CHAPTER 5

THE SCIENCE-POLICY INTERFACE: *Using The Entire Scientific Toolbox To Enhance the Air Quality Management System*

The preceding chapters demonstrate the significant progress made during the last decade in advancing scientific knowledge, and document current practices for managing O_3 pollution in North America. Improvements in the fundamental understanding of O_3 formation and accumulation have been accompanied by major advances in models and other analytical tools used to simulate O_3 production and transport. These tools are being applied, to various degrees, to provide diagnostic information on the efficacy of ongoing O_3 mitigation efforts as well as guidance for future emission-control decisions. At the same time, observations from monitoring networks indicate that peak O_3 concentrations have been reduced in many locations throughout the continent. In other locations, O_3 pollution abatement efforts appear to have prevented further degradation in air quality, despite significant growth in population and economic activity.

This chapter outlines development of a conceptual framework for an air-quality management process, which addresses further application of these developing tools and is intended as an initial step to aid policy makers in designing and evaluating future management strategies.

5. THE SCIENCE-POLICY INTERFACE

5.1 THE AIR-QUALITY MANAGEMENT PROCESS - *CURRENT PRACTICE*

Although all three North American countries exercise different air-quality management processes, certain elements are common to each. These common elements are illustrated in Figure 5.1, which identifies the essential process steps as well as the critical technical resources required for their accomplishment. Two components of the process — the determination of needed emission reductions and evaluation of results — (blue boxes in schematic) are the focus of this discussion.

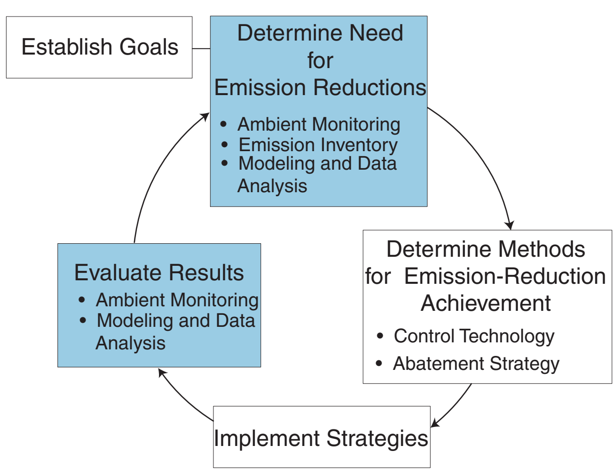

Figure 5.1 Typical Air-Quality Management Process

5.1.1 Determination of Needed Emission Reductions

The determination of emission reductions needed to meet a particular air-quality standard or objective may involve the use of emission inventories and monitoring-network data, as well as analyses using air-quality modeling systems (AQMS). These tools can provide focus to several components of the determination activity, by

- identifying areas not meeting air-quality standards;
- defining the severity of the compliance shortfall;
- identifying source regions for precursor emissions;
- estimating VOC/NO_x sensitivities and tradeoffs; and
- evaluating the effects of meteorology.

For example, ambient air-quality monitoring, as discussed in Section 3.6, can document the geographical distribution, magnitude, trends, and frequency statistics of O_3 concentrations as well as those of its precursors. In addition AQMS, along with emission inventories, can indicate source regions and provide insights on NO_x and/or VOC sensitivity. The types of analyses discussed in Section 3.5 can help assess the extent to which elevated levels of O_3 may be caused or aggravated by transport, and the areas that may potentially affect the region of concern. In addition, sensitivity analyses performed using AQMS (see Chapter 4) can indicate whether proposed emission reductions might mitigate a particular problem.

As discussed in Section 3.2, the relationship between O_3 and its precursors has historically been evaluated using AQMS. More recent policy decisions have focused on using additional information, including using a weight–of-evidence approach and observation-based models (OBM). For example, the U.S. Environmental Protection Agency in its "Draft Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-Hour Ozone NAAQS," (EPA, 1999) describes an approach that uses a wide range of available information to determine whether a control strategy is expected to achieve a specific standard.

5.1.2 Evaluation of Results

Fundamental to an effective air-quality management approach is an evaluation of whether the controls that have been put in place have had the desired effect. Historically, success has been measured by tracking air-quality improvements subsequent to implemented control measures. Many of the tools mentioned in Section 5.1.1 can be applied to this evaluative stage as well as for forecasting the needs for emission reduction.

