A History of Air Quality Management

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Abstract

A brief history of air pollution management in Canada is provided in this chapter. Whether the issue be acid rain, ground level ozone, particulate matter, air toxics, or emergency releases of air pollutants, Canada has traditionally built a management approach on: strong science; a desire to move in a similar direction to our southern friends, the U.S.A.; connections to the rest of the world; all delivered by a cadre of world class scientists feeding their results to decision makers.

Beyond the research and modelling that has explained some of the complexities of chemical behavior in the atmosphere, it is clear that Canada's management systems would not be as effective as they have been without a strong federal/provincial commitment to monitoring emissions and air quality as well as a balanced approach among governments, non-governmental organizations, private industry and academia to model, analyze and make sense of the observations. Canada's unique approach has been led by a number of exceptional people over the years and their contributions have kept Canada in the forefront of the scientific understanding and bridging the gap into regulation needed for effective air quality management.

Keywords

Trail smelter · Sudbury · Canada wide standards · Critical loads · Acid rain · Ground level ozone · Particulate matter · CEPA · Persistent organic pollutants · Heavy metals

2.1 Introduction

Building on the Introduction in Chap. 1, this chapter will provide a summary of the history of air pollution management in Canada from several perspectives. In Canada, air quality management has been driven by a rather small number of key issues which have required some decisions to be made and actions taken. In general, these key issues have been driven by the presence of a "smoking gun" which is scientifically based evidence of harm or effect caused by air pollution. There have been a number of key people who have contributed their expertise and their ingenuity at the right time to ensure that science drove air quality management forward. As a result, air pollution management in Canada tends to be fact-based and well-grounded in the scientific method. This leads to a different process for each issue and a need for consolidation at the management level. Adding to the complexity of this approach is the fact that Canada is a unique blend of jurisdictions all having an interest in, and some responsibility for, air quality management. This chapter focuses on the federal role while Chap. 18 provides some details about the specific management approaches of the provinces.

Our long peaceful border with the U.S.A. has been important in the management of air quality on both sides of the border. Both countries have been actively engaged

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Fig. 2.1 Rough timeline of historical AQ management

1900	First Trail Smelter was built.
	Acid rain recognized as an issue.
	Pollution incident in Glasgow.
	100 m stack built in Trail.
	Tetraethyl lead added to gasoline
	Muese incident.
	Special tribunal report on Trail awarding damages to U.S.
	Detroit/Winsor Reference to IJC.
	Deterioration in Great Lakes observed.
1950	ELA established.
	Donora incident.
	Great Smog of London.
	Beamish work on the La Cloche Lakes.
	Establishment of NAPs.
	First U.S. and Canadian Clean Air Acts.
	US Acid Rain program.
	Canadian Department of the Environment formed.
	Superstack constructed in Sudbury.
1975	Canadian Council of Ministers of the Environment (CCME).
	Great Lakes Water Quality Agreement.
	UN ECE LRTAP Convention.
	U.S. Clean Air Act. U.S. standard for PM_{10}.
	CARE established.
	Canadian Acid Rain Program.
	First NAPAP Assessment
	Task Force on Cleaner Vehicles and Fuels.
	Annex 15 added to GLWQA.
1990	Canada/US Air Quality Agreement.
	CEPA passed.
	CAMNet established.
	Canadian NOx/VOC Assessment.
	Scrubbers added to the Superstack.
	Northern Contaminants Program Established.
	CWS for particulate matter and ozone.
	Canada-Wide Acid Rain Strategy for Post 2000.
	Comprehensive Nuclear Test Ban Treaty
2000	U.S. standard for $PM_{2.5}$.
	UN ECE Heavy Metals Protocol.
	2004 Canadian Acid Deposition Science Assessment and Summary of Key Results.
	UNEP POPs Convention.
	Canada/U.S. Border Air Quality Strategy.
2007	Guidance Document for determination of achievement of CWS

internationally in the management of global air pollution and both have maintained leadership positions in international Air Quality Management circles. There has been an ongoing focus on being good neighbours.

The span of the chapter is large, it could be the topic of a whole book on its own, so the authors have chosen "representative" examples in many cases rather than attempting an exhaustive treatment in order to best tell a bit of a story. If readers find that their favorite situation or person is absent from the discussion, their forgiveness is requested, it is acknowledged that this is only a start and perhaps future writings can pick up on the wealth of material that is not found in this chapter.

Detailed descriptions of emission management for the various sectors are not given here but in more detailed chapters to come, for example, a thorough description of "Industrial Emissions Management" is given in Chap. 10.

2.2 Key Issues that have Driven Air Quality Management in Canada

Throughout this book there are many air quality issues mentioned and discussed to illustrate a number of the concepts and processes that make up Air Quality Management in Canada. There are, however, a few high profile issues which seem to have galvanized attention and action across the country and thus served to drive the process of Air Quality Management forward. The following issues and events are in this category:

- The Trail Smelter issue
- Acid rain – Sudbury
- Smog
  - Major incidents
  - Ground level ozone
  - Particulate matter
  - Sulphur in gas

- Air toxics
  - Great Lakes Water Quality Agreement
  - The Northern Contaminants Program
  - Canadian Environmental Protection Act (CEPA)
- Emergencies

In the following it is notable how there are similarities and differences in the way these situations were identified, described, recognized as important, characterized, studied, and finally resolved. The results of this resolution make up Canada's air quality regime, how we got here often provides insight as to why air pollution is managed the way it is today. A "history" is often linear in time but this one is not. Fig. 2.1 illustrates the timeline for some key air quality events mentioned in this chapter.

