Ambient Air Quality Objectives

14

Randolph P. Angle

Abstract

Ambient air quality objectives (AQOs), based on causal relationships between air pollution and environmental effects, are the cornerstone of air management. Nationally, Canada pioneered a three-tier framework in the 1970s, then experimented with a different approach, and is now moving to a structure echoing the original. A fully formulated ambient air quality objective has four main components—indicator, magnitude, averaging time, statistical form—and three supporting components—attainment date, endpoint, and measurement method. AQOs are developed following a three-stage risk paradigm consisting of prioritization, risk assessment and risk management. Reviewing scientific effects literature for a risk assessment is a challenging task in the selection of endpoints and the weighting of evidence. Provincial AQOs exist for a broad array of pollutants.

Keywords

Ambient air quality standard · Ambient air quality objective · Ambient air quality criteria · Air pollution effects · Air quality objective-setting · Air quality risk assessment · Air quality risk management

14.1 Introduction

As noted in the Introduction, an air quality management program is designed to achieve specific goals. Goals for the ambient environment are usually specified by ambient air quality objectives for different pollutants. An ambient air quality objective (AQO) is a numerical level of concentration or deposition that provides protection for human health and the environment. Two types of effects are considered—biological and physical. Biological effects include damage to human and animal health, damage to crops and damage to forests and native vegetation. Physical effects include damage to materials (metals, coatings, textiles, paper, leather, stone, and concrete), damage to structures (buildings, monuments, and art) and damage to atmospheric properties (visual range, colour, and clarity).

Ambient air quality objectives are based on scientific knowledge about the relationship between pollutant concentrations in the air and associated adverse effects. Such cause-effect relationships can be challenging to define. There are often wide ranges of response within a biological population. It can also be difficult to separate the effects caused by air pollution from those caused by the many other variables that influence biological systems. Ongoing research is needed to reduce uncertainties in the state of knowledge.

In the Canadian air quality community, ambient air quality objectives may appear under a variety of different, closely-related terms. Different writers and different jurisdictions will refer to *standards, objectives, benchmarks, guidelines, limits,* and *criteria* using specific definitions that stem from the particular legal or policy framework in which they are embedded. For example, the Canadian Council of Ministers of Environment defines *standard* as "a legally enforceable numerical limit or narrative statement, such as in a regulation, statute, contract, or other legally binding document, that has been adopted from a criterion or an objective" (CCME

R. P. Angle (✉)
R. Angle Consulting, Edmonton, Alberta, Canada
e-mail: rangle2009@gmail.com

E. Taylor, A. McMillan (eds.), *Air Quality Management,* DOI 10.1007/978-94-007-7557-2_14,

1999). The National Round Table (2008) used a similar definition. AQOs are used by government agencies for a variety of different purposes.

An AQO used in permitting (see the chapter on industrial emission management) is most likely to have a strong legal underpinning, and in this context might be regarded as a *limit*, "boundary that should not be crossed". When a permit application is being assessed, predicted concentrations using a dispersion model are compared with the AQO. Design modifications are required until the predicted values are below the AQO. After the facility is built and operating, monitored concentrations that exceed the AQO typically lead to some enforcement action by the regulator.

An AQO used for planning purposes serves either as an *objective*, "aim or goal" or as a *guideline*, "principle for determining a course of action". In long term planning, the objective specifies an end state that is desired at some future time. In short term planning, the objective provides guidance on how to proceed, for example, in managing an episode, or designing a monitoring study.

An AQO is also used as a communications tool for interpretation of measured or predicted concentrations, and as such might be regarded as a *criterion*, "test by which something can be judged". It is used to transform numbers into statements that will answer questions asked by politicians and the public, such as "is the air good or bad?" This usage is similar to the generic meaning of *standard*, "measure with which things are compared in order to determine their quality".

14.2 National Ambient Air Quality Objectives

The development of national ambient air quality objectives has been sporadic rather than ongoing. Legislative changes and the dynamics of federal-provincial relations have played an important role in the processes for establishing national AQOs.

14.2.1 The Canadian Clean Air Act

In 1969 the federal Department of National Health and Welfare formed an ad hoc Federal-Provincial Committee on Air Pollution. A subcommittee of senior officials was struck in 1970 to develop national ambient air quality objectives. The committee was formalized under the Clean Air Act of 1971. The committee articulated a three-level framework for ambient air quality objectives:

> The *maximum desirable level* is the long-term goal for air quality and provides a basis for an anti-degradation policy for unpolluted parts of the country and for the continuing development of pollution control technology. It provides guidance for land-use planners and technology developers. At lower levels, there is in essence "no effect" on any receptor. Persuasion and financial incentives would be the principal methods used to attain this objective (Federal-Provincial Advisory Committee 1976).

> The *maximum acceptable level* is intended to provide adequate protection against effects on soil, water, vegetation, materials, animals, visibility, and personal comfort and well-being. It represents the realistic objective today for all parts of Canada. When this level is exceeded, control action by a regulatory agency is indicated (Federal-Provincial Advisory Committee 1976).

> The *maximum tolerable level* denotes time-based concentrations of air contaminants beyond which, owing to a diminishing margin of safety, appropriate action is required without delay to protect the health of the general population (Working Group 1994).

The method for developing air quality objectives proceeded in three steps (e.g. Franson et al. 1982; Newill 1977): (1) scientific review: the relevant published literature was identified and then panels of experts systematically and critically reviewed the information to compile a report on what was known about the adverse effects of pollutants at various concentrations. The resulting documents were known as *air quality criteria*, or *guides*; (2) AQO selection: from the scientific knowledge summary, senior government officials developed the levels that would become the basis for air management; (3) implementation: regulators detailed the administrative steps necessary to achieve and maintain the AQOs.

Many of the criteria documents were compiled by the National Research Council's Associate Committee on Scientific Criteria for Environmental Quality (e.g. NRCC 1981, 1982). The Associate Committee evaluated available information on the probability of effects of contaminants on receptors in Canada together with the related fundamental principles and scientific knowledge. Members of subcommittees and panels were selected for individual competence and relevant experience with consideration for a balance among all sectors in Canada. Each report was reviewed according to a multi-stage procedure designed to preserve objectivity in the presentation of scientific knowledge. The scientific criteria provided a starting point for the Federal-Provincial Committee who was responsible for establishing the ambient objectives taking into account socioeconomic impacts and the state of technology.

By 1975 there were national ambient air quality objectives for sulphur dioxide, nitrogen dioxide, carbon monoxide, total suspended particulate and ozone. Table 14.1 shows the 2011 ambient air quality objectives for sulphur dioxide in all Canadian jurisdictions. The original national ambient air quality objectives have had an enduring influence on provincial AQOs. Manitoba adopted the same national three-level structure. British Columbia implemented a similar three-level structure: Level A (desirable levels), Level B (interim levels) and Level C (maximum levels).