5.1.3 Summary of Current Status

In conclusion to this brief overview of current management procedures it should be noted that, although many of the newer tools have the potential to augment and improve the development of control strategies, their application is still in an early stage: There is not a generally agreed upon technique for using these newer capabilities. Moreover, the iterative feedback relationship implied by Figure 5.1 is not well defined in most current management systems. The following section outlines a general scheme for incorporating these features more formally into air-quality management practices.

5.2 AN ITERATIVE PROGRESS-DRIVEN AIR QUALITY MANAGEMENT PROCESS - *PROCESS AND COMPONENTS*

The advanced air-quality management framework described in this chapter can be considered a second-generation approach, which departs from past standard practice in three important ways:

- The framework is *formally iterative*, in the sense that it expects at the outset to execute several feedback passes through steps of the implementation-evaluation process.

- The framework attempts to *optimize use of the full spectrum of technical tools* available for analysis. Thus, for example, complementary use of both AQMS and OBM is considered, along with other interpretive tools such as receptor analysis and weight-of-evidence procedures.

- When practical, the framework's verification procedure *transverses the total emission-response issue*, starting from control of emissions and penetrating down to verification of receptor responses. In a formal sense, this is described in terms of the three following steps:

  Step 1: Verify that implemented emission controls are performing according to specifications. This involves testing and evaluating the emission controls imposed by the regulatory system, and verifying that these control measures do in fact comply with specifications and established requirements.

  Step 2: Verify that the environmental resources (i.e., air, water, and soil) are responding appropriately to the emission changes achieved. This step demonstrates that the atmosphere has responded in the expected way to the emission reduction documented in Step 1. Depending upon the specific air-quality goal, Step 2 might involve monitoring the chemical loading of the pollutant species in the atmosphere and/or its deposition to the earth's surface, and documenting the trend associated with the emission changes.

  Step 3: Verify that the response of identified public health and welfare receptors agrees with expectations, given the observed changes in the quality of the environmental resources. This step demonstrates that the observed changes in environmental quality documented in Step 2 result in an expected and quantitative benefit to public health and welfare. This last step is the most difficult to demonstrate, and it may take many years to establish credible data for verification.

Clearly, responsibility and authority must be explicitly defined within the organizations performing these functions. It is also clear that Steps 1 through 3 become increasingly difficult as one proceeds down the list. Step 3 is especially demanding and may, in fact, not be feasible in many cases. The Canadian NO_x/VOC Assessment (AES, 1997) concluded that direct measurement of population health attributable specifically to decreasing ozone concentrations is complicated by other factors. The report goes on to say that if attention is limited to urban areas having robust ozone-concentration — human-health response data, then there is a fairly high confidence in the approach. It also should be noted that the inability to attempt or complete Step 3 should not preclude carrying out Steps 1 and 2.

The example outlined in TextBox 5.1 regarding lead (Pb) pollution in the United States illustrates how this three-step process can be applied. Pb pollution is a relatively straightforward problem and thus particularly well suited to mitigation through emission controls and the demonstration of the efficacy of these controls. Pb is a primary pollutant with, therefore, a direct and linear link between emissions and atmospheric loading. Moreover, Pb levels in blood provide a direct, easily measurable indicator of human exposure.

5.3 OZONE AIR-QUALITY MANAGEMENT – *ANOTHER LEVEL OF COMPLEXITY*

Because O_3 is a secondary pollutant with a nonlinear and variable response to its precursors, the processes that connect emissions to health effects in the case of O_3 pollution are considerably more complex than they are for Pb pollution. Thus, the application of the iterative progress-driven process to O_3 air-quality management is also complex.

Figure 5.5 provides a schematic depiction of how the iterative three-step process might be incorporated into O_3 air-quality management. The schematic meshes the iterative components of Steps 1 and 2 and incorporates many of the current air-quality management features shown in Figure 5.1. The processes and activities included in this schematic are based on a more detailed prescriptive procedure proposed by Demerjian, et al. (1995), which has been generalized here to make it more appropriate for use by all NARSTO member nations.

Initiation of the process, illustrated on the left-hand side of Figure 5.5, requires that the relationships between the photochemical production of O_3 and precursor concentrations and/or emissions be quantitatively characterized. In the recent past, AQMS have been the primary tool for quantifying these relationships and would presumably play a similar role in an O_3 management system of this type.

5.1 An Iterative Progress-Driven Air Quality Management System -The Simple Example of Lead (Pb) in the Environment

The successful reduction in environmental loading of Pb in the United States provides an illustrative example of the three-step "iterative progress-driven" process. Figures 5.2 through 5.4 document the success of Pb mitigation over the last two decades as it relates to each step in the process.