2.2.1 The Trail Smelter Case

The Trail smelter emissions ensured that air pollution became a recognized issue in Canada as early as 1896 when the first smelter was built. As the facility was expanded over the years, locals started to protest the smoke plume, and in the early 1920s a stack over 100 m tall was built. This served to disperse the fumes further down the Columbia River Valley and caused vegetation damage on farms on the American side of the border, over 20 km away.

Eventually, protests got so insistent that President Franklin D. Roosevelt wrote directly to the then Prime Minister of Canada, Richard Bennett, a very unusual step. A special tribunal was set up in response to the letter to decide whether "the Trail smelter should be required to refrain from causing damage in the State of Washington in the future and, if so, to what extent" (Allum 2006) and to consider the question of responsibility for damages.

Morris Katz (1901–1987) had graduated from McGill in 1929 with a PhD in chemistry and biochemistry. At the time the tribunal was set up, he was a chemist for the National Research Council of Canada. He was requested to study the Trail situation from a scientific perspective. His work on the effects of smelter fumes on vegetation (Katz et al. 1939), is a classic, and was generalized in his further work over the next decade (Katz 1949). Plant health was the "smoking gun" in this case although there were plenty of other effects observed.

The special tribunal reported its findings in 1941 in a landmark decision stating "No state has the right to use or permit the use of its territory in such a manner as to cause injury by fumes in or to the territory of another or the properties of the persons therein, when the case is of serious consequences and the injury is established by clear and convincing evidence" (Kaijser 2011).

Canada and the U.S.A. accepted the findings of the tribunal and $428,000 was paid to affected farmers. Through sulphur recovery and an air quality management plan based on meteorology, the problem was partly solved. Dr. Katz writes in 1963 "A large new industry was created to convert the waste sulfur oxides to sulfuric acid, ammonium sulfate, ammonium nitrate, and phosphate fertilizer. Today the Trail Smelter recovers about 91 % of the sulphur dioxide, formerly wasted, by conversion into these valuable by-products" (Katz 1963).

While this was not the end of the situation and several rounds have taken place since, the first Trail Smelter case set many precedents for air quality management not only in Canada, but worldwide. It established that pollutants from an industrial source could have impacts very far away from their emission. It also set the scene for the great care that the U.S.A. and Canada have taken since in managing the air pollution that crosses their lengthy border.

Morris Katz went on to be chairman, Canadian Section, Technical Advisory Board on Air Pollution, Defense Research Council Chemical Laboratories, International Joint Commission (IJC), where he continued his pioneering work on transboundary air pollution by looking at public health in the Detroit/Windsor area, (Katz 1955). This work laid the foundation for the creation of the International Air Quality Advisory Program (IAQAP) and the Michigan-Ontario Board created under the IJC in 1966.

In his later years, Dr. Katz became a Professor of Chemistry at Syracuse University before returning to Canada to work at York University where he remained as Professor, and Professor Emeritus of Chemistry until his death in 1987. Always ahead of his time, his work at York was on polycyclic aromatic hydrocarbons and their mutagenic properties.

2.2.2 Acid Rain

Some of the pollutants emitted from the Trail Smelter were sulphur and nitrogen oxides from combustion. "Acid rain" was identified as far back as the 19th century (Smith 1872) as a potential ecosystem stressor. Scandinavian scientists (e.g., Oden 1968) brought the issue to worldwide attention. In Europe, decades of work were done to show that ecosystem impacts were experienced in Scandanavian countries as a result of industrial activity in Germany and other European countries. In 1972 the First Stockholm Convention on Environment recognized acid rain as an issue.

In Canada, there was concern that the levels of air pollutants were not known, leading to the establishment of the National Air Pollution Surveillance Program (NAPS) in 1969. It was established under an agreement between the federal and eight provincial governments to monitor sulphur dioxide and particulate matter. In 1972 the first NAPS report was issued, based on the results of measurements at 36 stations (NAPS 2013). Chap. 3 illustrates the essential role NAPS plays today in Canada's air pollution management.

Technically, “acid rain” is quite a narrow issue, focussing on rainwater which has had its acidity increased due to contamination by chemicals such as sulphur and nitrogen oxides. The sulphur and nitrogen oxides combine with water in the atmosphere to form acids, most commonly sulphuric and nitric acid. These can be washed out with rain, snow and fog, sometimes a hundreds of kilometers from where they were emitted, even in another country, giving rise to the term “long-range transboundary air pollution” or LRTAP. The chemicals can also dry deposit on surfaces and this aspect is also considered part of the acid rain issue.

We now know that fish reproduction is affected about pH 5 and by pH 3 adult fish cannot survive, with some species being more sensitive than this. Impacts on biota are complex since impacts on bacteria and other aspects of the ecosystem can have effects much higher up the food chain (Harvey 1982). In addition to ecosystem impacts, health impacts as well as impacts on physical structures have been studied. It has been the ecosystem effects that have driven this issue, however.

Canada and the U.S. were engaged in the early discussions on acid rain in Europe, and in fact, Canada signed the United Nations Economic Commission for Europe (UN ECE) Convention on Long-Range Transboundary Air Pollution (LRTAP) in 1979 (UN ECE 2013b). This convention was based on one of the first “assessments” of long range transport of air pollutants (LRTAP) for Western Europe. A whole new methodology was developed and agreed to by scientists across Europe (as well as Canada and the U.S.A) which was based on using “transfer matrices” to represent the complex science describing the transfer of emissions from some countries to acid deposition in others.

