USING VISIBILITY ANALYSES AS AN ALTERNATIVE APPROACH TO REGULATE AIR QUALITY

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BACKGROUND

Air quality can be regulated using one of three metrics: ambient air quality, deposition and visibility. Of the three, visibility is the metric to which the public can most easily relate. Detailed scientific measurements are required to quantify air quality. Ambient air standards are generally related to the heath effects found is selected populations. Deposition is related to the soil acidification associated with sulfur dioxide or nitrogen oxides. Visibility has the advantage of being both scientifically measurable as well as being easily perceived by the public.

In the United States, ambient air quality is regulated to provide protection to human health and provide for general welfare. Initially, the focus was on "Criteria Pollutants" – SO_2, NO_X, particulate matter, etc. – that affect human health. Visibility is associated with environmental welfare.

Preventing visibility impairments (regional haze) in protected (Class I) areas is mandated in the 1977 Clean Air Act (CAA). As a result U.S. EPA and other government agencies had to develop means to monitor visibility and to develop models that could be used to assess visibility impairment or improvement associated with specific sources or groups of sources. The modeling technology has evolved over the past 20 years so that it is used today by Federal Land Managers (FLM) of protected areas to play an active role in the permitting processes performed by Federal or state regulatory agencies.

A Regional Haze Rule was promulgated in 1999 requiring many older facilities to be analyzed in order to help optimize investments in controls that will achieve the required improvement in visibility. In addition, large new sources are required to assess their impacts on visibility in Class I areas due to their emissions of various pollutants. This paper will examine the U.S. experience in modeling visibility impairment and to shed some light on the potential application of similar concepts in other countries.

HISTORY OF REGIONAL HAZE RULE

Millions of guests visit national parks, monuments and wilderness areas each year, and one of their primary reasons is to experience the scenic views for which these areas are renown (e.g., the Grand Canyon, Yosemite, Great Smoky Mountains, even the Statue of Liberty). Visual air quality in Class I areas has been significantly degraded due to various anthropogenic sources over the past 200 years. The current visual range is only 100 to 150 km in the West and 25 to 50 km in the East. This is half and a third of the visual range without manmade pollution in the west and east, respectively. In order for these areas to be protected for future generations of visitors, the

U.S. EPA established special protection for national parks and wilderness areas that stems back to the 1977 CAA Amendments.

The 1977 CAA Amendments, Section 169A, established visibility protection for Federal Class I Areas:

> *Congress hereby declares as a national goal the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from manmade air pollution.*

In 1980, the Code of Federal Regulations Part 51 (CFR 51), Subpart P, addressed visibility impairment that is "reasonably attributable" to one or a small group of sources. Extensive studies were undertaken to increase the scientific knowledge. Comprehensive monitoring was undertaken and used to develop modeling procedures and models that could withstand extensive public scrutiny. In the mid-1990s it became commonplace to use the modeling procedures to assess the effects of new sources seeking to locate near Class I areas. In 1999, the technology had advanced to the point that new regulations were published to address regional haze visibility impairment. Regional haze is caused by cumulative air pollutant emissions from many sources over a large geographic area. The July 1, 1999 Amendments established the Regional Haze rule to:

> *revise the existing visibility regulations in order to integrate provisions addressing regional haze impairment. [The Regional Haze Rule] establishes a comprehensive visibility protection program for Class I areas.*

The Regional Haze Rule requires the development of air quality reduction plans focused at reducing visibility impairment and improving visibility in 156 mandatory Class I areas, which include national parks over 6,000 acres (about 2,500 hectares) and wilderness areas and memorial parks over 5,000 acres (about 2,000 hectares) as defined in the CAA. Although this covers only about two percent of landmass that contains many of the most scenic areas, a typical regional haze modeling analysis may include Class I areas as great as 300 km from an emission source. As such, emission sources located almost anywhere in the continental U.S. may be subject to the regional haze analysis.

The goal of the Regional Haze Rule is to return Class I Areas to natural visibility conditions by 2064. States are to establish goals to improve visibility on the haziest days and ensure no degradation occurs on the clearest days. As such, the rules require assessment of visibility impacts from any new or major modifications to major stationary sources. In addition, installation of Best Available Retrofit Technology (BART) is also required for qualified existing facilities whose emissions of visibility-impairing pollutants cause or contribute to regional haze.

VISIBILITY IMPAIRMENT

Visibility can be affected by plume impairment (heterogeneous) or visibility (homogeneous). Plume impairment results when there is a contrast or color difference between the plume and a viewed background (the sky or a terrain feature). Plume impairment is generally only of concern when the Class I area is near the proposed source, such that minimal dispersion of the plume has occurred. The FLM consider "near" being a distance of 50 km or less. Current technology for controlling pollutants is such that plume impairment is rarely an issue.

Regional haze occurs at distances where the plume has become evenly dispersed into the atmosphere such that there is no definable plume. The primary causes of regional haze are sulfates (SO_4^{2-}) and nitrates (NO_3^-) (primarily as ammonium salts), which are formed from sulfur dioxide (SO_2) and oxides of nitrogen (NO_X) through chemical reactions in the atmosphere. Another source is organic carbon and elemental carbon associated with urban emissions. The resulting smog is measured as ground-level ozone. Atmospheric reactions take time. Near a source little NO_X or SO_2 will have formed nitrate or sulfate, whereas far from a source nearly all SO_2 will have formed sulfate and most NO_X will have formed nitrate. Similarly the urban emissions of hydrocarbons and elemental carbon take some time to react but are shorter-lived than the sulfates and nitrates. Particulate matter emissions also contribute to regional haze but to a lesser extent.