Table 14.1 Canadian air quality objectives for sulphur dioxide in μg/m³

Jurisdiction	Averaging Time		
	Short (1-h except as noted)	Intermediate (24-h except as noted)	Long (annual)
Canada—federal			
Maximum desirable	450	150	30
Maximum acceptable	900	300	60
Maximum tolerable	–	800	–
Newfoundland and Labrador	900	300 600 as 3-h	60
Nova Scotia	900	300	60
New Brunswick	900	300	60
Prince Edward Island	90	300	60
Quebec	525 as 4-min	228	52
Ontario			
Ambient air criteria	690	275	55
Point-of-impingement	830 as ½-h		
Manitoba			
Maximum desirable	450	150	30
Maximum acceptable	900	300	60
Maximum tolerable	–	800	–
Saskatchewan	450	150	30
Alberta	450	125 30 as a 30-day	20
British Columbia			
Level A	450	160, 375 as 3-h	25
Level B	900	260, 665 as 3-h	50
Level C	900–1300	360	80
Yukon	450	150	30
Northwest Territories	450	150	30
Nunavut	450	150	30
Metro Vancouver	450	125	30
Communauté métropolitaine de Montréal	1300 500 as 10-min	260	52

14.2.2 The Canadian Environmental Protection Act

In 1988, the Canadian Environmental Protection Act (CEPA) subsumed the Clean Air Act into broader legislation aimed at the overall management of toxic substances. Risk assessments were internalized within Environment Canada and Health Canada. In 1992 the CEPA National Advisory Committee formed a new federal-provincial working group on air quality objectives and guidelines. During a review of human health and environmental effects literature, the working group found that many air pollutants had no thresholds for effects. It was unclear how to define three scientifically defensible levels; the originators of the three-level framework had not provided any procedural details. Consequently the working group proposed a new framework with two levels (CCME 1999):

> The *Reference Level* is a level above which there are no demonstrated effects on human health and/or the environment. Reference levels are defined for all receptors for which effects information is available (human health, animals, vegetation, materials, and aesthetic atmospheric parameters).
>
> The *Air Quality Objective* represents the air quality management goal for the protection of the general public and the environment in Canada. It is a level based upon consideration of scientific, social, economic and technological factors.

This was quite similar to the two-level system that Canada had been using for the management of acid rain since 1983 (Federal/Provincial/Territorial Ministers of Environment and Energy 1998; Nixon and Curran 1998). A *critical load* is the threshold above which pollutant deposition harms the environment. Ecosystems that can tolerate acidic pollution have high critical loads, while sensitive ecosystems have low critical loads. The critical load for aquatic ecosystems is defined as the amount of wet sulphate deposition that protects 95 % of lakes from acidifying to a pH level of less than 6. A *target load* is the amount of pollution that is deemed achievable and politically acceptable when other factors (such as ethics, scientific uncertainties, and social and economic effects) are balanced with environmental considerations. The aim of the Eastern Canada Acid Rain Program, established in 1983, was to reduce wet sulphate deposition to a target load of no more than 20 kilograms per hectare per year (kg/ha/yr). This load would protect moderately sensitive aquatic ecosystems from acidification.

European countries apply the concept of *critical load* for deposition amounts and *critical level* for pollutant concentrations (Bull 1991). C*ritical load* is defined as "a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge". *Critical level* is defined as "concentrations of pollutants in the atmosphere above which direct adverse effects on receptors, such as human beings, plants, ecosystems or materials, may occur according to present knowledge" (UNECE 2012). The former refers to the quantity of pollutant deposited from air to the ground, whereas the latter is the gaseous concentration of a pollutant in the air. For comparison with the AQOs in Table 14.1, the sulphur dioxide critical levels are: for crops, an annual mean of 30 $\mu g/m^3$; for forests and natural vegetation, a winter mean (1 Oct to 31 Mar) of 20 $\mu g/m^3$; for forests and natural vegetation, an annual mean of 20 $\mu g/m^3$; for sensitive lichens, an annual mean of 10 $\mu g/m^3$ (APIS 2012). Critical levels have also been developed for ozone (Fuhrer et al. 1997).

The CEPA working group, operating with limited resources, had first reviewed the AQO for carbon monoxide using the three-level framework (Working Group 1994). After proposing the two-level framework, they recommended a protocol for the derivation of the reference level (Working Group 1996a) and a reference level for hydrogen fluoride (Working Group 1996b). The group also completed risk assessments for ozone (Working Group 1998) and particulate matter (Working Group 1999). These were used by the Canadian Council of Ministers of Environment in the development of the Canada-Wide Standards. A protocol for the derivation of the air quality objective and a risk assessment for total reduced sulphur compounds were in progress when federal resources were reallocated in 2000.

14.2.3 The Canadian Council of Ministers of the Environment

Under the auspices of the Canadian Council of Ministers of the Environment, in January 1998, the provincial and federal governments (with the exception of Quebec) signed the Canada-wide Accord on Environmental Harmonization. The Accord was designed for improved cooperation and better environmental protection across Canada. The standards development process included extensive stakeholder participation and several ancillary studies. In June 2000 the Canada-Wide Standards for Particulate Matter (PM) and Ozone was published (CCME 2000). These national ambient air quality objectives committed governments to reduce PM and ground-level ozone through jurisdiction-specific air quality management plans.

In April 2010 a new Comprehensive Air Management System for Canada was proposed (CCME 2010). Included in this system was the development of new Canadian Ambient Air Quality Standards (CAAQS) to drive air quality management actions in all jurisdictions. In areas where pollutant levels exceeded the standards, management efforts would focus on reducing emissions from all sources to move toward attainment of the standards. In areas where air quality met the standards, activities would be aimed at ensuring that pollutant levels did not rise above the standards. The standards would be developed, reviewed and strengthened over time through a process that included the consideration of practicality and achievability. Also included would be a set of action triggers at levels below the standards in order to keep them from being exceeded, and to prevent the standards from becoming "pollute-up-to" levels. Table 14.2 illustrates this approach. Such a tiered structure is reminiscent of the original three-level framework. A similar tiered response framework has been used in Alberta for managing acid deposition (CASA 1999) and for implementing the Canada-Wide Standards for Particulate Matter and Ozone (CASA 2003).