In Canada, early papers by Gorham reported acid lakes near Halifax, Nova Scotia and as a result of the smelter in Sudbury, Ontario (Gorham and Gordon 1963). However it wasn’t until a 1972 paper written by and Richard Beamish and Harold Harvey on fish mortality in the La Cloche Lakes near Sudbury provided a “smoking gun” that “acid rain” became the poster child for air pollution management (Beamish and Harvey 1972).

Richard Beamish first observed the effect of acid rain on fish in Ontario lakes while pursuing his PhD at the University of Toronto in the late 1960s, and the work on the La Cloche Lakes was part of his thesis work. He began his career with the Department of Fisheries and Oceans in Winnipeg after doing further studies at Woods Hole. After this he went to the Pacific Biological Station in Nanaimo where he headed the Groundfish Section, served as Station Director from 1980 to 1993. He was Commissioner and President of the Pacific Halibut Commission, a delegate to the North Pacific Marine Science Organization as well as the North Pacific Anadromous Fish Commission, and an affiliate professor of marine fisheries and aquaculture at Malaspina University College. He is an example of a long term government scientist who has held a leadership position in interdisciplinary environmental science in Canada for decades.

The regional nature of the issue was soon reflected in the work of Likens (Likens 1972; Likens et al. 1972), Kramer (Kramer 1973), Peter Dillon (Dillon et al. 1978), and many others, and what had been recognized as an international issue came close to home for Canadians.

During the 1960’s, a group of small Ontario lakes south of the TransCanada highway and east of Lake of the Woods was set aside by the Ontario Department of Lands and Forests as the Experimental Lakes Area (ELA) to investigate the eutrophication process which was plaguing the Great Lakes. David Schindler, who was at that time at Trent University, applied for a position at the ELA where he first identified detergent phosphates as being the culprit killing lakes. Subsequently, using the controlled environment of the ELA, he demonstrated that some fish are extremely sensitive to pH and that acidification can cause dramatic shifts in food chains by killing sensitive species (Schindler et al 1985).

Beyond the details of the acid rain issue itself, methodologies began to emerge by which scientists could assess each component of the issue, and beyond this to communicate their results to policy makers and the general public. In Canada, for example, emissions of sulphur and nitrogen were estimated (Environment Canada 1973) and extensive work was done to measure the emissions using in-stack techniques as well as various means of measuring the plumes emitted. It was determined that major sources were non-ferrous metal smelters, coal-fired generators as well as more distributed sources such as transportation (Summers and Whelpdale 1975). Work was done on the chemistry of the atmosphere to figure out how the acidification mechanism worked.

The physical behaviour of the pollutants was studied as they moved from emission to deposition point. The mechanisms of deposition were studied. All this information was assembled into models to describe the overall phenomenon (Clarke et al. 1989; Voldner et al 1981). And, finally, the effects on ecosystems and health were studied (Puckett 1979, Schindler 1988). It took scientists who had different specialities to be authoritative on each of these key pieces of the issue and hence it marked one of the very first times that an integrated scientific response was provided to such a complex and challenging issue.

This early work led to a deluge of science from both sides of the Canada/U.S.A. border working toward defining the extent and magnitude of the biological and chemical effects on surface waters of eastern North America. In 1975, the United States Environmental Protection Agency (US EPA) received $134 million (USD) per year for research on environmental issues associated with current energy production and use as well as the energy technologies under development for use in the future. Of course, air quality research received a major portion of this budget. However, it was also significant that acid rain research was specifically identified in this budget to receive approximately $12 million. This drove work in Canada as well. Canada and the US convened a group under the International Joint Commission to summarize what was known about the issue. Lester Machta and Howard Ferguson were two of the leaders of the work and assembled a set of four reports. These reports drove the signing, on August 5, 1980, of a Memorandum of Intent (MOI) between Canada and the USA. This work led in turn to the preparation of a series of "assessments" of the issue (e.g. Harvey et al. 1981; US/Canada Work Groups 3A 1981, 2 and 3B 1982, 1 1983; Schindler 1988; Atmospheric Environment Service 1998). This work proceeded in the midst of complaints that the costs of dealing with acid rain would lead to uncompetitive industry and huge overhead costs.

Nonetheless, in the 1970s and 1980s the emerging consensus on aquatic effects justified action on sulphur dioxide and nitrogen oxides emission controls. In 1985, a domestic "Acid Rain Control Program" was established. In the seven eastern provinces, a 40% sulphur dioxide emission reduction from 1980 levels by 1994 was required.

In Canada, one of the scientific breakthroughs in communicating the serious nature of the acid rain issue was the concept of "critical loads" which is the amount of acid deposition that a particular region can receive without being adversely affected. It was found that deposition of sulphates in precipitation in excess of 20 kg/ha per year damaged moderately sensitive aquatic ecosystems (UN ECE 2013a). The United States never did accept the concept of critical loads.

In 1981 U.S. President Ronald Reagan eliminated energy and environment research, which started at the US EPA and other agencies in 1975, but retained the $12 million (USD) per year for acid rain research. Work on the Canada/U.S. MOI was stopped until more scientific evidence could be presented on LRTAP and effects.

