CA Exhibit 13

Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II

25 Southwest

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On the Web: https://nca2018.globalchange.gov/chapter/southwest

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25 Southwest

Low water levels in Lake Mead

Key Message 1

Water Resources

Water for people and nature in the Southwest has declined during droughts, due in part to human-caused climate change. Intensifying droughts and occasional large floods, combined with critical water demands from a growing population, deteriorating infrastructure, and groundwater depletion, suggest the need for flexible water management techniques that address changing risks over time, balancing declining supplies with greater demands.

Key Message 2

Ecosystems and Ecosystem Services

The integrity of Southwest forests and other ecosystems and their ability to provide natural habitat, clean water, and economic livelihoods have declined as a result of recent droughts and wildfire due in part to human-caused climate change. Greenhouse gas emissions reductions, fire management, and other actions can help reduce future vulnerabilities of ecosystems and human well-being.

Key Message 3

The Coast

Many coastal resources in the Southwest have been affected by sea level rise, ocean warming, and reduced ocean oxygen—all impacts of human-caused climate change—and ocean acidification resulting from human emissions of carbon dioxide. Homes and other coastal infrastructure, marine flora and fauna, and people who depend on coastal resources face increased risks under continued climate change.

Key Message 4

Indigenous Peoples

Traditional foods, natural resource-based livelihoods, cultural resources, and spiritual well-being of Indigenous peoples in the Southwest are increasingly affected by drought, wildfire, and changing ocean conditions. Because future changes would further disrupt the ecosystems on which Indigenous peoples depend, tribes are implementing adaptation measures and emissions reduction actions.

Key Message 5

Energy

The ability of hydropower and fossil fuel electricity generation to meet growing energy use in the Southwest is decreasing as a result of drought and rising temperatures. Many renewable energy sources offer increased electricity reliability, lower water intensity of energy generation, reduced greenhouse gas emissions, and new economic opportunities.

Key Message 6

Food

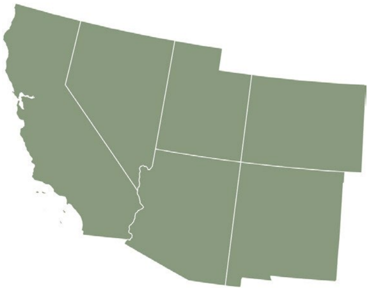
Food production in the Southwest is vulnerable to water shortages. Increased drought, heat waves, and reduction of winter chill hours can harm crops and livestock; exacerbate competition for water among agriculture, energy generation, and municipal uses; and increase future food insecurity.

Key Message 7

Human Health

Heat-associated deaths and illnesses, vulnerabilities to chronic disease, and other health risks to people in the Southwest result from increases in extreme heat, poor air quality, and conditions that foster pathogen growth and spread. Improving public health systems, community infrastructure, and personal health can reduce serious health risks under future climate change.

Executive Summary



The Southwest region encompasses diverse ecosystems, cultures, and economies, reflecting a broad range of climate conditions, including the hottest and driest climate in the United States. Water for people and nature in the Southwest region has declined during droughts, due in part to human-caused climate change. Higher temperatures intensified the recent severe drought in California and are amplifying drought in the Colorado River Basin. Since 2000, Lake Mead on the Colorado River has fallen 130 feet (40 m) and lost 60% of its volume, a result of the ongoing Colorado River Basin drought and continued water withdrawals by cities and agriculture.

The reduction of water volume in both Lake Powell and Lake Mead increases the risk of water shortages across much of the Southwest. Local water utilities, the governments of seven U.S. states, and the federal governments of the United States and Mexico have voluntarily developed and implemented solutions to minimize the possibility of water shortages for cities, farms, and ecosystems. In response to the recent California drought, the state implemented a water conservation plan in 2014 that set allocations for water utilities and major users and banned wasteful practices. As a result, the people of the state reduced water use 25% from 2014 to 2017.

Exposure to hotter temperatures and heat waves already leads to heat-associated deaths in Arizona and California. Mortality risk during a heat wave is amplified on days with high levels of ground-level ozone or particulate air pollution. Given the proportion of the U.S. population in the Southwest region, a disproportionate number of West Nile virus, plague, hantavirus pulmonary syndrome, and Valley fever cases occur in the region.

Analyses estimated that the area burned by wildfire across the western United States from 1984 to 2015 was twice what would have burned had climate change not occurred. Wildfires around Los Angeles from 1990 to 2009 caused $3.1 billion in damages (unadjusted for inflation). Tree death in mid-elevation conifer forests doubled from 1955 to 2007 due, in part, to climate change. Allowing naturally ignited fires to burn in wilderness areas and preemptively setting low-severity prescribed burns in areas of unnatural fuel accumulations can reduce the risk of high-severity fires under climate change. Reducing greenhouse gas emissions globally can also reduce ecological vulnerabilities.

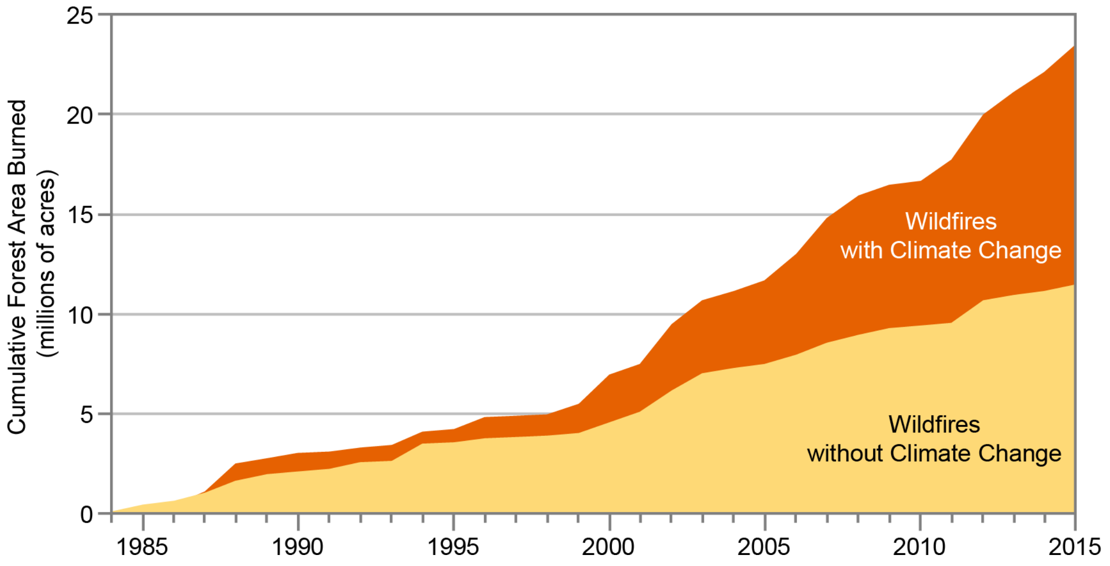
At the Golden Gate Bridge in San Francisco, sea level rose 9 inches (22 cm) between 1854 and 2016. Climate change caused most of this rise by melting of land ice and thermal expansion of ocean water. Local governments on the California coast are using projections of sea level rise to develop plans to reduce future risks. Ocean water acidity off the coast of California increased 25% to 40% (decreases of 0.10 to 0.15 pH units) from the preindustrial era (circa 1750) to 2014 due to increasing concentrations of atmospheric carbon dioxide from human activities. The marine heat wave along the Pacific Coast from 2014 to 2016 occurred due to a combination of natural factors and climate change. The event led to the mass stranding of sick and starving birds and sea lions, and shifts of red crabs and tuna into the region. The ecosystem disruptions contributed to closures of commercially important fisheries.

Agricultural irrigation accounts for approximately three-quarters of water use in the Southwest region, which grows half of the fruits, vegetables, and nuts and most of the wine grapes, strawberries, and lettuce for the United States. Increasing heat stress during specific phases of the plant life cycle can increase crop failures.

Drought and increasing heat intensify the arid conditions of reservations where the United States restricted some tribal nations in the Southwest region to the driest portions of their traditional homelands. In response to climate change, Indigenous peoples in the region are developing new adaptation and mitigation actions.

The severe drought in California, intensified by climate change, reduced hydroelectric generation two-thirds from 2011 to 2015. The efficiency of all water-cooled electric power plants that burn fuel depends on the temperature of the external cooling water, so climate change could reduce energy efficiency up to 15% across the Southwest by 2050. Solar, wind, and other renewable energy sources, except biofuels, emit less carbon and require less water than fossil fuel energy. Economic conditions and technological innovations have lowered renewable energy costs and increased renewable energy generation in the Southwest.

Climate Change Has Increased Wildfire



The cumulative forest area burned by wildfires has greatly increased between 1984 and 2015, with analyses estimating that the area burned by wildfire across the western United States over that period was twice what would have burned had climate change not occurred. *From Figure 25.4 (Source: adapted from Abatzoglou and Williams 2016).*

