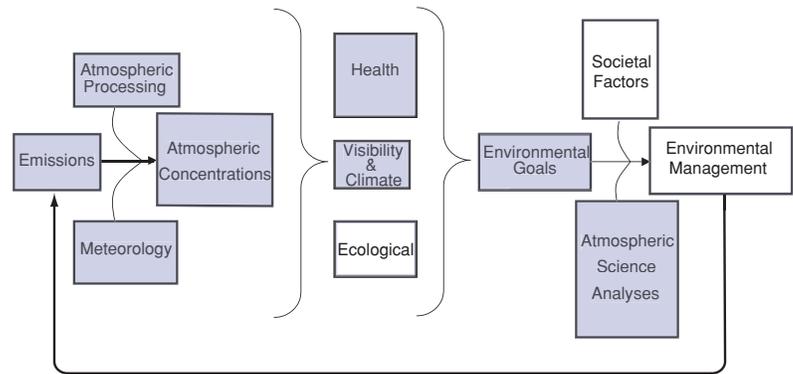


# CHAPTER 1

## Perspective for Managing PM

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*P*articulate Matter Science for Policy Makers: A NARSTO Assessment is a concise and comprehensive discussion of the current understanding of airborne particulate matter (PM) among atmospheric scientists. Its goal<sup>1</sup> is to provide policy makers who implement current air-quality standards<sup>2</sup> with relevant scientific information.

This chapter introduces the framework used to organize the Assessment, as well as the scientific scope and the regulatory setting. Background discussions of the PM problem address the nature of ambient particles; the scale, sources, and management of the problem; health and visibility impacts; and federal ambient PM standards and policy contexts for Canada, the United States, and Mexico.

The information contained in this Assessment addresses three key applications:

- Implementing fine and coarse PM standards.
- Designing implementation plans for PM management in concert with those for ozone and other ambient pollutants (e.g., NO<sub>x</sub>, SO<sub>2</sub>, VOCs, and CO), leading to effective multi-pollutant air-quality management approaches.

- Coordinating linkages between the atmospheric- and health-science communities to investigate the causal hypotheses of health impacts, characterize exposure, and contribute to long-term epidemiological studies.

Several other PM-related aspects, although important, are not addressed directly in this Assessment. Climate-change and ecosystem impacts, particularly noteworthy in this regard, are discussed extensively in other reports<sup>3</sup>, and thus not covered here.

The interface between health and atmospheric sciences is essential both because of the importance of health effects in establishing air-quality standards and because of the critical need for information exchange between the two scientific communities. Chapter 2 of this Assessment provides a brief overview of PM impacts on human health, to set a context for the remainder of the document.

The framework developed for organizing this Assessment is illustrated in Figure 1.1. Emphasizing the delivery of information for use by the policy community, the three principal components of the framework are:

**The Atmospheric Environment:** Understanding the relationships among pollutant emissions, their interactions with meteorology and other

<sup>1</sup> Specific guidance pertaining to this Assessment's objectives and target audience given to the PM Assessment Team by NARSTO's Executive Assembly and Executive Steering Committee appears in Appendix E.

<sup>2</sup> Canadian, U.S., and Mexican air-quality standards undergo continuous review as a part of ongoing evaluation procedures. While future modifications of these standards are possible, this Assessment accepts them in their current forms to help focus the presentation. Science review documents pertinent to current PM standards are CEPA (2000), Diario Oficial de la Federación (1994), NOM (1993), U.S. EPA (1996), and WGAQOG (1999).

<sup>3</sup> For comprehensive reviews of climate-change and ecosystem impacts in the context of PM refer to IPCC (2002), Environment Canada (1998), and NAPAP (1998).

atmospheric processes, and the resultant atmospheric-pollution loadings.

**Exposure and Impacts:** Understanding of cause-effect relationships among atmospheric pollutants, exposures and deposition, and impacts on human health, visibility, and ecological systems. This includes the important risk-characterization step directly supporting standard and environmental goal setting.

**Analysis and Public Policy:** Analysis and decision making by the policy community, considering atmospheric science and societal factors in relation to environmental goals, in formulating emission-reduction programs.

Because of its focus on atmospheric phenomena, this Assessment deals primarily with components on the left of Figure 1.1, although health and visibility effects are discussed.

## 1.1 THE NATURE OF AMBIENT PARTICLES

Individual particles are characterized by their sizes, shapes, and chemical composition. They can be solid or liquid, spherical or irregularly shaped, and can contain internal mixtures of species and phases. Particle surface composition may differ from bulk composition, and it is common for PM falling within any particular size range to include particles having a variety of shapes and compositions. “Semivolatile” species such as water,  $\text{NH}_4\text{NO}_3$ , and many organic compounds continually undergo exchanges between the gas and condensed phases, often resulting in pronounced compositional changes of PM with time.

PM is typically composed of a complex mixture of chemicals, a mixture strongly dependent on source characteristics. The terminology used to describe PM incorporates source characteristics, formation

### Framework for Informing PM Management

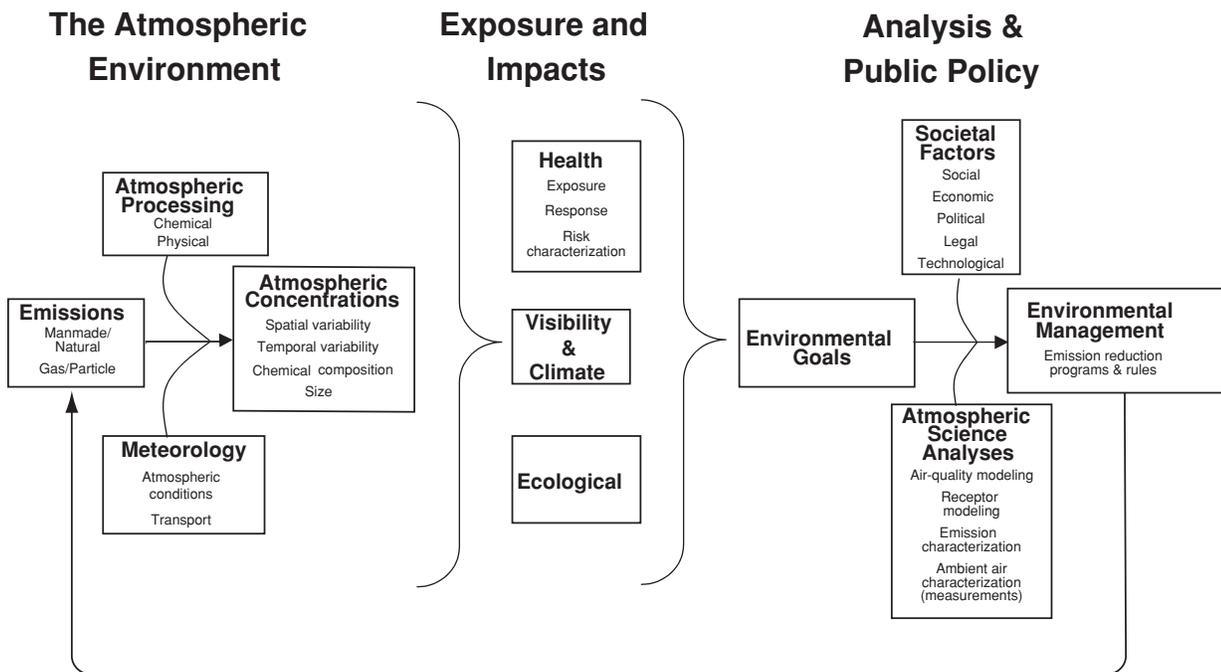


Figure 1.1. Framework for informing PM management.

mechanisms, particle sizes, and chemical composition. Other distinguishing features of PM, such as particle size, origin (primary or secondary), mode, and carbon content, also are used to describe PM. The terminology used in this Assessment is defined in Textbox 1.1 and in the glossary.