Meanwhile, in Europe, in 1981 the Organization for Economic Co-operation and Development (OECD) Air Management Group completed the first cost-benefit analysis of sulphur dioxide, sulphate aerosol and acid rain for Western Europe (OECD 1981), showing that benefits were at least comparable to costs and might considerably exceed them in monetary terms. In 1982, the Second Stockholm Convention focussed on acid rain and the progress made since the 1972 Convention. Canadian and American scientists and air quality managers participated in expert meetings and high level discussions.

In addition, the UN Economic Commission for Europe (ECE) began to focus on acid rain and the issue moved from OECD to ECE. The European Monitoring and Evaluation Program (EMEP) was established to coordinate and perform European acid rain monitoring and modelling. Canada and the USA contributed to the work of EMEP which established a Working Group on Effects to study air quality and deposition effects, and especially to define critical levels. In 1983, the UN ECE Protocol on sulphur dioxide was approved at a high level meeting in Munich and opened to be signed by countries. Canada signed this Protocol although the U.S.A. declined to do so (UN ECE 2013b).

In 1984–85, then US EPA Administrator Ruckelshaus proposed to do a lake survey in the United States to determine the extent of acid rain effects. A large supplemental appropriation (about $80 M USD/year) was obtained, with $10 M USD/year going to the United States Forestry Service (USFS) for surveys of forests. This support led to increased independent effort to build regional acid rain deposition models for North America. Increased effort was put into modelling photochemical oxidants on a regional basis (Clarke et al. 1989).

In 1990 the final National Acid Precipitation Assessment Program (NAPAP) Assessment of Acid Deposition was released as a multi-volume, comprehensive compilation of the state of science and technology for this issue. Around this time also, the US EPA, Environment Canada, the Ontario Ministry of the Environment, and the Electric Power Research Institute (EPRI) conducted a monitoring study for 2 years in order to produce an integrated air quality and atmospheric deposition data set for sulphur compounds which could be used to evaluate the performance of U.S. and Canadian regional atmospheric deposition models. Model improvements resulted from this work. Meanwhile, science showed that the 20 kg per hectare number used as a target under the Eastern Canada Acid Rain program was only sufficient to protect lakes that were "moderately sensitive".

The Canada/US Air Quality Agreement, discussed in Chap. 16, was signed on March 31, 1991, establishing national and eastern emission caps and requiring a substantial sulphur dioxide emission reduction in the United States as well.

In 1993, the Canadian Council of Ministers of the Environment (CCME) met with the Council of Energy Ministers in the first Joint Ministers Meeting (JMM). They created a Comprehensive Air Quality Management Framework for Canada along with a National Air Issues Steering Committee (NAISC) and a National Air Issues Coordinating Committee (NAICC) to implement it. In 1994, an Acid Rain Task Group was established under this mechanism to revisit the acid rain issue. In 1998, all 26 of the federal-provincial-territorial governments signed a "Canada-Wide Acid Rain Strategy for Post-2000" (CCME 2011) which has the long term goal of meeting critical loads through reduction of emissions. An important foundation of this strategy was its design as a framework for addressing the problem by protecting lakes and forests. The second phase of sulphur dioxide reduction was designed to bring wet sulphate deposition throughout eastern Canada to below "critical load" levels. In some areas these "critical loads" are as low as 8 kg/ha/year.

According to the 2012 Progress Report under the 1991 Canada/US Air Quality Agreement (Canada/United States 2012), "Canada's total emissions of sulphur dioxide have decreased by 57 % from 1990 levels while the U.S. has reduced total sulphur dioxide emissions from covered sources by 67 % from their 1990 emission levels. Between 2000 and 2010, Canada reduced total emissions of nitrogen oxides by 40 % in the transboundary ozone region while U.S. total nitrogen oxide emissions decreased by 42 % in the region."

The "acid rain" issue is often thought of as a "poster child" issue from a science/policy perspective. While publicly it is touted as a "solved" issue, and Canada and the US have been very successful in meeting the requirements of the Canada/US Air Quality Agreement, scientists have continued to raise concerns that critical loads are still being exceeded in many sensitive lakes, and that impacts are occurring on forests as well. Environment Canada's website as of October, 2012, states that "Between 21 and 75 % of eastern Canada, continues to receive levels of acid deposition in excess of critical loads." Lakes and their ecosystems have not recovered to pre-acid rain status and sensitive ecosystems are gone forever from many lakes.

With the realization that damage can occur at levels substantially below those that the emissions restrictions were designed to achieve, and with the continued focus federally being on eastern Canada, the Prairie Acid Rain Coalition was formed with Martha Kostuch as chair. In 2006, she argued that with the huge increases in energy production, Western Canada could see impacts from acid rain, especially forest health and growth, and demanded that the federal government do more monitoring in Saskatchewan and Manitoba where the problems could manifest. Unfortunately, Martha passed away in 2008. Efforts to address acid rain in the west refocused specifically on the Tar Sands development in Alberta.

In the east, resources for acid rain research were refocused on other emerging air quality issues and with the success of the Air Quality Agreement, there is little impetus to take a deeper look at the legacy of acid rain. It is known that acidification of lake systems cannot be "undone" and can have effects such as the release of heavy metals from soil and rock into the environment. Sect. 2.2.4.3 discusses heavy metals.