14.3 Expressing Ambient Air Quality Objectives

Our knowledge of air quality at a location is determined by various types of measurement data. For many pollutants automatic continuous air samplers draw air directly into robust pollutant-specific analytical equipment in the field, and can report the concentration immediately. Ideally an ambient air quality objective is related closely to the properties of the concentration data. There are four main components to an ambient air quality objective:

1. Indicator: generally the pollutant of concern in the air (e.g. sulphur dioxide), but it could also refer to rate of removal from the atmosphere (acidic deposition) or accumulation in a receptor.
2. Magnitude: the numerical value representing the concentration of the pollutant, usually a volumetric ratio (parts per million by volume, ppmv) or a gravimetric ratio (micrograms per cubic metre, $\mu g/m^3$) at a specified temperature and pressure (e.g. 25 °C and 1 atmosphere). For deposition, it would be expressed as mass per unit area per unit time (kilograms per hectare per year, kg/ha/y).
3. Averaging time: the interval of time over which continuously varying concentrations will be "averaged", that is, the sum of n measurements will be divided by n. The most

Table 14.2 Air quality levels and management actions under proposed new air management system for Canada

Level and description	Air management actions
Green: low pressure on air quality	Basic air quality surveillance Periodic reporting to the public on the state of air quality; public education Development planning based on principles of Keeping Clean Areas Clean and Continuous Improvement.
Yellow: air quality under pressure	Plan to reduce air quality deterioration Air quality monitoring to assess/identify relevant air quality issues Inventory and mapping of major emissions sources; modelling of emissions patterns Stakeholder involvement in air management efforts; public education and engagement. Economic and urban development policies to ensure air quality does not degrade
Red: Encroachment on Canadian Ambient Air Quality Standards	Rigorous action plan with key sources, contributions of stakeholders to reductions, milestones and timelines, periodic progress assessments, mapping and modelling Increased air monitoring and expansion of emissions inventory to all sources Public notification, education and engagement Sustainable economic and urban development policies to ensure improvements in air quality.
Black: non-attainment	Stronger action plan to achieve air quality improvements meeting the CAAQS Stepped-up air quality monitoring and source contribution assessment Stepped- up air zone management to meet CAAQS. Stepped-up coordination of actions at the regional airshed level

common averaging times are 1-h (1/2–h in Ontario), 24-h and annual (8760-h). Monitoring technology sometimes limits the available data for comparison and different types of models may be used to convert to a time period for which there is an objective (e.g. Alberta Environment 2011). Atmospheric dispersion models are also capable of producing estimates of concentrations averaged over virtually any time period, although for permitting shorter time periods are generally used. For deposition, the averaging time is usually one year.

4. Statistical Form (or metric): the calculations that must be performed on the basic data to determine whether an AQO is being met or exceeded. For example, the 30 $\mu g/m^3$ Canada-Wide Standard for Particulate Matter is based on the 98th percentile of 24-h averages over three consecutive years. For other pollutants, provincial AQOs sometimes specify an acceptable frequency of exceedance (e.g. Alberta Environment 2011). Most jurisdictions are silent on frequency although the stochastic nature of atmospheric turbulence is known to produce an exponential or log-normal concentration distribution (Barry 1977). The United States primary standards typically are not to be exceeded more than once per year.

Three additional supporting components are also need for full formulation of the AQO:

5. Date for Achievement: the time in the future when the objective is to be met. The Canada-Wide Standards for Particulate Matter and Ozone were to be achieved by 2010. Provincial AQOs generally apply from the time they are issued, after a fixed adjustment period (e.g. Alberta Environment 2011) or at a specified effective date (e.g. Alberta Environment 2010).
6. Endpoint: the specific type of outcome and measured effect that may result from exposure at or above the specified concentration. There is generally a lot of uncertainty in cause-effect data. Experts often disagree on the validity and interpretations of health effects data. Vegetation is subject to large species variability and distribution. Effects can be obvious or subtle. Odour may be an important consideration. Ultimately, some endpoint becomes

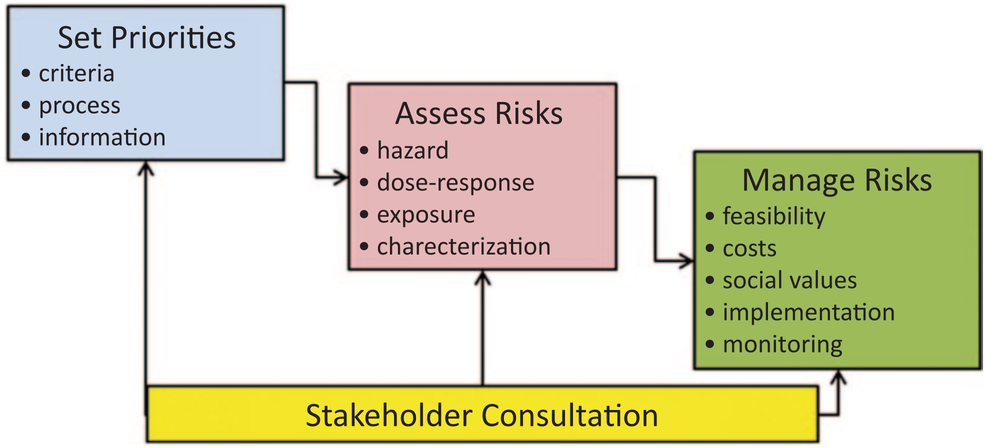

Fig. 14.1 Stages in setting ambient air quality objectives through a risk-based procedure

the determining factor in setting the AQO. Both Ontario and Alberta provide a general idea of the endpoints in their listings of AQOs (Ontario Ministry of Environment 2008; Alberta Environment 2010).

7. Methods for measurement: the techniques for determining concentrations or depositions. For consistency in making comparisons clearly defined methodologies are needed. This leads to supporting standards for measurement and testing (e.g. Saskatchewan Environment 2007) and the handling of data (e.g. CCME 2007).

Concentration in the air and deposition to ecosystems are not the only ways to represent air quality. Other important aspects of air quality are found in related atmospheric properties and in characteristics of the physical and biological receptors. Ambient air quality objectives can and have been set in terms of:

- Chemical content in vegetation, for example, fluoride in animal forage (Ontario Ministry of Environment 2008; Alberta Environment 2009)
- Sedimentation of particulate matter onto or into exposed receptacles, for example, dustfall (Ontario Ministry of Environment 2008; Alberta Environment 2010)
- Transmittance or reflectance of light through or from a spot of particulate matter collected on a filter, for example, coefficient of haze (Alberta Environment 2010)
- Rate of collection by molecular diffusion to a pollutant-specific absorbent material exposed in the field, for example, sulphation (Alberta Environment 2010)
- Odour perception, for example, in odour units (RWDI 2005)
- Visibility, for example, visual range or light extinction (RWDI Air 2008).

The statistical form of an AQO usually reflects its principal intended use. The Canada-Wide Standard for Particulate Matter and Ozone was developed to guide jurisdictional air quality planning. However, the statistical form for PM did not lend itself readily to comparisons with the output from simple dispersion model screening used in small source permitting or the short-term data from continuous monitoring. For these purposes Alberta developed an equivalent hourly AQO (Fu et al. 2000; Alberta Environment 2010).