As indicated in Table 1.1 and Figure 1.2, PM composition varies between the fine and coarse fractions. The fine fraction is characterized by constituents such as  $\text{SO}_4^-$ ,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ , metals, and hundreds of different organic carbon compounds.

The coarse fraction is characterized by materials typical of the earth’s crust (primarily suspended dust and construction debris) and grinding processes (metals).

Because of practical necessity it is common to characterize PM in terms of simplified, aggregate properties. Common characterizations include total mass concentration and total number concentration. Often such characterizations pertain to specified size ranges:  $\text{PM}_x$ , for example, is used to signify the mass concentration of particles falling within size-range x.

Table 1.1. Comparison of ambient particle fractions.

	Fine ( $\leq 2.5 \mu\text{m}$ )		Coarse ( $2.5 - 10 \mu\text{m}$ )
	Ultrafine ( $< 0.1 \mu\text{m}$ )	Accumulation ( $0.1 - 2.5 \mu\text{m}$ )	
<b>Formed from:</b>	Combustion, high-temperature processes, and atmospheric reactions		Break-up of large solids/droplets
<b>Formed by:</b>	Nucleation Condensation Coagulation	Condensation Coagulation Evaporation of fog and cloud droplets in which gases have dissolved and reacted	Mechanical disruption (crushing, grinding, and abrasion of surfaces) Evaporation of sprays Suspension of dusts Reactions of gases in or on particles
<b>Composed of:</b>	Sulfate, $\text{SO}_4^-$ Black carbon Metal compounds Low-volatility organic compounds	Sulfate, $\text{SO}_4^-$ Nitrate, $\text{NO}_3^-$ Ammonium, $\text{NH}_4^+$ Hydrogen ion, $\text{H}^+$ Black carbon Large variety of organic compounds Metals: compounds of Pb, Cd, V, Ni, Cu, Zn, Mn, Fe, etc. Particle-bound water	Suspended soil or street dust Fly ash from uncontrolled combustion of coal, oil, and wood Nitrates and chlorides from $\text{HNO}_3$ and HCl Oxides of crustal elements (Si, Al, Ti, and Fe) $\text{CaCO}_3$ , NaCl, and sea salt Pollen, mold, and fungal spores Plant and animal fragments Tire, brake-pad, and road-wear debris
<b>Typical Atmospheric half-life:</b>	Minutes to hours	Days to weeks	Minutes to hours
<b>Important Removal processes:</b>	Growth into accumulation mode Wet and dry deposition	Wet and dry deposition	Wet and dry deposition
<b>Typical Travel distance:</b>	<1 to 10s of km	100s to 1000s of km	<1 to 10s of km (100s to 1000s in dust storms)
Source: Adapted from Wilson and Suh (1997).			

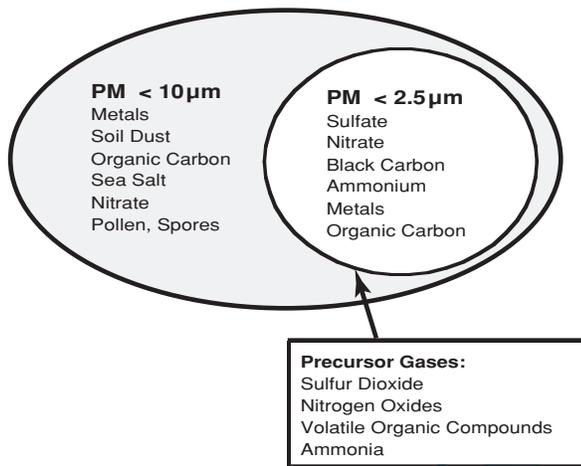


Figure 1.2. Representative composition of PM.

Particles directly emitted to the atmosphere are termed “primary” particles. Such particles can be coarse (e.g., dust, plant debris, pollen, sea spray) or fine (e.g., combustion products, a small fraction of sea spray). “Secondary” PM results from the condensation/deposition of gaseous precursors to the particulate phase. Although direct nucleation from the gas phase definitely is a contributing factor, most secondary material accumulates on pre-existing particles in the 0.1 to 1.0  $\mu\text{m}$  range and typically accounts for significant fractions of the  $\text{PM}_{2.5}$  mass. Ultrafine particles originate from combustion sources and from homogeneous nucleation of low vapor-pressure compounds. Although ultrafine particles contribute only a small fraction of PM mass, they often account for most of the particle number concentration. It is not unusual, for example, for the particle number concentration to increase by factors to 2 to 10 during nucleation events.

Measurements show that PM can be classified into four modes, which reflect particle origins. These are the coarse mode (particle diameter larger than  $\sim 2 \mu\text{m}$ ), the accumulation mode (0.1 to 2  $\mu\text{m}$ ), the Aitken mode (0.01 to 0.1  $\mu\text{m}$ ), and the nucleation mode ( $< 0.01 \mu\text{m}$ ). Coarse-mode particles are lost rapidly by sedimentation, and nucleation-mode particles grow and coagulate, typically migrating into the Aitken mode as a result. Accumulation-mode particles have longer lifetimes than larger or smaller particles because they settle slowly and have low diffusivities. Because of this, accumulation-mode particles can be transported extended distances – on

the order of 1000 km or more – before they are removed from the atmosphere.

The carbon fraction, which on average may represent from 1/5 to 1/2 of  $\text{PM}_{2.5}$  mass, is currently not well characterized by routine measurements. It typically consists of elemental carbon plus large numbers of different organic species and arises from direct emissions and as a result of transformation and condensation of gaseous organic compounds. Combined with technical difficulties in measuring the carbon fraction, this compositional complexity has resulted in the PM carbon component being poorly understood at present.

Terms such as “black carbon (BC),” “elemental carbon (EC),” and “soot” are often used interchangeably by air-quality, atmospheric, health, and industrial researchers, reflecting the presently high degree of ambiguity in this particular area. Textbox 1.2 describes the terminology used in this Assessment. Scientific considerations associated with this issue are discussed at length in later chapters.

