

MEMORANDUM

TO: Docket No. EPA-HQ-OAR-2012-0918
Air Quality Designations for the 2012 PM_{2.5} Standards

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SUBJECT: Calculation of Urban Increments to Support the Air Quality Designations for the 2012 PM_{2.5} Standards National Ambient Air Quality Standards (NAAQS) (SAN 5706)

Introduction

PM_{2.5} mass concentrations are generally higher in urban areas compared to surrounding regions. This “urban increment,” also known as the “urban excess,” is due to locally generated and largely directly-emitted PM_{2.5} in addition to regional contributions.^{1,2} Among the major contributors to PM_{2.5} mass, sulfates tend to originate from regional sources; organic carbon and nitrate originate from regional and local sources; and black/elemental carbon, associated soot, and crustal material tend to originate from local sources. Sulfate and nitrate also depend on the availability of ammonia, which may originate from regional or local emissions.

The goal of the urban increment analysis³ is to estimate the local contribution to urban PM_{2.5} as measured at violating FRM/FEM/ARM monitoring sites and thereby provide additional evidence to consider in deciding which nearby areas contribute to a violating monitor. The urban increment analysis can help isolate and better explain the contributions from urban and near-monitor emissions, separate from the regional background contributions.

An urban increment analysis is based on the premise that so-called “rural” contributions of PM_{2.5} concentrations typically result from a regional distribution of contributing sources caused by atmospheric formation and transport of secondary aerosols.⁴ These are often called regional sources and can include a small number or large collection of large point sources, smaller

¹ Rao, V. and N. Frank, A. Rush, F. Dimmick. Chemical Speciation of PM_{2.5} in Urban and Rural Areas. Special Studies, National Air Quality and Emissions Trends Report, 2003. Available at <http://www.epa.gov/airtrends/studies.html>

² Frank, N. H., The Chemical Composition of PM_{2.5} to support PM Implementation, EPA State / Local / Tribal Training Workshop: PM_{2.5} Final Rule Implementation and 2006 PM_{2.5} Designation Process, Chicago IL, June 20-21, 2007, http://www.epa.gov/ttn/naaqs/pm/presents/pm2.5_chemical_composition.pdf.

³ “Initial Area Designations for the 2012 Revised Fine Particle National Ambient Air Quality Standard” memorandum from Gina McCarthy, Assistant Administrator, April 16, 2013, to Regional Administrators, US EPA Regions I-X.

⁴ Although this memorandum refers to “urban” or “rural” areas, those are technical terms with meanings unique to the urban increment analysis. For purposes of this memorandum, “urban” refers to the area nearby a violation, while “rural” refers to the area outside the immediate area of violation.

stationary sources, and mobile sources – all outside the local area – as well as more distant contributions from other cities. Accordingly, the so-called rural concentrations of the major constituents of PM_{2.5} tend to be more spatially homogenous than the local or so-called urban concentrations and are less impacted by local source emissions. Due to these attributes, the urban increment analysis among one or more urban monitoring locations provides an indication of the type, size, and spatial patterns of nearby or local emission sources that are contributing to the concentrations experienced at the urban monitors.

The basic approach for the urban increment analysis is to calculate the difference between the measured PM_{2.5} at an urban area monitoring site and the regional background concentration as measured at a nearby rural area monitoring site(s). The difference between these two concentrations, defined as the urban increment, provides an estimate of local contributions to PM_{2.5} mass. The urban increment is calculated as follows:

$$\begin{aligned} \text{Urban Increment}_{PM_{2.5} \text{ (total or species)}} \\ &= \text{Urban Concentration}_{PM_{2.5} \text{ (total or species)}} \\ &\quad - \text{Regional Background Concentration}_{PM_{2.5} \text{ (total or species)}} \end{aligned}$$

As described above, individual chemical constituents of the measured PM_{2.5} mass can be linked to specific types of emission sources. Accordingly, looking at the individual components that comprise the urban increment can help identify likely local or ‘nearby’ emitted pollutants that contribute to the design value (DV) concentration. For example, in the eastern United States, large stationary sources such as electric generating units are the predominant contributors to the sulfate component of PM_{2.5}. High nitrate levels (i.e., from oxides of nitrogen and ammonia) often indicate the presence of localized mobile sources, local or regional fuel-combustion sources, a regional contribution from agricultural sources, or a combination of these sources. Carbonaceous mass – often a substantial component of urban excess – is typically associated with mobile sources, wood or biomass burning, and localized combustion sources. A high elemental carbon to organic carbon mass ratio can be a signature of diesel combustion source contributions, such as diesel trucks, construction engines, vehicles, ships, and trains. A high organic carbon to elemental carbon ratio, on the other hand, is often a signature of biomass burning.

