.

Table 2. Summary of Percent Changes per 10 Units of Pollutant, Comparing Average Estimates of Studies, Adjusted and Pooled Estimates

Pollutant	NT mortality (change per 10 units pollutant) average of estimates					Respiratory admissions (change per 10 units pollutant) average of estimates				CV admissions (change per 10 units pollutant) average of estimates			
	P1997	P2000	CAH	Adj	Pooled	P1997	P2000	CAH	Adj	P1997	P2000	CAH	Adj
PM ₁₀	1	0.8	0.76	0.46	0.32	0.7	1.7	2.1	0.99	0.6	2.3	1.4	1.3
PM _{2.5}			1.9	1.10									
SO ₂	0.6	2.25	2	1.16	0.85	0.4	2.76	3.7	1.60			1.1	0.0
NO ₂	1.15	1.19	1.9	1.10	0.2	0.4	2.49	4.9	1.44		3.9	6.55	2.3
CO	1.1	3.48	3.68	2.13	0					5	6	1.95	3.5
O ₃	0.3	0.4	1.38	0.80	0.3	0.8	1.1	2.8	0.64		4.52	4.5	2.6

Pooled = Pooled random effect model estimates (Stieb et al, 2003)

Adj = Mean CAH estimate adjusted for 42% overestimate

Table 3 presents the calculated mortality and morbidity estimates as incidences per year, using low, mean, high and adjusted risk estimates. Values ranged as in Table 1. Totals for all pollutants ranged from 248 to 567 annual deaths (using PM₁₀ as a particulate estimate), to between 236 to 1252 respiratory and 993 to 3036 cardiovascular deaths. Adjusted mean totals were higher than the lower end estimates for all total counts.

Table 3. Summary of Low, Mean, High, and Adjusted Mean in the Mortality and Morbidity Counts Averaged for Available Years in Current Study

Pollutant	NT mortality (incidences/year) calculated estimates				Respiratory admissions (incidences/year) calculated estimates				CV admissions (incidences/year) calculated estimates			
	low	mean	high	adj mean	low	mean	high	adj mean	low	mean	high	adj mean
PM ₁₀	44	77	109	45	59	176	293	102	101	284	466	165
PM _{2.5}	108	185	286	107								
SO ₂	22	51	100	30	30	72	140	42	10	52	100	30
NO ₂	108	137	166	79	59	290	532	168	629	937	1244	543
CO	6	10	14	6					26	126	162	73
O ₃	68	119	178	69	88	164	287	95	227	638	1064	370
Total	248	394	567	229								
Total *	312	502	744	291	236	702	1252	407	993	2037	3036	1181

* = total has been calculated with PM_{2.5} instead of PM₁₀

Table 4 compares the estimates taken from the three studies and adjusted values, calculated on current air quality and health outcome data. Detailed calculations for these estimates can be found in Appendix 3. This table shows the differences in estimated mortality and morbidity counts according to the respective study values. The adjusted estimate is lower than any of the studies for mortality, at 229 annual deaths, but higher than the initial Pengelly study for morbidity at 407 annual respiratory and 1239 cardiovascular admissions.

Table 4. Summary and Comparison of the Mortality and Morbidity Counts Using the Average Dose-response Calculated in the Three Studies with Adjusted Values, Applied to Current Hamilton Data

Pollutant	NT mortality (average incidences/year) average of estimates				Respiratory admissions (incidences/year) average of estimates				CV admissions (incidences/year) average of estimates			
	P1997	P2000	CAH	Adjusted	P1997	P2000	CAH	Adjusted	P1997	P2000	CAH	Adjusted
PM ₁₀	102	81	77	45	59	142	176	102	122	466	384	223
SO ₂	15	58	51	30	22	81	72	42		629	52	30
NO ₂	83	86	137	79	24	147	290	168	135	338	937	543
CO	3	10	10	6					20	50	126	73
O ₃	97	29	119	69	53	66	164	95		641	638	370
Total	300	264	394	229	158	436	702	407	277	2124	2137	1239

Table 5 compares the original study, the current study, adjusted risk estimate values, baseline 20% adjustments, and application of both adjustments, all calculated for 1997 values. As the values show, there is a substantial difference in total mortality and morbidity counts, depending on the assumptions underlying the calculations. Our most conservative estimate, the application of both the 42% adjustment and the baseline 20% model, estimated 96 deaths in 1997 due to PM₁₀, compared to HAQI initial estimate of 298, our initial estimate of 374, and 217 deaths if the GAM discrepancy is taken into consideration. For respiratory admissions, the most conservative estimate is only a few admissions lower than HAQI estimates (139 compared to 144, respectively), while the highest estimate stands at 607 admissions. The highest estimate for cardiovascular admissions is our initial estimate of 2000 admissions, while the most conservative estimate is 479 admissions, still higher than the 257 admissions estimated by HAQI in 1997.

Table 5. Summary of the Mortality and Morbidity Counts Using the Average Dose-response in HAQI, CAH and Both Adjustments; Applied to 1997 Hamilton Data

Pollutant	NT mortality (average incidences/year) average of estimates					Respiratory admissions (incidences/year) average of estimates					CV admissions (incidences/year) average of estimates				
	P1997 ₉₇	CAH ₉₇	Adj ₉₇	M-min 1997	M-min adj	P1997 ₉₇	CAH ₉₇	Adj ₉₇	M-min 1997	M-min adj	P1997 ₉₇	CAH ₉₇	Adj ₉₇	M-Min 1997	M-Min adj
PM ₁₀	97	73	43	24	14	48	144	83	46	27	112	280	157	84	49
SO ₂	16	53	31	27	16	28	69	40	35	20		56	31	45	26
NO ₂	81	134	78	46	27	20	244	142	83	48	125	888	497	303	176
CO	3	10	6	6	3						20	118	66	65	38
O ₃	102	105	61	62	36	48	150	87	75	44		659	369	329	191
Total	298	374	217	119	96	144	607	352	239	139	257	2000	1120	826	479

3.3 Results of Hamilton-specific Estimates

Hamilton-specific estimates revealed that, for NO₂ and CO, the values were comparable to the lower ranges of the literature estimates. For SO₂, estimates were slightly higher than the mean count from literature estimates, and Hamilton-specific O₃ estimates were at the higher end of the calculations (Table 6). Applying the 42% adjustment brought the Hamilton-specific total down closer to the mean of the literature estimates. The 20% baseline estimate lowered the total to 206 mortality incidences, compared to 248 for the low end of literature estimates. When both adjustments were applied, total mortality fell to 119. This Hamilton-specific value is still higher than the 96 incidences (see Table 5), which results from data averaged across all literature findings.

Table 6. Comparison of the Range of Mortality Counts Using Current Estimates with Averaged Hamilton-specific Estimates and Adjustments

Pollutant				NT mortality (incidences/year) range in estimates		M-min ₁₉₉₇	M-min adj
	low	mean	high	Hamilton	Adj		
PM ₁₀	44	77	109				
CoH				256	148	40	23
SO ₂	22	51	100	73	42	37	21
NO ₂	108	137	166	108	63	45	26
CO	6	10	14	5	3	4	2
O ₃	68	119	122	122	71	81	47
Total	248	394	511	564	327	206	119

CoH= coefficient of haze.

Table 7 summarizes all available calculations performed for non-traumatic mortality estimates.