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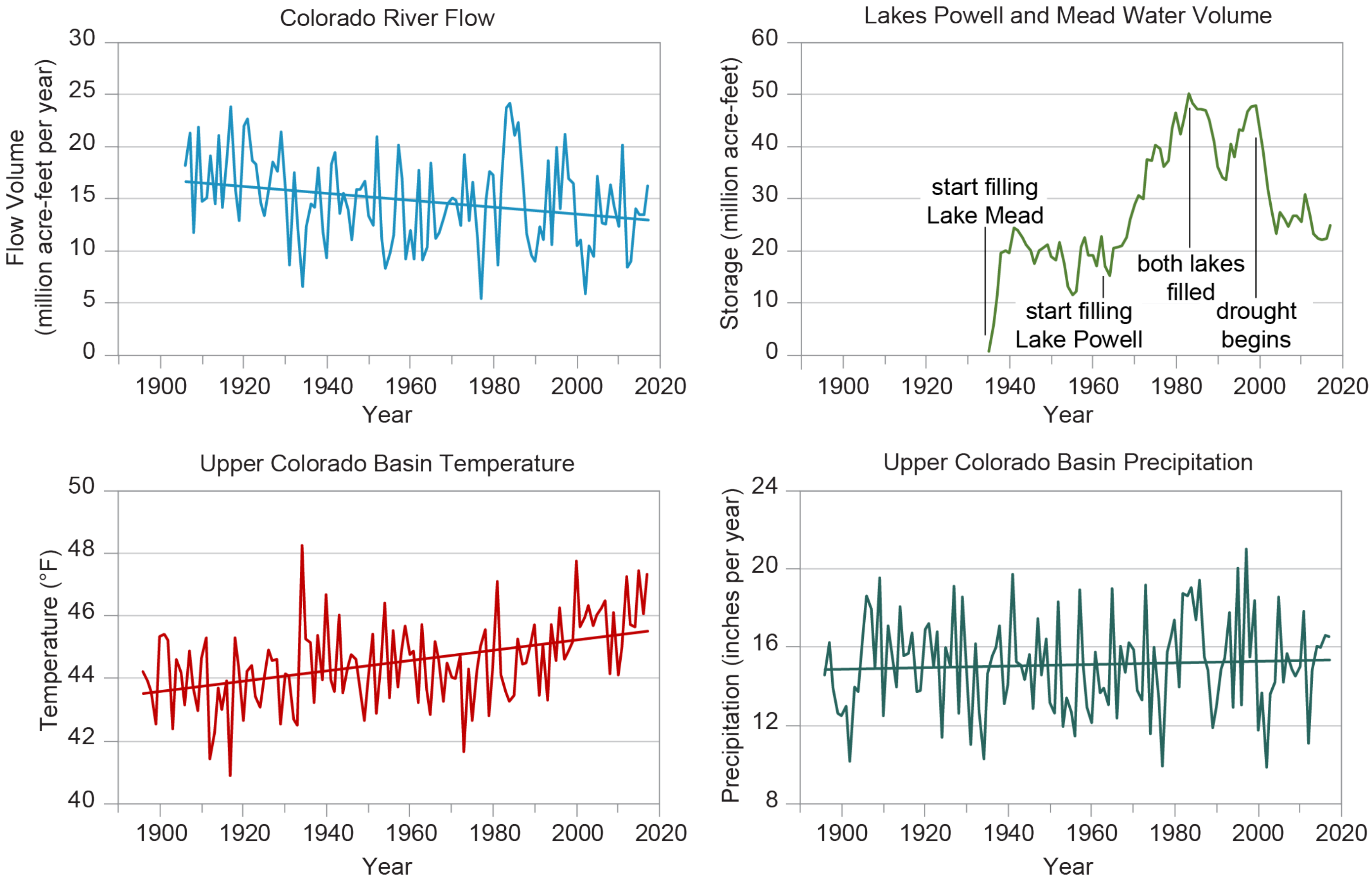
Severe Drought Reduces Water Supplies in the Southwest



Since 2000, drought that was intensified by long-term trends of higher temperatures due to climate change has reduced the flow in the Colorado River (top left), which in turn has reduced the combined contents of Lakes Powell and Mead to the lowest level since both lakes were first filled (top right). In the Upper Colorado River Basin that feeds the reservoirs, temperatures have increased (bottom left), which increases plant water use and evaporation, reducing lake inflows and contents. Although annual precipitation (bottom right) has been variable without a long-term trend, there has been a recent decline in precipitation that exacerbates the drought. Combined with increased Lower Basin water consumption that began in the 1990s, these trends explain the recently reduced reservoir contents. Straight lines indicate trends for temperature, precipitation, and river flow. The trends for temperature and river flow are statistically significant. *From Figure 25.3 (Sources: Colorado State University and CICS-NC. Temperature and precipitation data from: PRISM Climate Group, Oregon State University,* http://prism.oregonstate.edu*, accessed 20 June 2018).*

Background

The Southwest region encompasses diverse ecosystems, cultures, and economies, reflecting a broad range of climate conditions, including the hottest and driest climate in the United States. Arizona, California, Colorado, New Mexico, Nevada, and Utah occupy one-fifth of U.S. land area, extending across globally unique ecosystems from the Sonoran Desert to the Sierra Nevada to the Pacific Coast. The region is home to 60 million people, with 9 out of 10 living in urban areas and the total population growing 30% faster than the national average.[1] The Nation depends on the region for more than half of its specialty crops such as fruits, nuts, and vegetables.[2] The Southwest also drives the U.S. technology sector, with more than 80% of the country's technology capitalization located in California.[3]

Ecosystems in the Southwest gradually transform from deserts and grasslands in hotter and lower elevations in the south to forests and alpine meadows in cooler, higher elevations in the north. Natural and human-caused wildfire shapes the forests and shrublands that cover one-quarter and one-half of the region, respectively.[4] To conserve habitat for plants and wildlife and supply clean water, timber, recreation, and other services for people, the U.S. Government manages national parks and other public lands covering half of the Southwest region.[5] Climate change is altering ecosystems and their services through major vegetation shifts[213] and increases in the area burned by wildfire.[7]

The California coast extends 3,400 miles (5,500 km),[8] with 200,000 people living 3 feet (0.9 m) or less above sea level.[9] The seaports of Long Beach and Oakland, several international airports, many homes, and high-value infrastructure lie along the coast. In addition, much of the Sacramento–San Joaquin River Delta is near sea level. California has the most valuable ocean-based economy in the country, employing over half a million people and generating $20 billion in wages and $42 billion in economic production in 2014.[10] Coastal wetlands buffer against storms, protect water quality, provide habitat for plants and wildlife, and supply nutrients to fisheries. Sea level rise, storm surges, ocean warming, and ocean acidification are altering the coastal shoreline and ecosystems.

Water resources can be scarce because of the arid conditions of much of the Southwest and the large water demands of agriculture, energy, and cities. Winter snowpack in the Rocky Mountains, Sierra Nevada, and other mountain ranges provides a major portion of the surface water on which the region depends. Spring snowmelt flows into the Colorado, Rio Grande, Sacramento, and other major rivers, where dams capture the flow in reservoirs and canals and pipelines transport the water long distances. Complex water laws govern allocation among states, tribes, cities, ecosystems, energy generators, farms, and fisheries, and between the United States and Mexico. Water supplies change with year-to-year variability in precipitation and water use, but increased evapotranspiration due to higher temperatures reduces the effectiveness of precipitation in replenishing soil moisture and surface water.[11,12,13,14]

Agricultural irrigation accounts for nearly three-quarters of water use in the Southwest region,[15,16] which grows half of the fruits, vegetables, and nuts[2] and most of the wine grapes, strawberries, and lettuce[17] for the United States. Consequently, drought and competing water demands in this region pose a major risk for agriculture and food security in the country. Through production and trade networks, impacts to regional crop production

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can propagate nationally and internationally (see Ch. 16: International, KM 1)[18]

Parts of the Southwest reach the hottest temperatures on Earth, with the world record high of 134°F (57°C) recorded in Death Valley National Park, California[19] and daily maximum temperatures across much of the region regularly exceeding 98°F (35°C) during summer.[20] Greenhouse gases emitted from human activities have increased global average temperature since 1880[21] and caused detectable warming in the western United States since 1901.[22] The average annual temperature of the Southwest increased 1.6°F (0.9ºC) between 1901 and 2016 (Figure 25.1).[23] Moreover, the region recorded more warm nights and fewer cold nights between 1990 and 2016),[24] including an increase of 4.1°F (2.3°C) for the coldest day of the year. Parts of the Southwest recorded the highest temperatures since 1895, in 2012,[25] 2014,[26] 2015,[27] 2016,[28] and 2017.[29]

Extreme heat episodes in much of the region disproportionately threaten the health and well-being of individuals and populations who are especially vulnerable (Ch. 14: Human Health, KM 1).[30] Vulnerability arises from numerous factors individually or in combination, including physical susceptibility (for example, young children and older adults), excessive exposure to heat (such as during heat waves), and socioeconomic factors that influence susceptibility and exposure (for example, hot and poorly ventilated homes or lack of access to public emergency cooling centers).[31,32,33] Communicable diseases, ground-level ozone air pollution, dust storms, and allergens can combine with temperature and precipitation extremes to generate multiple disease burdens (an indicator of the impact of a health problem).

Episodes of extreme heat can affect transportation by reducing the ability of commercial airlines to gain sufficient lift for takeoff at major regional airports (Ch. 12: Transportation, KM 1).[34]

Temperature Has Increased Across the Southwest

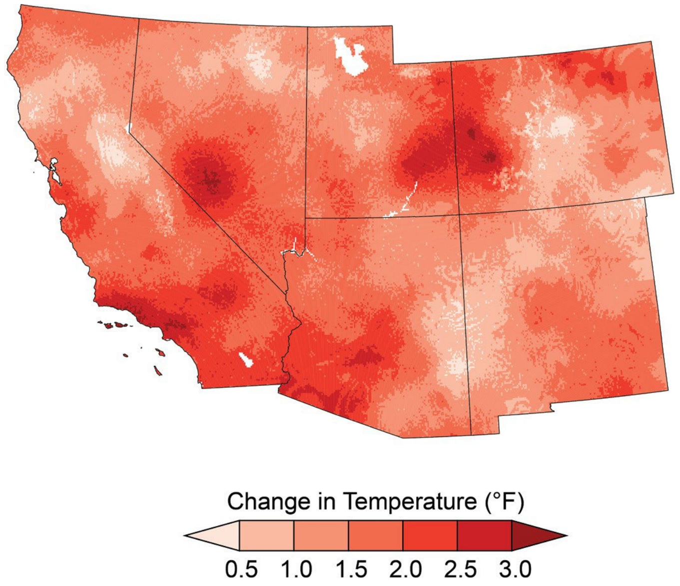


Figure 25.1: Temperatures increased across almost all of the Southwest region from 1901 to 2016, with the greatest increases in southern California and western Colorado.[23] This map shows the difference between 1986–2016 average temperature and 1901–1960 average temperature.[23] Source: adapted from Vose et al. 2017.[23]

Native Americans are among the most at risk from climate change, often experiencing the worst effects because of higher exposure, higher sensitivity, and lower adaptive capacity for historical, socioeconomic, and ecological reasons. With one and a half million Native Americans,[35] 182 federally recognized tribes,[36] and many state-recognized and other non-federally recognized tribes, the Southwest has the largest population of Indigenous peoples in the country. Over the last five centuries, many Indigenous peoples in the Southwest have either been forcibly restricted to lands with limited water and resources[37,38,39] or struggled to get their federally reserved water rights recognized by other users.[40] Climate change exacerbates this historical legacy because the sovereign lands on which many Indigenous peoples live are becoming increasingly dry.