Beyond the research aspects of the acid rain issue, it served as a catalyst in Canada for the formation of a small, cohesive group of scientists who were recognized worldwide as not only being leaders in their fields but also able to communicate their messages effectively (Brydges 2004). Many of this group spent their whole careers working in scientific areas to support air quality management but have retired over a period from 2000 through the present. Perhaps one of their biggest successes was communicating the importance of air pollution to Canadians.

The Sudbury Smelter

Prior to the construction of the Superstack, the waste gases from the smelter in Sudbury contributed to severe local ecological damage. The use of open coke beds in the early to mid-20th century as well as logging for fuel resulted in a near-total loss of native vegetation. Exposed rocky outcrops were stained black, first by the pollution from the roasting yards, then by the acid rain. In some places there was a blackened and acidified layer that penetrated up to three inches into the once pink-gray granite.

The Superstack was built in 1972 at an estimated cost of 25 million dollars to disperse sulphur gases and other byproducts of the smelting process away from the city of Sudbury. After the stack was built, these gases, from the largest nickel smelting operation in the world at the Copper Cliff processing facility could be detected in the atmosphere around Greater Sudbury in a radius of 240 km. The stack is 380 m (1,250 ft) tall. This makes it the second tallest free-standing structure (behind the CN Tower) in Canada at the same height as the Empire State Building.

Construction of the Superstack was followed by an environmental reclamation project which included rehabilitation of existing landscapes and selected water bodies such as Lake Ramsey. Over three million new trees were planted within the Greater Sudbury area in an ambitious greening program. In 1992, Inco and the city were given an award by the United Nations in honour of these environmental rehabilitation programs.

While the Superstack lowered the ground-level pollution in the city, it dispersed sulfur dioxide, and nitrogen dioxide gases over a much larger area. The heavily industrialized Ohio Valley contributed to the ecological problem of lakes as far north as northern Ontario. Research from data gleaned up to the late 1980s demonstrated acid rain to have affected the biology of some 7,000 lakes.

Prior to Vale's purchase of Inco, a major construction effort by Inco in the early 1990s added scrubbers to cleanse waste gases before pumping them up the Superstack. These upgrades were completed in 1994 and emissions from then on have been much reduced. Despite the 90 % reduction in the sulfur dioxide and other gases, carbon dioxide and water vapour remain the most visible components and continue to contribute to the Sudbury Superstack's image as a pollution source.

SO_2 reductions have reached the point where the natural draught from the heat of the plume is no longer sufficient to provide enough buoyancy and natural gas burners and fans are now needed to move the SO_2 up the stack.

In contrast to the reduction of SO_2 emissions, Inco's Superstack still stands out in North America in its arsenic, nickel and lead emissions to the atmosphere. Using data compiled by the Commission for Environmental Cooperation (Taking Stock 1997), Inco alone accounts for 20 % of all of the arsenic emitted in North America, 13 % of the lead and 30 % of the nickel. Although it is not strictly fair to compare a nickel-copper smelter to a lead smelter, by so doing one can get an idea of how poor the containment of lead is at Copper Cliff. In 1998, Inco emitted 146.7 metric tons of lead at Copper Cliff with a smelter production of 238,500 metric tons of nickel-copper matte. The EPA regulations in the United States require a primary lead smelter to limit emissions of lead to 3.0 gm per MT of product. With this emission factor, Copper Cliff would be required to limit emissions of lead to approximately 1.0 MT per year, demonstrating that the actual emission is about 150 times greater than allowed by US regulations for a lead smelter. Steps are underway to reduce emissions. As a result of the lead emissions from the Inco Superstack, the surrounding community of Copper Cliff was found to have levels of lead in soil tests at a level sufficient to cause harm to young children (Pollution Probe 2003).

This illustrates that although air quality issues are generally considered and managed as independent entities, there is a large overlap in them with some sources contributing to a range of pollution issues. Air toxics are discussed further in Sect. 2.2.4.

2.2.3 Smog (Ground Level Ozone and PM)

"Smog" is a sort-of generic term which bows to the importance of smoke and fog, but does not really address the components in a manner that is conducive to understanding the air quality implications. Smog has a number of "active ingredients" including ground level ozone and particulate matter which, while they often appear together in the air, present rather different air quality management issues.

Major Incidents

The global history of air pollution management goes as far back as the discovery of fire. Since the industrial revolution there has been recorded public outcry, without which, it seems, no action is taken. In England, for example, under Henry V (1413–1422) steps were taken to regulate the movement of coal in London and taxation was employed to restrict its use. Over 1,000 smog-related deaths occurred in 1909 in Edinburgh and Glasgow, Scotland (Encyclopedia Britannica 2013). The word "smoke-fog" was first used by Mr. De Voeux in his report to the Manchester Conference of the Smoke Abatement League on this event.

While severe pollution incidents have occurred many times throughout history, perhaps the three most famous "air pollution episodes" occurred in the Meuse Valley in 1930, in Donora in 1948 and in London in 1952 (Phalen and Phalen 2012).

In the 25 km from Huy to Liege along the Meuse River in the 1920s there were 4 coke ovens, 3 steel mills, 4 glass factories and 3 zinc smelters. On December 1, 1930 a heavy fog descended. At first people became ill, but then on the third day, 60 people died. It wasn't until December 5 that the deadly fumes dissipated. As well as people, many cattle died and effects were reported in wild animals as well. The severity of the incident did not lead to anti-pollution measures and in September, 1972, an industrial accident coupled with a severe fog produced another incident heavy in sulfur dioxide. Fortunately, there were no deaths from that one.