Table 7. Summary and Comparison of Mortality Counts Estimated for All Available Models, Based on 1997 Hamilton Pollution Values

Pollutant	NT mortality (average incidences/year) average of estimates					Pooled	Hamilton	Chronic
	P1997 ₁₉₉₇	CAH ₁₉₉₇	Adj ₁₉₉₇	M-min	M-min adj			
PM ₁₀	97	73	43	24	14	31		
PM _{2.5}		110	64					232
CoH							256	
SO ₂	16	53	31	27	16	22	73	
NO ₂	81	134	78	46	27	14	108	
CO	3	10	6	6	3	0	5	
O ₃	102	105	61	62	36	23	122	
Total	298	374	217	119	96	90		232
Total **		411	238				564	

M-min adj = Adjusted value of M-min, for overestimate of 42%

Pooled = Pooled random effect model estimates (Stieb et al, 2003)

Hamilton = Hamilton-specific dose-response estimates

Chronic = Estimates based on chronic exposures to particulates (Pope et al., 2002)

CoH= Coefficient of haze

Total ** = Totals calculated with PM_{2.5} or CoH as particulate measure

4. DISCUSSION

Applying the 42% adjustment to the averaged estimates resulted in lowering the CAH estimates by almost half, from 77 to 45 deaths due to a $10\mu\text{g}/\text{m}^3$ increase in PM_{10} , compared to 102 deaths estimated by HAQI 1997. Total mortality counts were reduced from 300 average deaths estimated by HAQI and 394 by CAH, to 229 for the adjusted model. Total respiratory admissions increased from HAQI's estimate of 158 to 407 using the conservative adjustments. The most dramatic increase, even using adjusted estimates, was for total cardiovascular admissions. HAQI estimated 277 admissions, CAH estimated 2137, while the 42% adjustment estimated 1239 admissions using averaged pollution data.

Using the 20% baseline model lowered values further below adjusted values. While SO_2 and O_3 estimates were higher than HAQI estimates for mortality, totals remained lower. Applying both adjustments lowered this value further to 96 deaths in 1997, a difference of 74% from CAH estimates. For morbidity estimates, the numbers were slightly different. Except for PM_{10} , adjusted morbidity estimates were above both HAQI and CAH estimates. Application of both adjustments resulted in only a slight decrease compared to HAQI estimates for respiratory morbidity, but almost double for cardiovascular admissions. However, in comparison to initial CAH calculations, respiratory admissions had decreased by 77%, while cardiovascular admissions had decreased by 76%.

Pooled random effects model estimates resulted in 90 deaths associated with air pollution, comparable to the 96 estimated by applying both adjustments. Chronic estimates of $\text{PM}_{2.5}$ -related mortality revealed 232 counts. Chronic estimates based on cohort studies are considered to be the "gold standard" for assessing health effects related to air pollution, due to their ability to assess life expectancy and incidence, course and remission of disease (Kunzli and Tager, 2000), giving significance to this type of research. The difference between these two estimates emphasizes the importance of considering both acute and chronic exposure studies separately.

A cautionary note is required with respect to the totals given above. They should be interpreted as general aids to decision-making rather than exact counts of death and illness. Uncontrolled confounding of co-pollutants may influence the totals. Although we used multipollutant models to derive estimates, some models did not control for all criteria pollutants simultaneously. In addition, each study may contain estimation error that is not accounted for in our simple averages of effect.

The comparison of the CAH estimates to the original HAQI findings shows that the current estimates identify a larger number of health outcomes due to air pollution. This difference is pronounced in hospital admissions, hinting to the possibility of increased sensitivity in current estimates for discerning the health risks attributable to air pollution. However, calculating the estimates using the 42% overestimation adjustment and the baseline 20% model both separately and together resulted in significantly lower estimates, except for total cardiovascular admissions that remained substantially higher. The correspondence between our conservative GAM and 20% baseline model adjustment, and the pooled random effects suggests that approximately 90 to 96 deaths are associated with ambient air pollution exposure.

The Hamilton-specific estimates revealed that the total estimates of non-traumatic mortality were initially at the higher end of the range found in our literature review. With the adjustments, the values are comparable to lower end estimates. Yet these values remained slightly higher than estimates that were not based on Hamilton-specific data. It has to be noted that the inclusion of CoH does not necessarily imply an equal measure of particulates. Specifically, NO₂ and CO related mortality values were lower than the average, while SO₂ and O₃ were higher than the averages.

5. CONCLUSION

This study has estimated mortality and hospital admissions associated with ambient air pollution in Hamilton. Dose-response relationships were derived based on exposure estimates published in the peer-reviewed literature (see sections 2 and 3 as well as Appendix 3). These estimates were applied to recent data on air pollution and health outcomes available through governmental sources.

Recent scientific discoveries identified software limitations in the GAM models used in time-series modeling. Applying the adjustments to account for an approximately 42% overestimate lowered the average annual mortality rate to 229, respiratory admissions to 407, and an average 1181 incidences for cardiovascular admissions.

If further assumptions are taken into account by using a baseline 20% model of 1997 pollution values, annual mortality rates drop to 119, respiratory admissions to 239, cardiovascular admissions to 826. Applying the 42% adjustment to these values revealed mortality counts of 96 (compared to original 1997 estimates of 374), respiratory admissions at 139 (compared to 607) and cardiovascular admissions at 479 (compared to 2000). Pooled random effects model estimates reveal 90 deaths associated with air pollution, while chronic estimates of particulate pollution (PM_{2.5}) result in 232 deaths. This wide range shows that the possibilities of public health estimates depend on the assumptions that underlie the analysis.

Although we used multipollutant models for our estimates, there is the potential for confounding variables due to the uncontrolled effects of co-pollutants as not all models control for all criteria pollutants. Therefore, our totaled mortality estimates could exceed the actual number of deaths associated with air pollution and thus, should be viewed with caution.

The “file drawer” consideration may also lead to overestimates in the air pollution effect (Levy et al. 2000). Published research generally favours significant findings, while insignificant findings are rarely reported. Since our study relies on published articles, there may be a bias in favour of positive findings and consequently higher estimates.

Some scholars have also suggested that using short-term dose-response estimates is inappropriate for studies that assess annual estimates (McMicheal et al., 1998). The reason for this criticism stems from the notion that some of the deaths, while premature, may have occurred during the same year, regardless of pollution exposure. Following this logic, overestimates of annual mortality may accrue due to the use of short-term estimates. Because so few studies estimate

chronic effects, we had to rely mainly on short-term models for calculating our estimates. Given this limitation, it is possible that we have overestimated mortality.

Other considerations suggest our study may underestimate the total burden of illness due to air pollution in Hamilton. Our estimates only include mortality and acute health effects from air pollution. Other important health effects such as the development and exacerbation of asthma (Tenias et al., 1998; Yu et al., 2000), reproductive abnormalities (Bobak and Leon, 1999; Wang et al., 1997), elevated cancer rates (Beeson et al., 1998; Cohen, 2000) and less serious respiratory conditions such as infectious respiratory diseases (Kim et al., 1996) are excluded from this analysis.

Due to our emphasis on multipollutant models, we had insufficient data to implement random effects models that weight for statistical uncertainty in the estimates. We have, however, included estimates of meta-analyses based in the United States and Europe. These results generally show lower estimates for particulate matter and ozone than our average calculations, but the most recent estimates produce aggregate estimates that are similar to our 20% adjusted model.

In this report, we have identified air pollution as a major source of mortality and hospital admissions in Hamilton. We have not linked the health estimates to specific sources, but this represents an important area for future research. Over the past five years, SO₂ has remained fairly stable, suggesting the industrial sources are not increasing. It appears that gaseous pollutants most closely associated with transportation emissions and particulates have increased over the study period (1995-99). The scientific evidence on the health effects of these pollutants (i.e., O₂, NO₂, CO) has also advanced. The combination of increasing pollution and growing scientific knowledge leads to the conclusion that these sources should be the focus of concerted policy efforts in the realm of land use and transportation planning. Both of these areas fall within the jurisdiction of the city. Future research combining the methods used in this report with source apportionment could supply more definitive guidance for priority setting in local decision-making.