Further, climate change affects traditional plant and animal species, sacred places, traditional building materials, and other material cultural heritage. The physical, mental, emotional, and spiritual health and overall well-being of Indigenous peoples rely on these vulnerable species and materials for their livelihoods, subsistence, cultural practices, ceremonies, and traditions.[41,42,43,44]

In parts of the region, hotter temperatures have already contributed to reductions of seasonal maximum snowpack and its water content over the past 30–65 years,[45,46,47,48,49] partially attributed to human-caused climate change.[45,46,48,49] Increased temperatures most strongly affect snowpack water content, snowmelt timing, and the fraction of precipitation falling as snow.[48,50,51,52,53,54]

The increase in heat and reduction of snow under climate change have amplified recent hydrological droughts (severe shortages of water) in California,[14,55,56,57,58] the Colorado River Basin,[12,13,59] and the Rio Grande.[45,60] Snow droughts can arise from a lack of precipitation (dry snow drought), temperatures that are too warm for snow (warm snow drought), or a combination of the two.[48,51]

Periods of low precipitation from natural variations in the climate system are the primary cause of major hydrological droughts in the Southwest region,[61,62,63,64,65,66,67,68] with increasing temperatures from climate change amplifying recent hydrological droughts, particularly in California and the upper Colorado River Basin.[12,13,14,56,57,59]

Under the higher scenario (RCP8.5), climate models project an 8.6°F (4.8°C) increase in Southwest regional annual average temperature by 2100.[23] Southern parts of the region could get up to 45 more days each year with maximum temperatures of 90°F (32°C) or higher.[23] Projected hotter temperatures increase probabilities of decadal to multi-decadal megadroughts,[61,62,69,70] which are persistent droughts lasting longer than a decade,[69] even when precipitation increases. Under the higher scenario (RCP8.5), much of the mountain area in California with winters currently dominated by snow would begin to receive more precipitation as rain and then only rain by 2050.[71] Colder and higher areas in the intermountain West would also receive more rain in the fall and spring but continue to receive snow in the winter at the highest elevations.[71]

Increases in temperature would also contribute to aridification (a potentially permanent change to a drier environment) in much of the Southwest, through increased evapotranspiration,[69,70,72,73] lower soil moisture,[74] reduced snow cover,[71,75,76,77] earlier and slower snowmelt,[75] and changes in the timing and efficiency of snowmelt and runoff.[50,54,75,76,78,79] Some research indicates increasing frequency of dry high-pressure weather systems associated with changes in Northern Hemisphere atmospheric circulation.[80,81] These changes would tend to increase the duration and severity of droughts[67,74] and generate an overall drier regional climate.[69,70,72]

Climate models project an increase in the frequency of heavy downpours, especially through atmospheric rivers,[74,82] which are narrow bands of highly concentrated storms that move in from the Pacific Ocean. A series of strong atmospheric rivers caused extreme flooding in California in 2016 and 2017. Under the higher scenario (RCP8.5), models project increases in the frequency and intensity of atmospheric rivers.[83,84,85,86] Climate models also project an increase in daily extreme summer precipitation in the Southwest region, based on projected increases in water vapor resulting from higher temperatures.[20,87,88] Projections of summer total precipitation are uncertain, with average projected totals not differing substantially from what would be expected due to natural variations in climate.[88]

The Southwest generates one-eighth of U.S. energy, with hydropower, solar, wind, and other renewable sources supplying one-fifth of regional energy generation.[89] By installing so much renewable energy, the Southwest has lowered its per capita and per dollar greenhouse gas emissions below the U.S. average.[90] Climate change can, however, decrease hydropower and fossil fuel energy generation.[91] California has enacted mandatory greenhouse gas emissions reductions,[92] and Arizona, California, Colorado, Nevada, and New Mexico have passed renewable portfolio standards to reduce fossil fuel dependence and greenhouse gas emissions.[93]

What Is New in the Fourth National Climate Assessment

This chapter builds on assessments of climate change in the Southwest region from the three previous U.S. National Climate Assessments.[94,95,96] Each assessment has consistently identified drought, water shortages, and loss of ecosystem integrity as major challenges that the Southwest confronts under climate change. This chapter further examines interconnections among water, ecosystems, the coast, food, and human health and adds new Key Messages concerning energy and Indigenous peoples.

Since the last assessment, published field research has provided even stronger detection of hydrological drought, tree death, wildfire increases, sea level rise, and warming, oxygen loss, and acidification of the ocean that have been statistically different from natural variation, with much of the attribution pointing to human-caused climate change. In addition, new research has provided published information on future vulnerabilities and risks from climate change, including floods, food insecurity, effects on the natural and cultural resources that sustain Indigenous peoples, illnesses due to the combination of heat with air pollution, harm to mental health, post-wildfire effects on ecosystems and infrastructure, and reductions of hydropower and fossil fuel electricity generation.

This chapter highlights many of the increasing number of actions that local governments and organizations have been taking in response to historical impacts of climate change and to reduce future risks (Figure 25.2). Some examples include voluntary water conservation and management in California and the Colorado River Basin, restoring cultural fire management in California, and rooftop solar policies in California, Colorado, and Nevada. Many state and local governments have issued climate change assessments and action plans.

Actions Responding to Climate Change Impacts and Vulnerabilities

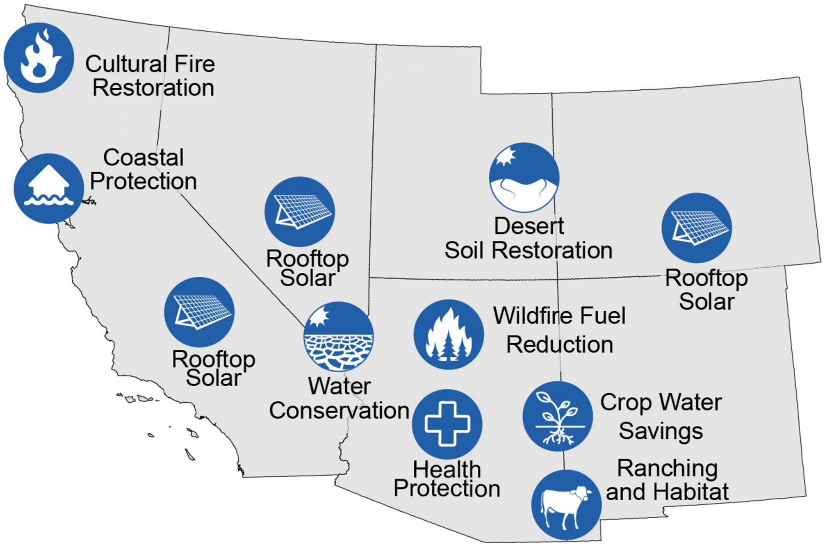


Figure 25.2: These examples illustrate actions that people, communities, and governments are taking in response to past impacts of climate change and future vulnerabilities. **Coastal protection**: In response to sea level rise and storm surge in San Francisco Bay, federal, state, and local agencies, supported by voter-approved funds, are restoring coastal habitats and levees to protect cities from flooding. **Crop water savings**: The risk of reduced food production increases as climate change intensifies drought. In the Gila River Basin, local government agencies have lined 15 miles (24 km) of irrigation canals to reduce seepage from the canals, saving enough water to irrigate approximately 8,500 acres (3,400 hectares) of alfalfa and other crops each year. **Cultural fire restoration**: Reintroduction of cultural burning by the Yurok Tribe in northern California reduces wildfire risks and protects public and tribal trust resources. **Desert soil restoration**: In Utah, transplanting native and drought-resistant microbial communities improves soil fertility and guards against erosion. **Health protection**: To reduce heat-associated injury and deaths on Arizona trails, the City of Phoenix and Arizona tourism organizations developed a campaign “Take a Hike. Do it Right.” Signs at trailheads and on websites remind hikers to bring water, stay hydrated, and stay aware of environmental conditions. **Ranching and habitat**: The Malpai Borderlands Group in Arizona and New Mexico integrates native plant and wildlife conservation into private ranching. **Rooftop solar**: The state governments of California, Colorado, and Nevada have enacted policies that support rooftop solar on homes, which reduces greenhouse gas emissions, improves reliability of the electricity generation system, and creates local small businesses and new jobs. **Water conservation**: Drought in the Colorado River Basin has reduced the volume of water in both Lake Mead and Lake Powell by over half. The United States, Mexico, and state governments have mobilized users to conserve water, keeping the lake above a critical level. **Wildfire fuel reduction**: In response to severe wildfires, the City of Flagstaff, Arizona, enacted a bond to fund reduction of fire fuels in forests around the town. Source: National Park Service.

Key Message 1

Water Resources

Water for people and nature in the Southwest has declined during droughts, due in part to human-caused climate change. Intensifying droughts and occasional large floods, combined with critical water demands from a growing population, deteriorating infrastructure, and groundwater depletion suggest the need for flexible water management techniques that address changing risks over time, balancing declining supplies with greater demands.

Higher temperatures intensified the recent severe drought in California and are amplifying drought in the Colorado River Basin. In California, the higher temperatures intensified the 2011–2016 drought,[14,56,97,98,99] which had been initiated by years of low precipitation,[57,58] causing water shortages to ecosystems, cities, farms, and energy generators. In addition, above-freezing temperatures through the winter of 2014–2015 led to the lowest snowpack in California (referred to as a warm snow drought) on record.[47,55,98,100] Through increased temperature, climate change may have accounted for one-tenth to one-fifth of the reduced soil moisture from 2012 to 2014 during the recent California drought.[14] In the ongoing Colorado River Basin drought, high temperatures due mainly to climate change have contributed to lower runoff[12,59] and to 17%–50% of the record-setting streamflow reductions between 2000 and 2014 (Figure 25.3).[13] In the Rio Grande, higher temperatures have been linked to declining runoff efficiency[60] and reductions in snowpack.[45]

Increased temperatures, especially the earlier occurrence of spring warmth,[101] have significantly altered the water cycle in the Southwest region. These changes include decreases in snowpack and its water content,[46,47,48,49,102] earlier peak of snow-fed streamflow,[103] and increases in the proportion of rain to snow.[49,103] These changes, attributed mainly to climate change,[49,103] exacerbate hydrological drought.