## 1.2 SCALE, SOURCES, AND MANAGEMENT OF THE PROBLEM

**P**M mass concentrations vary significantly on both temporal and spatial scales. The highest PM loadings, excluding dust storms and fires, usually occur in major urban centers and small industrial areas where local sources strongly influence air quality. Long-range transport of PM and precursor gases has been documented for ground-level ozone and its precursors, as well as nitrate and sulfate compounds on regional, continental, and transoceanic scales. Figure 1.3 illustrates the potential for PM to be an issue at all spatial scales depending on the relative contributions of precursor gases and primary particles.

Varying source contributions and meteorological influences drive a large dynamic range of seasonal and diurnal variations in PM mass concentration and composition. Consequently PM composition and its relationships to copollutants, especially ground-level ozone, also vary (see Chapter 6). Generally, the long-term behavior of daily-averaged PM mass

**Box 1.1. Terminology**

The aerosol literature has experienced a proliferation of diffusely defined terminology (e.g., fine particles, total suspended particulate matter, aerosols, superfine particles, ultrafine particles, hyperfine particles, nanoparticles, . . . ), a situation which has served to obscure scientific communication in the field. In an attempt to limit this tendency, this Assessment restricts itself to a limited number of terms, defined below. This terminology is consistent with that used by the Intergovernmental Panel on Climate Change.

**Suspended particulate matter (PM):** Any non-gaseous material (liquid or solid) which, owing to its small gravitational settling rate, remains suspended in the atmosphere for appreciable time periods.

**Aerosol:** A mixture of suspended PM and its gaseous suspending medium.

The terminology denoting suspended PM subclasses is selected primarily, but not totally, on the basis of physicochemical processes involved in formation and growth of the particles (see Chapter 3, Figure 3.2, which describe four “modes”: coarse, accumulation, Aitken, and nucleation).

**Ultrafine particles:** Particles operationally defined (mainly within the health-sciences community) as those having diameters less than 0.1  $\mu\text{m}$

**Fine particles:** Particles operationally defined as those smaller than 2.5  $\mu\text{m}$  aerodynamic diameter. Fine-particle measurements include the accumulation mode (nominally 0.1 to 2.5  $\mu\text{m}$ ), where most of the submicron mass is found and, depending on measurement technique, may include ultrafine particles, where most of the particle number concentration is found. Because filter-based  $\text{PM}_{2.5}$  sampling techniques collect all particles smaller than 2.5  $\mu\text{m}$ , such “fine-particle” samples implicitly include ultrafine particles. However, because the properties and effects of ultrafine particles are different from those of larger particles, it is often useful to separately identify “fine” and “ultrafine” particles as distinct fractions of  $\text{PM}_{2.5}$ .

**Coarse particles:** Particles extending through the high end of the aerosol size distribution. This Assessment adopts the proposed regulatory definition, which includes those particles between 2.5  $\mu\text{m}$  and 10  $\mu\text{m}$  aerodynamic diameter ( $\text{PM}_{10-2.5}$ ). Many “coarse-particle” sampling techniques also collect particles in the finer ranges. Thus reported data designated as “coarse-particle” data may or may not include contributions from finer modes, and these contributions can be significant.

**$\text{PM}_{10}$ :** The mass concentration of particles smaller than 10  $\mu\text{m}$ . In practice,  $\text{PM}_{10}$  samplers do not provide perfectly sharp cuts at 10  $\mu\text{m}$ . Instead, size-dependent collection efficiencies typically decrease from 100 percent at  $\sim 1.5 \mu\text{m}$  to 0 percent at  $\sim 15 \mu\text{m}$ , and are equal to 50 percent at 10  $\mu\text{m}$ .

**Primary PM:** PM that is emitted directly to the atmosphere in solid or liquid form.

**Secondary PM:** PM formed in the atmosphere through condensation/deposition of gaseous precursors.

concentrations exhibits a strongly skewed distribution, dominated by a large number of low values and a small number of high values. At urban sites, with multiple years of data, mean PM mass concentrations can range between 4 and 8 times the estimated natural background levels, implying that anthropogenic activities make substantial contributions to ambient PM loadings in both urban and non-urban locations. The relative source contributions to ambient PM vary both geographically and seasonally. Table 1.2 summarizes the major source contributions to primary and secondary PM.

Effective PM management usually requires consideration of both anthropogenic and natural sources. Within this context, this Assessment identifies two broad source categories: manageable and unmanageable. At one extreme, manageable emissions can be identified readily with industrial sources, commercial operations, power plants, residential dwellings, and transportation. At the other extreme, unmanageable emissions result from volcanic eruptions, windblown sea spray, dust storms from remote arid areas, and forest or brush fires initiated by lightning strikes or spontaneous combustion. Other unmanageable emissions include

### Box 1.2. The Carbon Fraction

The “**carbon fraction**” may refer to black carbon and primary organic and/or secondary organic carbon.

**Black carbon (BC)** is the light-absorbing carbonaceous material in atmospheric particles; most BC is primary. Terms that are sometimes used interchangeably include elemental carbon (EC), soot, and graphitic carbon. BC is chemically complex: it can include light-absorbing solids or liquids, and its composition varies with the source. Conventional analytical methods<sup>a</sup> for BC do not measure its composition, but rather measure parameters that serve as indicators of BC concentrations. For historical reasons, specific measurement methods often use a particular term (e.g., BC, EC, soot, etc.) to identify the measured quantity; for example, BC and EC are often used to indicate optical and thermal measurement methods, respectively. In this Assessment, we use BC generically and apply other terms only when required by context

**Organic carbon (OC)** includes both primary emissions and secondary organic PM. Secondary organics are produced in the atmosphere by chemical transformations of volatile organic compounds (VOCs) or by the uptake of organic gases by particles.

Organic compounds play an important role in the PM problem:

(a) *Small organic molecules* ( $C_1$  to  $C_6$  compounds) occur in the atmosphere mainly as vapors. These reactive compounds contribute significantly to photochemical reactions leading to ozone generation, as well as the oxidation of  $SO_2$ ,  $NO_x$  and VOCs.  $SO_2$  and  $NO_x$  oxidation lead to  $SO_4^{=}$  and  $HNO_3$  formation, and contribute significantly to secondary inorganic PM. The oxidation of certain high molecular-weight VOCs can lead to the formation of products with low volatilities that contribute to secondary organic PM. The most significant of these precursors include aromatics (e.g., toluene, xylenes, trimethyl-benzenes) emitted by transportation and industrial sources and terpenes (e.g.,  $\alpha$ - and  $\beta$ -pinene, limonene) and the sesquiterpenes emitted by biogenic sources.

(b) *Very high molecular-weight organics* ( $C_{25}$  and greater) exist primarily in the condensed phase at ambient temperatures, and thus are emitted mainly as primary organic particles. These particles can be fine or ultrafine, depending on the emission source and ambient conditions.

(c) *Intermediate molecular-weight organic compounds* exhibit a range of volatilities, which depend both on the molecular weight and the molecular structure. Some of these compounds (for example four-ring polycyclic aromatic hydrocarbons) exist in both the gas and particle phases and are referred to as semivolatile compounds.