Visibility can be degraded by light scattered into and out of the line of sight and by light absorption along the line of sight. It can be characterized by the light-extinction coefficient, which represents the attenuation of light per unit distance (e.g., million meters [Mm]) due to scattering and absorption by various substances such as ammonia sulfate [$(NH_4)_2SO_4$], ammonia nitrate (NH_4NO_3), soil, and carbon particles in the atmosphere as well as particulates formed through gas-phase reactions.

The FLM's Air Quality Related Values Workgroup (FLAG) Report defines the method for assessing the potential impact on visibility as the "change in extinction coefficient." The extinction coefficient, b_{ext}, is inversely related to the visual range. A visibility analysis evaluates the extent of the extinction coefficient change in the areas of interest.

When the relative humidity is high, ammonium nitrates and ammonium sulfates in the atmosphere undergo conglomeration that causes increased visibility impairment. Relative humidity is a much more important factor in visibility impairment east of the Mississippi River than in a relatively drier west.

REGIONAL HAZE MODELING ANALYSIS

CALPUFF has been used under the direction of the FLM and the U.S. EPA to assess air quality visibility impacts as outlined in the FLM's FLAG Report. The CALPUFF model implements many of the scientific findings from various field studies over the past decades. The CALPUFF model is capable of modeling linear chemical transformation effects by using pseudo-first-order chemical reaction mechanisms for the conversion of SO_2 to SO_4^{2-} and NO_x, which consists of nitrogen oxide (NO) and NO_2, to NO_3^-. Several chemical transformation methods were incorporated in the CALPUFF model, which include the MESOPUFF II scheme, RIVAD/ARM3 scheme, Secondary Organic Aerosol Computation, or even user-specified transformation rates.

Depending on the selected chemical transformation option, background concentrations of ozone and ammonia are also utilized based on monthly monitoring measurements or default values. Moreover, hourly representative background ozone data can also be used. Under certain circumstances, ammonia in the ambient air may be the limiting factor in the nitrate formation. However, the current CALPUFF model is not able to reflect the directly emitted ammonia in the chemical transformation. Furthermore, light scattering is most efficient for particles in the range between 1 and 2 microns. Conglomeration of sulfate or nitrate molecules due to the hygroscopic effects produces the particle sizes with the most light scattering efficiency. Due to the significantly different contribution of fine particulates (e.g., $PM_{2.5}$) to light extinction than that of coarser particulates (e.g., PM_{10}), speciation of emitted particulate matter (especially from combustion sources) has generally been required in permitting activities. In CALPUFF, both dry and wet depletion of pollutants from the ambient air can also be included in the analysis.

While CAPLUFF is the preferred dispersion model in the U.S. to evaluate the long-range transport phenomenon for the purposes of Class I analyses, its relative simplistic treatment of atmospheric chemistry hinders its capacity to assess complex photochemical reactions and secondary particulate matter formation in the atmosphere. For a regional scale modeling analysis involving hundreds of emission sources with the formation of secondary pollutants through complex atmospheric chemistry, grid models such as CAMx and CMAQ would be candidate dispersion models in lieu of CALPUFF.

To date not much attention has been paid to organic and inorganic carbons and the visibility impairment that might be caused by diesel engines and gasoline-power vehicles. The contribution of these sources is expected to decrease sharply in the decade ahead with the new low-sulfur diesel fuel rule and ever-tighter controls on gasoline-powered vehicles.

VISIBILITY ANALYSES APPLICATIONS

For new source permit applications in the U.S., applicants may be required to perform a regional haze analysis to assess the impact of emissions from the proposed sources on nearby Class I areas. The VISCREEN and PLUVUE II dispersion models are recommended to estimate plume visibility (< 50 km from source). The CALPUFF Modeling system is recommended for assessing visibility impacts from sources, which is typically greater than 50 km and as far as 300 or more km from a Class I Area.

The Regional Haze rule requires an assessment by the states of optimum ways to achieve visibility improvement. Typically this will involve the study of all sources in an area, especially older sources to develop a cost-effective way of achieving requisite improvement. Based on the degree of contribution to regional haze, new or modified sources must meet certain limits on emissions or requirements of control technologies established in the course of permitting. In the U.S., older sources, typically those built before the Clean Air Act, are allowed to continue to operate as they have in the past. As required by the rule, a fleet of these older sources that meet certain criteria will have to comply with the BART requirements. Modeling analyses play a critical role in determining whether retrofit control technology is necessary.

Visibility analyses have not been applied in urban areas. Other approaches are used to reduce the number of days that exceed the ozone standard. Nonetheless, the techniques in a visibility analysis could be potentially applicable to these situations.

CONCLUSION

Restoring visibility in protected scenic areas in the U.S. as mandated in the regional haze rule requires the leverage of both public policy and scientific means to evaluate the impacts of visibility-impairing activities as well as benefits of various control measures. Performing modeling analyses by correctly utilizing CALPUFF or other models (e.g., CAMx or CMAQ) can provide many valuable insights to the issue. Moreover, regulating regional haze also generates benefits by reducing the effects of many other environmental issues (e.g., acid deposition, urban smog, and secondary particulate matter).

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