With continued greenhouse gas emissions, higher temperatures would cause more frequent and severe droughts in the Southwest.[11,56,62,65,80] This would also lead to drier future conditions for the region.[70,74] Higher temperatures sharply increase the risk of megadroughts—dry periods lasting 10 years or more.[61,62,65] Under the higher scenario (RCP8.5), models project annual declines of river flow in southern basins (the Rio Grande and the lower Colorado River) and either no change or modest increases in northern basins (northern California and the upper Colorado River).[78,104,105,106,107] Snowpack supplies a major portion of water in the Southwest, but with continued emissions, models project substantial reductions in snowpack, less snow and more rain, shorter snowfall seasons, earlier runoff,[55,71,78,79,108,109] and warmer late-season stream temperatures.[110] Fewer days with precipitation would lead to increased year-to-year variability.[111,112,113] Substantial increases in precipitation would be needed to overcome temperature-induced decreases in river flow.[13] The combination of reduced river flows in California and the Colorado River Basin and increasing population in southern California, which imports most of its water, would increase the probability of future water shortages.[114]

In response to the recent California drought, the state government implemented a water conservation plan in 2014 that set allocations for water utilities and major users and banned wasteful practices such as watering during or after a rainfall, hosing off sidewalks, and irrigating ornamental turf on public street medians.[115] As a result, the people of the state reduced water use 25% from 2014 to 2017, when abundant rains allowed the state to lift many restrictions while continuing to promote water conservation as a way of life.[116]

The Southern Nevada Water Authority used similar measures to reduce water use per person 38% from 2002 to 2016.[117] Water utilities in the Colorado Front Range also used similar conservation practices to reduce water use more than 20% in the early 2000s.[118] While many southwestern cities have reduced total and per-person water use since the 1990s despite growing populations,[119] ongoing drought has increased competition for reliable water supplies in many locations. In parts of Colorado, Nevada, and Utah, population growth has prompted proposals for new water diversions and transfers from agriculture. While desalination of seawater and brackish water has been proposed as a partial solution to water scarcity, its high energy requirement creates greenhouse gas emissions and its capital costs are high.[15]

Atmospheric rivers, which have caused many large floods in California,[120] may increase in severity and frequency under climate change.[82,83,107,121,122,123,124] In the winter of 2016–2017, a series of strong atmospheric rivers generated high runoff in northern California and filled reservoirs. At Oroville

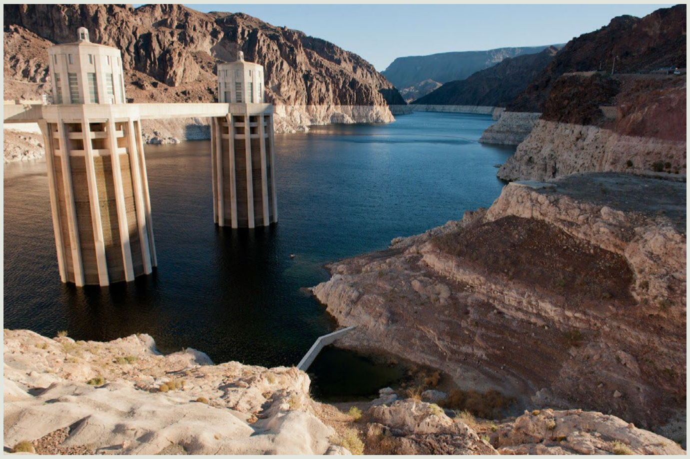
Dam, high flows eroded the structurally flawed emergency spillway, caused costly damage, and led to the preventive evacuation of people living downstream. In addition to the immediate threat to human life and property, this incident revealed two water supply risks. First, summer water supplies are reduced when protective flood control releases of water from reservoirs are necessary in the spring.[108] Second, several studies have concluded that deteriorating dams, spillways, and other infrastructure require substantial maintenance and repair.[125,126] In U.S.–Mexico border cities with chronic urban storm water and pollutant runoff problems[127] and populations vulnerable to flooding,[127,128] projected increases in heavy precipitation[88] would increase risks of floods.

Wet periods present a water resource opportunity because increased infiltration from the surface into the ground recharges groundwater aquifers. Groundwater was critical for farmers during the California drought, especially for fruit and nut trees and grapevines.[129,130,131] Overdraft of groundwater, however, caused land subsidence (sinking), which can permanently reduce groundwater storage capacity and damage infrastructure as the ground deforms.[132]

In light of projected future changes in the hydrologic cycle, water resource planners and scientists are testing new techniques to combine results from multiple climate and hydrology models, downscale climate model output to finer geographic scales, calculate changing water demands, and use forecasts for flood control.[133,134,135,136] Integrating data from satellites, climate and hydrology models, and field observations remains difficult with existing water management tools, methods, and legal requirements.

Box 25.1: Collaborative Management of Colorado River Water

Since 2000, Lake Mead on the Colorado River has fallen 130 feet (40 m) and lost 60% of its volume,[137,138,139] a result of the ongoing Colorado River Basin drought and continued water withdrawals by cities and agriculture (Figure 25.3). This is the lowest level since the filling of the reservoir in 1936.[139] The reduction of Lake Mead increases the risk of water shortages across much of the Southwest and reduces energy generation at the Hoover Dam hydroelectric plant at the reservoir outlet. Local water utilities, the governments of seven U.S. states, and the federal governments of the United States and Mexico have voluntarily developed and implemented solutions to minimize the possibility of water shortages for cities, farms, and ecosystems. The parties have taken four key actions:



Hydrological drought in Lake Mead, Nevada, on March 10, 2014. Photo credit: U.S. Bureau of Reclamation.

1. Arizona, California, and Nevada agreed in 2007, with Mexico joining in 2012, to allow users to store water in Lake Mead for later years, rather than being forced to use it immediately or lose their rights.[140]

2. The United States and Mexico agreed in 2014 to release water for eight weeks to re-water the Colorado River Delta in Mexico in order to improve wildlife habitat and to conduct research on environmental restoration.[141]

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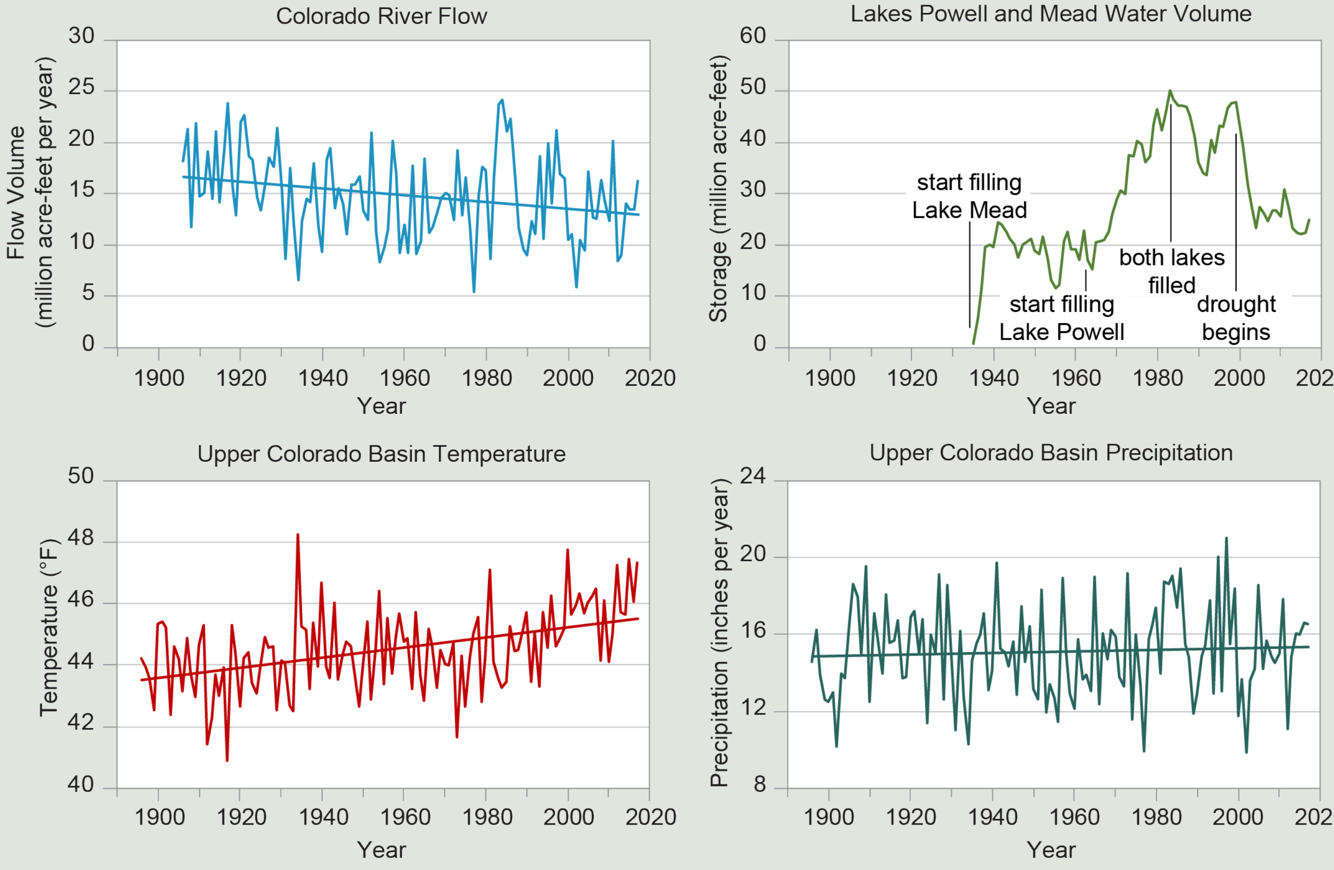
Box 25.1: Collaborative Management of Colorado River Water, *continued*

3. The water agencies of Denver, Las Vegas, Los Angeles, and Phoenix and the U.S. Bureau of Reclamation in 2015 set up the Colorado River System Conservation Pilot Program, a fund for local water conservation projects. A second phase extended conservation projects to all of the Colorado River Basin.

4. Mexico agreed in 2017 to absorb a share of water shortages if Lake Mead fell below a specific elevation. The agreement continues Mexico's right to bank unused water in Lake Mead for future use. With financial and other U.S. assistance, Mexico will pursue water conservation projects and environmental restoration within the Colorado River Delta.

Currently, stakeholders are engaged in drought contingency planning for multiple climate futures, implementing management strategies that make sense for the range of climate futures, and preserving options when possible.[142]

Severe Drought Reduces Water Supplies in the Southwest



Colorado River Flow

Lakes Powell and Mead Water Volume

Upper Colorado Basin Temperature

Upper Colorado Basin Precipitation

Figure 25.3: Since 2000, drought that was intensified by long-term trends of higher temperatures due to climate change has reduced the flow in the Colorado River (top left), which in turn has reduced the combined contents of Lakes Powell and Mead to the lowest level since both lakes were first filled (top right). In the Upper Colorado River Basin that feeds the reservoirs, temperatures have increased (bottom left), which increases plant water use and evaporation, reducing lake inflows and contents. Although annual precipitation (bottom right) has been variable without a long-term trend, there has been a recent decline in precipitation that exacerbates the drought. Combined with increased Lower Basin water consumption that began in the 1990s, these trends explain the recently reduced reservoir contents. Straight lines indicate trends for temperature, precipitation, and river flow. The trends for temperature and river flow are statistically significant. Sources: Colorado State University and CICS-NC. Temperature and precipitation data from: PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, accessed 20 June 2018.

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Key Message 2

Ecosystems and Ecosystem Services

The integrity of Southwest forests and other ecosystems and their ability to provide natural habitat, clean water, and economic livelihoods have declined as a result of recent droughts and wildfire due in part to human-caused climate change. Greenhouse gas emissions reductions, fire management, and other actions can help reduce future vulnerabilities of ecosystems and human well-being.

