United States Environmental Protection Agency

Health Risk and Exposure Assessment for Ozone

Second External Review Draft

Executive Summary

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U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
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Introduction

As part of the review of the ozone National Ambient Air Quality Standards (NAAQS), EPA has prepared this Risk and Exposure Assessment (REA) to provide estimates of exposures to O3 and resulting mortality and morbidity health risks. The health effects evaluated in this REA are based on the findings of the O3 ISA (U.S. EPA, 2012) that short term O3 exposures are causally related to respiratory effects, and likely causally related to cardiovascular effects, and that long term O3 exposures are likely causally related to respiratory effects. The assessment evaluated total exposures and risks associated with the full range of observed O3 concentrations. In addition, the REA estimated the incremental changes in exposures and risks between just meeting the existing standard of 75 ppb and just meeting potential alternative standard levels of 70, 65, and 60 ppb using the form and averaging time of the existing standard, which is the annual 4th highest daily maximum 8-hour O3 concentration, averaged over three consecutive years. The results of the REA help to inform the O3 Policy Assessment (PA) in considering the adequacy of the existing O3 standards, and potential risk reductions associated with potential alternative levels of the standard.

As described in the conceptual framework and scope in Chapters 2 and 3, respectively, the health REA discusses air quality considerations (Chapter 4) and evaluates exposures and lung function risk in 15 urban case study areas (Chapters 5 and 6, respectively) and risks based on application of results of epidemiology studies in a subset of 12 urban case study areas (Chapter 7) . In addition, to place the urban area analyses in a broader context, the assessment estimated the national burden of mortality associated with recent O3 levels, and evaluated the representativeness of the urban areas in characterizing O3 exposures and risks across the U.S. (Chapter 8). To further facilitate interpretation of the results of the exposure and risk assessment, Chapter 9 provides a synthesis of the various results, focusing on comparing and contrasting those results to identify common patterns, or important differences. It also includes an overall integrated characterization of exposure and risk in the context of key policy relevant questions.

Conceptual Framework and Scope

The REA provides information to answer key policy-relevant risk questions with regards to evaluation of the adequacy of the existing standards and evaluation of potential alternative standards such as:

"*To what extent do risk and/or exposure analyses suggest that exposures of concern for O_3-related health effects are likely to occur with existing ambient levels of O_3 or with levels that just meet the O_3 standard?*

To what extent do alternative standards, taking together levels, averaging times and forms, reduce estimated exposures and risks of concern attributable to O_3 and other photochemical oxidants, and what are the uncertainties associated with the estimated exposure and risk reductions?"

In answering these questions, the REA evaluates total exposures and risks associated with the full range of observed O_3 concentrations, as well as the incremental changes in exposures and risks for just meeting the existing standard and just meeting several alternative standards. With regard to selecting alternative levels for the 8-hour O_3 standards for evaluation in the quantitative risk assessment, we base the range of levels on the evaluations of the evidence provided in the first draft PA, which received support from the CASAC in their advisory letter on the first draft PA. The

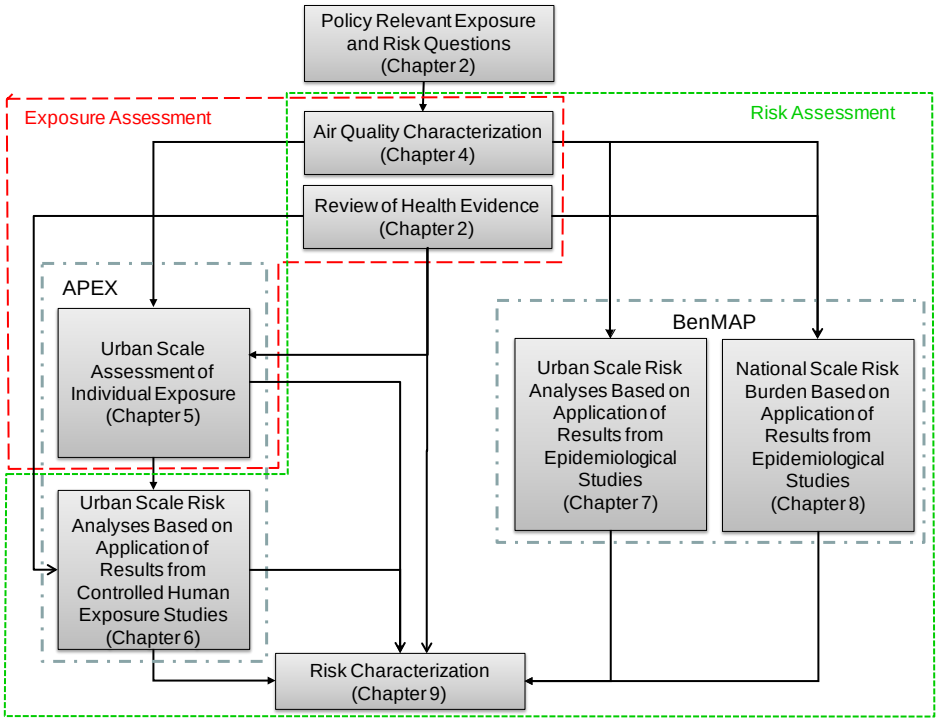
first draft PA recommended evaluation of 8-hour maximum concentrations in the range of 60 to 70 ppb, with possible consideration of levels somewhat below 60 ppb.