APPENDICES

Appendix 1: Air Quality Indicators

Table 1-1. Annual Average of Air Pollutants in Hamilton

	PM ₁₀ (µg/m ³)	PM _{2.5} (µg/m ³)	SO ₂ (ppb)	CO (ppm)	NO ₂ (ppb)	NO (ppb)	NO _x (ppb)	O ₃ (ppb)
1995	27.90	17.58	6.43	0.60	19.25	17.00	37.00	19.18
1996	28.30	17.83	7.34	0.90	20.08	17.53	37.10	18.47
1997	24.98	15.73	6.80	0.65	18.15	14.93	33.25	19.63
1998	30.48	19.20	6.14	0.85	20.87	16.57	37.40	20.83
1999	30.30	19.09	6.56	0.75	21.65	16.50	38.23	21.20

Note: PM_{2.5} is calculated as 0.63(PM₁₀)

Source: Ministry of Environment Ambient Air Pollution Reports, 1995-1999

SINGLE POLLUTANTS

Figure 1-2. Plot of Average PM₁₀ Values for 1995-1999

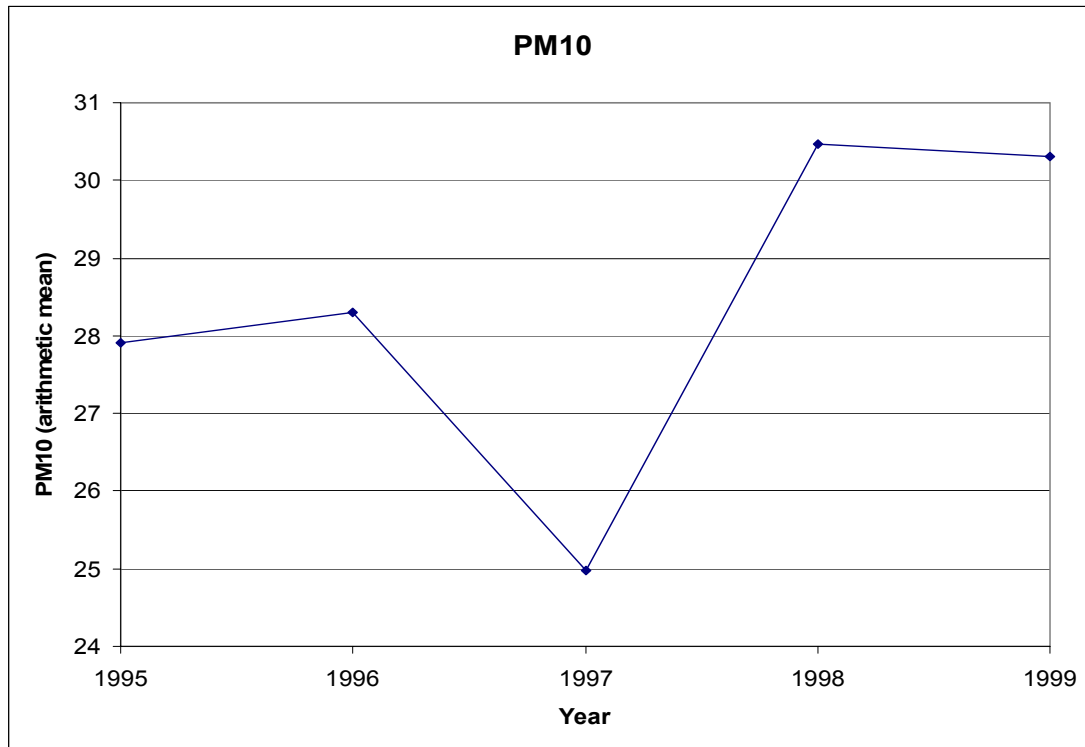


Figure 1-3. Plot of Average SO₂ Values for 1995-1999

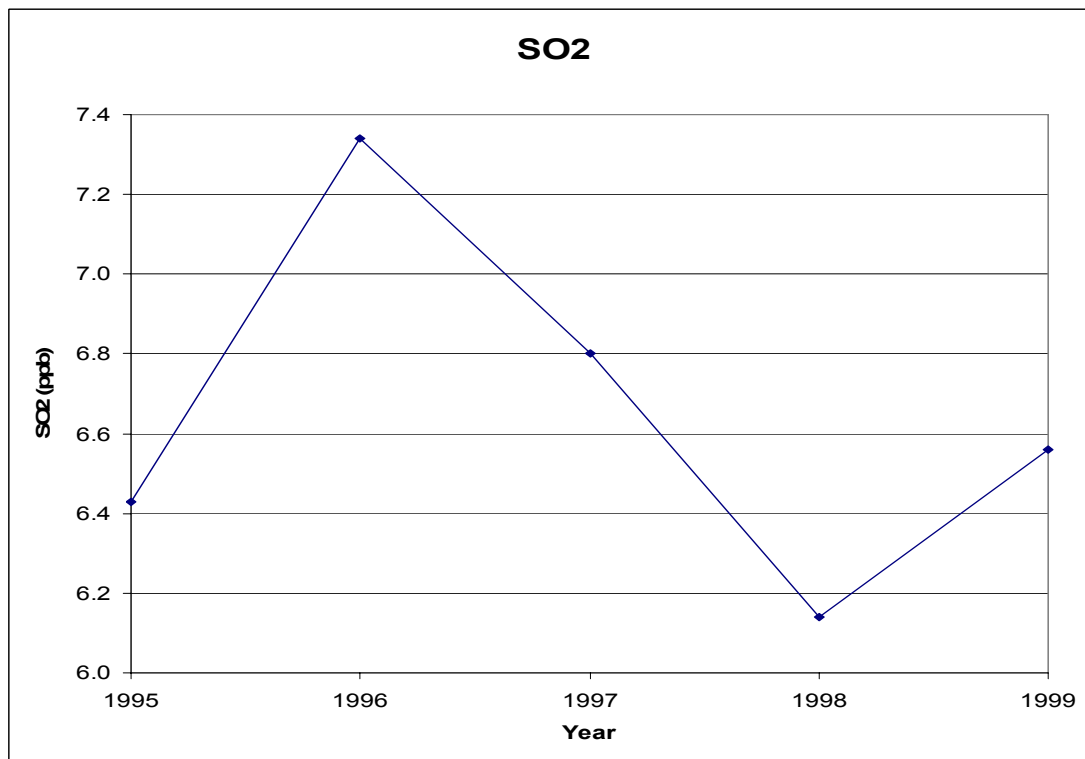


Figure 1-4. Plot of Average NO₂ Values for 1995-1999

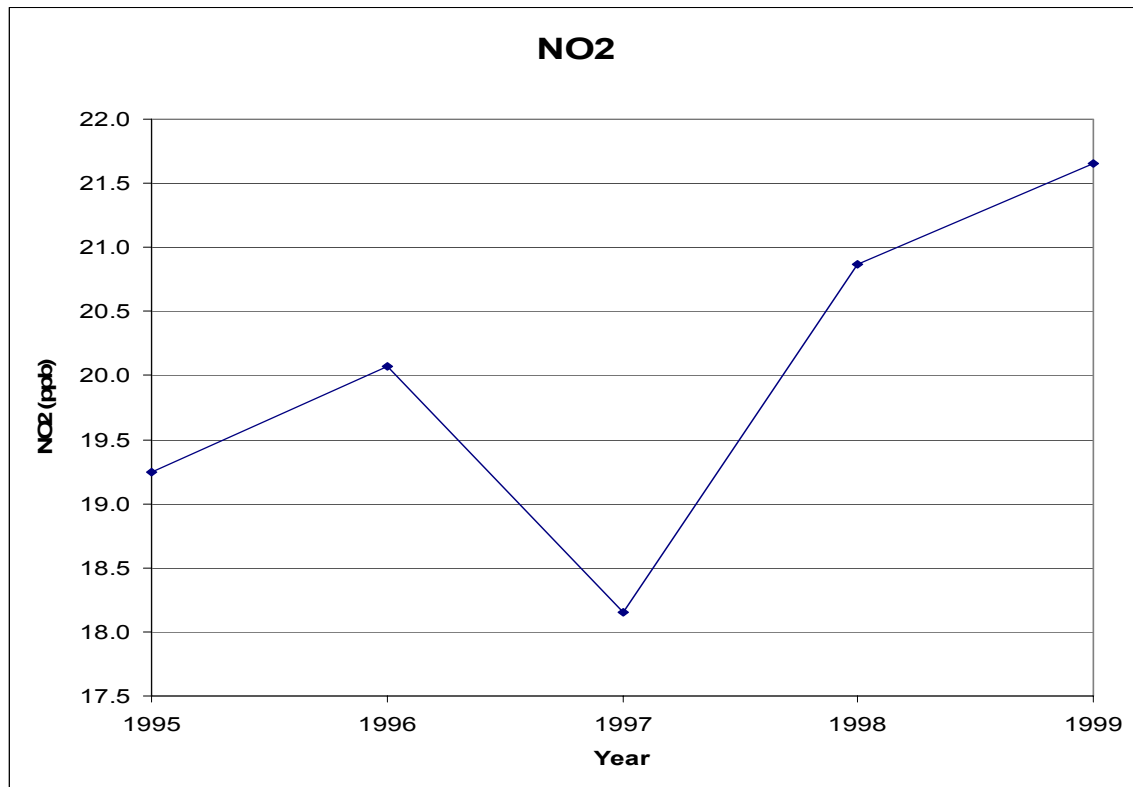


Figure 1-5. Plot of Average CO Values for 1995-1999

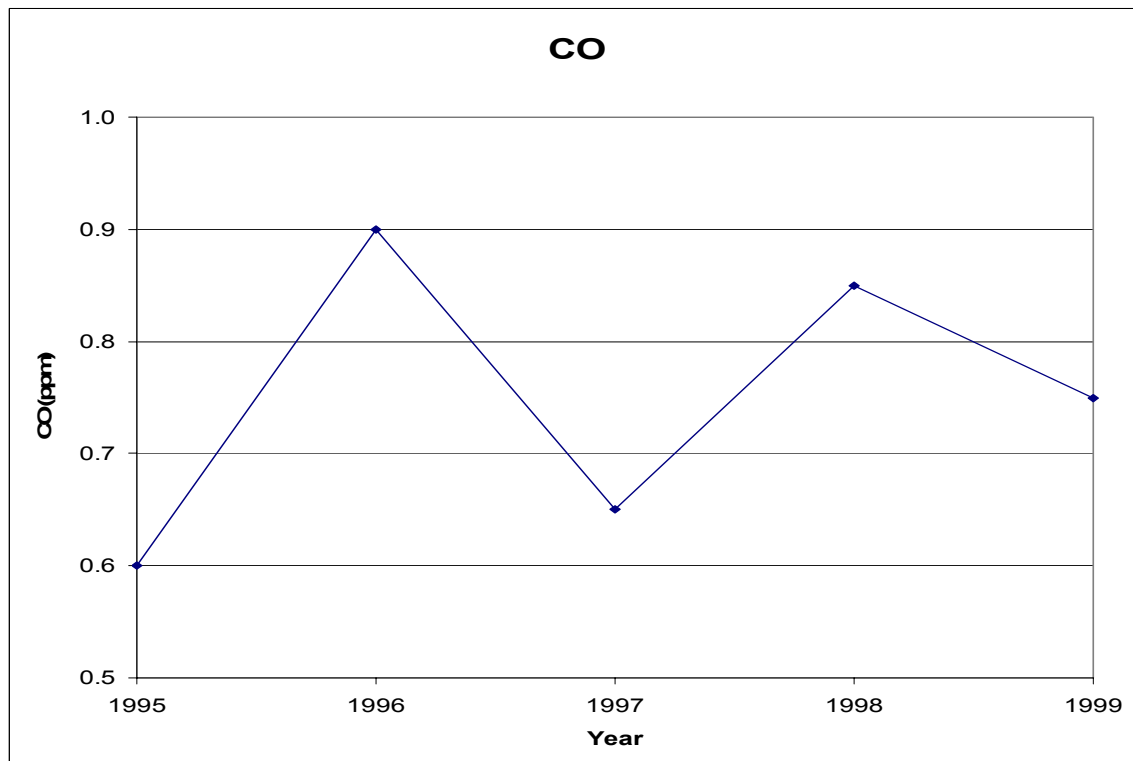
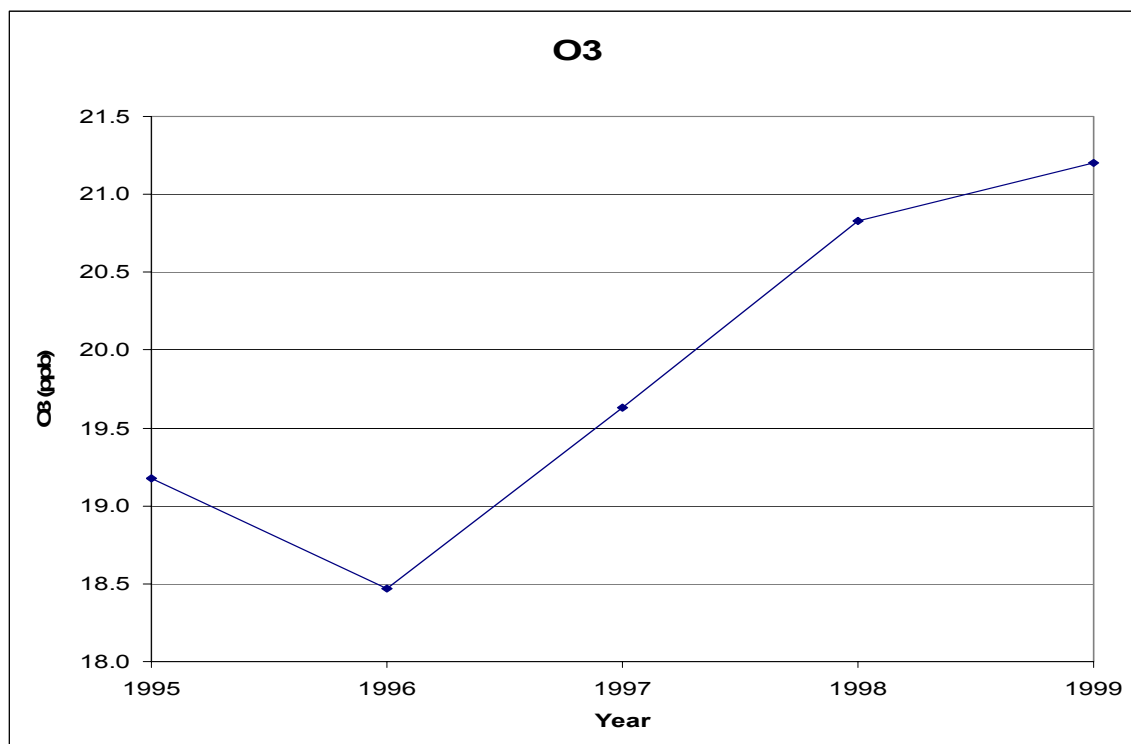