The forests and other ecosystems of the Southwest region that provide natural habitat and essential resources for people have declined in fundamental ways due in part to climate change. Vast numbers of trees have died across Southwest forests and woodlands,[143,144,145,146] disproportionately affecting larger trees.[147] Tree death in mid-elevation conifer forests doubled from 1955 to 2007 due in part to climate change.[146] Field measurements showed that changes attributable, in part, to climate change, including increases in temperature, wildfire,[7] and bark beetle infestations,[148,149] outweighed non-climate factors such as fire exclusion or competition for light.[146]

Wildfire is a natural part of many ecosystems in the Southwest, facilitating germination of new seedlings and killing pests. Although many ecosystems require fire, excessive wildfire can permanently alter ecosystem integrity.[150,151] Climate change has led to an increase in the area burned by wildfire in the western United States.[7,152] Analyses estimate that the area burned by wildfire from 1984 to 2015 was twice what would have burned had climate change not occurred (Figure 25.4).[7] Furthermore, the area burned from 1916 to 2003 was more closely related to climate factors than to fire suppression, local fire management, or other non-climate factors.[152]

Climate change has driven the wildfire increase,[7,153] particularly by drying forests and making them more susceptible to burning.[154,155] Specifically, increased temperatures have intensified drought in California,[14] contributed to drought in the Colorado River Basin,[12,13]

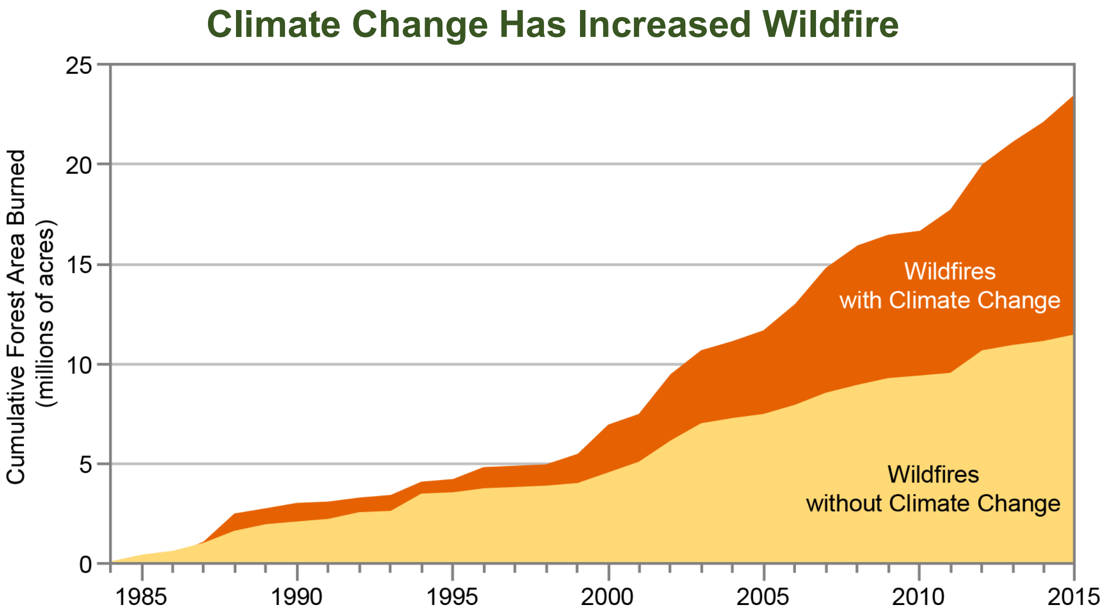
Climate Change Has Increased Wildfire

Figure 25.4: The cumulative forest area burned by wildfires has greatly increased between 1984 and 2015, with analyses estimating that the area burned by wildfire across the western United States over that period was twice what would have burned had climate change not occurred. Source: adapted from Abatzoglou and Williams 2016.[7]

reduced snowpack,[46,49,156] and caused spring-like temperatures to occur earlier in the year.[101] In addition, historical fire suppression policies have caused unnatural accumulations of understory trees and coarse woody debris in many lower-elevation forest types, fueling more intense and extensive wildfires.[150,157]

Wildfire can threaten people and homes,[159] particularly as building expands in fire-prone areas. Wildfires around Los Angeles from 1990 to 2009 caused $3.1 billion in damages (unadjusted for inflation).[159] Respiratory illnesses and life disruptions from the Station Fire north of Los Angeles in 2009 cost an estimated $84 per person per day (in 2009 dollars).[160] In addition, wildfires degraded drinking water upstream of Albuquerque with sediment, acidity, and nitrates[161,162] and in Fort Collins, Colorado, with sediment and precursors of cancer-causing trihalomethane, necessitating a multi-month switch to alternative municipal water supplies.[163,164]

Ecosystems can naturally slow climate change by storing carbon, but recent wildfires have made California ecosystems and Southwest forests net carbon emitters (they are releasing more carbon to the atmosphere than they are storing).[6,144,165] Wildfire has also exacerbated the spread of invasive plant species and damaged habitat. For example, repeated wildfire in sagebrush in Nevada and Utah has caused extensive invasions of cheatgrass, reducing habitat for the endangered sage-grouse.[64,166]

Post-wildfire erosion damages ecosystems by denuding hillsides, such as occurred in Valles Caldera National Preserve in New Mexico when the 2011 Las Conchas Fire generated the biggest local erosion event in 1,000 years.[167] In New Mexico, consecutive large wildfires degraded habitat and reduced abundance of six out of seven native coldwater fishes and some native insects, although nonnative fishes were less affected.[168]

With continued greenhouse gas emissions, models project more wildfire across the Southwest region.[169,170,171,172,173] Under higher emissions (SRES A2)[174] (see the Scenario Products section of App. 3), fire frequency could increase 25%,[172] and the frequency of very large fires (greater than 5,000 hectares) could triple.[169] The Santa Ana winds and other very dry seasonal winds increase fire risk in California[175] and Mexico.[176] Under higher emissions (SRES A2), sediment flows after fires would double in one-third of western U.S. watersheds modeled,[177] with the sediment potentially damaging ecosystems, homes, roads, and rail lines (Ch. 12: Transportation; Ch. 17: Complex Systems). Under the higher scenario (RCP8.5), cumulative firefighting costs for the Southwest could total $13 billion from 2006 to 2099 (in 2015 dollars, discounted at 3%).[178]

Reducing greenhouse gas emissions can reduce ecological vulnerabilities to wildfire.[179] For example, under a higher emissions scenario (SRES A2), climate change could triple burned area (in a 30-year period) in the Sierra Nevada by 2100, while under a lower emissions scenario (SRES B1[174]), fire would only slightly increase.[173]

Allowing naturally ignited fires to burn in wilderness and preemptively setting low-severity prescribed burns in areas of unnatural fuel accumulations can reduce the risk of high-severity fires under climate change.[180,181,182,183,184] These actions can naturally reduce or slow climate change because long-term storage of carbon in large trees can outweigh short-term emissions.[185,186] Proactive use of fire in Yosemite, Sequoia, and Kings Canyon National Parks has improved the resilience of giant sequoias and other trees to severe fires and protected their stores of carbon.[187,188,190,191]

Climate change has also contributed to increased forest pest infestations, another major cause of tree death in Southwest forests and woodlands (Ch. 17: Complex Systems, Box 17.4). Bark beetle infestations killed 7% of western U.S. forest area from 1979 to 2012,[148,149] driven by winter warming due to climate change[103,192] and by drought.[193] Tree death from bark beetles in Colorado increased organic matter in local streams, elevating precursors of cancer-causing trihalomethane in local water treatment plants[194] to levels that exceed the maximum contaminant levels for drinking water specified by the U.S. Environmental Protection Agency.[195] Without greenhouse gas emissions reductions, further increases in heat and drought could kill many more trees,[143,196,197] especially affecting piñon pine,[198] whitebark pine,[199] and tall old-growth trees.[200] Drought hastens tree mortality over a wide range of temperatures.[201] On the Colorado Plateau in Utah, five years of hotter temperatures in experiments killed microbial biocrusts, which conserve soil fertility and protect soils from erosion.[202,203,204] In addition, grasslands[205,206] and desert plants[207,208] are vulnerable to increased plant death.

Field research in Southwest ecosystems has detected geographic shifts (Ch. 7: Ecosystems) of both plant and animal species, partly attributable to climate change. In Yosemite National Park, forest shifted into subalpine meadows from 1880 to 2002,[209] and small mammals shifted 1,600 feet (500 m) upslope from 1914 to 2006,[210] with climate change outweighing other factors as the cause.[209,210] Across the United States, including the Southwest, birds shifted northward between 0.1 and 0.5 miles (0.2 to 0.8 km) per year from 1975 to 2004, and analyses attribute the shift to climate change.[211,212]

Continued climate change would cause north–south or upslope shifts of biomes (major vegetation types) in the Southwest as vegetation follows cooler temperatures.[213] Areas highly vulnerable to such biome shifts include the Arizona Sky Islands[214] and the Sierra Nevada.[215] Potential shifts of suitable habitat for individual species include the shifting of Joshua tree habitat out of much of Joshua Tree National Park,[207,216] American pika habitat shifting off of mountain tops,[217,218] and upslope or northward shifts of numerous birds and reptiles across the Southwest.[219,220,221] Climate change may also cause shifts in the timing of plant and animal life events (phenology), including flower blooming, plant leafing, and breeding time of birds and other animals.[222,223,224] The arrival of migrating broad-tailed hummingbirds in Colorado advanced five days between 1975 and 2011.[225] Plant species that provide essential food (nectar) for the hummingbirds also shifted in phenology (Ch. 7: Ecosystems), but much more than the birds, potentially jeopardizing breeding success.

To prepare for potential future ecological changes, U.S. federal agencies have begun to integrate climate change science into resource management planning in the Southwest. For example, the U.S. National Park Service has developed park plans with specific actions for managing resources under climate change.[226] On private lands, planning that integrates native plants and wildlife into working landscapes such as farms, orchards, and ranches can promote conservation outside of protected areas and provide valued ecosystem services,

The 2013 Rim Fire in California burned more than 257,000 acres, the second largest wildfire in the Sierra Nevada and the third largest fire in California since 1932. Photo credit: Mike McMillan, U.S. Forest Service.

as demonstrated for rangelands by the Malpai Borderlands Group in Arizona and New Mexico.[227,228] In response to severe wildfires, the City of Flagstaff, Arizona, enacted a bond to provide funds to thin forest around the town perimeter.[229,230] Ecosystem restoration provides an opportunity to integrate climate change considerations into natural resource management.[231] Desert research scientists have developed the ability to grow microbial biocrusts and are testing whether translocating biocrusts that are adapted to thrive at higher temperatures can restore the soil-stabilizing, nutrient-fixing, and other services that these organisms provide in many Southwest desert ecosystems.[232,233,234] Finally, conservation of forests, especially coast redwoods, which have the highest carbon densities of any ecosystem in the world,[235] can slow or reduce climate change by naturally removing carbon from the atmosphere.[6]

Key Message 3

The Coast

Many coastal resources in the Southwest have been affected by sea level rise, ocean warming, and reduced ocean oxygen—all impacts of human-caused climate change—and ocean acidification resulting from human emissions of carbon dioxide. Homes and other coastal infrastructure, marine flora and fauna, and people who depend on coastal resources face increased risks under continued climate change.