O_3 concentrations from 2006-2010 are used in estimating exposures and risks for the 15 urban case study areas. Because of the year-to-year variability in O_3 concentrations, the assessment evaluates scenarios for meeting the existing and potential alternative standards based on multiple years of O_3 data to better capture the high degree of variability in meteorological conditions, as well as reflecting years with higher and lower emissions of O_3 precursors. The 15 urban case study areas were selected to be generally representative of U.S. populations, geographic areas, climates, and different O_3 and co-pollutant levels. These urban case study areas include Atlanta, GA; Baltimore, MD; Boston, MA; Chicago, IL; Cleveland, OH; Dallas, TX; Denver, CO; Detroit, MI; Houston, TX; Los Angeles, CA; New York, NY; Philadelphia, PA; Sacramento, CA; St. Louis, MO; and Washington, D.C.

We have identified the following goals for the urban area exposure and risk assessments: (1) to provide estimates of the percent of people in the general population and in at-risk populations and lifestages with O_3 exposures above health-based benchmark levels; (2) to provide estimates of the percent of people in the general population and in at-risk populations and lifestages with impaired lung function (defined based on decrements in FEV1) resulting from exposures to O_3; (3) to provide estimates of the potential magnitude of premature mortality associated with both short-term and long-term O_3 exposures, and selected morbidity health effects associated with short-term O_3 exposures; (4) to evaluate the influence of various inputs and assumptions on risk estimates to the extent possible given available methods and data; (5) to gain insights into the spatial and temporal distribution of risks associated with O_3 concentrations just meeting existing and alternative standards, patterns of risk reduction associated with meeting alternative standards relative to the existing standard, and uncertainties in the estimates of risk and risk reductions.

In working towards these goals, we follow a conceptual framework, shown in the figure below, comprised of air quality characterization, review of relevant scientific evidence on health effects, modeling of exposure, modeling of risk, and risk characterization. As shown in this framework, modeling of personal exposure and estimation of risks, which rely on personal exposure estimates, are implemented using the Air Pollution Exposure model (APEX)[1] (U.S. EPA, 2012a,b). Modeling of population level risks for endpoints based on application of results of epidemiological studies is implemented using the environmental Benefits Mapping and Analysis Program (BenMAP)[2], a peer reviewed software tool for estimating risks and impacts associated with changes in ambient air quality (U.S. EPA, 2013). The overall characterization of risk draws from the results of the exposure assessment and both types of risk assessment.

[1] APEX is available for download at http://www.epa.gov/ttn/fera/human_apex.html
[2] BenMAP is available for download at http://www.epa.gov/air/benmap/



Air Quality Considerations

In this analysis, we employed a photochemical model-based adjustment methodology (Simon et al, 2012) to estimate the change in observed hourly O3 concentrations at a given set of monitoring sites resulting from across-the-board reductions in U.S. anthropogenic NOx and/or VOC emissions. This information was then used to adjust recent O3 concentrations (2006-2010) in the 15 case study areas to reflect just meeting the existing standard of 75 ppb and just meeting potential alternative standard levels of 70, 65, and 60 ppb. Because the form of the existing O3 standard is based on the 3-year average of the 4th highest daily 8-hour maximum, we simulate just meeting the standard for two periods, 2006-2008 and 2008-2010.

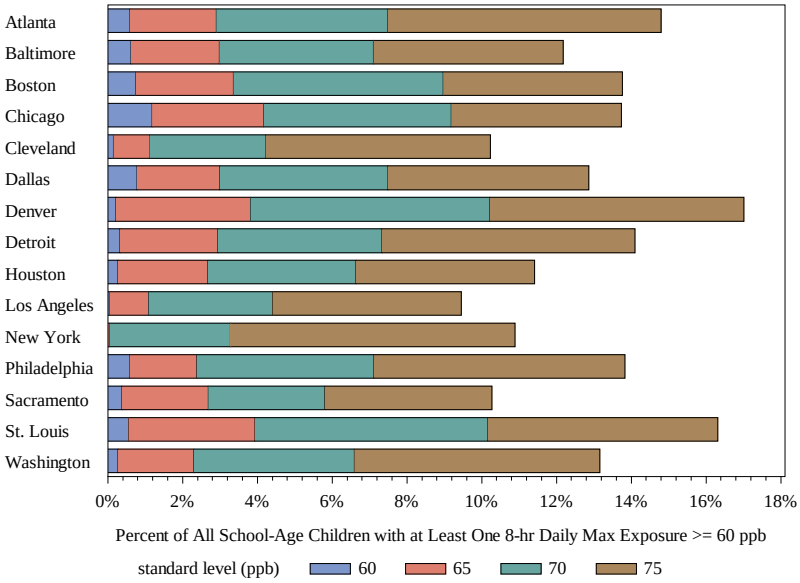
The use of the model-based adjustment methodology is an example of how we have brought improvements into this review that better represent current scientific understanding. The model-based adjustment methodology represents a substantial improvement over the quadratic rollback method used to adjust O3 concentrations in past reviews. For example, while the quadratic rollback was a purely mathematical technique which attempted to reproduce the distribution of observed O3 concentrations just meeting various standards, the new methodology uses photochemical modeling to simulate the response in O3 concentrations due to changes in precursor emissions based on current understanding of atmospheric chemistry and transport. Second, quadratic rollback used the same mathematical formula to adjust concentrations at all monitors within each urban case study area for all hours, while model-based adjustment methodology allows the adjustments to vary both spatially across each case study area and temporally across hours of the day and across seasons. Finally, quadratic rollback was designed to only allow decreases in O3