Urban Increment Methodology

To facilitate the calculation of urban increments to support initial area designations for the 2012 primary annual PM_{2.5} NAAQS, the EPA developed a general approach to use 2010-2012 PM speciation measurements from the routine urban and rural speciation monitoring networks – respectively, the Chemical Speciation Network (CSN) and Interagency Monitoring of Protected Visual Environments (IMPROVE).⁵ The urban increment methodology focuses on five major

⁵ At the time that states and tribes were required to make boundary recommendations to the EPA, 2010-2012 speciation measurements were the most up-to-date information available. Urban increments derived from these data are representative of more recent air quality and are appropriate for use in the EPA’s analyses and technical support documents.

chemical constituents of PM_{2.5} mass: sulfate, nitrate, organic carbon mass (OM), elemental carbon (EC), and crustal material. These chemical constituents of PM_{2.5} are derived from measured speciation values using the SANDWICH method, which entails a material balance to ensure that the PM_{2.5} chemical constituents sum to the total urban increment associated with average PM_{2.5} and exactly represent the PM_{2.5} mass measured by the PM_{2.5} FRM.^{6,7} The EPA then used this information to determine the “Urban Concentration” and the “Regional Background Concentration.”

To determine the “Urban Concentration” and most accurately describe the composition of the PM_{2.5} design value at violating PM_{2.5} monitoring locations, the EPA used 12 consecutive calendar quarters of measurements from CSN monitors collocated with a PM_{2.5} FRM, and required that each quarter have a minimum of 11 observations of each PM_{2.5} component. When sufficient collocated speciation data at the exact location of each violating monitor site were not available, the EPA used data from other nearby speciation monitors to represent the conditions at the violating monitor site(s). As described in the next section, the EPA then adjusted the PM_{2.5} chemical constituents to account for distance from the violating location and for differences in average PM_{2.5} mass.

The EPA derived the “Regional Background Concentration” by averaging across multiple rural monitor sites, where available, to best represent the regional contributions to PM_{2.5} mass in each calendar quarter. The EPA also used monitors in nearby, smaller urban areas to estimate regional background contributions as the upwind concentrations. Using the measured concentrations from multiple monitors to represent regional influence when calculating the urban increment reduces the potential bias associated with a singular rural/urban monitor pairing. As with the violating location, the EPA required sufficient quarterly data for all PM_{2.5} chemical constituents. The selected rural monitors were generally located within a 150-mile radius of the violating PM_{2.5} monitor site in order to reasonably reflect average background and the influence of upwind emissions. For this simple methodology, however, determinations of a rural site’s regional representativeness did not take into account the influences of topography, intra-quarter differences in daily transport, or the likelihood that some locations may be more representative of upwind concentrations and corresponding emission influence.

Some areas of the United States have limited rural monitoring locations with 12 consecutive quarters of sufficient PM_{2.5} speciation data surrounding the DV monitoring locations. To maximize the number of background monitoring sites for this urban increment calculation, the EPA paired background locations with the violating monitor on a quarter-by-quarter basis. (Accordingly, although the number of included background locations may vary from quarter to quarter, their average PM_{2.5} component concentrations are temporally consistent with the

⁶ The SANDWICH technique stands for measured Sulfate, Adjusted Nitrate, Derived Water, Inferred Carbonaceous mass Hybrid Material Balance Approach. It identifies the PM_{2.5} constituents that are represented by the measured PM_{2.5} with the FRM or FEM monitor.

⁷ Frank, N. H. *Retained Nitrate, Hydrated Sulfates, and Carbonaceous Mass in Federal Reference Method Fine Particulate Matter for Six Eastern U.S. Cities*. J. Air & Waste Manage. Assoc. 2006 56:500–511.

analyzed data from the violating monitor.) The EPA then summarized the resulting urban increments as 3-year averages by calendar quarter and PM_{2.5} chemical constituent.