14.4 Developing Ambient Air Quality Objectives

Most jurisdictions set their AQOs using some type of a risk-based approach to environmental safety. The fundamentals of risk assessment and risk management with some history are outlined in McColl et al. (2000). Adaptations for air quality are described by Bailey (1999) and Caton and Bates (2002). For most applications in air quality objective setting, there are three basic stages shown in Fig. 14.1. Risk communication is sometimes viewed as part of the process after managing the risks.

The procedure begins with issue prioritization, followed by risk assessment and consideration of risk management options (e.g. Caton and Bates 2002). The risk assessment stage looks at the nature of the hazard, the dose-response relationship, the population of receptors that are exposed, and the estimated impacts on the exposed receptor population. The risk management stage integrates information from the risk assessment with economic, technical, ethical, social, legal, ecological, and achievability factors. Stakeholders are generally engaged in some way throughout the process. This procedure is comprehensive and thus also very expensive and time-consuming. The ultimate decision is taken by the government agency or political leaders on behalf of its citizens. The Canada-Wide Standards for Particulate Matter and Ozone were developed in a lengthy process following this framework.

14.4.1 Setting Priorities

Priorities are generally set by air quality agencies either internally or in consultation with stakeholders. One or more

Table 14.3 Summary of some methods for setting priorities with stakeholders

Method	Brief Description	Advantages	Disadvantages
Expert Panels (Leiss 2008)	Independent specialists arrive at recommendations through consensus	Brings together best available expertise	Dominant scientist may over influence
		Yields high scientific credibility	Tendency to go beyond field of competence
Nominal Group Technique (Delbecq and de Ven 1971)	Participants give views, generate a list of ideas and concerns, vote or rank the list, have structured small group discussions, and repeat the ranking or voting	Minimizes conflict	Opinions may not converge
		Ensures relatively equal participation	Cross-fertilization of ideas may be constrained
		Provides sense of closure	Process may appear to be too mechanical
		Simpler multi-voting without discussion can be used with the internet	
Consensus Development Conference (Crowe 2009)	Meeting to debate summary statements and seek agreement on the most important	Accommodates a large number of participants	Requires extensive preparation
		Can be used with the internet	
Focus Groups (I-TECH 2008)	Structured conversation to obtain in-depth information about people's feelings, values, and ideas	Way to get feedback on specific proposals	Generally does not come to consensus or make a decision
Delphi Technique (Brown 1968)	Works through a number of cycles of anonymous written discussion and judgment, controlled by the process manager	Avoids groupthink and personality conflict	Slow and time consuming
		Gives time to think carefully, be rigorous and revise thinking	Intended primarily for experts
		Progressively refines content to convergence	
Criteria Weighting Method, or Multi-Criteria Analysis (DCLG 2009)	Participants establish a relevant set of criteria, assign a priority ranking, and then rank alternatives	Understandable, rational, structures the complexity	May be difficult to get agreement on weightings and criteria
			May be slow and protracted
Paired Comparisons (Brown and Peterson 2009)	Each member of the decision team compares each option with every other option	Quick and easy to set up simple binary choices	Works best with 6 to 12 alternatives
			May be tedious and time-consuming Mechanical

chemical screening tools may be used (Five Winds 2004; Caton et al. 1988). An air pollution agency typically sets its internal priorities based on considerations of: pending industrial developments, quantity of emissions, number of emitting sources, toxic substance lists; commitments to others (e.g. other governments, Council of Environment Ministers, environmental groups, consultative groups); scheduled reviews; new information related to environmental/ human health effects; and preliminary evaluation of risks.

If an agency chooses to involve its stakeholders, typically some sort of deliberative process is used to arrive at priorities. Table 14.3 summarizes some methods, many of which can also be used as ways of engaging stakeholders in both the risk assessment and risk management stages.

14.4.2 Assessing Risks

Risk assessment is the scientific evaluation of the likelihood of adverse health effects due to exposure of a human or an ecological component. Risk assessment is comprised of four major steps:

1. *Hazard identification* describes the type of adverse effect associated with the pollutant based on existing scientific literature.
2. *Dose-response assessment* determines the relationship between the amount of exposure and the probability of an adverse effect;
3. *Exposure assessment* determines the concentration, frequency, duration and continuity of exposure over time.
4. *Risk characterization* provides a summary of the risk assessment methods, sources of evidence, uncertainties and results for use by decision-makers and communicators.

Risk assessments rely heavily on the available scientific information. Aside from being very labor intensive and time consuming, they can be often be limited by the lack of good quality studies. There is a need for ongoing research programs to fill knowledge gaps and generate the scientific information needed to update AQOs.

Reviewing Scientific Literature

Hazard identification and dose-response (cause-effect) are assessments for air pollutants are generally based on existing scientific literature and are subject to all of the challenges of conducting a comprehensive literature review. One major problem is evaluating the quality of research and deciding whether or how to use lower quality information (Randolph 2009). Most reviewers do this implicitly and with their own personal biases; however explicit evaluation schemes do exist. Randolph (2009) provides one example of a scoring chart. Priestley et al. (2006) provided a summary of criteria to be used in selecting human and animal studies.

Davies and Haggerty (2002) used a rigorous scheme to rate the confidence in each study as high, medium or low. A set of eligibility criteria allowed for the systematic selection of studies. The technical quality of the eligible studies was judged against a pre-defined set of quality criteria derived from leading experts. A Confidence Rating was assigned to each study by weighing the strengths and weaknesses of the study, using a check-list for guidance. Each study was read and rated as "high", "moderate" or "low" independently by two or three knowledgeable professionals.

This systematic evaluation of studies is an example of an objective methodological approach to "weight of evidence". Priestley et al. (2006) concluded that weight-of-evidence is not a clearly defined approach. The term is often used metaphorically to imply that some evaluation has taken place, but generally there is no clear indication of how this was done. The term is also used theoretically to indicate simply a conceptual framework.

The other big challenge with the effects literature review is the selection of endpoints. An endpoint is a characteristic of a human or ecological component that may be affected by exposure to the pollutant. Endpoints can include any of the various levels of biological organization: molecules, organelles, cells, groups of cells (tissues, organs, and organ systems), organisms (individual living things), populations (groups of organisms of one type that live in the same area), communities (populations living together in the same area), and ecosystems (a community and its non-living surroundings (Odum 1993). Most studies of the effects of pollutants on living things focus on the organism and its groups of cells. Typical ecological endpoints include: visible injury, photosynthesis, stomatal conductance, dark respiration, biomass, crop yield, root growth, decomposition, nutrient uptake, mortality, gross anomalies, and fecundity. Medical endpoints can be concerned with the status of various organ systems (respiratory, cardiovascular, gastrointestinal, neurological, reproductive, ocular, immunological) in individuals or the distribution of such effects within an exposed population.