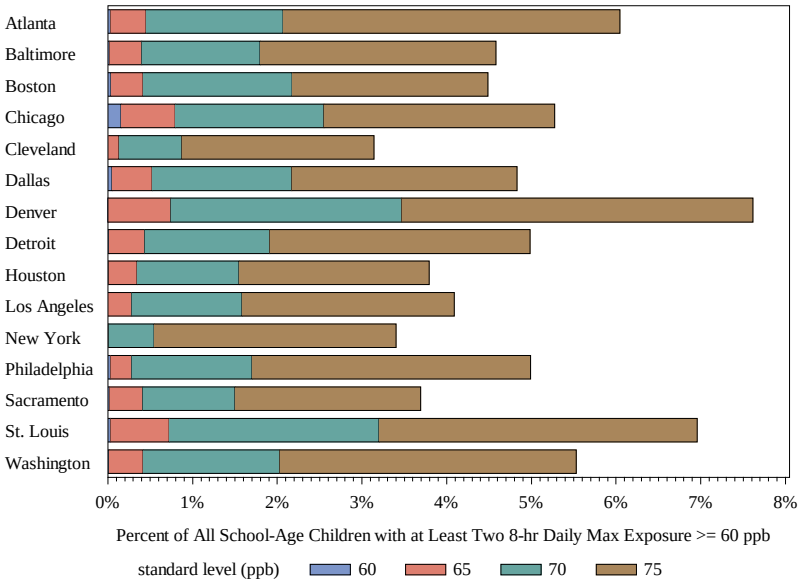
concentrations, while the model-based adjustment methodology allows both increases and decreases in O3 concentrations, which more accurately reflects the scientific understanding that increases in O3 concentrations may occur in response to reductions in NOx emissions in some situations, such as in urban areas with a large amount of NOx emissions.
Several general trends are evident in the changes in O3 patterns across the case study areas and across the different standards under consideration. In all 15 case study areas, peak O3 concentrations tended to decrease while the lowest O3 concentrations tended to increase as the concentrations were adjusted to meet the existing and potential alternative standards. In addition, high and mid-range O3 concentrations generally decreased in rural and suburban portions of the case study areas, while O3 response to NOx reductions was more varied within urban core areas. In particular, while the annual 4th highest daily maximum 8-hour concentrations generally decreased in the urban core of the case study areas in response to reductions in NOx emissions, the seasonal mean of the daily maximum 8-hour O3 concentrations did not change significantly, though it did exhibit some increases or decreases in the various case study areas as the distribution of O3 was further adjusted to meet lower potential alternative standards.

The adjustments to O3 to reflect just meeting existing and potential alternative standards are conducted by decreasing only emissions of anthropogenic NOx and VOC within the U.S. As such, the estimated changes in exposure and risk, based on these air quality changes, are solely attributable to changes in U.S. emissions.

Human Exposure Modeling

The population exposure assessment evaluated exposures to O3 using the APEX exposure model which uses time-activity diary and anthropometric data coupled with local meteorology, population demographics, and O3 concentrations to estimate the percent of study groups above exposure benchmarks. The analyses examined exposure to O3 for the general population, all school-aged children (ages 5-18), asthmatic school-aged children (ages 5-18), asthmatic adults (ages > 18), and older persons (ages 65 and older), with a focus on populations engaged in moderate or greater exertion, for example, children engaged in outdoor recreational activities. Exposure is assessed in the 15 urban case study areas for recent O3 (2006-2010) and for O3 adjusted to just meet existing and potential alternative standards for two design value periods (2006-2008 and 2008-2010). The analysis provided estimates of the percent of several populations of interest exposed to concentrations above three health-relevant 8-hour average O3 exposure benchmarks: 60, 70, and 80 ppb. These benchmarks were selected so as to provide some perspective on the public health impacts of O3-related health effects that have been demonstrated in human clinical and toxicological studies, but cannot currently be evaluated in quantitative risk assessments, such as lung inflammation and increased airway responsiveness. The ISA includes studies showing significant effects at each of these benchmark levels (U.S. EPA, 2012).
The analysis found that children are the population of greatest concern for O3 exposures due to the greater amount of time they spend outdoors engaged in moderate or higher exertion activities and the fact that children have the highest percent of exposures of concern of any of the at-risk populations. As a result, we focus on the results for children in this discussion. The two figures below show the average across 2006-2010 of the percentage of school-aged children experiencing 8-hour exposure greater than 60 ppb for at least one exposure (top) and for at least two exposures (bottom) per year. Based on this information, no more than 26 percent of any





Average percent increases in percent of all school-age children exposed at or above 60 ppb-8hr for each study area over all years, for at least one exposure (left) and for at least two exposures (right) per year.