(d) The nucleation and condensation of high molecular-weight organic vapors can occur as hot combustion gases mix with cool ambient air. The effect of such processes on size distributions of organic particles in the atmosphere depends on the composition of the exhaust gases and on ambient conditions. These processes are described with emission models.

A major challenge for the scientific community is to resolve the carbon estimates predicted by chemical transport models or estimated by receptor models in conjunction with ambient observations. Currently, BC and OC measurements are highly method dependent and only 10 to 20 percent of the organic species can be identified. Typically OC measurements are scaled by an empirical multiplicative factor to account for the molecular form of the organic compounds. This factor may range from 2.0 in an aged air mass to 1.4 near fresh emission sources. Often a typical value of 1.4 is applied leading to potential underestimation of OC particle mass<sup>b</sup>. Such ambiguities could be resolved if there were analytical techniques available to measure organic particle speciation. Measurements of speciation would also provide insights into origins of ambient organic PM and would facilitate evaluations of chemical-transport models.

<sup>a</sup> There are multiple methodologies in use for BC, many of which also estimate total carbon (TC) and OC. By definition  $TC = OC + BC$ . TC methodologies agree well, but the  $OC + BC$  split may differ by ~30% depending on methodology.

<sup>b</sup> OM (organic matter) is the emerging terminology to represent reported concentrations for OC in recognition that they are manipulated, or adjusted, to account for the presence of hydrogen and oxygen and other non-carbon atoms. This Assessment uses OC synonymously with OM.

sulfur gases from terrestrial and marine sources,  $\text{NO}_x$  from soil respiration and lightning strikes, and organic vapors from vegetation. Residing between these extremes are sources/events that relate directly or indirectly to human activities, including prescribed burning, vegetation clearing for agriculture, and windblown dust from changes in land use (surface mining, agriculture, and construction). Some “fugitive” particle sources are included in emission inventories, while others are not. Sources that relate indirectly to human activities are considered manageable in the context of this Assessment.

Cases where unmanageable emissions cause exceedances of current PM air-quality standards are uncommon and usually identifiable as special events (e.g., visible smoke or dust plumes). These events can be recorded for explicit consideration in determining compliance with standards. Unmanageable natural emissions are usually a minor (<20 percent) portion of the  $\text{PM}_{2.5}$  mass during average situations. However, at the present time, confidence in determining the overall importance of natural OC contributions is low.

From a practical standpoint, manageable sources can be classified as being either managed or unmanaged. Managed emitters are those arising from human activity that are subject to permits and/or to emission reduction strategies within a given political

jurisdiction. Conversely, unmanaged emitters also arise from human activity, but are not easily subject to such measures. This may be due to the nature of the emissions (e.g., difficult to control) and possibly because they are assumed to be relatively small sources. In this context, measures can be undertaken to reduce unmanaged emissions, albeit at a cost that may not be considered acceptable.

### 1.3 HEALTH IMPACTS

A considerable and growing body of evidence shows an association between adverse health effects and exposure to ambient levels of PM. Epidemiological studies of large populations have frequently shown a statistical association between elevated levels of PM mass ( $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$  and  $\text{PM}_{10-2.5}$ ). These statistically stable estimates of excess risk most readily emerge in studies of large populations over long time periods. The adverse health outcomes observed in these studies are commonly (though not exclusively) cardiac and respiratory in nature. Such diseases are also relatively common in the general population, and the increased incidences seen in these studies correspond to statistically significant numbers of additional cases in observed populations. While the PM-associated risks represent a small percentage increase over baseline cardiorespiratory disease occurrence in North America, in aggregate, the absolute number of PM-associated health effects is large.

The total personal PM exposure of individuals, which includes both their ambient (outdoor) and indoor environments, is related to the ambient-air content of PM. The ambient-air concentration of PM and other pollutants has been extensively studied as a potentially controllable variable that influences human health.

Increases in adverse health outcomes have been observed for both short- and long-term

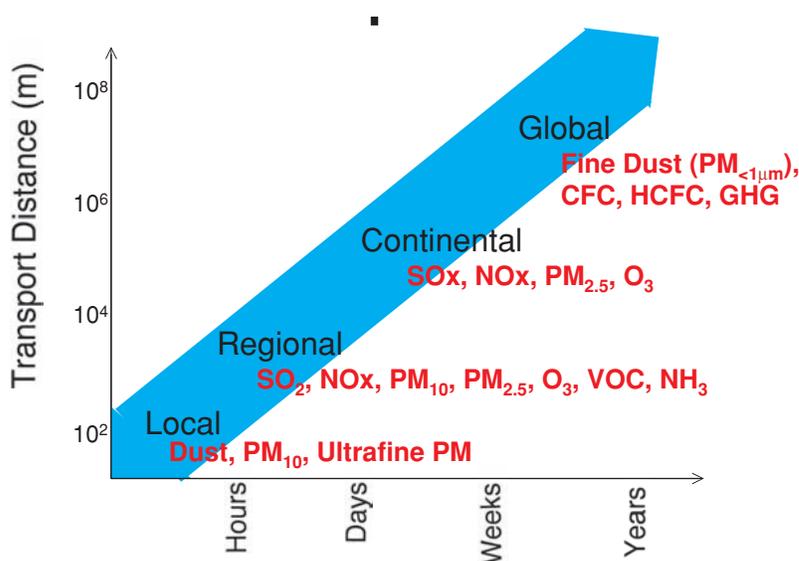


Figure 1.3. Illustrative transport scales for PM and other atmospheric pollutants.

Table 1.2. General descriptions of PM emissions and source types.

Emissions		General Source Types
Primary	Crustal / Soil Dust / Road Dust	Paved / unpaved roads, vehicle tire and brake wear, construction, agricultural and forestry operations, and high wind events.
	Salt (NaCl)	Oceans, road salt and salt pans / dry lake beds.
	Biogenic material	Pollen, spores and plant waxes.
	Metals	Industrial processes and transportation
	Black carbon	Fossil-fuel combustion (especially diesel engines).
	Semivolatile organic compounds (direct condensation of organic vapors at ambient conditions) and non-volatile organic compounds	Fossil fuel combustion, surface coatings and solvents, cooking, and industrial processes. Forest fires and biomass burning.
Semivolatile and volatile organic compounds (forming secondary organic aerosols)		
Secondary	Sulfur dioxide (forming sulfate particles)	Electrical utilities, transportation, mining and smelting, and industrial processes.
	Ammonia (contributing to formation of ammonium sulfate and ammonium nitrate)	Agriculture and animal husbandry, with minimal contributions from transportation and industrial processes.
	Nitrogen oxides (forming ammonium nitrate with ammonia)	All types of fossil-fuel combustion, and to a minor degree microbial processes in soils.

exposures to PM, and for a range of ambient PM indicators including total suspended particles (TSP), PM<sub>10</sub>, PM<sub>10-2.5</sub> and PM<sub>2.5</sub>. A higher potency has typically been observed for PM<sub>2.5</sub> compared to other PM indicators, consistent with the concept that smaller particles penetrate further down the respiratory tract. Nonetheless, the epidemiological literature does demonstrate some level of association with the larger PM metrics.