Step 1: Figure 5.2 presents the trend in U.S. Pb emissions for the period 1970–1994 (U.S. EPA, 1997). The data show a significant emission decrease as a result of the control programs mandated by the U.S. Clean Air Act. The largest emission reductions were from the phase out of leaded gasoline. Unleaded gasoline was first introduced in the United States in 1975 for use in vehicles equipped with catalytic converters. The total market share of unleaded gasoline in 1975 was 13%. However, its use climbed steadily in the intervening years, with a market share of ~ 50% in 1982 and 99% in 1994. On January 1, 1996, leaded gasoline was prohibited for use in highway vehicles in the United States.

Step 2: Figure 5.3 illustrates the empirical connection that was established between the estimated Pb emissions shown in Figure 5.2 and actual air quality. The figure shows the trend in the maximum observed quarterly Pb concentrations measured at 122 sites from 1977-1985 and 208 sites from 1986-1996. The measurement sites are located predominantly in urban areas and represent a cross-section of the major metropolitan areas of the United States. Based on these data, the percentage reduction in the maximum quarterly Pb concentrations over the period 1977 – 1994 was 97%, which is consistent with the emission estimates presented in Figure 5.2.

Step 3: Figure 5.4, which presents the geometric mean blood Pb levels of children aged 1-5 years since 1976, provides some empirical connection between the mitigation efforts adopted in Step 1 and the health benefits they were intended to engender. The data, from the National Health and Nutrition Examination Surveys (NHANES), cover three distinct study periods over the past two decades within selected urban centers of the U.S. These data indicate that the geometric mean blood Pb levels of children, ages 1-5 years were reduced by 82% over the period from 1976-1980 to 1991-1994. Over this same period, Pb emissions and mean ambient Pb concentrations in urban areas were reduced by more than 95%. Considering that the exposure avenues for young children include Pb paint dust within households, as well as ambient air, these data appear to be reasonably consistent.

The combined data summarized above provide a direct demonstration of the effectiveness of Pb emission controls on air quality, exposure, and response (in terms of elevated lead blood levels) of susceptible populations. Except for directly demonstrating the health-effect response of the susceptible population to the reduced levels of Pb in the blood, the three-step process is virtually complete and suggests that health risks associated with Pb emissions from automobiles have been successfully managed in the United States.

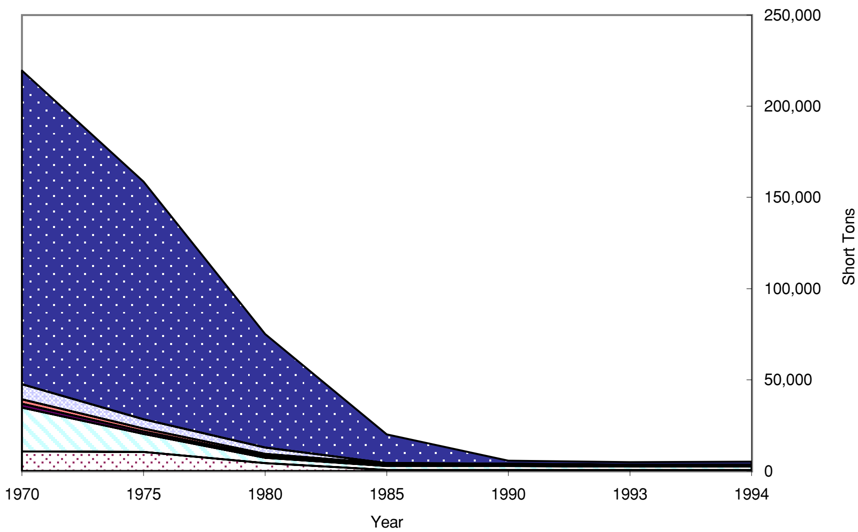

Figure 5.2 Total estimated U.S. Pb emissions by major source category from 1970 to 1994. After U.S. EPA (1997).