Note: New York level 60 was not modeled. We do not know what the percent risk would be for NY under the 60 ppb alternative standard, but it would not necessarily be zero.

study group in any study area was exposed at least once at or above the 60 ppb-8hr benchmark, when meeting the existing standard. When meeting a standard level of 70 ppb, less than 20 percent of any study group in any study area was exposed at least once at or above the 60 ppb-8hr exposure benchmark. Meeting a standard level of 65 ppb is estimated to reduce the percent of persons at or above an exposure benchmark of 60 ppb-8hr to 10 percent or less of any study group and study area.

For the exposure benchmark of 70 ppb-8hr, less than 10 percent of any study group, including all school-age children, in any study area, was exposed at least once at or above the exposure benchmark when meeting the existing standard. For the highest exposure benchmark of 80 ppb-8hr, less than 1 percent of any study group in any study area was exposed at least once at or above the exposure benchmark when meeting the existing standard. These percentages are even smaller when meeting the lower alterative standard levels.

For two or more exceedances at the 60 ppb-8hr benchmark, less than 15 percent of any study group in any study area experience 8-hour exposure greater than 60 ppb-8hr when meeting the existing standard. There were no persons estimated to experience any multi-day exposures at or above 80 ppb-8hr for any study group in any study area, while 2.2 percent or less of persons were estimated to experience two or more exposures at or above 70 ppb-8hr, when meeting the existing standard or any of the alternative standard levels.

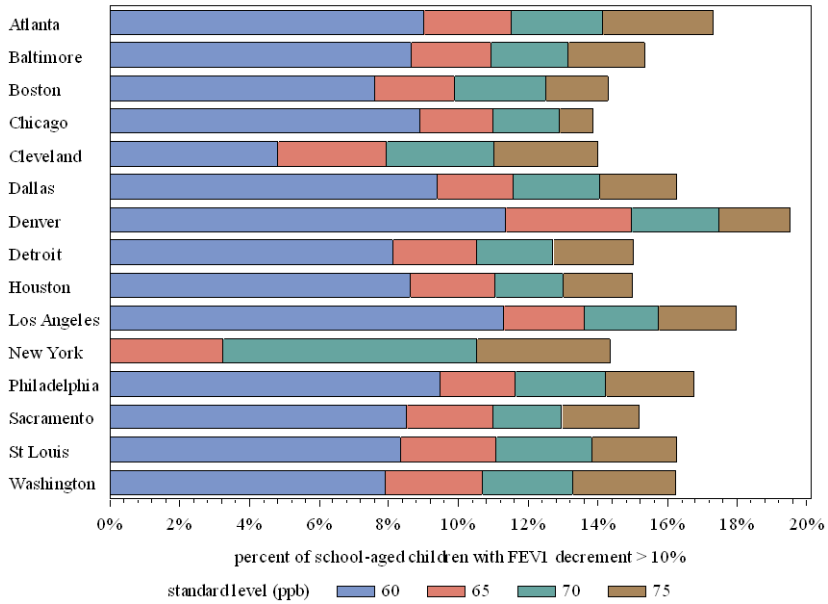
In addition, the exposure assessment also identified the specific microenvironments and activities that contribute most to exposure and evaluated at what times and how long individuals were in key microenvironments and were engaged in key activities, with a focus on persons experiencing the highest daily maximum 8-hour exposure within each

study area. That analysis found that: (1) Children are an important exposure population subgroup, largely as a result of the combination of high levels of outdoor time and engagement in moderate or high exertion level activities. (2) Persons spending a large portion of their time outdoors during afternoon hours experienced the highest 8-hour O3 exposure concentrations given that O3 concentrations in other microenvironments were simulated to be lower than ambient concentrations. (3) Highly exposed children on average spend half of their outdoor time engaged in moderate or greater exertion levels, such as in sporting activities. Highly exposed adults also spent their outdoor time engaged in moderate or greater exertion levels though on average, not as frequently as children.

Health Risks Based on Controlled Human Exposure Studies

This analysis uses the estimates of exposure from APEX, combined with results from controlled human exposure studies, to estimate the number and percent of at-risk populations (all children, children with asthma, adults aged 18-35, adults aged 36-55, and outdoor workers) experiencing selected decrements in lung function. The analysis focuses on estimates of the percent of each at-risk population experiencing a reduction in lung function for three different levels of impact: 10, 15, and 20 percent decrements in FEV1. These levels of impact were selected based on the literature discussing the adversity associated with increasing lung function decrements (US EPA, 2012, Section 6.2.1.1; Henderson, 2006). Lung function decrements of 10 percent and 15 percent in FEV1 are considered moderate decrements; 10 percent is considered potentially adverse for people with lung disease, while a 15 percent is potentially adverse for active healthy people. A 20 percent decrement in FEV1 is considered a large decrement that is potentially adverse for healthy people and can potentially cause more serious effects in people with lung disease.