Health effects studies generally fall into three categories: animal toxicology, human experimental and human observational (see the chapter Air Quality Impacts on Health). Environmental effects studies can be categorized in much the same way. Analogous to animal toxicology there are laboratory studies of potted plants in growth chambers or greenhouses. The experiments are done with the plant species of interest, so there is no issue similar to extrapolation from animals to humans, but there are concerns about how well laboratory conditions reproduce actual outdoor field conditions. There is also a challenge in determining the appropriate plant species to consider, especially since there are wide variations in sensitivity to air pollutants. A jurisdiction may choose to ignore results for plants that do not grow in the area, or may focus on crops of economic value. Analogous to clinical trials, there are controlled field exposures, using open top chambers or free air enrichment fumigation systems. Analogous to human observational studies, there are uncontrolled field exposures which use "real-world" conditions, available data and additional measurements. Ecosystem techniques have been summarized by Chen and Goldstein (1986) and types of field exposures have been described by Eberhardt and Thomas (2008).

The risk analysis documentation is called a Science Assessment in the Canadian national process (e.g. Working Group 1999), a Rationale Document in Ontario (e.g. Ontario Ministry of Environment 2006), and an Assessment Report in Alberta (e.g. WBK & Associates 2004). While the content varies somewhat with the pollutant, typically these reports would contain:

a. General pollutant information (identification and uses; physical, chemical and biological properties; environmental fate and behaviour)
b. Emissions and concentrations (natural and anthropogenic sources; ambient concentrations)
c. Effects on humans and animals, Acute and Chronic (respiratory; cardiovascular; gastrointestinal; neurological; reproductive and developmental; genetic; cancer)
d. Effects on vegetation (visible injury; photosynthesis; growth and yield)
e. Effects on materials (electrochemical corrosion; chemical attack)
f. Ambient monitoring methods (continuous, integrated and passive)
g. Existing air quality objectives elsewhere.

In addition to narrative around each of the topics, such reports may contain tabular or graphical summaries of effects observed at various concentrations and exposure durations. Table 14.4 provides an example of a summary effects table.

Exposure assessment draws upon existing ambient air quality monitoring data, but since station density is rarely adequate for accurate categorization, interpolations and extrapolation need to be made using statistical or dispersion models. For humans who spend much of their time indoors and who move extensively through different regions of air quality, it can be challenging to estimate exposure accurately. For ecosystems and vegetation, relevant ambient air quality monitoring data tends to be even sparser.

If there insufficient effects literature, it may be necessary to initiate a specific research program to collect the relevant data for the pollutant and receptors of concern. For example, in the mid-1990s production and use of ethylene by the pet-

Table 14.4 Summary of effects on vegetation for ethylene exposures over 48 h. (Alberta Environment 2003)

Species	Concentration (µg/m^3)	Duration of Exposure	Effect
Barley	57	3 days	41 % reduction in seed yield
Barley	34	14 days	63 % reduction in seed yield
Canola	57	31 days	20 % reduction in seed yield
Canola	40	87 days	Seed yield 63 % lower than in "background" treatment (12 µg/m^3)
Field peas	288	16 days	50 % reduction in seed yield
Pea seedlings	12	60 h	Inhibition of epicotyl elongation
Bean seedlings	92	60 h	Inhibition of epicotyl and root elongation, radial expansion of hypocotyl
Begonia	173	10 days	Flower quality and number decreased significantly
Easter lily	58	77 days	Flowering and plan quality significantly decreased
Oat	40	100 days	Floret number 26 % lower than in "background" treatment (8 µg/m^3)

rochemical industry in Alberta was increasing. Nearby agricultural producers were concerned that ethylene might affect plant growth and yield. The scientific literature yielded little about ethylene effects on crops commonly grown in Alberta. Government and industry cooperatively sponsored the Alberta Ethylene Crop Research Project from 1997 to 2001 (Alberta Research Council 2002). The results of the project (e.g. Archambault and Li 2001) provided key scientific information and were instrumental in finalizing Alberta's AQO for ethylene.

Risk Characterization

Risk characterization summarizes and integrates the information on hazard, dose-response, and exposure. It provides information about harmful effects for various exposures and the uncertainties or level of confidence in that information. The risk characterization provides a summary of the critical findings of the risk assessment process in language that can be understood by other scientists, regulators, stakeholders, and the general public (McColl et al. 2000). Effective risk characterization depends upon transparency, clarity, consistency and reasonableness (Science Policy Council 2000). The assessment documents produced by Ontario and Alberta may be regarded as "risk characterizations" although they do not use the term.

In the risk assessment documents emerging from Canadian federal process, risk characterization has appeared as a final chapter in the science assessment (e.g. Working Group 1999) or as a section in an Executive Summary (e.g. Working Group 1998). However, in these documents risk characterization is intended "to evaluate the weight of evidence presented in the Science Assessment Document to determine whether or not the findings support a causal association."

14.4.3 Managing Risks

The risk management stage integrates information from the risk assessment with economic and technical factors as well as ethical, social, legal, and achievability considerations. Information about existing background levels and trends in emissions is examined and various types of socio-economic studies may be conducted to inform the decision (see Introduction).

Background concentrations constitute one of the major uncertainties for some pollutants. Scientists often define "background" as the concentrations in pristine conditions unaffected by man-made disturbances, while air quality managers define background as the concentrations arriving at the upwind boundary of their jurisdiction. The air entering a jurisdiction will be a combination of natural and man-made pollution from upwind sources (McKendry 2006). Determining the actual concentrations for pollutants like ozone can be problematic. Reid (2007) summarizes the controversy about background ozone concentrations with reported values ranging from 15–60 ppb. High background concentrations due either to natural sources or transport from upwind source regions may severely limit the ability of a jurisdiction to meet the Canada-Wide Standard for Ozone. The achievement determination guidance document (CCME 2007) contains explicit procedures to account for transboundary flow, background levels and natural events.

The composition of the team making the risk management decision about the ambient air quality objective often determines the range of factors considered and the depth of analysis. Teams within a regulatory agency may be mindful of the means of implementation, the reaction of various stakeholder groups, and the disposition of senior decision-makers. Teams from multiple departments of a government may look more closely at impacts on affected parties, potential media attention, and consistency with the overall program of the government. There will be discussions about the significance of various effects, the importance of various species (indigenous and imported), public values, aesthetics and economics.

Teams drawn from the fourteen air quality jurisdictions in Canada bring different regional priorities, different economic concerns, different management structures and different philosophies to the table. Socio-economic impacts like facility closures and unemployment may need to be assessed and parts of the risk assessment may be questioned. The Canadian Council of Ministers of the Environment works with a consensus decision making model (CCME 2011a) and has developed a toolkit (CCME 2011b) to assist in forging agreements among governments with disparate interests. Teams that include stakeholders extend the perspectives even further, adding considerations such as industry competitiveness on the one hand and environmental justice on the other. The risk assessment and the socio-economic analysis may be questioned and external reviews may be sought (e.g. Royal Society 2001).