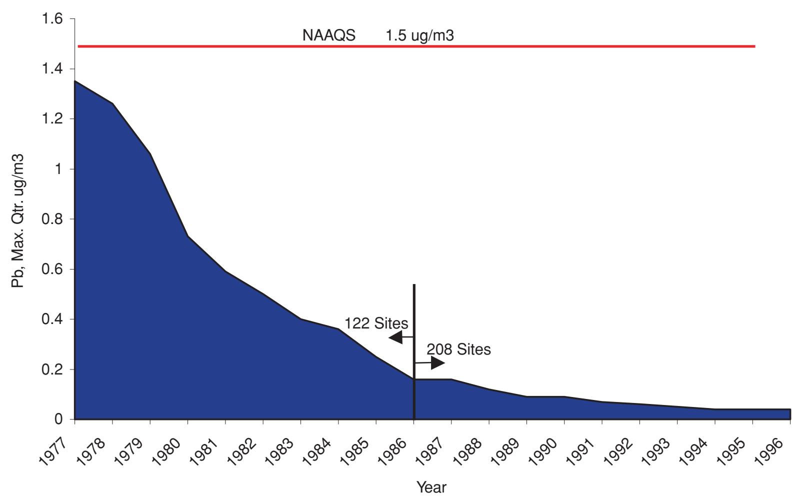

Figure 5.3 Maximum quarterly observed lead (Pb) particulate concentrations (in mg/m^3) at U.S. monitoring sites from 1977 to 1996. After U.S. EPA (1997).

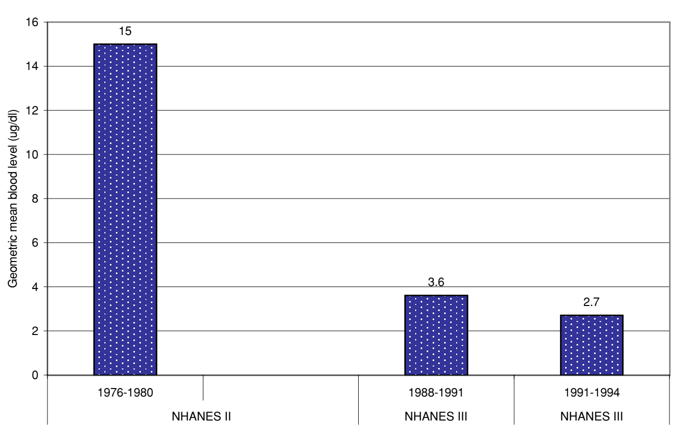

Figure 5.4 Geometric mean blood lead (Pb) levels of children ages 1-5 years over three distinct study periods over the past two decades. Data taken from Brody et al. (1994) and Pirkle et al. (1994).

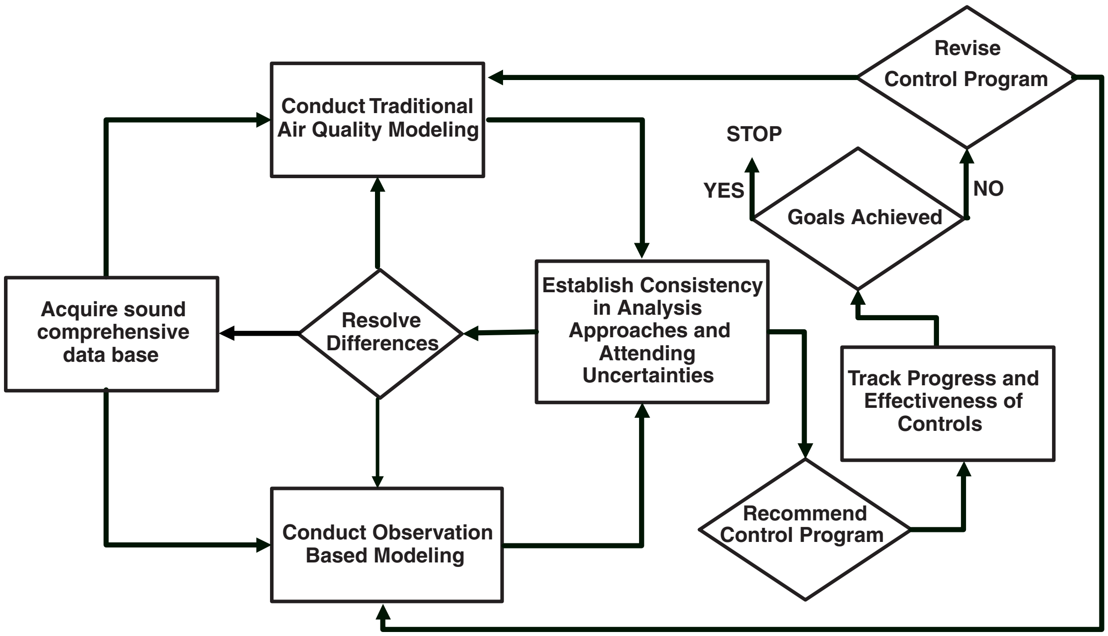

Figure 5.5 A Schematic of the Iterative Progress-Driven Ozone Air-Quality Management Process

However, AQMS are no longer the only tool available for this task. Observation-based models (described in Section 3.7), along with advances in the instrumentation for measuring O_3 precursors, provide a complementary means for deriving these relationships and thus of testing the reliability of AQMS predictions. This type of approach is already beginning to be implemented as seen in the "weight-of-evidence" approach under consideration in the United States (U.S. EPA, 1999).