Two models were used to estimate lung function risks. One model was based on application of a population level exposure-response (E-R) function consistent with the approach used in the previous O3 review, and the other model was based on application of an individual level risk function (the McDonnell-Stewart-Smith (MSS) model), which is being introduced in this review. The main differences between the two models are that the MSS model includes responses for a wider range of exposure protocols (under different levels of exertion, lengths of exposures, and patterns of exposure concentrations) than the exposure-response model of previous reviews. Both models have a logistic form and are less sensitive to changes at very low concentrations of O3 than to higher O3 concentrations. As a result, the models show very few FEV1 responses > 10% when ambient concentrations are below 20 ppb and very few FEV1 responses > 15% when ambient concentrations are below 40 ppb. Because the individual level E-R function approach allows for a more complete estimate of risk, we focus on the results of the MSS model for this discussion.



Average percent increases in percent of all school-age children with FEV1 decrement ≥ 10 percent in each study area over all years

Note: New York level 60 was not modeled. We do not know what the percent risk would be for NY under the 60 ppb alternative standard, but it would not necessarily be zero.

Lung function risks were estimated for each of the 15 urban case study areas for recent air quality (2006-2010) and for air quality adjusted to just meet existing and alternative standards for two design value periods (2006-2008 and 2008-2010). As with the exposure assessment, we focus on lung function decrements in children as they are the populations likely to have the greatest percentage at risk due to higher levels of exposure and greater levels of exertion. The figure above shows the risks just meeting the existing and potential alternative standard levels, where risk is taken to be the average value for each study area (over all years) of the percent of school-aged children with FEV1 decrement of 10 percent or greater. This figure shows that there are significant decreases in incremental risk for all 15 cities in the progression from the level of the existing standard, 75 ppb to the alternative standard levels of 70, 65, and 60 ppb. The risks in this figure for Washington, DC, for example, are about 16.3 percent for the existing standard level of 75 ppb and about13.3 percent for the alternative standard level of 70 ppb. The length of the brown bar is the incremental risk reduction (3 percent) in going from the existing standard of 75 ppb to the 70 ppb alternative standard. The pattern of reductions for lung function decrements larger than 15 and 20 percent are similar.

Health Risks Based on Application of Results of Epidemiological Studies

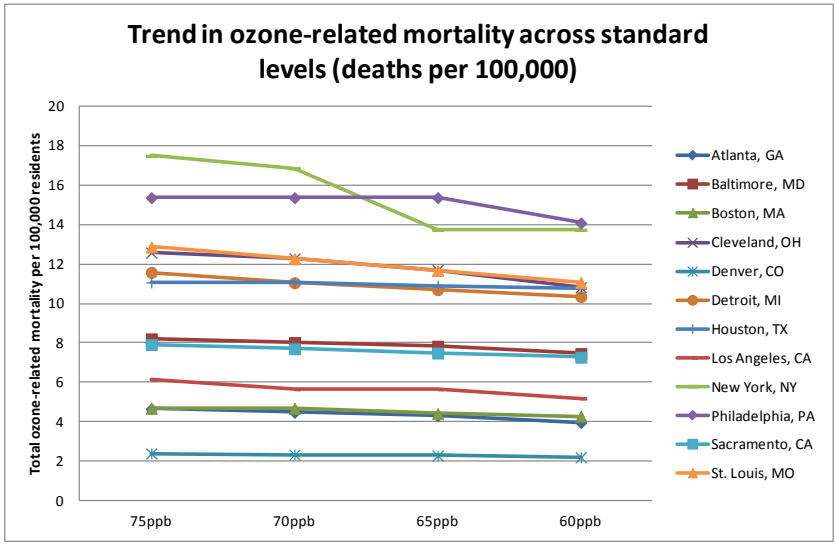
The epidemiology-based risk assessment evaluated mortality and morbidity risks from short-term exposures, as well as mortality risks from long-term exposures to O3, by applying concentration-response (C-R) functions derived from epidemiology studies. Most of the endpoints evaluated in epidemiology studies are for the entire study population. Because most mortality and hospitalizations occur in older persons, the risk estimates for this portion of the analysis are thus more focused in adults rather than children, and thus differ in focus compared to the human exposure and lung function risk assessments. The analysis included both a set of urban area case studies and a national-scale assessment.