Analytical Protocol

The EPA used the following steps to derive the urban increment (UI) at each urban CSN location and DV site:

- 1) The EPA generated quarterly average concentrations of five SANDWICHed PM_{2.5} constituents (sulfate, nitrate, OM, EC, and crustal material) for each CSN and IMPROVE site that produced at least 11 observations for each constituent.⁸ Values for estimated ammonium nitrate (AN) based on measured nitrate are provided, (i.e. NO₃*1.29) and used in step 5 to produce a SANDWICHed estimate for its UI.⁹ The data elements are described in the data dictionary (see Attachment A) and can be found on the PM Designations website at <http://www.epa.gov/pmdesignations/2012standards/techinfo.htm>.
- 2) Urban CSN sites (UCS) include sites that are either “URBAN AND CENTER CITY” or “SUBURBAN,” based on land use data. A UCS is eligible for this analysis if it provided 12 consecutive calendar quarters with sufficient data for each chemical constituent.
- 3) For each UCS and quarter, the EPA identified the eligible rural sites to be those within 150 miles of the urban monitor or, if no rural locations were within 150 miles, then the EPA identified the nearest rural site. The EPA considered non-UCS CSN sites and IMPROVE data as “rural.” Attachment B identifies the rural and UCS site pairings.
- 4) For each calendar quarter and UCS, the EPA computed the average concentration of each PM_{2.5} constituent among all eligible rural sites associated with that UCS.
- 5) Except for nitrate, the EPA estimated the UI for each UCS chemical constituent as the numerical difference between the UCS and average rural values. For the nitrate UI –
 - a. The UI was initially estimated as the numerical difference between UCS and rural nitrate mass (N_u and N_r, respectively) which are derived from measured nitrate (NO₃) and expressed as ammonium nitrate by multiplying by 1.29.⁹
 - b. The above measurement-derived difference is then multiplied by the ratio of SANDWICHed UCS nitrate mass (SN_u) to the UCS measurement derived value

⁸ The SANDWICH estimates represent fine particle mass as measured by the PM_{2.5} FRM. For sulfate and nitrates, they include the associated ammonium and particle bound water. The estimate for OM is derived by material balance.

⁹ Because ammonium is 29% of ammonium nitrate, this multiplier converts nitrate concentration into ammonium nitrate.

(N_u). This ratio accounts for the portion of the urban increment that is retained by the $PM_{2.5}$ FRM.¹⁰

- c. Finally, the expression is multiplied by 1.12 to produce “hydrated retained ammonium nitrate,” to be consistent with the SANDWICH calculations.

$$i.e., \quad UI_{\text{nitrate}} = (N_u - N_r) * (SN_u / N_u) * 1.12$$

- 6) The EPA set to zero any negative derived quarterly UI's. Negative values could occur when the estimated average rural concentration is similar to its paired urban value.
- 7) For each calendar quarter, the EPA estimated the UI at the DV site using one of three possible metrics:
 - a. As the value at a collocated UCS, if eligible UCS data were available;
 - b. Otherwise, as a distance weighted average among all eligible UCS in the same consolidated statistical area (CSA), if such data were available;
 - c. Otherwise, as the regional default value derived from the UI among all eligible UCS. These regional default values are spatial means of UIs from sites in the same NOAA climate region.¹¹

As indicated in Attachment B, the three types of UIs among all eligible UCS are specified as “coloc,” “csamon” and “default.” Attachment B also provides the included UCS for the csamon values.

- 8) As necessary, to estimate the UI at the DV site, the EPA adjusted the initial value:

If the 3-year quarterly average $PM_{2.5}$ mass at the DV site was different than the derived $PM_{2.5}$ mass associated with the UCS (or default value), then the EPA adjusted the estimate value from step 7 to allow the UI among the constituents to sum to the “total” $PM_{2.5}$ UI. The EPA made this adjustment by scaling the OM and EC constituents up or down to achieve material balance with the total.¹² In the

¹⁰ The SANDWICH procedure is designed to account for atmospheric particle nitrate that is retained by the $PM_{2.5}$ monitor. A part of this comes from local emission sources and the remainder from more distant sources. With this ratio, the retained fractions of each part are identical.

¹¹ <http://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php>

¹² The adjustments, which are only made for OM and EC, essentially assume that the difference between DV-site and CSN-site $PM_{2.5}$ mass and associated increments are only attributed to carbon. This default assumption is reasonable in light of the large uncertainties in both the calculation of OM, and the material balance approach inherent in SANDWICH.

event that the initially calculated UI for OM and EC were both zero, then the EPA adjusted the largest UI among the other constituents.¹³

In all cases, CSN measurements with less than 12 quarters of data collocated with the DV location can be used to corroborate or adjust the UI values derived with the general methods described above.

Attachments

- A: PM_{2.5} chemical constituent data dictionary
- B: Urban rural pairings and types of UI for each DV site

¹³ In the event that examination of monitor siting and potential influence of local emissions suggest that non-carbonaceous sources may be responsible for the local urban gradient in PM_{2.5} concentrations in the vicinity of the DV monitor, then an alternate estimate of the DV composition and its urban increment should be considered. Such alternative approaches may include assigning the excess mass to PM_{2.5} constituents in proportion to the local emissions or in proportion to their initial calculated UI values.