At the Golden Gate Bridge in San Francisco, sea level rose 9 inches (22 cm) between 1854 and 2016 (Figure 25.5),[236] and in San Diego, sea level rose 9.5 inches (24 cm) from 1906 to 2016.[237] Tidal gauges around the world show increases in sea level,[238,239] and analyses show that climate change caused most of this rise by melting of land ice and thermal expansion of ocean water.[21,240,241] Non-climate-related land level changes influence relative sea level change. For example, between Cape Mendocino, California, and the Oregon border, lifting of the land at the San Andreas Fault has caused a drop in relative sea level between 1933 and 2016. Past earthquakes in the northern California coastal zone have abruptly lowered the shoreline and raised relative sea level.[242]

Under the higher scenario (RCP8.5), continued climate change could raise sea level near San Francisco by 30 inches (76 cm) by 2100, with a range of 19–41 inches (49–104 cm).[242] Currently, 200,000 people in California live in areas 3 feet (0.9 m) or less above sea level.[9] Projections of sea level rise show that this population lives in areas at risk of inundation by 2100.[9] Storm surges and high tides on top of sea level rise would exacerbate flooding.[242] In Redwood City, one-fifth of houses and one-quarter of roads are at risk of flooding under the higher scenario (RCP8.5) by 2100.[243] Sea level rise and storm surge could completely erode two-thirds of southern California beaches by 2100[244] and cause saltwater infiltration that would spoil groundwater at Stinson Beach in Marin County, California.[245] Major seaports in Long Beach and Oakland and the international airports of San Francisco, Oakland, and San Diego are vulnerable. Projected sea level rise and storm surges could cause as much as $5 billion (2015 dollars, undiscounted) in damage to property along the California coast from 2000 to 2100 under the higher scenario (RCP8.5).[178] In Point Reyes National Seashore, sea level rise threatens to inundate habitat for the endangered western snowy plover, harbor seals,[246] and northern elephant seals,[247] as well as archaeological Indigenous sites.

Governments and private landowners along the California coast have built seawalls, revetments, and other structures to protect against

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sea level rise and storm surge, armoring 10% of the coastline.[248] Because hard structures often alter natural water flows and increase coastal erosion, many parties are now exploring how to restore dunes, reefs, wetlands, and other natural features to protect the coast by breaking wave energy, to increase wildlife habitat, and to preserve public access to the coast.[249]

Local governments on the California coast are using projections of sea level rise to develop plans to reduce future risks. The City of San Francisco[250] is implementing a plan that limits building in low-lying areas, constructs terraced wetlands at India Basin to facilitate upland migration of marsh habitat, and protects San Francisco International Airport with berms and seawalls along the 8-mile (13 km) shoreline. Golden Gate National Recreation Area has produced a detailed spatial analysis of the vulnerability of the marsh, paths, and buildings at Crissy Field to sea level rise and storm surges and has developed adaptation options, including moving infrastructure and establishing protective wetlands on inundated land.[251] In 2016, residents of the nine counties of the San Francisco Bay passed Measure AA, which provides funding for wetlands restoration to naturally reduce risks of flooding and inundation due to sea level rise and storm surge.

Ocean waters off the California coast and around the world warmed 0.6° to 0.8ºF (0.3° to 0.5ºC) from 1971 to 2010,[252] mainly due to human-caused climate change.[21] Over the past century, sea surface temperatures in the northeast Pacific Ocean (including those off the coast of California) also experienced large year-to-year and decade-to-decade variations in response to changes in wind and weather patterns that altered the exchange of heat between the ocean and atmosphere and within the upper ocean,[253] but showed overall warming from 1920 to 2016 (Figure. 25.6).

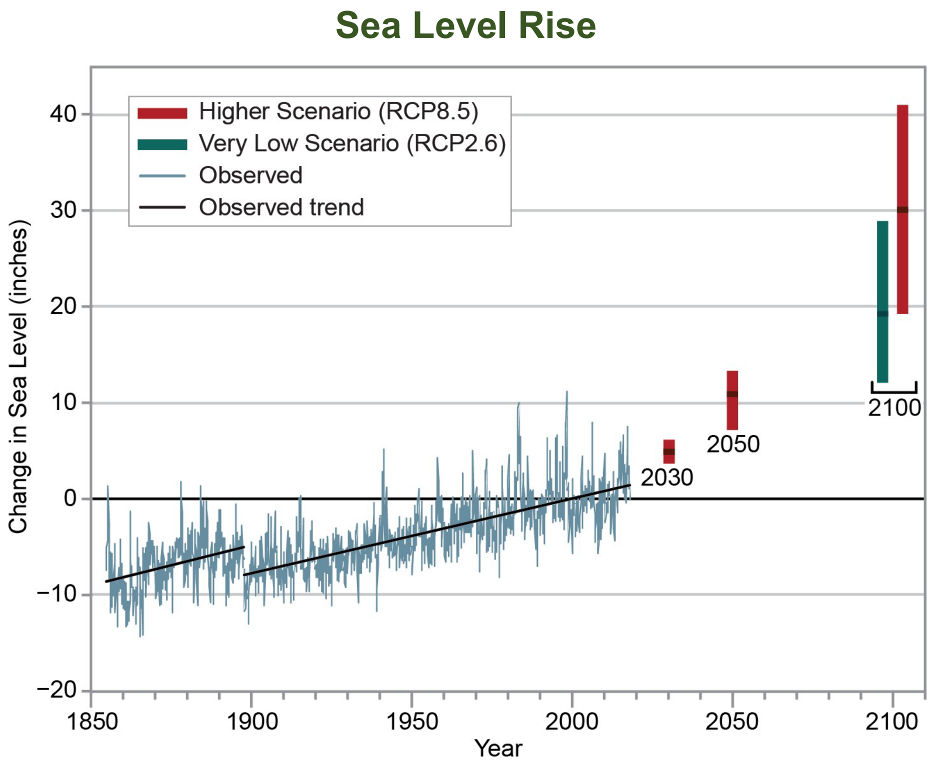
Sea Level Rise

Figure 25.5: Sea level rise increases risks to infrastructure. At the Golden Gate Bridge in San Francisco, California, the tidal gauge with the longest time series in the Western Hemisphere shows that sea level has risen nearly 9 inches (22 cm) since 1854 (blue line).[236,295] In 1897, the tidal gauge was moved, which caused a slight shift downward of the numerical level but no change in the long-term trend (trends indicated by the black lines). The bars show models projections of sea levels under a higher scenario (RCP8.5; red) and a very low scenario (RCP2.6; green).[242] The change in sea level is shown relative to the 1991–2009 average. Source: National Park Service.

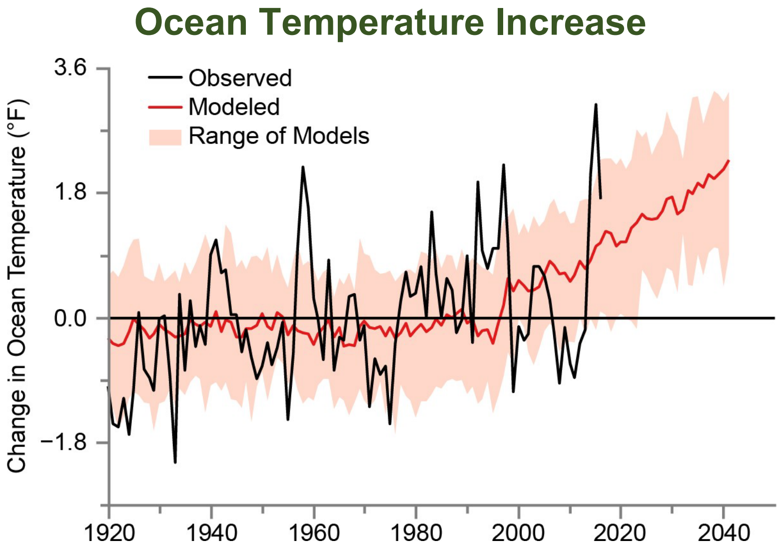

Figure 25.6 Ocean warming increases risks to fisheries and shellfish. The graph shows observed ocean temperatures of the California Current from measurements (black line); modeled temperatures, extended into the future under the higher scenario (RCP8.5; red line); and the range of 10% to 90% of the 28 models used (pink).[254,296,297] Sources: National Park Service and NOAA.

The marine heat wave along the Pacific Coast from 2014 to 2016 occurred due to a combination of natural factors and climate change.[254] The event led to the mass stranding of sick or starving birds and sea lions and shifts in pelagic (open water) red crabs and tuna into the region.[255] The ecosystem disruptions contributed to closures of commercially important fisheries and substantial reductions in California salmon catches in 2016 and 2017.[256,257,258] Ocean warming also contributed to an increase in harmful blooms of algae along the Pacific Coast.[259,260,261,262] These harmful algal blooms have produced domoic acid, which can kill people who eat tainted shellfish[261,263] and kill California sea lions.[261,264,265] Harmful algal blooms and shellfish contamination in the record warm year of 2015 delayed the commercially important Dungeness crab fishery, which contributed to a substantially reduced catch. Shifts in the timing of Dungeness and rock crab fisheries into whale migration season in 2016 contributed to increases in whale entanglements in fishinggear.[266]

Continued climate change could warm California Current waters 4°–7°F (2°–4°C) above the 1980–2005 average by 2100 (Figure 25.6).[267] This could contribute to more harmful algal blooms,[259,261] deaths of birds and sea lions, closures of fisheries, and economic loss to sectors dependent upon coastal marine resources. Under higher emissions (SRES A2), 28 fish species, including coho salmon and steelhead, could shift northward more than 180 miles (300 km) by 2050 due to higher sea surface temperatures.[268] Marine heat waves may also increase in frequency, possibly causing local disappearance of some fish and economic losses.[269]

Observed ocean water acidity off the coast of California increased 25% to 40% (decreases of about 0.10 to 0.15 pH units) from the preindustrial era (circa 1750) to the early 2000s[270,271] due to increasing emissions of carbon dioxide from human activities.[21,272] Modeling studies show that human-caused changes in ocean acidity have increased beyond what would be expected from natural variations in the early-to-mid-20th century.[273] Along the California coast, during some episodes of naturally acidic spring/summer upwelling of deeper ocean water, ocean acidity has quadrupled (a decrease of 0.7 pH units) to some of the most acidic values in the world.[274] Increased ocean acidity along California's coast has dissolved shells of some small planktonic sea snails (pteropods), exceeding their adaptive capacity, which was developed from evolution in natural acidic upwellings.[275,276,277] In contrast, nearshore kelp forests in the northern Channel Islands off the California coast experienced few acidic events compared to local mainland sites in one three-year study.[278]