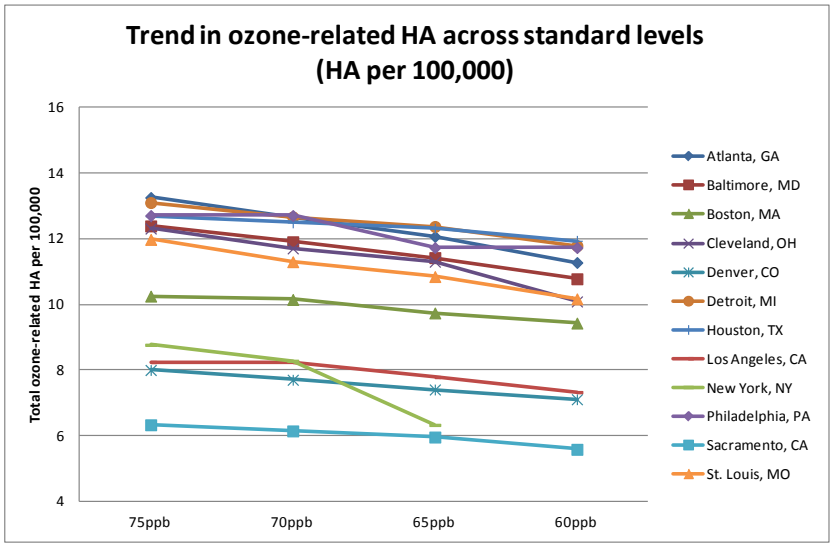
The urban case study analyses evaluated mortality and morbidity risks, including emergency department (ED) visits, hospitalizations, and respiratory symptoms associated with recent O3 concentrations (2006-2010) and with O3 concentrations adjusted to just meet the existing and alternative O3 standards. Mortality and hospital admissions (HA) were evaluated in 12 urban areas (a subset of the 15 urban areas evaluated in the exposure and lung

function risk assessments), while ED visits and respiratory symptoms were evaluated in a subset of areas with supporting epidemiology studies. The 12 urban areas were: Atlanta, GA; Baltimore, MD; Boston, MA; Cleveland, OH; Denver, CO; Detroit, MI; Houston, TX; Los Angeles, CA; New York, NY; Philadelphia, PA; Sacramento, CA; and St. Louis, MO. The urban case study analyses focus on risk estimates for the middle year of each three-year attainment simulation period (2006-2008 and 2008-2010) in order to provide estimates of risk for a year with generally higher O3 levels (2007) and a year with generally lower O3 levels (2009).

In previous reviews, O3 risks were estimated for the portion of total O3 attributable to North American anthropogenic sources (referred to in previous O3 reviews as "policy relevant background"). In contrast, this assessment provides risk estimates for the urban areas for O3 concentrations down to zero, reflecting the lack of evidence for a detectable threshold in the C-R functions (ISA, 2012), and the understanding that U.S. populations may experience health risks associated with O3 resulting from emissions from all sources, both natural and anthropogenic, and within and outside the U.S.

The two figures to the right show the results of the mortality (top) and respiratory hospital admissions (bottom) risk assessments for all 12 urban areas associated with short-term exposure to O3, showing the effect on the incidence per 100,000 population just meeting the existing 75 ppb standard and potential alternative O3 standards of 70, 65, and 60 ppb in 2007. The overall trend across urban areas is small decreases in mortality and morbidity risk as air quality is adjusted to just meet incrementally lower standard levels. In New York, there are somewhat greater decreases, reflecting the relatively large emission reductions used to adjust air quality to just meet the 65 ppb alternative standard, and the substantial change in the distribution of O3 concentrations that resulted. Risks vary substantially across urban areas; however, the general pattern of reductions across the alternative





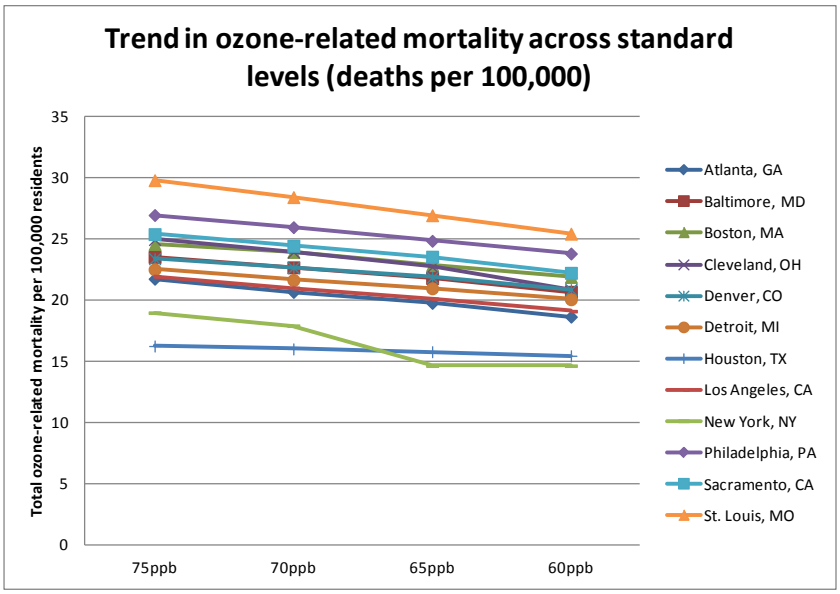
Impacts of just meeting existing and alternative standard levels on short-term mortality risk per 100,000 population (top) and on respiratory hospital admissions risk per 100,000 population for 2007 (bottom)

Note: New York level 60 was not modeled. We do not know what the percent risk would be for NY under the 60 ppb alternative standard, but it would not necessarily be zero.

standards is similar between urban areas. Risks are generally slightly lower in 2009 relative to 2007; though the patterns of reductions are very similar between the two years. On average, compared with meeting the existing standard, mortality and respiratory hospitalization risks decrease by 5% or less for a level of 70 ppb, 10% or less for a level of 65 ppb, and 15% or less for a level of 60 ppb. Larger risk reductions are estimated on days with higher O3.