Individuals and groups are guided by their *worldview*, the comprehensive philosophy or conception of the world and human life that serves as a framework for organizing perceptions, shaping attitudes and interpreting reality. Inevitably there will be differences of opinion about the significance of effects, the relative importance of various endpoints, the weight of evidence, the cost of implementation, "fairness" and other factors that enter into risk management deliberations. A variety of tools are available to bring people together for constructive dialogue. Ultimately, the regulatory agency must balance a variety of perspectives and the AQO is a judgment on behalf of society as to what risks to health and ecosystems are acceptable.

14.4.4 Engaging Stakeholders

The Introduction provides an overview of the approaches and methods used to engage stakeholders. These can all be used in the process for setting ambient air quality objectives as can the techniques for group priority-setting outlined earlier in this chapter. All Canadian jurisdictions provide opportunities for stakeholder input at various stages of the objective-setting process. Ontario uses stakeholder meetings and the Environmental Bill of Rights registry website (Ontario Ministry of Environment 1999). Environment Canada uses the CEPA Registry website and other project-specific forms of consultation. Alberta involves stakeholder representatives in the entire objective-setting process, from priority-setting through risk assessment to risk management (Blair et al. 2007; Alberta Environment 2005).

CCME (1993) follows a set of principles in designing a stakeholder engagement process for its initiatives. The government of Canada (Privy Council Office 2000) has directed that a "citizen focus" be built into all federal government activities, programs and services. Health Canada (2000) developed a toolkit with a variety of methods for engaging the public in decision-making, Smith (2003) provided a practical guide, and the Health Council of Canada (Gauvin et al. 2005) explored the conditions for successful public involvement. The Canadian Institutes of Health Research have published both a framework (2009a) for engaging citizens in its research and a handbook (2009b) to introduce staff to the breadth of considerations in planning citizen engagement activities.

14.5 Provincial Ambient Air Quality Objectives

The risk assessment-risk management framework can be applied at various scales of effort. At one extreme, the development of Canada-Wide Standards for PM and Ozone required the pooling of talent and finances from the federal government, the ten provinces, and three territories. At a more modest level of effort many provinces, for example, Ontario and Alberta, have been able to develop AQOs for a wide variety of pollutants. There are also some shortcuts than can be used in some situations to streamline the process. Five useful approaches that have been used alone or in combination are:

1. **As Good As:** A community can decide it wants air quality "as good as" another community, "as good as" an earlier time in its own history, or "as good as" that experienced during particular time periods in the year (Newill 1977). No analysis of effects is required. The decision can be taken by community leaders or there can be extensive polling of residents. Non-degradation seeks to maintain current levels, that is, air quality in the future is to be "as good as" it is now.

   The Canada-Wide Acid Rain Strategy for Post 2000 (Federal/Provincial/Territorial Ministers of Environment and Energy 1998) included a policy called "keeping clean areas clean" that identified the need to manage emissions of SO_2 and NO_x to ensure deposition levels do not approach the critical loads. The Canada-Wide Standards for Particulate Matter and Ozone (CCME 2000) also contained provisions for "keeping clean areas clean" through the application of pollution prevention, continuous improvement and best management practices.
2. **Best of Class:** Air quality objectives from other jurisdictions are reviewed, and the most stringent from a relevant jurisdiction is selected. A relevant jurisdiction can be defined in terms of population, climate, types of industries, economic structure, legal framework, regulatory philosophy or other characteristic. This provides a quick and inexpensive way to put forward new objectives, relying on decisions taken elsewhere. However, there is the danger of adopting a number that was designed for an entirely different purpose (BC Ministry of Healthy Living and Sport 2010).

   Ontario (Bailey 1999) has reviewed its AQOs against other jurisdictions and Alberta (Alberta Environment 2010) has adopted some of its AQOs from other jurisdictions. Many provinces continue to use the numbers established under the old federal Clean Act in 1974.
3. **Effects-based:** At the end of risk assessment, the scientists conducting the assessment use their expert judgment

to select an air quality objective that protects against significant effects. There is no consideration of costs, achievability and other factors, all of which are deferred to implementation.

Ontario establishes Ambient Air Quality Criteria at levels below which adverse health and/or environmental effects are not expected. For non-carcinogens the criteria can be based on the no-observed-adverse-effect level (NOAEL) or lowest-observed- adverse-effect level (LOAEL) with or without "safety" or "uncertainty" factors applied. For carcinogens (cancer-causing pollutants) the Criteria are generally based on a probability of 1 in a million or 10 in a million over a lifetime. Odour, vegetation, soiling, visibility, corrosion or other effects are also considered and a pollutant may have multiple ambient air quality criteria. The criteria apply to general air quality independent of location and are used for environmental assessments, special studies using ambient air monitoring data, and the assessments of general air quality in a community (Ontario Ministry of Environment 2008).

Ontario also establishes *point of impingement* limits to review applications for permits and to assess compliance with Ontario regulations (Ontario Ministry of Environment 1999). Point of Impingement limits are used with dispersion models for permitting. They apply to a ½-h averaging time. The numerical values are generally derived from the criteria using a factor of 15 to convert from annual average concentrations and a factor of three to convert 24-hour averaging times (Bailey 1999).

4. **Exposure Reduction:** Applying the principle of continuous improvement, an AQO is expressed as a required percentage decrease in concentrations. Some analysis may be undertaken to determine the benefits of exposure reduction.

   Environment Canada's Clean Air Regulatory Agenda (Environment Canada 2007) set intended emission reductions targets ranging from 20 to 55% which, given the linear relationship between emissions and ambient air quality, implies similar reductions in ambient concentrations in the vicinity of the sources making the reductions.

   Under the proposed new Comprehensive Air Management System for Canada, new Canadian Ambient Air Quality Standards would be informed by using a new Population Exposure Improvement methodology (CCME 2010). This method links ambient concentrations to the size of the population exposed. The potential standards could then be set by specifying the desired reduction in exposed population.

5. **Worker Extrapolation:** Occupational health standards are modified to serve as objectives for ambient air outside the workplace (Cannon 1986; Bailey 1999). The adjustment factor typically ranges from 100 to 1000. An adjustment calculation could proceed as follows: start with the 8-hour Threshold Limit Value (TLV) of the American Conference of Government Industrial Hygienists; divide by 10 to take into account the greater susceptibility of the general population; multiply by 8/24 (the ratio of the number hours workers are exposed to the number of hours a member of the general public might be exposed); multiply by 5/7 (the ratio of the number of days in a week a worker is exposed to the number of days in a week that a member of the general public might be exposed); multiply by 30/70 (the ratio of the number of years a worker is exposed to the number of years a member of the general public might be exposed in a lifetime). Further adjustments might be made for uncertainty in knowledge (e.g. divide by another factor of 10) or some other difference depending on the pollutant. Occupational exposure limits are available for a wide range of chemicals and provide a relatively simple way to take advantage of the extensive risk assessment conducted by the occupational health organizations.