Donora was a heavily industrialized town of almost 13,000 residents situated in inner bend of the high, narrow river valley of the Monongahela River, about 32 km south of Pittsburgh. Various United Steel facilities including a steel and wire works, zinc works and coal mining emitted chloride, fluoride, hydrogen sulfide, sulfur dioxide, cadmium oxide, as well as soot and ash into the air. On Tuesday, October 26, 1948, an inversion formed in the valley and persisted for 5 days until it rained on Sunday, October 31, trapping the pollutants in the USA's worst air pollution incident. A medical doctor at the scene, Dr. R.W. Koehler, wrote as he observed a passing train: "they were firing up for the grade and the smoke was belching out, but it did not rise…It just spilled out over the lip of the stack like a black liquid, like ink or oil, and rolled down to the ground and lay there." Twenty people died due to respiratory tract infections from hypoxia and due to obstruction in their air passages by pus from infected lungs. Most of the 5 women and 15 men who died were elderly and succumbed on the third day of the episode. 6,000 people were affected. Although US Steel settled out of court, this incident provided some of the impetus behind the passage of the U.S. Federal Clean Air Act in 1955 (Shenk 1970).

But the episode that galvanized the world's attention on air pollution as an issue was the "great smog of London" which started on Friday, December 5, 1952. The meteorological situation was such that an "inversion" limited the dispersion of pollutants in the vertical and the circulation pattern held them together in a vortex over the city. The situation persisted for five days with visibility so poor that people were afraid to leave their homes in case they would get lost.

Hospitals were crowded and eventually the numerical tally was made. There had been about 4,000 more deaths than normal for a five-day period, with many of those who died having pre-existing heart or lung disease. Deaths due to chronic respiratory disease increased tenfold and hospital admissions for respiratory illness increased threefold. Claims to the national health insurance system were 108 % above normal.

The British didn't immediately recognize the horrifying nature of the incident but as details emerged, public thinking about air pollution and how it should be managed was changed forever, not only in Britain but in Canada and other countries as well. One person who experienced the London Smog first hand and brought his interest in impacts of pollution on human health to Canada, was David Bates.

In Canada, this issue was first recognized in the late 1950s when damage was noticed to crops of tobacco grown along the north shore of Lake Erie. The "weather fleck" damage was shown to occur following higher than normal concentrations of ozone (50–150 ppb). Air quality management in this period was driven by voluntary actions. For example, the Sarnia region, heavily industrialized already, initiated the Sarnia-Lambton Environmental Association (SLEA) in 1952. It still monitors ambient environmental conditions today, and shares information with the community as well as government agencies.

At that time, air quality objectives were set in a two stage process, with NRC providing a synthesis of the science of the pollutant, and a Federal-Provincial Committee establishing objectives by factoring in other dimensions.

Ground Level Ozone

Ozone was discovered by Schonbein in Basel, Switzerland in the middle of the 19th century. He met Michael Faraday when he was in England teaching German at a boarding school and noted that an electric spark is often followed by a memorable smell. Later, when he became a professor of chemistry back in Basel, he was able to show that the smell was caused by ozone, which he went on to show could be intensely irritating (Ruben 2001).

It was noted in early aircraft such as the deHavilland Comet that oxygen masks used at altitudes over 10,000 m deteriorated rapidly. When Dr. David Bates joined the Royal Victoria Hospital in Montreal in 1956, he was interested in this problem in the context of how ozone might react with peoples' lungs. He did an experiment with the first DC-8 by putting rubber bands in places onboard the airplane and running a control experiment with rubber bands in a box on the ground, measuring ozone simultaneously in both places. This experiment was made possible because ozone measurement methods had just been developed. From this work it was estimated that ozone levels in the cockpit would average about 50 ppb. Subsequently, the compressors controlling cabin pressure in aircraft were modified to minimize ozone releases reducing the symptoms that aircrew had complained about (Young et al. 1962).

These early results encouraged Dr. Bates to focus on the small airways of the lung and over the next few decades he and other researchers developed a good understanding of the effects of ozone exposure (Bates 2006). Inflammation in the lung was found to be an early effect of ozone exposure, persisting up to 24 h after the exposure ceased. It was later found that although the lung responds to ozone exposure by thickening its coating of mucus to recover functionally, this underlying inflammation may persist and damage the pulmonary structure.

It was recognized that ozone and other photochemical oxidants in lesser amounts could be formed in the atmosphere by the photochemical oxidation of hydrocarbons and other organic pollutants in the presence of nitrogen dioxide and other pollutants such as aldehydes, ketones, alcohols, and organic acids. In the Los Angeles area, peak values of 500–750 parts per billion (ppb) in air by volume were measured, and other American cities began to record elevated levels. Mexico City and other big urban centers worldwide were beginning to take a much more serious interest in air pollution. While it was still not absolutely clear what the specific contributions of ozone and particulate matter were, it was now very clear that air pollution causes significant human health effects.

There are several key differences between the air pollution caused by ground level ozone and that caused by acid rain. Ozone is not "released" from sources as a pollutant, rather it forms in the atmosphere under certain conditions (such as the presence of sunlight) from "precursors" which are emitted. In fact nitrogen oxides, that are also part of the acid rain issue, play an important role in the atmospheric chemistry causing the formation of ozone. The other chemical family that is important in the process are the volatile organic compounds (VOCs). In addition, it was later discovered that the oxidants that were formed with ozone played a role in the formation of acid rain and other acidic deposition, thus relationships between air pollution and health can be complex (Bates and Sizto 1987).