We also evaluated mortality risks in the 12 urban areas associated with long-term O3 exposures (based on the April to September average of the peak daily one-hour maximum concentrations). The figure below shows the results of long-term mortality risk assessments for all 12 urban areas, showing the effect on the incidence per 100,000 population just meeting the existing standard and potential alternative O3 standard levels of 70, 65, and 60 ppb in 2007. Risks from long-term exposures after just meeting the existing standard are substantially greater than risks from short-term exposures, ranging from 16 to 20 percent of respiratory mortality across urban areas. However, the percent reductions in risks are similar to those for mortality from short-term exposures, e.g., less than 10 percent reduction in risk relative to just meeting the existing standard in most areas when just meeting the 70 ppb and 65 ppb alternative standards, and less than 20 percent reductions when just meeting the 60 ppb alternative standard level.

Mortality and morbidity risks generally do not show large responses to meeting existing or alternative levels of the standard for several reasons. First, these risks are based on C-R functions that are approximately linear along the full range of concentrations, and therefore reflect the impact of changes in O3 along the complete range of 8-hour average O3 concentrations. This includes days with low baseline O3 concentrations that are predicted to have increases in O3 concentrations, as well as days with higher starting O3 concentrations that are predicted to have decreases in O3 concentrations as a result of just meeting existing and potential alternative standards. Second, these risks reflect changes in the urban-area wide monitor average, which will not be as responsive to air quality adjustments as the design value monitor, and which includes monitors with both decreases and increases in 8-hour concentrations. Third, the days and locations with predicted increases in O3 concentrations (generally those with low to midrange starting O3 concentrations) resulting from just meeting the existing or alternative standard levels generally are frequent enough to offset days and locations with predicted decreases in O3. The focus of the epidemiological studies on urban area-wide average O3 concentrations, and the lack of thresholds coupled with the linear nature of the C-R functions mean that in this analysis, the impact of a peak-based standard (which seeks to reduce peak concentrations



Impacts of just meeting existing and alternative standard levels on long-term mortality risk per 100,000 population for 2007

Note: New York level 60 was not modeled. We do not know what the percent risk would be for NY under the 60 ppb alternative standard, but it would not necessarily be zero.

regardless of effects on low or mean concentrations) on estimates of mortality and morbidity risks based on results of those studies is relatively small. However, we are not able to draw strong conclusions about the results across urban areas, because of the limited number of urban areas represented for most of the endpoints.

The national-scale epidemiology-based risk assessment evaluated only mortality associated with recent O3 concentrations across the entire U.S for 2006-2008. The national-scale assessment is a complement to the urban scale analysis, providing both a broader assessment of O3-related health risks across the U.S. It demonstrates that there are O3 risks across the U.S, not just in urban areas, even though the O3 levels in many areas were lower than the existing standard level. We estimated 15,000 premature O3-related non-accidental deaths (all ages) annually associated with short-term exposure to recent O3 levels across the continental U.S. for 2007, May-September. For long-term mortality, we estimated 45,000 premature O3-related adult (age 30 and older) respiratory deaths annually for 2007, April-September. While we did not assess the changes in risk at a national level associated with just meeting existing and potential alternative standards, just meeting existing and potential alternative standards would likely reduce O3 concentrations both in areas that are not meeting those standards and in locations surrounding those areas, leading to risk reductions that are not captured by the urban scale analysis.

Representativeness of Exposure and Risk Results

As part of this assessment, we conducted several analyses to determine the extent to which our selected urban areas represent: (1) the highest mortality and morbidity risk areas in the U.S.; and (2) the types of patterns of O3 air quality changes that we estimate would be experienced by the overall U.S. population in response to emissions reductions that would decrease peak O3 concentrations to meet the existing standard or lower alternative O3 standard levels.

We selected urban areas for the exposure and risk analyses based on criteria that included O3 levels, at-risk populations, and related factors that were designed to ensure we captured areas and populations likely to experience high O3 exposures and risks. Based on the comparisons of distributions of risk characteristics, the selected urban case study areas represent urban areas that are among the most populated in the U.S., have relatively high peak O3 levels, and capture well the range of city-specific mortality risk effect estimates. The analyses found that the O3 mortality risk for short-term O3 exposures in the 12 urban study areas are representative of the full distribution of U.S. O3-related mortality, representing both high end and low end risk counties. For the long-term exposure related mortality risk metric, the 12 urban study areas are representative of the central portion of the distribution of risks across all U.S. counties, however, the selected 12 urban areas do not capture the very highest (greater than 98th percentile) or lowest (less than 25th percentile) ends of the national distribution of long-term exposure-related O3-related risk.