Higher carbon emissions (SRES A2) could increase the acidity of California coastal waters 40% (a decrease of 0.15 pH units) above 1995 levels by 2050.[270] In addition to damaging marine ecosystems, ocean acidification increases risks of economic losses in the shellfish industry. One ecosystem modeling study suggests negative effects of projected ocean acidification on California's state-managed crab, shrimp, mussel, clam, and oyster fisheries, but an increase in the urchin fishery.[279] Warming of ocean waters has reduced oxygen concentrations in the California Current System by 20% from 1980 to 2012.[280,281] Dissolved oxygen variations in waters far offshore affect oxygen concentrations in the California Current System nearshore.[280,282] This deoxygenation contributed to an expansion of Humboldt squid, a species that thrives in deoxygenated water, in the northeastern Pacific Ocean in the late 1990s.[283,284] Invading Humboldt squid prey on hake and other fish that are commercially important to coastal fishing communities.[283]

Climate change may reduce ocean oxygen in Pacific Ocean waters to levels lower than any naturally occurring levels as early as 2030[285] or 2050.[273] Reduced oxygen could decrease rockfish habitat off southern California by 20% to 50%.[286] Further deoxygenation may harm bottom-dwelling marine life, shrink open-water habitat for hake and other economically important species,[287] and increase the number of invasions by squid. Tracking the variability of ocean waters and fish populations and adjusting catch quotas accordingly can reduce pressures on fisheries stressed by climate change,[288] actions that have been identified as parts of the National Oceanic and Atmospheric Administration's (NOAA) Fisheries Climate Science Strategy.[289]

With continued climate change, risks would cascade from one area to another. For example, projected warmer winter temperatures in the Sierra Nevada would increase winter runoff, reduce spring and summer freshwater inflows into San Francisco Bay, and increase salinity in the Bay 3 to 5 grams per kilogram of water by 2100.[290,291,292] Also, sea level rise and storm surge would compound effects inland of river and stream flooding, putting houses and roads at risk of inundation and damage.[293,294]

Key Message 4

Indigenous Peoples

Traditional foods, natural resource-based livelihoods, cultural resources, and spiritual well-being of Indigenous peoples in the Southwest are increasingly affected by drought, wildfire, and changing ocean conditions. Because future changes would further disrupt the ecosystems on which Indigenous peoples depend, tribes are implementing adaptation measures and emissions reduction actions.

Droughts in the Southwest have contributed to declines in traditional Indigenous staple foods, including acorns, corn, and pine nuts.[298,299,300] Drought and increasing heat intensify the arid conditions of reservations where the United States restricted some tribal nations in the Southwest region to the driest portions of their traditional homelands.[301] Navajo elders tell of the increasingly arid conditions over the last half of the 20th century that contributed to declines in culturally significant crops, the flow of specific water springs and seeps, and wildlife populations, such as eagles.[44,302] Projected reductions in water supply reliability,[13,114] coupled with water agreements that involve selling or leasing tribal water to neighboring communities, could place tribal water supplies at risk during severe shortages. As water supplies decrease and water demand increases, tribes are at risk of finding themselves committed to providing purchased water to other entities, resulting in situations in which, in the words of one elder, "water sold must be delivered, regardless of the condition of the selling reservation. In this worst-case scenario, the Community will have to breach its contracts for the survival of its people."[303]

In addition to drought, wildfires affect traditional resources, including fish, wildlife, and plants, such as tanoaks and beargrass, upon which some Southwest tribes rely for food and cultural uses.[304,305,306] Continued climate change would reduce populations of some fish, wildlife, and plants that serve as traditional foods, medicines, and livelihood and cultural resources.[298,307,308] Reduced availability of traditional foods often contributes to poorer nutrition and an increase in diabetes and heart disease.[298,309] Reductions in runoff would, for example, increase the salinity of Pyramid Lake in Nevada, reducing fish biodiversity and affecting the cui-ui fish, the primary cultural resource of the Pyramid Lake Paiute Tribe.[310] Tribes in the Southwest that depend on livestock are at risk of climate-related degradation of rangelands.[44,311,312] Many California tribes, including the Miwok, Paiute, Western Mono, and Yurok, among others, are concerned about the loss of acorns—a nutritious traditional food, medicine, and basketry component[313,314]—due to sudden oak death, which can increase with changes in humidity and temperature.[44,312,315] Changes in plant and animal ranges (Ch. 7: Ecosystems, KM 1) can also affect mental and spiritual health, disrupting cultural connections to disappearing plant and animal relatives and to place-based identity and practices.[42,316] Changes in marine ecosystems affect resources for Indigenous peoples (Ch. 15: Tribes). Ocean warming affects salmon and other fish on which Pacific Coast tribes rely for subsistence, livelihoods, and cultural identity.[307,317,318,319,320] Ocean warming and acidification, as well as sea level rise, increase risks to shellfish beds (which reduces access for traditional harvesting),[298] pathogens that cause shellfish poisoning,[307,311] and damage to shellfish populations, which can cause cascading effects in food and ecological systems upon which some tribes depend.[298,321]

Although Indigenous peoples have adapted to climate variations in the past, historical intergenerational trauma, extractive infrastructure, and socioeconomic and political pressures[322,323] reduce their adaptive capacity to current and future climate change (Ch 15: Tribes, KM 1 and 3).[324] Still, in response to climate change, Indigenous peoples in the Southwest are developing new adaptation and mitigation actions based on a cultural model focused on relationships between humans and nonhumans.[313,325,326] Traditional ecological knowledge of specific plants and habitats can enable Indigenous peoples to provide early detection of invasive species and support to ecological restoration.[327] Some tribes, such as the Tesuque Pueblo of New Mexico, use their knowledge to reintegrate traditional foods into their diets. Other tribes, such as the Karuk Tribe,[304] North Fork Mono,[313] and Mountain Maidu[328] use traditional ecological knowledge to guide natural resource management. The Yurok Tribe, Gila River Indian Community, and Tohono O'odham Nation, among others, are developing climate adaptation plans, often in partnership with universities and other research institutions (Ch. 15: Tribes, KM 3 and Figure 15.1).

Many Indigenous peoples in the Southwest region have traditionally used fire as a tool central to cultural and spiritual practices. They use fire to protect and enhance species used for basket weaving, medicines, and traditional foods.[306,313,328,329,330,331,332] This cultural use of fire offers an important tool for adaptation and mitigation, as traditional burning reduces fuel accumulations that can lead to high-severity wildfires (see Case Study "Cultural Fire and Climate Resilience" and Figure 25.7).[331,333]

Case Study: Cultural Fire and Climate Resilience

Indigenous peoples in the Southwest have traditionally used fire as a tool central to social, cultural, and spiritual practices. They use fire to increase ecosystem resilience, reduce fuel loads, manage crops, and protect species used for basket weaving, medicines, and traditional foods.[306,313,328,329,330,331,332] Tribal entities are restoring cultural burning practices and management principles that guide the use of fire on the landscape to reduce wildfire risks and protect public and tribal trust resources.[331,333] For example, Yurok tribal members have formed the Cultural Fire Management Council (CFMC), in partnership with the Nature Conservancy Fire Learning Network, Firestorm Inc., Yurok Forestry/Wildland Fire, Northern California Indian Development Council, and the U.S. Department of Agriculture (USDA) Forest Service, to bring fire back to the landscape for ecosystem restoration.[334] The collaboration builds capacity and trains Yurok and local fire crews through the Prescribed Fire Training Exchange. "Restoration of the land means restoration of the people," said CFMC President Margo Robbins, "Returning fire to the land enables us to continue the traditions of our ancestors."[334]

Cultural Fire on Yurok Reservation

Figure 25.7: Andy Lamebear, a Yurok Wildland Fire Department firefighter and Yurok tribal member, ignites a cultural burn on the Yurok Reservation. The tribe uses low- to medium- intensity fires to enhance the production of plant-based medicines, traditional basket materials, native fruits, and forage for wildlife. Cultural burning also reduces risks of catastrophic wildfire. Photo courtesy of the Yurok Tribe.

Key Message 5

Energy

The ability of hydropower and fossil fuel electricity generation to meet growing energy use in the Southwest is decreasing as a result of drought and rising temperatures. Many renewable energy sources offer increased electricity reliability, lower water intensity of energy generation, reduced greenhouse gas emissions, and new economic opportunities.

Hydroelectric generation depends on sufficient water supplies. The severe drought in California, intensified by climate change,[14,56] reduced hydroelectric generation by two-thirds from 2011 to 2015.[335] Drought in the Colorado River Basin[13,59] caused river runoff, on which hydroelectric generation depends,[12,336,337] to decline. By 2016, Lake Mead, which stores water for drinking, agriculture, and the Hoover Dam hydroelectric plant, had fallen by half (Box 25.1 and Figure 25.3). Although the Bureau of Reclamation maintained constant electricity generation at Hoover Dam throughout the drought, this decline potentially reduces maximum generation capacity.

In California, utilities increased fossil fuel generation of electricity to compensate for the drought-driven decline in hydroelectricity, increasing state carbon dioxide emissions in the first year of the drought (2011 to 2012) by 1.8 million tons of carbon, the equivalent of emissions from roughly 1 million cars.[338,339] A drop in the price of natural gas also contributed to the increase, although the shift from hydroelectric to fossil fuels cost California an estimated $2.0 billion (in 2015 dollars).[340] Other southwestern states also shifted some generation from hydropower to fossil fuels.[89]

Under a higher scenario (RCP8.5), declines in snowpack and runoff in the Colorado River and Rio Grande Basins and a shift of spring runoff to earlier in the year[105] would reduce hydroelectric power potential in the region by up to 15% by 2050.[91] Under a very low scenario (RCP2.6), hydroelectric generation may remain unchanged, demonstrating the positive benefits of emissions reductions.[91] With increased precipitation, hydroelectric potential could increase,[342] except in cases of reservoir spillage to protect dams in extreme storms.[343]

The efficiency of water-cooled electric power plants that burn fuel depends on the temperature of the external cooling water, so climate change could reduce energy efficiency up to 15% across the Southwest region by 2050.[91] Since higher temperatures also increase electric resistance in transmission lines, electricity losses in many transmission lines across the Southwest could reach 5% by 2080 under a lower scenario (RCP4.5) and 7% under a higher scenario (RCP8.5).[344] Under the higher scenario (RCP8.5), water demand by thermoelectric plants in the Southwest is projected to increase 8% by 2100.[345] In a 10-year drought, summer electric generating potential in the Southwest could fall 3% to 9% under higher emissions (SRES A2) or 1% to 7% under lower emissions (SRES B1; Figure 25.8).[346]