Figure 1-6. Plot of Average O₃ Values for 1995-1999



Appendix 2: Health Outcome Data

Table 2-1. Mortality and Morbidity Data for Hamilton Used in the analysis

	Non-traumatic mortality			Morbidity			
	All	CV	Resp	All	CV	CHF	Resp
1995	3,730	1,445	370	39,854	5,612	814	2,249
1996	3,694	1,422	367	41,149	7,702	1,123	3,085
1997	3,868	1,419	353	39,420	7,468	1,176	2,738
1998				40,044	7,322	1,108	3,266
1999				39,993	7,572	1,031	3,330
average	3,764	1,429	363	40,092	7,135	1,050	2,934

NT= non-traumatic

CV = cardiovascular

CHF = congestive heart failure

Resp = respiratory

Source: Central West Health Planning Information Network, 2001

Appendix 3: Detailed Literature Summary Tables

Table 3-1. Comparison of % Increases in Non-traumatic Deaths in Relation to Increases of 10 Units per Pollutant

Reference	Location	Multi Pollutant models	% change in daily mortality for each 10 unit increase in pollutant				
			Particulates (µg/m ³)	SO ₂ (ppb)	NO ₂ (ppb)	CO (1 ppm)	O ₃ (ppb)
Borja-Aburto et al. (1998)	Mexico City, Mexico	PM _{2.5} , O ₃ , NO ₂ (4 day lag)	PM _{2.5} = 1.68% (0.2, 3.14)				
Burnett et al. (1998a)	Estimates derived for Hamilton, Canada	CO, NO ₂ , SO ₂ , O ₃		2.2%	1.5%	2.0%	1.7%
Burnett et al. (1998b)	Toronto	CO	PM ₁₀ = 1.5% (1.1, 1.9) PM _{2.5} = 2.5% (1.7, 3.3)	3.89% (2.9, 4.86)	2.3% (1.6, 2.8)	4.95% (3.8, 6.1)	1.5% (1.2, 1.9)
Gwynn et al. (2000)	Buffalo, US	PM ₁₀ , CO	PM ₁₀ = 1.07% (0.02, 2.1)			4.1% (CI) (1.0, 7.2)	
Fairley (1999)	Santa Clara County, CA, USA	CO, NO ₂ , O ₃ , NO ₃	PM _{2.5} = 4.46%				2.47%
Kelsall et al. (1997)	Philadelphia, USA	TSP, SO ₂ , NO ₂ , O ₃	TSP = 0.31% (0, 0.61)	0.84% (0.11, 1.57)			0.94% (0.35, 0.15)
Morgan et al. (1998)	Sydney, Australia	PM ₁₀ , NO ₂ , O ₃	PM ₁₀ = 0.8% (0.0, 1.6)				
Saez et al. (2001)	3 Spanish Cities	SO ₂ , BS	BS = 0.64% (0.2, 1.1)	1.1% (0.2, 1.9)			
Chronic:							
Dockery et al. (1993)	6 US cities	yes	PM _{2.5} : 0.68% (0.5, 0.8)				
Reanalysis of cities			PM _{2.5} : 0.69% (0.6, 0.8)				
Pope et al. (1995) ACS study	151 US cities	yes	PM _{2.5} : 0.48% (0.44, 0.51)				
Reanalysis of ACS (2000)		yes	PM _{2.5} : 0.48% (0.45, 0.52)				
Not used in the calculation of current estimate:							
Pengelly et al. (2000)	Toronto, Canada	depending on average calculation	PM ₁₀ = 0.8% PM _{2.5} = 1.5% (0.85, 2.2)	2.2%	1.19%	3.48% (24 hr)	0.4%

Table 3-2. Comparison of % Increases in Non-traumatic Deaths in Relation to Increases of 10 Units per Pollutant for Studies Using Single-Pollutant Models and Meta-analysis Studies

		% change in daily mortality for each 10 unit increase in pollutant				
Reference	Location	Particulates ($\mu\text{g}/\text{m}^3$)	SO ₂ (ppb)	NO ₂ (ppb)	CO (1 ppm)	O ₃ (ppb)
Alberdi Odriozola et al. (1998)	Madrid, Spain	TSP = 0.6%				
Diaz et al.(1999)	Madrid, Spain	TSP = 0.72%	2.1%			
Garcia-Aymerich et al. (2000)	Barcelona, Spain	BS = 1.1% (0.5, 1.7)	4.2% (2.2, 6.1)	2.9% (0.7, 5.1)		0.95% (0.2, 1.6)
Goldberg et al. (2001)	Montreal	TSP = 0.65% PM _{2.5} = 1.96%				
Gouveia et al. (2000)	Sao Paulo, Brazil	PM ₁₀ = 0.51% (0.1, 0.9)	4.5 % (1.1, 7.9)			0.43% (0.00, 0.85)
Katsouyanni et al. (1997)	12 European cities	PM ₁₀ = 0.44% (0.2, 0.6)	1.1% (0.8, 1.3)			
Michelozzi et al. (1998)	Rome, Italy	TSP = 0.66% (0.31, 1.02)		1.54% (0.14, 2.97)		
Morgan et al.(1998)	Sydney, Australia			1.5% (0.2, 2.1)		0.7% (0.0, 1.3)
Neas et al. (1999)	Philadelphia, USA	TSP= 0.56% (0.27, 0.86)				
Meta-analysis articles:						
Daniels et al. (2000)	20 US cities	PM ₁₀ = 0.54% (0.33, 0.76)				
Klemm et al. (2000)	6 US cities (reanalysis)	PM ₁₀ =0.8% (0.5, 1.1)	PM _{2.5} =1.3% (0.9, 1.7)	SO ₄ =1.6% (0.9, 2.4)		
Samet et al. (2000)	20 US cities	PM ₁₀ = 0.51% (0.07, 0.93)				
Thurston & Ito (2001)	Combined analysis					0.56% (0.32, 1.08)

Table 3-3. Comparison of % increases in indicated morbidity values in relation to 10 unit increase per pollutant

Reference	Location	multi-pollutants	measure	% change in daily morbidity for 10 unit increase in pollutant					
				Particulates ($\mu\text{g}/\text{m}^3$)	SO ₂ (ppb)	NO ₂ (ppb)	CO (1 ppm)	O ₃ (ppb)	
Ballester et al. (2001)	Valencia, Spain	single pollutant	<i>card hosp adm</i>		1.1% (0.2, 2.1)				
Burnett et al. (1997a)	Hamilton	O ₃ , CO	<i>resp hosp adm</i>					1.5% (0.7, 2.2)	
Burnett et al. (1997b)	Toronto	T, DP for PM ₁₀ , +SO ₂ , O ₃ for NO ₂ + PM, NO ₂ , CO for O ₃	<i>card hosp admin</i> <i>resp hosp admin</i>	2.3% (0.3, 4.4) 2.1% (0.9, 3.3)		8.7% (3.2, 14.5) 4.9% (1.0, 9.0)	2.5% (0.2, 4.9)	4.5% (1.6, 7.5) 4.9% (2.7, 7.1)	
Burnett et al. (1999)	Toronto	gaseous pollutants	<i>card hosp adm</i>	PM ₁₀ =0.50% PM _{2.5} =0.75%					
Gywnn et al. (2000)	Buffalo, NY	each gas against particulates	<i>resp hosp adm</i>	PM ₁₀ = 2.1%(0.7, 3.5) SO ₄ ²⁻ = 0.5%(0.3, 0.7)	3.7% (1.3, 6.1)			2.0% (0.9, 3.0)	
Morgan et al. (1998)	Sydney	single pollutant	<i>card hosp adm</i>	PM ₁₀ = 0.7(0.2-1.3)		4.4% (3.06-5.8)			
Morris et al. 1998	Chicago	PM ₁₀ , NO ₂ , SO ₂ , O ₃	<i>chf hosp adm</i>				2.6% (1.0-3.9)		