Over the next decades, in addition to Dr. Bates, other Canadian scientists became active in studying the health effects of air pollution and this link between health scientists and air quality became an important feature of Canadian air quality management.

Dr. Rick Burnett, of Health Canada, pioneered use of data available through our health care system to do statistical analyses of large data bases on hospital admissions among others. Dr. Burnett worked with colleagues in Canada at Harvard and worldwide, who followed up with work substantiating the health consequences of air pollution. He established links with all the foremost authorities in the area, using powerful statistical analyses to reveal relationships in huge data bases. Studies done in the 1990s established the links between air pollution and health in many useful ways (Burnett et al. 1994a, 1994b, 1995, 1997, 1998, 1999).

Dr. Jeff Brook pioneered making the complex measurements needed to support studying the linkages between air quality and health in the field. Once associations are found from data, specific studies linking pollutant exposure to effects directly are important, as are characterizations of pollutants, (Brook and Johnson 2000, Brook et al. 2002). More about this in the next section on particulates.

The results of these studies have been important in designing the most effective air quality management approaches. The ozone issue revolutionized the engagement of the health community in air quality issues. With early analysis based on Canadian hospital admission data, it was shown that health effects were significant, piquing the interest and engagement of a wider health expert community. A Canadian NOx/VOC Assessment was published by Environment Canada in 1996 through the Canadian Council of Ministers of the Environment (CCME), which had issued a Management Plan for Nitrogen Oxides and Volatile Organic Compounds (Phase 1) in 1990. The Assessment included several volumes and presented a compelling, integrated overview of what was known about ground level ozone at the time, including the health dimension. As with the assessment work done on acid rain, governments began to take action.

The CCME, previously mentioned, had coordinated work on National Ambient Air Quality Objectives (NAAQOs) since the mid-eighties. They also worked towards "harmonization" of federal and provincial environmental management policies and programs as described in Chap. 15. While it wasn't until the Canada-Wide Accord on Environmental Harmonization was signed in 1998 that this was formalized, this kind of thinking drove much of the air quality management of the 1990s. The Accord was principle based including consideration of: polluter pays, precaution, pollution prevention, science-based, transparent, consensus-based and inclusive (role for Aboriginals) and flexible implementation.

The Federal-Provincial Working Group on Air Quality Objectives and Guidelines (WGAQOG) had developed objectives for carbon monoxide, total suspended particulate and sulphur dioxide in previous years. They now worked to determine a "reference level" for ozone (a level above which there are no demonstrated effects on human health and/or the environment). This technical group took into account all the latest work on effects and concluded that there was no such level for ground level ozone. They then took a pragmatic approach to protecting the health of Canadians (Federal-Provincial Working Group on Air Quality Objectives and Guidelines 1996, 1998, 1999). "The Canada-wide Standards for PM and Ozone… represent a balance between achieving the best health and environmental protection possible and the feasibility and costs of reducing the pollutant emissions that contribute to PM and ground-level ozone in ambient air" (CCME 2013).

The CCME then coordinated action to lower smog levels in problem areas of the country. In June 2000, the federal, provincial and territorial governments (except Quebec) signed the Canada-wide Standards (CWS) for Particulate Matter (PM) and Ozone which committed governments to reduce PM and ground-level ozone by 2010. The CWS and related provisions for ozone are: A CWS of 65 ppb, 8-hour averaging time, by 2010; achievement to be based on the fourth highest measurement annually, averaged over 3 consecutive years.

The CWS reflected driving principles such as: continuous improvement and keeping clean areas clean. Since Canada has an enviably clean atmospheric environment, these principles were to stress that it is not acceptable to pollute up to the level of the CWS, these are levels to be attained in areas of higher pollution. Hence special measures are needed in these areas as they develop to prevent pollution.

There is still further research to be done to clarify the time scales on which health effects depend and to sort out the finer details of the volatile organic compounds' role in the chemistry of ozone. If there are health outcomes due to chronic low level exposure that differ from outcomes of acute exposure, the form of the standard may need revision to protect health (Jerrett et al. 2009).

This is a very different approach to that taken in the USA to protect their Class 1 areas. It is also notable that the CWS does not explicitly consider visibility as an issue the way it has been considered in the United States. See Chap. 8 and 16 for more details.

A number of "joint initial actions" by federal and provincial governments were agreed to, including: providing more thorough and timely air quality information to governments, industry and the public by linking jurisdictional databases of ambient air quality data and facilitating access to existing public information; reducing emissions from the transportation sector and from residential wood burning; and developing national multi-pollutant emission reduction strategies for: Pulp and Paper; Lumber and Allied Wood Products; Electric Power; Iron and Steel; Base Metals Smelting; and Concrete Batch Mix and Asphalt Mix Plants.

The complex atmospheric chemistry that takes precursors and converts them over hours and hundreds of kilometers into ozone presents a challenge not only to the chemist, but also to the air quality manager. Recognizing that there is a significant transboundary component to the ground level ozone issue, in December, 2000, the Canada/U.S. Air Quality Agreement was modified by the addition of an annex on transboundary management of the precursors of ozone including specific objectives for volatile organic compounds and nitrogen oxides, to reduce transboundary flows of tropospheric ozone and their precursors.