Thresholds in ambient PM concentration-health response relationships generally have not been observed in epidemiology studies. Some evidence suggests that there may be regional differences in the potency of PM indicators, possibly a reflection of regional differences in PM composition. Additionally, some evidence exists linking increases in adverse health outcomes to specific sources of PM.

Evidence of improved health is also associated with reductions in PM exposure. Studies have been both opportunistic in nature, taking advantage of significant reductions in PM pollution over short time

periods to examine mortality and other health endpoints, or have been designed to follow individuals or groups as their exposure to air pollution has changed. Such studies, while requiring careful interpretation, offer the opportunity to examine the benefits of specific air-quality interventions, as well as to compare the benefits of specific changes in the air-pollution mix. Pursuit of these situations offers the potential for considerable insight.

Hypotheses have been advanced to explain how various chemical and physical parameters of PM may interact with the body to provide mechanistic explanations for health outcomes (Chapter 2, Textbox 2.6). These hypotheses are being evaluated in toxicological studies using laboratory animals and controlled exposure of human subjects. However, to date none of these hypotheses have been proven or eliminated from consideration. Continuing tests of these hypotheses will require collaboration between aerosol scientists and health scientists in order to identify and characterize the hypothesized PM

constituent or parameter, the PM indicators usually monitored, and other pollutants. Such collaboration will enhance efforts in the fields of toxicology, clinical studies, and in both short-term and long-term epidemiological investigations.

The scientific understanding of PM health effects has been greatly facilitated using a “pollutant source-to-receptor response” paradigm as shown in Figure 1.4. This paradigm is useful for identifying information needs through targeted research efforts, for integrating information to establish ambient air-quality standards, and the concomitant control strategies for achieving such standards. Further progress in reducing the uncertainties in the linkages within the paradigm will require continued and closer collaboration between atmospheric and health scientists.

## 1.4 VISIBILITY IMPACTS

Perhaps the most common symptom of air pollution recognizable to the public is obscured visibility, usually referred to as haze. Optically, PM interferes with visibility by absorbing or scattering (i.e., reflecting) visible light. For example, BC absorbs light and  $\text{SO}_4^{=}$  is highly reflective. Light scattering is roughly proportional to the mass concentration of fine particles, while light absorption is roughly proportional to the mass concentration of the light-absorbing species such as BC. This

degradation in visibility is manifested as a reduction in the distance to which one can see and a decrease in the apparent contrast and color of distant objects, causing a washed-out or hazy appearance. The relationship between visibility and PM is discussed further in Chapter 9.

As a result of past efforts to reduce primary particle emissions from sources, observation of plumes from individual sources has declined significantly since the 1970s. However, haze is a concern for urban areas such as Mexico City and Los Angeles, and over much larger geographic regions in parts of North America, especially over the eastern half. In the East, an accumulation of ambient fine particles frequently results in haze extending over thousands of square kilometers. The haze problem, especially in the Desert Southwest of the United States and in the Rocky Mountain areas of Canada and the United States where visibility was once considered pristine - limited only by the “physical limit” of the light-scattering properties of air - is considered a regional issue, the result of additive contributions of multiple sources.

Visibility improvement, although secondary in importance to human health as a driver for air pollution regulation across North America, nevertheless will be a continuing consideration in the evolution of air-quality goals and standards, and is a continuing aesthetic concern of the public.

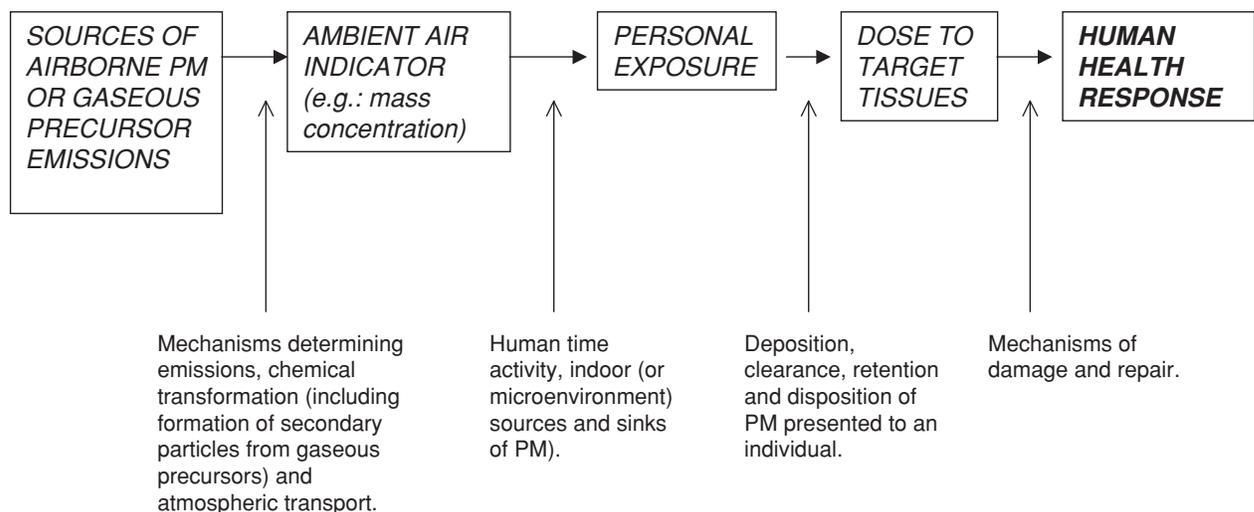


Figure 1.4. NRC framework for evaluating risks extending from pollutant sources to responses (NRC, 1998).

## 1.5 FEDERAL AMBIENT PM STANDARDS AND POLICY CONTEXTS

Canada, the United States, and Mexico have all adopted formal national ambient air-quality standards for particles<sup>4</sup>. In each case, these standards represent ambient concentrations and target achievement dates. National ambient air-quality standards are summarized in Table 1.3 and discussed more fully in the following sections.

### 1.5.1 Canada

In Canada, a federal/provincial Working Group on Air Quality Objectives and Guidelines prepares the science assessments outlining the current state of knowledge on effects, dose-response relationships, and risk information resulting in science-based recommendations for ambient objectives or standards. For particles, Canada Wide Standards (CWS) for PM were developed within a multi-stakeholder framework under the Canadian Council of Ministers for the Environment<sup>5</sup>. These standards represent a balance of factors (science, economics, technological feasibility, and societal interests) designed to select an achievable standard that will reduce human-health and environmental impacts. These standards may not be fully protective of public health and will be reviewed in 2005. Within the CWS is an obligation for Keeping Clean Areas Clean. Jurisdictions recognize that polluting “up to a limit” is not acceptable and that the best strategy to avoid future problems is keeping clean areas clean. Jurisdictions are working with stakeholders and the public to establish implementation programs that apply pollution prevention and best management practices.