   The method is generally used when there is no literature for health effects at anticipated environmental exposure levels. It provides a quick way to create ambient objectives for use in permitting. Many US state agencies have applied this approach to manage toxic air pollutants, and thus Canadian jurisdictions adopting the same objective have indirectly also used this approach. It is not presently known whether an AQO derived in this way would approximate an AQO derived from an appropriate set of scientific health effects studies.

The "best of class", and "worker extrapolation" approaches rely upon risk assessments done by other jurisdictions. The "exposure reduction" and "as good as" approaches eliminate any explicit risk assessment and move immediately to risk management. In the effects-based approach the AQO emerges from the risk assessment, and risk management consists of planning for implementation.

Initially most provinces adopted the national maximum acceptable levels of 1974–75 while a few adopted the national maximum desirable levels. For many provinces, these levels are still in effect, as Table 14.1 illustrated for sulphur dioxide. More than three decades have passed since these AQOs were derived and much new information has emerged. Particulate matter and ozone have been the focus of recent national updates. For the other pollutants, a few provinces have independently undertaken reviews using their own processes.

Provinces have also found that AQOs are needed for a variety of other pollutants of concern within their jurisdictions. For example, Quebec, Ontario, Manitoba, Alberta and British Columbia have AQOs for formaldehyde. In 2011 Canadian air quality jurisdictions had the following numbers of AQOs as a reflection of their respective industrial bases and the concerns of citizens: Ontario (339), Quebec (79), Alberta (48), Manitoba (26), Newfoundland (23), British

Columbia (12), Saskatchewan (10), New Brunswick (6), Yukon (6), Northwest Territories (6), Nova Scotia (6), Prince Edward Island (5), Nunavut (2), Metro Vancouver (6), Communauté métropolitaine de Montréal (9).

14.6 Conclusion

Ambient air quality objectives have been an important part of air quality management in Canada since the 1970s. Under the Canadian Clean Air Act of 1971 a three-tier framework for objectives was developed and levels were established for sulphur dioxide, nitrogen dioxide, carbon monoxide, ozone and total suspended particulate. The Clean Air Act was subsumed into the Canadian Environmental Protection Act in 1988 and a different approach to AQOs was explored. In 2000, the Canadian Council of Ministers of the Environment produced updated air quality objectives for $PM_{2.5}$ and ozone. In 2010 the Canadian Council of Ministers of Environment proposed a new air management system for Canada with new national AQOs as a key component. AQO development has followed a three-stage risk paradigm in which priorities are set, risks are assessed and then risks are managed. Risk assessment has struggled with choosing appropriate endpoints and evaluating the quality of scientific studies. A variety of methods have been used to engage stakeholders. The provinces have produced AQOs for a large number of pollutants, sometimes applying shortcut methods.

References

Alberta Environment (2003) Assessment report on ethylene for developing ambient air quality objectives. Alberta Environment, Edmonton

Alberta Environment (2005) Alberta ambient air quality objectives work plan 2005–2008. Environmental Policy Branch, Edmonton

Alberta Environment (2009) Alberta ambient air quality objectives: hydrogen fluoride. Government of Alberta, Edmonton

Alberta Environment (2010) Alberta ambient air quality objectives and guidelines. Air Policy Branch, Edmonton

Alberta Environment (2011) Using ambient air quality objectives in industrial dispersion modelling and individual industrial site monitoring. Alberta Environment, Edmonton

Alberta Research Council (2002) Alberta's ethylene crop research project. Alberta Research Council. Edmonton

APIS (2012) Critical loads and critical levels—a guide to the data provided in APIS. Air pollution information system. www.apis.ac.uk. Accessed 28 Apr 2012

Archambault D, Li X (2001) Report III. Response of barley, field pea, canola and tree seedlings to ethylene exposure. Alberta Research Council, Edmonton

Bailey S (1999) Reviewing Ontario's air standards. Standards development branch. Ontario Ministry of Environment, Toronto

Barry PJ (1977) Stochastic properties of atmospheric diffusivity. In: Sulphur and its inorganic derivatives in the Canadian Environment, National Research Council, Ottawa

BC Ministry of Healthy Living and Sport (2010) Proposed provincial framework for the development of ambient air quality objectives. Victoria

Blair L, Fu L, Angle R (2007) Alberta's multi-stakeholder process for developing ambient air quality objectives. Extended abstract. Paper #164. Air and waste management association 100th annual conference & exhibition, Pittsburgh

Brown B (1968) Delphi process: a methodology used for the elicitation of opinions of experts. The Rand Corporation, Santa Monica

Brown TC, Peterson GL (2009) An enquiry into the method of paired comparison: reliability, scaling, and Thurstone's law of comparative judgment. United States Department of Agriculture, Ft. Collins

Bull KR (1991) The critical loads/levels approach to gaseous pollutant emission control. Environ Pollut 69:105–123

CASA (1999) Application of critical, target and monitoring loads for evaluation and management of acid deposition. Alberta Environment, Edmonton

CASA (2003) Particulate matter and ozone management framework. Clean Air Strategic Alliance, Edmonton

CCME (1993) Guidelines for consultations and partnerships involving stakeholders in CCME. Canadian Council of Ministers of the Environment, Winnipeg

CCME (1999) Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg

CCME (2000) Canada-Wide standards for particulate matter (PM) and ozone. Canadian Council of Ministers of the Environment, Winnipeg

CCME (2007) Guidance document on achievement determination, Canada-wide standards for particulate matter and ozone, revised. Canadian Council of Ministers of the Environment, Winnipeg

CCME (2010) Comprehensive air management system: a proposed framework to improve air quality management. Canadian Council of Ministers of the Environment, Winnipeg

CCME (2011a) Strengthening consensus: reinforcing the CCME Consensus Decision-Making (CDM) model. Canadian Council of Ministers of the Environment, Winnipeg

CCME (2011b) Consensus building: a table guide & toolkit. Canadian Council of Ministers of the Environment, Winnipeg

Cannon JA (1986) The regulation of toxic air pollutants: a critical review. JAPCA 36(5):562–573

Caton RB, Bates DV (2002) Updating BC provincial air quality objectives—an options discussion paper. BC Ministry of Water, Land & Air Protection, Victoria

Caton RB, Schroeder WH, Young JWS (1988) Priority-setting strategies for airborne toxic chemicals. Intern J Environmental Studies 31:111–127

Chen CW, Goldstein RA (1986) Techniques for assessing ecosystem impacts of air pollutants. In: Legge AH and Krupa SV (eds) Air pollutants and their effects on the terrestrial ecosystem. John Wiley & Sons, New York