Specific provisions related to transboundary flow were written into the CWS as well. Canada and the U.S.A. each declared a Pollution Emission Management Area (PEMA) for the application of the Annex. For Canada it included 301,330 km^2 south of the 48th parallel from the Ottawa River to east of Lake Superior. For the United States, the area was comprised of the states of Connecticut, Delaware, Illinois, Indiana, Kentucky, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New York, New Jersey, Ohio, Pennsylvania, Rhode Island, Vermont, West Virginia and Wisconsin as well as the District of Columbia. For Canada, the response was focused less on NOx from stationary sources and more on VOCs from a number of vehicular and off-road engine applications.

In 2003, an update "Atmospheric Science of Ground-level Ozone: Update in Support of the Canada-Wide Standards for Particulate Matter and Ozone" was released (CCME 2003). It concluded that the overall science had not changed dramatically since the 1996 assessment but that action should continue on the basis of those recommendations.

In 2007 a detailed "Guidance Document on Achievement Determination" for CWS was developed under the CCME by a Working Group on Monitoring and Reporting having largely similar membership to the Working Group on Air Quality Objectives and Guidelines (CCME 2007).

In the 2012 Progress Report under the Canada/US Air Quality Agreement, there is a table that shows preliminary 2010 emissions from the United States and Canadian PEMA. There are NOx reductions mainly from on-road mobile sources and electric power generation. VOC reductions are primarily form on-road and nonroad mobile sources and solvent utilization. In general, over the last decade, on-road vehicle emission reduction has driven the overall decline in emissions.

Particulate Matter

As has already been discussed, advances in the management of air quality in Canada have been linked closely to advances in associated sciences, especially monitoring. It is similarly true with particulate matter. Of course the Trail Smelter and other large industries had been known to produce large amounts of "smoke" and the "smog" incidents associated with ozone exposure had also been associated with visibility impairments, but it wasn't until the mid-twentieth century that the solid dust which was transported by the atmosphere began to be characterized as "particulate matter" and studied and eventually managed as a separate issue. The smog" events discussed in the section on ground level ozone were, of course, particulate events as well and the two issues tended to be managed as one until the science developed sufficiently to provide relatively clear characterizations of the pieces requiring different approaches to management.

In Canada and the United States, the highly industrialized Detroit River area was the subject of complaints from people in the 1940s. This area contains the cities of Detroit and Windsor as well as a number of smaller municipalities. Governments gave a reference to the International Joint Commission in January, 1949, to protect public health and welfare on either side of the international border from industrial emissions, including those from vessel traffic on the river.

Under the leadership of Morris Katz, a sampling study was designed using accordion-pleated filters in high volume samplers which filtered the air at a measured rate of about 50 cubic feet per minute. First, a six week study was conducted at 32 sampling sites in Detroit, which was followed by a similar study at 25 sites in and around Windsor. The total weight of particulates was measured and samples were analyzed for silicon, calcium, aluminum, iron, magnesium, lead, manganese, copper, zinc, titanium, tin, molybdenum, barium, nickel, vanadium, chromium, cadmium, beryllium, antimony, and cobalt (in decreasing order of results by median weight). These measurements were used to select high and low pollution areas in Detroit and Windsor which contained well defined population groups. This work was followed up by a health pretest in 1953 in which field trials of questionnaires were carried out. The Detroit Health Department and the City of Windsor participated by studying general health and medical care records.

Several interesting outcomes resulted from this work:

- Vessel emissions of black smoke, fly ash, and gaseous combustion products were found to be particularly objectionable because of their nearness to residential, recreational and civic land uses. A voluntary control program was initiated in 1954 sponsored by the IJC with the cooperation of the Lake Carriers and Dominion Maritime Associations as well as conversion of vessels for more efficient fuel-burning.
- In the organic fraction, more than 20 metallic elements were identified as well as chlorides, sulfates, nitrates, fluorides, and carbonates. The distribution of lead was correlated with the density of vehicular traffic.
- Organic constituents began to receive increased attention as they were recognized as potent carcinogens. The increasing incidence of lung cancer was associated with exposure to polycyclic aromatic compounds in particular the benzopyrenes in the atmosphere.

This work and its results indicate that it was recognized early on that particulate matter is exceptionally inhomogeneous in the atmosphere and that it varied enormously in composition depending on its source and the atmospheric processes to which it was exposed.

In the 1950s, dustfall was measured in many Canadian cities. Suburban levels were found to be rather constant with large variations in the industrial and commercial areas of a city. The air in downtown and industrial sections contains about twice to more than three times the air-borne dust found in suburban zones. It was recognized early that smoke particles of submicron size contribute very little to the weight of air-borne dust but influence soiling and visibility characteristics. Filtering air through paper tape and measuring the optical density of the stain deposited led to the Coefficient of Haze (CoH) per 1000 ft of air. The highest levels were found during the heating season winter months and minimum levels in the summer. Weekly and daily cycles were also noted with levels lowest on weekends and highest in the mornings, about 8–9 a.m.

Robert Edward Munn was born in 1919 in Winnipeg, Manitoba and graduated from McMaster University in 1941. He joined the Meteorological Division of the Canadian Department of Transport, forerunner of the Atmospheric Environment Service (AES) after graduating, and trained as a meteorologist in Short Course and Advanced Course #3. After initial postings, he completed an M.A. degree in 1946, was posted to Gander, Newfoundland, and then moved to the Public Weather Office in Halifax after the war ended. There he began to write and publish technical papers such as "A Survey of the Persistence of Precipitation at Halifax".

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