In June 2000, Ministers agreed to a set of initial actions which will be undertaken by provincial/territorial and federal governments, to reduce pollutants that cause PM and ozone. The industrial sectors included in these actions have been selected

because they are significant emitters of the relevant precursors are common to most jurisdictions and affect many communities across Canada, and because effective action requires a multi-jurisdictional approach. The industrial sectors covered include: transportation, residential wood burning, pulp and paper, lumber and allied wood products, electric power, iron and steel, base metals smelting, and concrete batch and asphalt mix plants. The delivery date for completed reduction measures under the initial actions is 2005.

The CWS for PM will be reviewed as follows:

- By the end of 2005 complete additional scientific, technological and economic analysis: 1) to reduce information gaps and uncertainties and revise or supplement the PM and ozone CWSs as appropriate for the year 2015, and 2) report to Ministers in 2003 on the findings of the PM and ozone environmental and health science, including a recommendation on a PM<sub>10-2.5</sub> CWS.
- By the end of year 2010 assess the need and, if appropriate, revise the CWSs for PM and ozone for target years beyond 2015.

Under Part 1, Section 64 (c) of the Canadian Environmental Protection Act (CEPA, 1999), PM<sub>10</sub> and particularly PM<sub>2.5</sub>, has been declared a toxic substance. This declaration states that “a substance is toxic if it is entering or may enter the environment in a quantity or concentration or under conditions that constitute or may constitute a danger in Canada to human life or health.” The declaration is based principally on the sufficient weight of evidence of mortality and morbidity in the general population exposed to ambient concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> examined in recent extensive epidemiological analyses in Canada and in other countries (at ambient concentrations currently occurring in Canada), as well as on supporting data in experimental and controlled human exposure studies. To ensure that the Canadian federal government is fully able to manage PM in the context of the CEPA, the gaseous precursors (SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub> and VOCs) to secondary

<sup>4</sup> In some countries, ambient air standards have also been adopted by other jurisdictions (e.g., at the municipal, state or provincial level). This assessment is also intended to speak to implementation at that level, though only national regulatory backgrounds are discussed.

<sup>5</sup> For additional information on Canada Wide Standards for Particulate Matter and Ozone refer to : [http://www.ccme.ca/initiatives/standards.html?category\\_id=5](http://www.ccme.ca/initiatives/standards.html?category_id=5).

Table 1.3. Existing PM standards and their implementation timetables.<sup>a</sup>

Country	Current Standards	Implementation Timing
<b>Canada</b>	PM <sub>2.5</sub> of 30 µg/m <sup>3</sup> 24-hr averaging time to be achieved by 2010, achievement to be based upon the 98 <sup>th</sup> percentile ambient measurement annually, measured over three consecutive years. <sup>b</sup>	In June 2000, Ministers agreed to a set of initial actions to reduce pollutants that cause PM and ozone, which will be undertaken by provincial/territorial and federal governments. The delivery date for completed reduction measures under the initial actions is 2005.
<b>United States</b>	For PM <sub>2.5</sub> , the 3-yr average of the 98 <sup>th</sup> percentile of 24-hr average concentrations at each population-oriented monitor must not exceed 65 µg/m <sup>3</sup> , and the 3-yr average of the annual arithmetic mean concentration from single or multiple community-oriented monitors must not exceed 15 µg/m <sup>3</sup> . <sup>c</sup>  For PM <sub>10</sub> , the fourth highest 24-hr concentration over 3 years must not exceed 150 µg/m <sup>3</sup> , and the 3-yr average annual mean concentration must not exceed 50 µg/m <sup>3</sup> . <sup>c</sup>  Improve visibility on the haziest days and ensure no degradation on the clearest days, with the ultimate goal of reaching natural background conditions in 60 years.	For PM no later than the end of 2005, the U.S. EPA plans to designate non-attainment areas. From the date of designation, states will have 3 years to develop and submit implementation plans for attainment with deadlines to be set as early as 5 years and as late as 12 years after designation.  To achieve visibility goals, states are required to develop an initial 10-15 year plan, in the same time frame as their PM state implementation plans, that is to be revised every 10 years starting in 2018.
<b>Mexico</b>	PM <sub>10</sub> maximum allowable concentration of 150 µg/m <sup>3</sup> 24-hr mean and an annual arithmetic mean of 50 µg/m <sup>3</sup> . <sup>d</sup>  Total Suspended Particles (TSP) maximum allowable concentration of 260 µg/m <sup>3</sup> 24-hr mean and an annual arithmetic average of 75 µg/m <sup>3</sup> . <sup>d</sup>	The Secretariat of Health has set air-quality Normas Oficiales Mexicanas (NOMs) that now must be met by all jurisdictions of the country.

<sup>a</sup> Some states and provinces have standards more stringent than national standards, for example California's PM standards.

<sup>b</sup> By the end of 2005 complete analysis to reduce information gaps and uncertainties and revise or supplement the PM and ozone CWSs as appropriate for the year 2015; and report to Ministers in 2003 on the findings of the PM and Ozone environmental and health science, including a recommendation on a PM<sub>10-2.5</sub> Canada-Wide-Standard.

<sup>c</sup> The Clean Air Act requires that the NAAQS be reviewed every 5 years and a review process for the PM NAAQS is underway. As part of this review process, an updated Criteria Document, which summarizes the relevant scientific information about the sources, transformations, concentrations, and health and environmental impacts of PM, has been developed. Based on the information in the updated Criteria Document and supplementary analyses, a decision whether to retain or revise the NAAQS is now expected in late 2003 to early 2004.

<sup>d</sup> The Secretariat of Health is in the process of reviewing existing NOMs. The new NOM for particulate matter is anticipated to include three size fractions: TSP, PM<sub>10</sub> and PM<sub>2.5</sub>.

PM formation are also being reviewed in the context of the CEPA toxic definition. Canada is in the process of developing risk-management instruments in response to the CEPA declaration.

## 1.5.2 United States

Under the U.S. Clean Air Act, the U.S. EPA has set National Ambient Air Quality Standards (NAAQS)

## CHAPTER 1

for airborne particles since 1971.<sup>6</sup> Over time, the standards have evolved with an increasing focus on particle size, increasing stringency for smaller particles, and a move toward more robust statistical forms.

With advice from the Clean Air Scientific Advisory Committee, primary standards have been set for  $PM_{2.5}$  and  $PM_{10}$  based upon scientific criteria indicating the kind and extent of all identifiable effects on public health that may be expected, and allowing an adequate margin of safety requisite to protect public health. The PM NAAQS reflect consideration of the fine and coarse fraction as separate pollutants, both of which are related to adverse health impacts. The standards reflect information from community studies showing statistical associations between health effects and both short- and long-term exposures to PM.

The Clean Air Act requires that the NAAQS be reviewed every 5 years and a review process for the PM NAAQS is underway. As part of this review process, an updated Criteria Document, which summarizes the relevant scientific information about the sources, transformations, concentrations, and health and environmental impacts of PM, has been developed.<sup>7</sup> Based on the information in the updated Criteria Document and supplementary analyses, a decision whether to retain or revise the NAAQS is now expected in late 2003 to early 2004.