Based on the combined and thoroughly analyzed and evaluated results of AQMS and observation-based models, network measurements, and other relevant considerations (e.g., adverse economic/social impacts, political acceptance, and scientific credibility), an emission-control strategy as shown on the right-hand side of Figure 5.5 can be formulated and implemented. Application of the emission control strategy also effectively meshes the components of Steps 1 and 2 in tracking and evaluating air-quality and environmental-response data.

As applied to O_3 air-quality management the three-step, iterative process of verification proceeds as follows:

Step 1. Verification of the effectiveness of specific emission controls

Direct measurement of precursor emissions from specific sources would demonstrate that the emission control program is meeting its objective and maintaining its expected effectiveness over time. However, as discussed in Section 3.3, for many categories of sources direct measurement of emissions is not feasible either from a technical or a cost standpoint. For these sources it may only be possible to establish whether control equipment has been installed (if required) and is being properly operated. (In fact, even in the relatively simple Pb example the emissions were estimated rather than measured directly.)

Step 2. Verification that air quality (i.e., O_3 concentration) is responding to emission changes

Because of the complexity of the O_3 system, this step requires at least two coupled tests:

- Demonstration, through ambient measurements of precursor species, that precursor concentrations in the airshed have responded as expected to changes in precursor emissions; and

- Demonstration, through ambient measurements of O_3, that it has responded as expected to the changes in precursor concentrations, which have occurred as a result of implemented controls.

To determine whether changes have occurred as expected, one would have to predict what changes should have occurred as a result of the control strategies. AQMS can be used to estimate expected changes in both O_3 and precursor concentrations in response to changes in emissions. The types of O_3 and precursor monitoring available and the issues associated with this monitoring are discussed in Section 3.6.

Step 3. Verification that O_3 abatement has resulted in health and welfare benefits

This step is the most difficult to achieve. If epidemiological and ecological data demonstrate the deleterious effects of O_3 pollution, they should also reflect the benefits of realized O_3 mitigation and thus could be used to extrapolate cost-to-benefit ratios. However, for this to be a viable part of an air-quality management process, additional work would be needed to develop methods and techniques to establish quantitative relationships between costs and realized benefits, as well as mechanisms for tracking changes.

Additional iterative steps

Failure of any of the demonstration tests outlined above indicates the need for further review and evaluation and an iteration of the process through further data analysis and model evaluation, tracking of abatement strategy effectiveness, as well as the formulation and implementation of alternate abatement strategies. This would be followed by the re-initialization of the process at Step 1. There are a variety of reasons why control strategies might not achieve expected results. It is important that the management process provide the means to identify and understand the reasons for not meeting expected goals.

A key facet of the O_3 air-quality management process is the integration of a wide spectrum of scientific tools into an iterative and intrinsically progress-driven management scheme. Fundamental to the process is the acquisition of reliable and comprehensive data through network monitoring that can be used to conduct traditional air-quality modeling (i.e., through the application of an AQMS) as well as applying observation-based modeling approaches. The results from these two types of analyses and estimates of the uncertainties attending the calculations are then reviewed and compared to establish consistency and a sense of the reliability of the models. If there are significant differences, further data must be acquired and additional analyses performed to resolve these differences. Then based on consistency between the analytical tools, responsible agencies should recommend a control program and establish a monitoring and data analysis strategy to track the progress and effectiveness of the controls (i.e., Steps 1 and 2). Because of the complexity of the O_3 problem, diagnostic modeling as well as data analyses are needed to provide feedback regarding the effectiveness of the controls and identify the need for modifications in control options to achieve the desired air-quality improvement.

In conclusion, one should note that more than $150 billion is spent annually in North America to meet environmental regulations (U.S. EPA, 1991). It is reasonable to expect that robust analytical measures be in place to demonstrate the progress, success and effectiveness of the air-quality management system. For this reason, the establishment of an iterative progress-driven environmental management process could improve the development of any credible, pollution mitigation program. In the case of O_3 pollution, such a process is even more essential because of the complexities of the physical and chemical processes that cause the problem and the difficulties that have been experienced in its mitigation. There is still a need for further development of techniques, from both a policy and a scientific/technical standpoint, before such a process could be fully implemented.