While we selected urban areas to represent those populations likely to experience elevated risks from O3 exposure, we did not include amongst the selection criteria the responsiveness of O3 in the urban area to decreases in O3 precursor emissions that would be needed to just meet existing or potential alternative standards. The additional analyses we conducted suggest that many of the urban case study areas may show O3 responses that are typical of other large urban areas in the U.S., but may

not represent the response of O3 in other populated areas of the U.S. These other areas, including suburban areas, smaller urban areas, and rural areas, would be more likely than our urban case study areas to experience area-wide average decreases in mean O3 concentrations and, therefore, decreases in mortality and morbidity risks, as O3 standards are met. Even though large urban areas have high population density, the majority of the U.S. population lives outside of these types of urban core areas, and thus, a large proportion of the population is likely to experience greater mortality and morbidity risk reductions in response to reductions in 8-hour O3 concentrations than are predicted by our modeling in the 12 selected urban case study areas.

Because our selection strategy for risk modeling was focused on identifying areas with high risk, we tended to select large urban population centers. This strategy was largely successful in including urban areas in the upper end of the O3 risk distribution. However, this also led to an overrepresentation of the populations living in locations where we estimate increasing mean seasonal O3 would occur in response to decreases in O3 precursor emissions that would be needed to just meet existing or alternative standards. The implication of this is that our estimates of mortality and morbidity risk reductions for the selected urban areas should not be seen as representative of potential risk reductions for most of the U.S. population, and are likely to understate the average risk reduction that would be experienced across the population.

Synthesis

To facilitate interpretation of the results of the exposure and risk assessment, this assessment provides a synthesis of the various results, focusing on comparing and contrasting those results to identify common patterns, or important differences. Consistent with the available evidence, we estimated exposures relative to several health-based exposure benchmarks, lung function risks based on a threshold exposure-response model of lung function decrements, and mortality and morbidity risks based on non-threshold C-R functions. These three different analyses result in differing sensitivities of results to changes in O3. Because the three metrics are affected differently by changes in O3 at low concentration levels, it is important to understand these changes in O3 at low concentrations in interpreting differences in the results across metrics.

The exposure benchmark analysis is the least sensitive to changes in O3 in the lower part of the distribution of starting O3 concentrations, because the lowest of the exposure benchmarks is at 60 ppb, above the portion of the distribution of starting O3 concentrations where we saw increases. Since the modeled exposures will always be less than or equal to the monitor concentrations, a benchmark of exposure at 60 ppb is above the range of O3 concentrations where the model-based adjustment approach estimates increases in concentrations. Thus, this metric is most reflective of the decreases in O3 at high concentrations that are expected to result from just meeting the existing and potential alternative standards.

The lung function risk analysis is less sensitive than the mortality and morbidity risk assessments to changes at very low concentrations of O3, because the risk function is logistic and shows little response at lower O3 dose rates that tend to occur when ambient concentrations are lower (generally less than 20 ppb for the 10 percent FEV1 decrement and generally less than 40 ppb for the 15 percent FEV1 decrement). However, because there are still some increases that occur in the 50 to 60 ppb range where the estimated risk is more

responsive, there may be some reduction in the net risk decrease.
The mortality and morbidity risk assessment is the analysis that is most sensitive to the increases in O3 in the lower part of the distribution of starting O3 concentrations that we estimated would occur as the existing and alternative standards are met in some urban areas. Mean O3 concentrations for the urban areas change little between air quality scenarios for meeting the existing and alternative standards, because mean concentrations reflect both the increases in O3 at lower concentrations and the decreases in O3 occurring on days with high O3 concentrations. This leads to small net changes in mortality and morbidity risk estimates for many of the urban case study areas. However, both the net change in risk and the distribution of risk across the range of O3 concentrations may be relevant in considering the degree of additional protection provided by just meeting existing and alternative standards.

In conclusion, we have estimated that exposures and risks remain after just meeting the existing standards and that that in many cases, just meeting potential alternative standard levels results in reductions in those exposures and risks. Meeting potential alternative standards has larger impacts on metrics that are not sensitive to changes in lower O3 concentrations. When meeting the 70, 65, and 60 ppb alternative standards, the percent of children experiencing exposures above the 60 ppb health benchmark falls to less than 20 percent, less than 10 percent, and less than 3 percent in the worst O3 year for all 15 case study urban areas, respectively. Lung function risk also drops considerably as lower standards are met. When meeting the 70, 65, and 60 ppb alternative standards, the percent of children with lung function decrements greater than or equal to 10 percent in the worst year falls to less than 21 percent, less than 18 percent, and less than 14 percent in the worst O3 year for all 15 case study urban areas, respectively. Mortality and respiratory hospitalization risks decrease by 5% or less for a level of 70 ppb, 10% or less for a level of 65 ppb, and 15% or less for a level of 60 ppb. These smaller changes in the mortality and morbidity risks, relative to the exposures and lung function risk reductions, reflect the impact of increasing O3 on low concentration days, and the non-threshold nature of the C-R function. Larger mortality and morbidity risk reductions are estimated on days with higher baseline O3 concentrations.

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