After the U.S. EPA establishes a PM NAAQS and a 3-year period of monitoring leads to a determination of attainment status, states found in non-attainment are responsible for developing State Implementation Plans (SIPs) that demonstrate how they will attain and maintain air quality in compliance with the NAAQS. Following the 1997 PM NAAQS promulgation, a new national monitoring network using a reference monitor for  $PM_{2.5}$  had to be installed across the country. The 3-year monitoring period began in 1998 and 1999. Attainment designations are expected to coincide with the completion of the 5-year review cycle of the PM NAAQS so that no later than the end of 2005, the U.S. EPA plans to

designate areas as “attainment,” “non-attainment,” or “unclassifiable” with respect to the PM NAAQS. From the date of designation, states will have three years to develop and submit SIPs for non-attainment areas. Attainment dates for the PM NAAQS have not been set; however, the Clean Air Act allows attainment deadlines to be set as early as 5 years and as late as 12 years after designation.

In addition to the PM NAAQS, the U.S. EPA has also adopted regulations to decrease regional haze and improve visibility in national parks and wilderness areas.<sup>8</sup> These regulations require states to develop progress goals for each protected area that will improve visibility on the haziest days and ensure no degradation on the clearest days, with the ultimate goal of reaching natural background conditions in 60 years. To achieve these goals, states are required to develop an initial 10- to 15-year plan that is to be revised every 10 years starting in 2018.

The timelines for the development of PM SIPs and regional-haze plans are linked. Although the exact schedule for implementation is not finalized, the regional-haze plans could be due as early as 2004 and PM SIPs as early as 2006.

The Prevention of Significant Deterioration (PSD) program, aimed at keeping clean areas clean through new source review and approval procedures, is likely to change from the basis now used for PM analysis about the time PM SIPs are due. Current guidance directs that analysis be done using  $PM_{10}$  as a surrogate, given the absence of sufficient  $PM_{2.5}$  monitoring, emissions, and modeling information. It is expected this information will become available over the next several years.

### 1.5.3 Mexico

All the environmental legislation in Mexico is covered through the General Law of Ecological Equilibrium for the Protection of the Environment by different regulations and official norms. The regulations pertaining to the Protection and Control

<sup>6</sup> For additional information on U.S. NAAQS for PM and ozone refer to: <http://www.epa.gov/ttn/oarpg/naaqsfm/>.

<sup>7</sup> Air Quality Criteria for Particulate Matter. Research Triangle Park, NC, USA: Office of Research and Development, U.S. Environmental Protection Agency.

<sup>8</sup> For additional information on the U.S. regional haze regulations, refer to: <http://www.epa.gov/oar/vis/>.

of Atmospheric Pollution indicate the goal that air quality should be satisfactory in all human-inhabited areas of the country illustrating the Secretariat of Health's concern for human health, and responsibility for coordinating and enforcing needed legislation.

All of the criteria pollutants have an official or legal norm (Normas Oficiales Mexicanas, NOMs)<sup>9</sup>. These explain the possible effects on the environment and public health while at the same time setting a maximum allowable limit, usually expressed as an ambient concentration limit.

### 1.5.4 Implementation of Scientific Information into Decision Making

In developing environmental policy, air-quality decision makers follow a decision path:

- Identify the problem
- Set a target

- Design a management plan
- Implement the plan
- Track success
- Revise the target
- Revise the management plan.

The path is applicable across regulatory systems and requires scientific information. To meet the decision-maker's information needs, an iterative flow of information between the science and policy communities should exist. Such an iterative process is illustrated in Figure 1.5. The NARSTO Ozone Assessment (NARSTO, 2000) identified three major steps in the context of accountability in air-quality management:

1. Verification of the effectiveness of controls
2. Verification that air quality is responding to emission changes

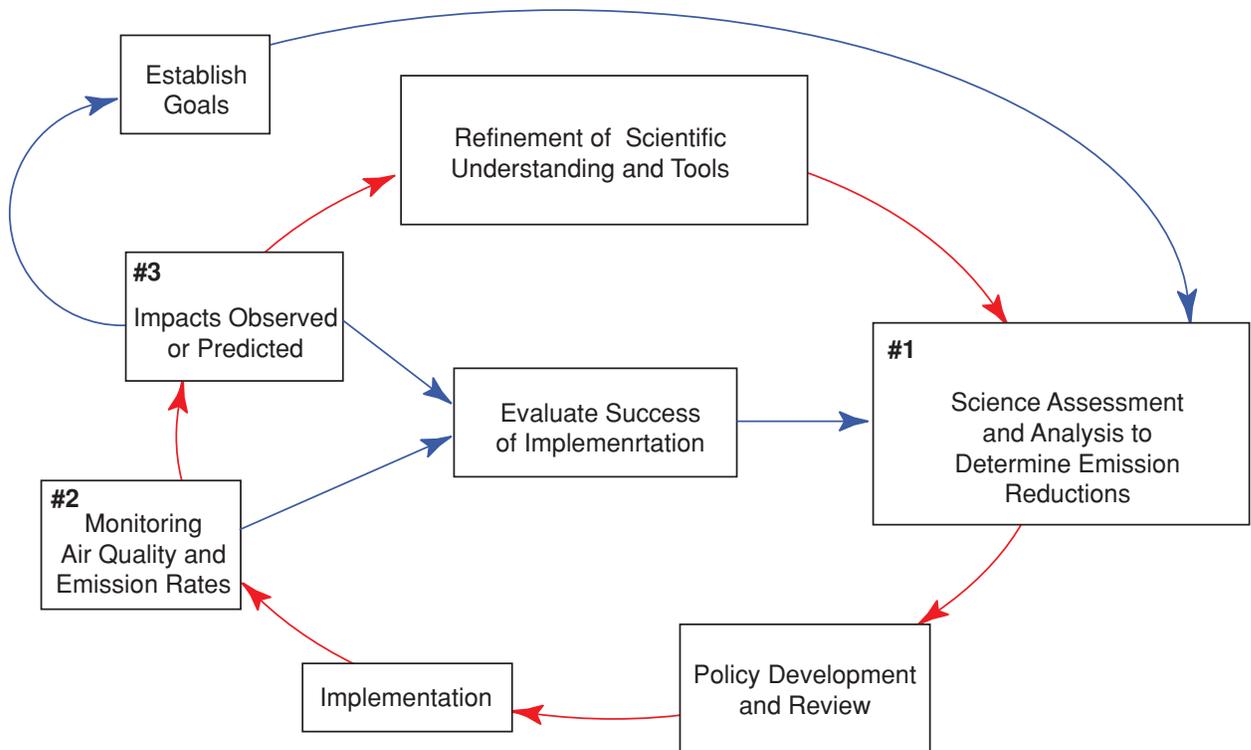


Figure 1.5. Iterative communication for managing air quality to reduce health and environmental impacts in the context of current scientific understanding and accountability.