Appendix 4: Detailed Calculations of Risk Estimates

Calculations for NT mortality for PM_{2.5}

PM 2.5	base	change per 10	%change	pollutant	outcome	42% Adj
1995	nt mort			(arith mean)		
mean	3730	1.9	0.0019	16.7	118	69
minimum		1.5	0.0015		93	54
maximum		2.5	0.0025		156	90
Pengelly 1997		N/A				
Pengelly 2000		N/A				

PM 2.5	base	change per 10	%change	pollutant	outcome	42% Adj
1996	nt mort			(arith mean)		
mean	3694	1.9	0.0019	17.0	119	69
minimum		1.5	0.0015		94	55
maximum		2.5	0.0025		157	91
Pengelly 1997		N/A				
Pengelly 2000		N/A				

PM 2.5	base	change per 10	%change	pollutant	outcome	42% Adj
1997	nt mort			(arith mean)		
mean	3868	1.9	0.0019	15.0	110	64
minimum		1.5	0.0015		87	50
maximum		2.5	0.0025		145	84
Pengelly 1997		N/A				
Pengelly 2000		N/A				

Calculations for chronic exposures to PM_{2.5} and mortality

PM 2.5 Chronic exp	1995 mean	LCI	UCI	1996 mean	LCI	UCI	1997 mean	LCI	UCI	Average
Six Cities	424	311	498	427	314	502	395	290	464	415
Reanalysis of 6 cities	430	374	498	433	377	502	400	348	464	421
ACS	299	274	318	301	276	320	278	255	296	293
Reanalysis of ACS	299	280	324	301	283	327	278	261	302	293
Pope	249	62	498	251	63	502	232	58	464	244

Note: LCI = lower confidence interval
UCI = upper confidence interval

Calculations for respiratory morbidity for PM₁₀

particulates	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1995	resp			(arith mean)		
mean	2249	2.1	0.0021	27.9	132	76
min		0.7	0.0007		44	25
max		3.5	0.0035		220	127
Pengelly 1997		0.7	0.0007		44	25
Pengelly 2000		0.8	0.0008		50	29
Dominici		0.27	0.00027		17	10

particulates	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1996	resp			(arith mean)		
mean	3085	2.1	0.0021	28.3	183	106
min		0.7	0.0007		61	35
max		3.5	0.0035		306	177
Pengelly 1997		0.7	0.0007		61	35
Pengelly 2000		0.8	0.0008		70	41
Dominici		0.27	0.00027		24	14

particulates	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1997	resp			(arith mean)		
mean	2738	2.1	0.0021	25.0	144	83
min		0.7	0.0007		48	28
max		3.5	0.0035		240	139
Pengelly 1997		0.7	0.0007		48	28
Pengelly 2000		1.7	0.0017		116	67
Dominici		0.27	0.00027		18	11

particulates	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1998	resp			(arith mean)		
mean	3266	2.1	0.0021	30.5	209	121
min		0.7	0.0007		70	40
max		3.5	0.0035		349	202
Pengelly 1997		0.7	0.0007		70	40
Pengelly 2000		1.7	0.0017		169	98
Dominici		0.27	0.00027		27	16

particulates	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1999	resp			(arith mean)		
mean	3330	2.1	0.0021	30.3	212	123
min		0.7	0.0007		71	41
max		3.5	0.0035		353	205
Pengelly 1997		0.7	0.0007		71	41
Pengelly 2000		1.7	0.0017		172	99
Dominici		0.27	0.00027		27	16

Calculations for CV morbidity for PM₁₀

particulates	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1995	CV			(arith mean)		
mean	5612	1.5	0.0015	27.9	235	136
min		0.7	0.0007		110	64
max		2.3	0.0023		360	209
Pengelly 1997		0.6	0.0006		94	54
Pengelly 2000		2.3	0.0023		360	209
Dominici		0.27	0.00027		42	25

particulates	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1996	CV			(arith mean)		
mean	7702	1.5	0.0015	28.3	327	190
min		0.7	0.0007		153	88
max		2.3	0.0023		501	291
Pengelly 1997		0.6	0.0006		131	76
Pengelly 2000		2.3	0.0023		501	291
Dominici		0.27	0.00027		59	34

particulates	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1997	CV			(arith mean)		
mean	7468	1.5	0.0015	25.0	280	162
min		0.7	0.0007		131	76
max		2.3	0.0023		429	249
Pengelly 1997		0.6	0.0006		112	65
Pengelly 2000		2.3	0.0023		429	249
Dominici		0.27	0.00027		50	29

particulates	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1998	CV			(arith mean)		
mean	7322	1.5	0.0015	30.5	335	194
min		0.7	0.0007		156	91
max		2.3	0.0023		514	298
Pengelly 1997		0.6	0.0006		134	78
Pengelly 2000		2.3	0.0023		514	298
Dominici		0.27	0.00027		60	35

particulates	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1999	CV			(arith mean)		
mean	7572	1.5	0.0015	30.3	344	200
min		0.7	0.0007		161	93
max		2.3	0.0023		528	306
Pengelly 1997		0.6	0.0006		138	80
Pengelly 2000		2.3	0.0023		528	306
Dominici		0.27	0.00027		62	36

Calculations for NT mortality for SO₂

SO ₂	base	change per 10	%change	pollutant	outcome	42% Adj
1995	nt mort			(arith mean)		
calculated mean	3730	2.00	0.002	6.4	48	28
Minimum		0.84	0.00084		20	12
Maximum		3.89	0.00389		93	54
Pengelly 1997		0.60	0.0006		14	8
Pengelly 2000		2.25	0.00225		54	31

SO ₂	base	change per 10	%change	pollutant	outcome	42% Adj
1996	nt mort			(arith mean)		
calculated mean	3694	2.00	0.002	7.3	54	31
min		0.84	0.00084		23	13
max		3.89	0.00389		105	61
Pengelly 1997		0.60	0.0006		16	9
Pengelly 2000		2.25	0.00225		61	35

SO ₂	base	change per 10	%change	pollutant	outcome	42% Adj
1997	nt mort			(arith mean)		
calculated mean	3868	2.00	0.002	6.8	53	31
min		0.84	0.00084		22	13
max		3.89	0.00389		102	59
Pengelly 1997		0.60	0.0006		16	9
Pengelly 2000		2.25	0.00225		59	34

Calculations for respiratory morbidity for SO₂

SO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1995	resp			(arith mean)		
mean	2249	3.70	0.0037	6.4	53	31
min		1.30	0.0013		19	11
max		6.10	0.0061		88	51
Pengelly 1996		1.50	0.0015		22	13
Pengelly 2000		2.76	0.00276		40	23

SO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1996	resp			(arith mean)		
mean	3085	3.70	0.0037	7.3	84	49
min		1.30	0.0013		29	17
max		6.10	0.0061		138	80
Pengelly 1996		1.50	0.0015		34	20
Pengelly 2000		2.76	0.00276		62	36