Canadian Institutes of Health Research (2009a) CIHR's framework for citizen engagement. Canadian Institutes of Health Research, Ottawa

Canadian Institutes of Health Research (2009b) CIHR'S citizen engagement handbook. Canadian Institutes of Health Research, Ottawa

Crowe S (2009) Setting priorities for treatment uncertainties—a review of methods. James Lind Alliance, Oxford

DCLG (2009) Multi-criteria analysis: a manual. Department of Communities and Local Government, London

Davies DB, Haggerty SE (2002) Health effects associated with short-term exposure to low levels of hydrogen sulphide (H_2S)—a technical review. Alberta Health and Wellness, Edmonton

Delbecq A, Van de Ven AH (1971) A group process model for problem identification and program planning. J Appl Behav Science 7:466–492

Eberhardt LL, Thomas JM (2008) Designing environmental field studies. Ecological Monographs 61(1):53–73

Environment Canada (2007) Regulatory framework for air emissions. Government of Canada, Ottawa

Federal-Provincial Advisory Committee on Air Pollution (1976) Criteria for national air quality objectives: sulphur dioxide, suspended

particulates, carbon monoxide, oxidants (ozone) and nitrogen dioxide. Fisheries and Environment Canada, Ottawa
Federal/Provincial/Territorial Ministers of Environment and Energy (1998) Canada-Wide acid rain strategy-post 2000: strategy and supporting document. Halifax, Nova Scotia. October 19, 1998. Minister of Public Works and Government Services Canada, Ottawa
Five Winds International (2004) Setting priorities for ambient air quality objectives. Alberta Environment, Edmonton
Franson MAH, Franson RT, Lucas AR (1982) Environmental standards: a comparative study of Canadian standards, standard setting processes and enforcement. Environment Council of Alberta, Edmonton
Fu L, Myrick B et al (2000) One-hour equivalent of a 24-hour average particulate matter standard and its potential application in the index of the quality of the air (IQUA). Presented at the air and waste management association conference, Banff, Alberta, 10–12 April 2000
Fuhrer J, Skirby L, Ashmore MR (1997) Critical levels for ozone effects on vegetation in Europe. Environ Pollut 97(1–2):91–106
Gauvin FP, Abelson J, MacKinnon MP, Watling J (2005) Primer on public involvement. Health Council Canada, Toronto
Health Canada (2000) Health Canada Policy toolkit for public involvement in decision making. Ministry of Public Works and Government Services Canada, Ottawa
I-TECH, the international training and education center for health (2008) Organizing and conducting focus groups. University of Washington, Seattle
Leiss W (2008) Development of the expert panel process in Canada, 1995–2005. Royal society of Canada, Ottawa
McColl S, Hicks J, Craig L, Shortreed J (2000) Environmental health risk management: a primer for Canadians. Institute for risk research, Waterloo
McKendry IG (2006) Background concentrations of $PM_{2.5}$ and ozone in British Columbia, Canada. British Columbia Ministry of Environment, Victoria
NRCC (1981) Hydrogen sulphide in the atmospheric environment: scientific criteria for assessing its effects on environmental quality. National research council Canada associate committee on scientific criteria for environmental quality, Ottawa
NRCC (1982) Effects of aerosols on atmospheric processes. National research council Canada associate committee on scientific criteria for environmental quality, Ottawa
National Round Table on the Environment and the Economy (2008) Developing ambient air quality objectives for Canada: advice to the minister of the environment. National round table on the environment and the economy, Ottawa
Newill VA (1977) Air quality standards. In: Air pollution, 3rd edn, Vol. V. Academic Press, New York
Nixon A, Curran T (1998) Acid rain. Parliamentary research branch, government of Canada, Ottawa
Odum EP (1993) Ecology and our endangered life-support systems, 2nd edn. Sinhauer, Sunderland
Ontario Ministry of Environment (1999) Setting environmental quality standards in Ontario: the ministry of the environment's standards plan. Ontario ministry of environment, Toronto
Ontario Ministry of Environment (2006) Rationale for the development of Ontario air standards for toluene. Ontario ministry of environment, Toronto
Ontario Ministry of Environment (2008) Ontario's ambient air quality criteria (sorted by chemical name). Ontario ministry of environment, Toronto
Priestly B, Drew R, McNeil J, Abramson M, Forbes A (2006) Ambient air quality standards setting: an approach to health-based hazard assessment. National Health and Medical Research Council and Environmental Health Committee, Canberra
Privy Council Office (2000) Policy statement and guidelines on consulting and engaging Canadians. Government of Canada, Ottawa
Randolph JJ (2009) A guide to writing the dissertation literature review. Practical Assessment, Research and Evaluation Volume 14, Number 13
Reid N (2007) A review of background ozone in the troposphere. Ontario ministry of environment, Toronto
Royal Society of Canada (2001) Report of an expert panel to review the socio-economic models and related components supporting the development of Canada-wide standards for particulate matter and ozone. Royal Society of Canada, Ottawa
RWDI Air (2005) Final report odour management in British Columbia: review and recommendations. BC Ministry of Water, Land and Air Protection, Victoria
RWDI Air (2008) Establishing a visibility goal for wilderness and urban areas in British Columbia and Canada. BC Ministry of Environment, Victoria
Saskatchewan Environment (2007) Air monitoring directive for Saskatchewan. Saskatchewan Environment, Regina
Science Policy Council (2000) Risk characterization handbook. United States Environmental Protection Agency, Washington
Smith BL (2003) Public policy and public participation: engaging citizens and community in the development of public policy. Atlantic Regional Office, Health Canada, Halifax
UNECE (2012) ICP modelling and mapping critical loads and levels approach. http://www.unece.org/env/lrtap/WorkingGroups/wge/definitions.html. Accessed 29 April 2012
WBK & Associates (2004) Assessment report on ammonia for developing ambient air quality objectives volume 1. Alberta Environment, Edmonton
Working group on air quality objectives and guidelines (1994) National ambient air quality objectives for carbon monoxide: desirable, acceptable & tolerable levels. Environment Canada and Health Canada, Toronto
Working group on air quality objectives and guidelines (1996a) A protocol for the development of national ambient objectives, Part 1, Science assessment document and derivation of the reference level(s). Environment Canada and Health Canada, Toronto
Working group on air quality objectives and guidelines (1996b) National ambient air quality objectives for hydrogen fluoride (HF) science assessment document. Environment Canada and Health Canada, Toronto
Working group on air quality objectives and guidelines (1998) National ambient air quality objectives for particulate matter. Executive Summary. Public Works and Government Services, Ottawa
Working group on air quality objectives and guidelines (1999) National ambient air quality objectives for ground-level ozone science assessment document. Health Canada and Environment Canada, Ottawa