<sup>9</sup> Information on Mexican air quality NOMs can be found at <http://www.ssa.gob.mx/dirgsa/NOM.HTML>.

3. Verification that abatement measures have results in health and environmental benefits.

These accountability steps also need to be iterative, and should include evaluation of the overall impact of the implementation program on ambient PM, provide ongoing application of science tools to refine implementation programs, and inform the public about progress of specific source types in reducing emissions ensuring a public accountability for the improvement of air quality. The communication regarding this progress in reducing emission rates can be complemented by discussion of improvements in public health and the environment according to the paradigm presented in Figure 1.4. An accountability framework that will enable measurement of progress towards the goal of protecting human health is needed.

The iterative process moves through stages of gathering new scientific information, performing assessments, developing policy, tracking outcomes, improving the knowledge base, and revising the policies and implementation plans and is consistent with the framework presented in Figure 1.1. Based upon North American experience in managing the acid rain and ground-level ozone problems, this cycle typically takes 8 to 10 years. The PM observations begun in the mid-1980s in Canada and the United States have improved upon previous observations. Ambient air-quality standards have been evolving with the most recent ones set in 1997 (United States) and 2000 (Canada) and implementation plans are being designed now. Thus, the PM management process has moved about two-thirds of the way through the first iteration.

History has shown that the results of major field studies and special projects continue to feed the development of science tools and air-quality policy 10 to 15 years after the specific studies are completed as the associated knowledge is assimilated across the community. Thus it is important to take a long-term view to supporting innovative research and exploring new approaches to improving scientific understanding. In the scientific discussions in Chapters 2 through 9 in this Assessment, such suggested improvements are highlighted in italicized

text; a full discussion of of recommendations, along with cross-links to the Assessment's content is provided in Chapter 11.

The optimal mechanism for ensuring that policy-makers have the most recent scientific results is to improve the dialogue between the scientific research community and the policy community, making it as continuous as possible. This communication has been facilitated by public- and private-sector partnerships, which have been effective in bringing forward a variety of scientific views and collective understanding of the science at early stages before emissions management decisions are put in place. Continuation of the public-sector/private-sector partnerships for effective and timely communication should be continued and fostered. Over the past decade there have been major changes in the science/policy dialogue on air quality, which like air-quality management, is following a philosophy of "continual improvement."

## 1.6 THE STRUCTURE OF THE ASSESSMENT

This Assessment is organized along disciplinary lines, as illustrated in the framework of Figure 1.1. Topics addressed in the Assessment are:

- **Gaseous and particulate pollution emissions**, from both natural and anthropogenic sources, including the temporal and spatial nature of these emissions. (Chapter 4)
- **Atmospheric processes**, the chemical and physical reactions and interactions that take place in the atmosphere, affecting the composition and distribution of gaseous and particulate pollutants. These processes are influenced by meteorology and topography and determine the short- and long-term chemical composition of the atmosphere. (Chapter 3)
- **Meteorology**, the fundamental atmospheric conditions (temperature, solar irradiation, humidity, precipitation, wind speed and direction) that determine the dispersion and

transport of natural and man-made pollutant species throughout the global atmosphere. (Chapter 3)

- **Atmospheric concentrations**, the spatial and temporal characterization, primarily at the surface, of particle composition and size, and the magnitude of particle and precursor or copollutant gas concentrations. (Chapter 6)
- **Visibility and Climate** impacts that occur as a result of PM absorbing and/or scattering visible radiation, obscuring one’s ability to view objects or scenes and perturbing the Earth’s radiation balance. Such impacts result directly from the particles themselves, as well as indirectly as the result of PM effects on cloud-formation processes. (Chapter 9)
- **Atmospheric science analyses**, the application of current understanding by tools, such as emission characterization, ambient characterization, receptor modeling, and chemical-transport modeling, to elucidate the relative contributions of different sources, both

local and distant, to a region’s PM problem. (Chapters 4, 5, 6, 7 and 8)

In addition to these scientific components, this Assessment presents region-specific analyses (Chapter 10), which examine nine North American regions and provide individual PM problem overviews for these areas. These overviews are framed as “conceptual models” of PM source-receptor behavior as shown schematically in Figure 1.6. Intended to compile and summarize the most advanced and pertinent knowledge of source-receptor behavior, these conceptual models are the outcome of the atmospheric analyses and combine information from a variety of sources, including emission

**Box 1.3. The Value of a Conceptual Model**

Conceptual models identify the most effective approaches for managing PM to achieve air-quality standards, potentially significant disbenefits (temporary or otherwise), copollutant responses, and opportunities for copollutant reductions, by facilitating an understanding of the balance between limiting chemical and physical processes in each source environment or airshed.

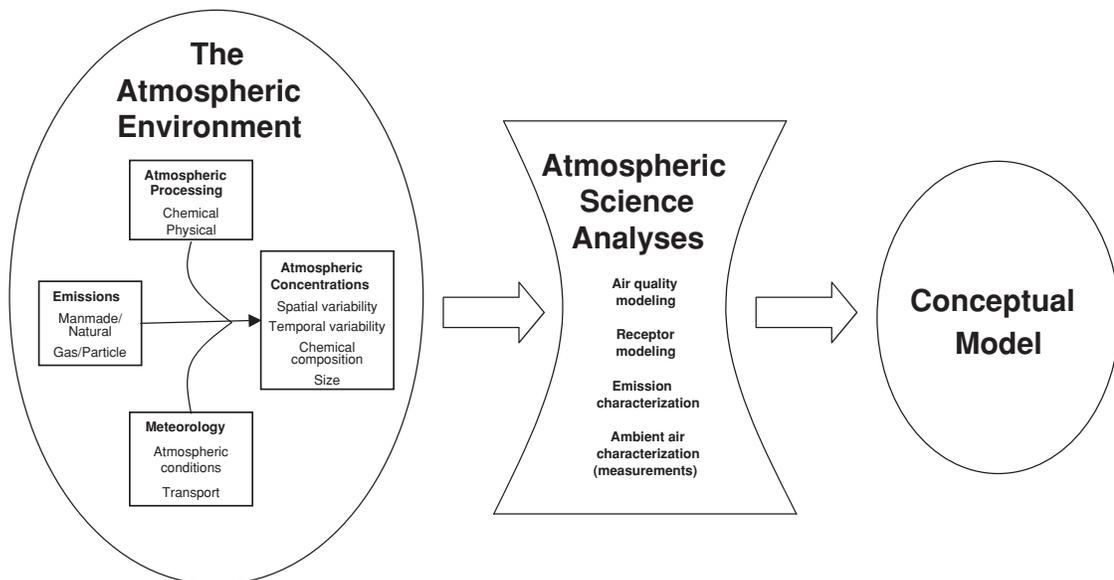


Figure 1.6. Development of conceptual models of PM behavior, based upon the application of science tools in the context of the best understanding of the atmospheric environment.

## CHAPTER 1

characterizations, air-quality measurements, and meteorological observations as well as analyses from chemical-transport and receptor model investigations.

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