SO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1997	resp			(arith mean)		
mean	2738	3.70	0.0037	6.8	69	40
min		1.30	0.0013		24	14
max		6.10	0.0061		114	66
Pengelly 1996		1.50	0.0015		28	16
Pengelly 2000		2.76	0.00276		51	30

SO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1998	resp			(arith mean)		
mean	3266	3.70	0.0037	6.1	74	43
min		1.30	0.0013		26	15
max		6.10	0.0061		122	70
Pengelly 1996		1.50	0.0015		30	17
Pengelly 2000		2.76	0.00276		55	32

SO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1999	resp			(arith mean)		
mean	3330	3.70	0.0037	6.6	81	47
min		1.30	0.0013		29	17
max		6.10	0.0061		134	78
Pengelly 1996		1.50	0.0015		33	19
Pengelly 2000		2.76	0.00276		61	35

Calculations for cardiovascular morbidity for SO₂

SO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1995	CV			(arith mean)		
mean	5612	1.10	0.0011	6.4	40	23
min		0.20	0.0002		7	4
max		2.10	0.0021		75	44
Pengelly 1996		N/A				0
Pengelly 2000		N/A				0

SO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1996	CV			(arith mean)		
mean	7702	1.10	0.0011	7.3	62	36
min		0.20	0.0002		11	7
max		2.10	0.0021		118	68
Pengelly 1996		N/A				0
Pengelly 2000		N/A				0

SO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1997	CV			(arith mean)		
mean	7468	1.10	0.0011	6.8	56	32
min		0.20	0.0002		10	6
max		2.10	0.0021		107	62
Pengelly 1996		N/A				0
Pengelly 2000		N/A				0

SO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1998	CV			(arith mean)		
mean	7322	1.10	0.0011	6.1	49	28
min		0.20	0.0002		9	5
max		2.10	0.0021		94	54
Pengelly 1996		N/A				0
Pengelly 2000		N/A				0

SO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1999	CV			(arith mean)		
mean	7572	1.10	0.0011	6.6	55	32
min		0.20	0.0002		10	6
max		2.10	0.0021		105	61
Pengelly 1996		N/A				0
Pengelly 2000		N/A				0

Calculations for NT mortality for NO₂

NO ₂	base	change per 10	%change	pollutant	outcome	42% Adj
1995	nt mort			(arith mean)		
our	3730	1.90	0.0019	19.3	137	79
min		1.50	0.0015		108	63
max		2.30	0.0023		166	96
Pengelly 1997		1.15	0.00115		83	48
Pengelly 2000		1.19	0.00119		86	50

NO ₂	base	change per 10	%change	pollutant	outcome	42% Adj
1996	nt mort			(arith mean)		
our	3694	1.90	0.0019	20.1	141	82
min		1.50	0.0015		111	65
max		2.30	0.0023		171	99
Pengelly 1997		1.15	0.00115		85	50
Pengelly 2000		1.19	0.00119		88	51

NO ₂	base	change per 10	%change	pollutant	outcome	42% Adj
1997	nt mort			(arith mean)		
our	3868	1.90	0.0019	18.2	134	78
min		1.50	0.0015		106	61
max		2.30	0.0023		162	94
Pengelly 1997		1.15	0.00115		81	47
Pengelly 2000		1.19	0.00119		84	49

Calculations for respiratory morbidity for NO₂

NO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1995	resp			(arith mean)		
mean	2249	4.90	0.0049	19.3	213	123
min		1.00	0.001		43	25
max		9.00	0.009		391	227
Pengelly 1996		0.40	0.0004		17	10
Pengelly 2000		2.49	0.00249		108	63

NO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1996	resp			(arith mean)		
mean	3085	4.90	0.0049	20.1	304	176
min		1.00	0.001		62	36
max		9.00	0.009		558	324
Pengelly 1996		0.40	0.0004		25	14
Pengelly 2000		2.49	0.00249		154	90

NO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1997	resp			(arith mean)		
mean	2738	4.90	0.0049	18.2	244	142
min		1.00	0.001		50	29
max		9.00	0.009		448	260
Pengelly 1996		0.40	0.0004		20	12
Pengelly 2000		2.49	0.00249		124	72

NO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1998	resp			(arith mean)		
mean	3266	4.90	0.0049	20.9	334	194
min		1.00	0.001		68	40
max		9.00	0.009		614	356
Pengelly 1996		0.40	0.0004		27	16
Pengelly 2000		2.49	0.00249		170	99

NO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1999	resp			(arith mean)		
mean	3330	4.90	0.0049	21.7	354	205
min		1.00	0.001		72	42
max		9.00	0.009		650	377
Pengelly 1996		0.40	0.0004		29	17
Pengelly 2000		2.49	0.00249		180	104

Calculations for cardiovascular morbidity for NO₂

NO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1995	CV			(arith mean)		
mean	5612	6.55	0.00655	19.3	709	411
min		8.70	0.0087		942	547
max		4.40	0.0044		477	276
Pengelly 1996		0.00	0		0	0
Pengelly 2000		4.40	0.0044		477	276

NO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1996	CV			(arith mean)		
mean	7702	6.55	0.00655	20.1	1013	587
min		8.70	0.0087		1345	780
max		4.40	0.0044		680	395
Pengelly 1996		0.00	0		0	0
Pengelly 2000		4.40	0.0044		680	395

NO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1997	CV			(arith mean)		
mean	7468	6.55	0.00655	18.2	888	515
min		8.70	0.0087		1179	684
max		4.40	0.0044		596	346
Pengelly 1996		0.00	0		0	0
Pengelly 2000		4.40	0.0044		596	346

NO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1998	CV			(arith mean)		
mean	7322	6.55	0.00655	20.9	1001	580
min		8.70	0.0087		1329	771
max		4.40	0.0044		672	390
Pengelly 1996		0.00	0		0	0
Pengelly 2000		4.40	0.0044		672	390

NO ₂	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1999	CV			(arith mean)		
mean	7572	6.55	0.00655	21.7	1074	623
min		8.70	0.0087		1426	827
max		4.40	0.0044		721	418
Pengelly 1996		0.00	0		0	0
Pengelly 2000		4.40	0.0044		721	418

Calculations for NT mortality for CO

CO	base	change per 10	%change	pollutant	outcome	42% Adj
1995	nt mort			(arith mean)		
our	3730	3.68	0.00368	0.6	8	5
min		2.00	0.002		4	3
max		4.95	0.00495		11	6
Pengelly 1997		1.00	0.001		2	1
Pengelly 2000		3.48	0.00348		8	5

CO	base	change per 10	%change	pollutant	outcome	42% Adj
1996	nt mort			(arith mean)		
our	3694	3.68	0.00368	0.9	12	7
min		2.00	0.002		7	4
max		4.95	0.00495		16	10
Pengelly 1997		1.00	0.001		3	2
Pengelly 2000		3.48	0.00348		12	7

CO	base	change per 10	%change	pollutant	outcome	42% Adj
1997	nt mort			(arith mean)		
our	3868	3.68	0.00368	0.7	10	6
min		2.00	0.002		5	3
max		4.95	0.00495		13	8
Pengelly 1997		1.00	0.001		3	2
Pengelly 2000		3.48	0.00348		9	5

Calculations for respiratory morbidity for CO

CO	morbidity	change per 1	%change	pollutant	outcome	42% Adj
1995	CV			(arith mean)		
mean	814	1.95	0.0195	0.6	10	6
min		0.40	0.004		2	1
max		2.50	0.025		12	7
Pengelly 1996		2.40	0.024		12	7
Pengelly 2000		6.00	0.06		29	17

CO	morbidity	change per 1	%change	pollutant	outcome	42% Adj
1996	CV			(arith mean)		
mean	1123	1.95	0.0195	0.9	20	11
min		0.40	0.004		4	2
max		2.50	0.025		25	15
Pengelly 1996		2.40	0.024		24	14
Pengelly 2000		6.00	0.06		61	35

CO	morbidity	change per 1	%change	pollutant	outcome	42% Adj
1997	CV			(arith mean)		
mean	1176	1.95	0.0195	0.7	16	9
min		0.40	0.004		3	2
max		2.50	0.025		21	12
Pengelly 1996		2.40	0.024		20	11
Pengelly 2000		6.00	0.06		49	29

CO	morbidity	change per 1	%change	pollutant	outcome	42% Adj
1998	CV			(arith mean)		
mean	1108	1.95	0.0195	0.9	19	11
min		0.40	0.004		4	2
max		2.50	0.025		25	14
Pengelly 1996		2.40	0.024		24	14
Pengelly 2000		6.00	0.06		60	35

CO	morbidity	change per 1	%change	pollutant	outcome	42% Adj
1999	CV			(arith mean)		
mean	1031	1.95	0.0195	0.8	16	9
min		0.40	0.004		3	2
max		2.50	0.025		21	12
Pengelly 1996		2.40	0.024		20	11
Pengelly 2000		6.00	0.06		49	29

Calculations for cardiovascular morbidity for CO

CO	mortality	change per 1	%change	pollutant	outcome	42% Adj
1995	CV			(arith mean)		
mean	5612	1.95	0.0195	0.6	66	38
min		0.40	0.004		13	8
max		2.50	0.025		84	49
Pengelly 1996		2.40	0.024		81	47
Pengelly 2000		6.00	0.06		202	117

CO	morbidity	change per 1	%change	pollutant	outcome	42% Adj
1996	CV			(arith mean)		
mean	7702	1.95	0.0195	0.9	135	78
min		0.40	0.004		28	16
max		2.50	0.025		173	101
Pengelly 1996		2.40	0.024		166	96
Pengelly 2000		6.00	0.06		416	241

CO	morbidity	change per 1	%change	pollutant	outcome	42% Adj
1997	CV			(arith mean)		
mean	7468	1.95	0.0195	0.7	102	59
min		0.40	0.004		21	12
max		2.50	0.025		131	76
Pengelly 1996		2.40	0.024		125	73
Pengelly 2000		6.00	0.06		314	182

CO	morbidity	change per 1	%change	pollutant	outcome	42% Adj
1998	CV			(arith mean)		
mean	7322	1.95	0.0195	0.9	129	75
min		0.40	0.004		26	15
max		2.50	0.025		165	96
Pengelly 1996		2.40	0.024		158	92
Pengelly 2000		6.00	0.06		395	229

CO	morbidity	change per 1	%change	pollutant	outcome	42% Adj
1999	CV			(arith mean)		
mean	7572	1.95	0.0195	0.8	118	69
min		0.40	0.004		24	14
max		2.50	0.025		151	88
Pengelly 1996		2.40	0.024		145	84
Pengelly 2000		6.00	0.06		363	211

Calculations for NT mortality for O₃

O ₃	base	change per 10	%change	pollutant	outcome	42% Adj
1995	nt mort			(arith mean)		
our	3730	1.38	0.00138	19.2	99	57
Random EB		0.8	0.0008		57	33
Random no EB		0.56	0.00056		40	23
Pengelly 1997		1.35	0.00135		97	56
Pengelly 2000		0.4	0.0004		29	17

O ₃	base	change per 10	%change	pollutant	outcome	42% Adj
1996	nt mort			(arith mean)		
our	3694	1.38	0.00138	18.5	94	55
Random EB		0.8	0.0008		55	32
Random no EB		0.56	0.00056		38	22
Pengelly 1997		1.35	0.00135		92	54
Pengelly 2000		0.4	0.0004		27	16

O ₃	base	change per 10	%change	pollutant	outcome	42% Adj
1997	nt mort			(arith mean)		
our	3868	1.38	0.00138	19.6	105	61
Random EB		0.8	0.0008		61	35
Random no EB		0.56	0.00056		42	25
Pengelly 1997		1.35	0.00135		102	59
Pengelly 2000		0.4	0.0004		30	18

Calculations for respiratory morbidity for O₃

O ₃	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1995	resp			(arith mean)		
Mean	2249	2.8	0.0028	19.2	121	70
Min		1.5	0.0015		65	38
Max		4.9	0.0049		212	123
Pengelly 1997		0.9	0.0009		39	23
Pengelly 2000		1.12	0.00112		48	28

O ₃	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1996	resp			(arith mean)		
Mean	3085	2.8	0.0028	18.5	160	93
Min		1.5	0.0015		86	50
Max		4.9	0.0049		280	162
Pengelly 1997		0.9	0.0009		51	30
Pengelly 2000		1.12	0.00112		64	37

O ₃	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1997	resp			(arith mean)		
Mean	2738	2.8	0.0028	19.6	150	87
Min		1.5	0.0015		80	47
Max		4.9	0.0049		263	153
Pengelly 1997		0.9	0.0009		48	28
Pengelly 2000		1.12	0.00112		60	35

O ₃	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1998	resp			(arith mean)		
Mean	3266	2.8	0.0028	20.8	190	110
Min		1.5	0.0015		102	59
Max		4.9	0.0049		333	193
Pengelly 1997		0.9	0.0009		61	35
Pengelly 2000		1.12	0.00112		76	44

O ₃	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1999	resp			(arith mean)		
Mean	3330	2.8	0.0028	21.2	198	115
Min		1.5	0.0015		106	61
Max		4.9	0.0049		346	201
Pengelly 1997		0.9	0.0009		64	37
Pengelly 2000		1.12	0.00112		79	46

Calculations for cardiovascular morbidity for O₃

O ₃	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1995	CV			(arith mean)		
Our average	5612	4.5	0.0045	19.2	485	281
Minimum		1.6	0.0016		172	100
Maximum		7.5	0.0075		808	469
Pengelly 1997		NA				0
Pengelly 2000		4.52	0.00452		487	282

O ₃	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1996	CV			(arith mean)		
Our average	7702	4.5	0.0045	18.5	641	372
Minimum		1.6	0.0016		228	132
Maximum		7.5	0.0075		1069	620
Pengelly 1997		NA				0
Pengelly 2000		4.52	0.00452		644	374

O ₃	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1997	CV			(arith mean)		
Our average	7468	4.5	0.0045	19.6	659	382
Minimum		1.6	0.0016		234	136
Maximum		7.5	0.0075		1098	637
Pengelly 1997		NA				0
Pengelly 2000		4.52	0.00452		662	384

O ₃	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1998	CV			(arith mean)		
Our average	7322	4.5	0.0045	20.8	685	397
Minimum		1.6	0.0016		244	141
Maximum		7.5	0.0075		1142	662
Pengelly 1997		NA				0
Pengelly 2000		4.52	0.00452		688	399

O ₃	morbidity	change per 10	%change	pollutant	outcome	42% Adj
1999	CV			(arith mean)		
Our average	7572	4.5	0.0045	21.2	722	419
Minimum		1.6	0.0016		257	149
Maximum		7.5	0.0075		1204	698
Pengelly 1997		NA				0
Pengelly 2000		4.52	0.00452		726	421

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