Any increase in water requirements for energy generation from fossil fuels would coincide with reduced water supply reliability from projected decreases in snowpack[46,77] and earlier snowmelt.[75,347] Increased agricultural water demands under higher temperatures could affect the seasonal demand for hydropower electricity.[105] The water consumption, pollution, and greenhouse gas emissions of hydraulic fracturing (fracking) make that source of fuel even less adaptive under climate change.[348] Substantial energy and carbon emissions are embedded in the pumping, treatment, and

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transport of water, so renewable-powered water systems are less energy and carbon intense than ones powered by fossil fuels.[349]

Economic conditions and technological innovations have lowered renewable energy costs and increased renewable energy generation in the Southwest. For example, wind energy generation in California rose by half from 2011 to 2015, and solar energy generation increased by 15 times.[335]

Solar, wind, and other renewable energy sources, except biofuels, emit less carbon and require less water than fossil fuel energy. By cutting carbon emissions, renewable energy can reduce future impacts of climate change on nature and human well-being.[30,350,351,352] After the first year of the drought, when natural gas burning increased to compensate for a loss of hydroelectric energy, solar and wind energy sources in California increased enough to displace 15% of fossil fuel burning for electricity from 2012 to 2017, thereby reducing state greenhouse gas emissions by 6%.[335] Increased electricity generation by renewable sources can cut water needs up to 90% in the Southwest, depending on the fraction of production derived from fossil fuels.[353,354] Under a higher scenario (RCP8.5), conversion of two-thirds of fossil fuel plants to renewables would reduce water demand by half.[345]

State energy policies are facilitating the switch to renewable energy. Arizona, California, Colorado, Nevada, and New Mexico have enacted renewable energy portfolio standards.[93] California has set the highest standard: 50% of energy generation from renewable sources by 2030. In 2017, renewable energy sources supplied 32% of California energy generation.[355] By 2013, these standards had averted 26 trillion watt-hours of fossil fuel generation in the Southwest and 3% of carbon emissions nationally and had produced $5 billion in health benefits from reduced air pollution (in 2013 dollars; $5.2 billion in 2015 dollars).[356] Potential future benefits of existing renewable portfolio standards include carbon emission reductions of 6% nationally and health benefits of $560 billion (in 2013 dollars; $577 billion in 2015 dollars) from 2015 to 2050.[357]

Electricity Generation Capacity at Risk Under Continued Climate Change

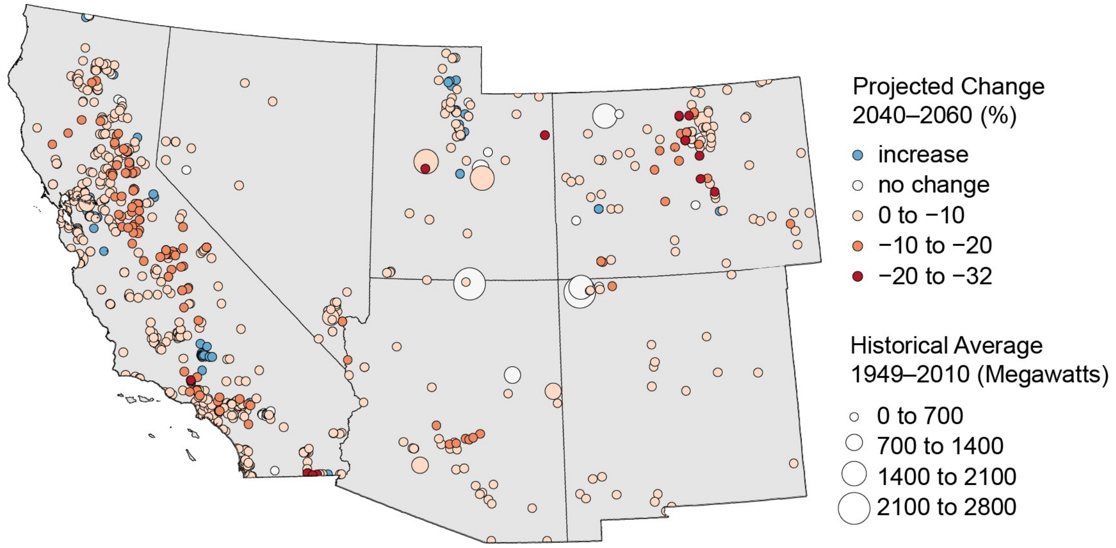

Figure 25.8: Under a higher emissions scenario (SRES A2[174]), heat-induced reduction of energy efficiency and reduced water flows would reduce summer energy generation capacity across the Southwest region. These projected reductions would increase risks of electricity shortages. The map shows projected changes for the period 2040–2060 compared to the period 1949–2010. Source: adapted from Bartos and Chester 2015.[346] Reprinted by permission from Macmillan Publishers Ltd. *This figure was revised in June 2019. See Errata for details: https://nca2018.globalchange.gov/downloads*

Distributed solar energy systems place individual solar panels on roofs, on parking lot canopies, and other built places. The high number of sunny days in the Southwest and the great extent of existing rooftops and parking lots create a high potential for distributed solar generation, which could provide two-thirds of electricity use in California.[358] Distributed solar uses land that has already been urbanized and is close to energy users, reducing the need for transmission lines and transmission line electricity losses. Compared to industrial centralized solar power systems, distributed solar causes less death and disruption to wildlife that are already vulnerable to climate change, such as birds and endangered desert tortoises.[359] California, Colorado, and Nevada have enacted policies that support rooftop solar on homes, in particular net metering, in which customers sell their excess solar electricity to the grid.[360] Distributed wind energy systems can provide similar benefits.

Arizona, California, Colorado, Nevada, and New Mexico have enacted energy efficiency standards for utilities. California and New Mexico have also enacted policies that decouple utility profits from electricity sales.[361] White or reflective roofs, known as cool roofs, increase energy efficiency of buildings. Under a higher scenario (RCP8.5), cool roofs would reduce urban heat islands in Los Angeles and San Diego 2°–4°F (1°–2°C) by 2050 and decrease energy use and the use of air conditioning.[362] Urban tree planting in Phoenix that would increase tree cover from 10% to 25% would provide daytime cooling of up to 2°C in local neighborhoods.[363]

Newer technologies now allow generating plants to use nontraditional water sources, including saline groundwater, recycled water from landscaping, and municipal and industrial wastewater. For example, the Palo Verde Nuclear Generating Station in Arizona uses municipal wastewater.[361] Other plants in the region use extremely water-efficient hybrid wet–dry cooling technology. For instance, the Afton Generating Station in New Mexico is a natural gas combined-cycle plant that uses hybrid cooling to reduce water intensity by 60% compared to conventionally cooled plants.[361]

Electric cars can reduce fossil fuel use and greenhouse gas emissions compared to gasoline-powered vehicles. The relative greenhouse gas emissions from electric and gasoline vehicles depend on how the electricity is generated.[364,365] If the electricity is produced from renewable sources, then the operating emissions for electric vehicles are near zero, although the manufacturing of the vehicle emitted greenhouse gases. Conversely, if the electricity is produced completely from fossil fuel, the emissions from the electric vehicle are higher because of the limit of energy efficiency of large power plants and transmission line losses. Because sunlight, wind, and other renewable resources are intermittent and sometimes not available at times of demand, charging at night and improvements in battery technology would facilitate renewable energy generation.

Key Message 6

Food

Food production in the Southwest is vulnerable to water shortages. Increased drought, heat waves, and reduction of winter chill hours can harm crops and livestock; exacerbate competition for water among agriculture, energy generation, and municipal uses; and increase future food insecurity.

Climate change has altered factors fundamental to food production and rural livelihoods in the Southwest, particularly the shortage of water caused by droughts in California[14,56] and the Colorado River Basin.[13] The California drought led to losses of more than 10,000 jobs and the fallowing of 540,000 acres (220,000 hectares), at a cost of $900 million in gross crop revenue in 2015.[130] Increased temperatures in the Southwest also affected agricultural productivity from 1981 to 2010.[366]

Food production depends on reliable surface and groundwater supplies, which decline from droughts and reductions in snowpack and soil moisture.[67] Irrigated agriculture and livestock water use accounted for approximately three-quarters of total water use in the Southwest in 2010, excluding Colorado, which has wide-ranging dryland wheat production.[16,367,368] In the recent California drought, domestic wells dried out in some rural communities, but increased groundwater pumping from deeper wells prevented some agricultural revenue losses.[369] Falling groundwater tables increase pumping costs and require drilling to deepen wells.[130] Drought-related agricultural changes, stricter drilling regulations, and rapid aquifer depletion have already led to a decline in irrigation in parts of the region. According to climate projections for lower and higher emissions scenarios (RCP4.5 and RCP8.5), future changes in climate would reduce aquifer recharge in the southern part of the region by 10%–20%,[370] removing some of the secondary water source responsible for buffering effects of severe drought. In the Gila River Basin of New Mexico, farmers shift to groundwater pumping when surface water supplies are reduced, despite associated increases in production costs.[371] Under continued climate change, increased drought risk[13] and higher aridity[70] could expose some agricultural operations in the Southwest to less reliable surface and groundwater supplies (Ch. 10: Ag & Rural, KM 1).

Under continued climate change, higher temperatures would shift plant hardiness zones northward and upslope (Figure 25.9). These changes would affect individual crops differently depending on optimal crop temperature thresholds. Some crops, including corn[372] and rice,[373] are already near optimal thresholds in the Southwest. Increasing heat stress during specific phases of the plant life cycle can increase crop failures, with elevated temperatures associated with failure of warm-season vegetable crops and reduced yields or quality in other crops.[374] While crops grown in some areas might not be viable under hotter conditions, crops such as olives, cotton, kiwi, and oranges may replace them.[375] In parts of the Southwest region, increasing temperatures would prompt geographic shifts in crop production, potentially displacing existing growers and affecting rural communities.[376] Wine grape quality can be particularly influenced by elevated temperatures.[377] Increased levels of ozone and carbon dioxide near the surface, combined with increases in temperature, can decrease food quality and nutritive values of fruit and vegetable crops.[378,379]

Because many fruit and nut trees require a certain period of cold temperatures in the winter, decreased winter chill hours under continued climate change would reduce crop yields, though the magnitude may vary considerably.[380] In Yolo County, California, reduced winter chill may make conditions too hot for walnut cultivation by 2100.[381] California almond acreage has nearly doubled over the last two decades due to high foreign demand and the favorable Mediterranean climate. California now produces over 80% of world almond supply.[382] Since almonds also have a relatively high water requirement, both water and adequate cool winter temperatures will be important factors to maintain California tree nut production under climate change.

Projected Shift in Agricultural Zones

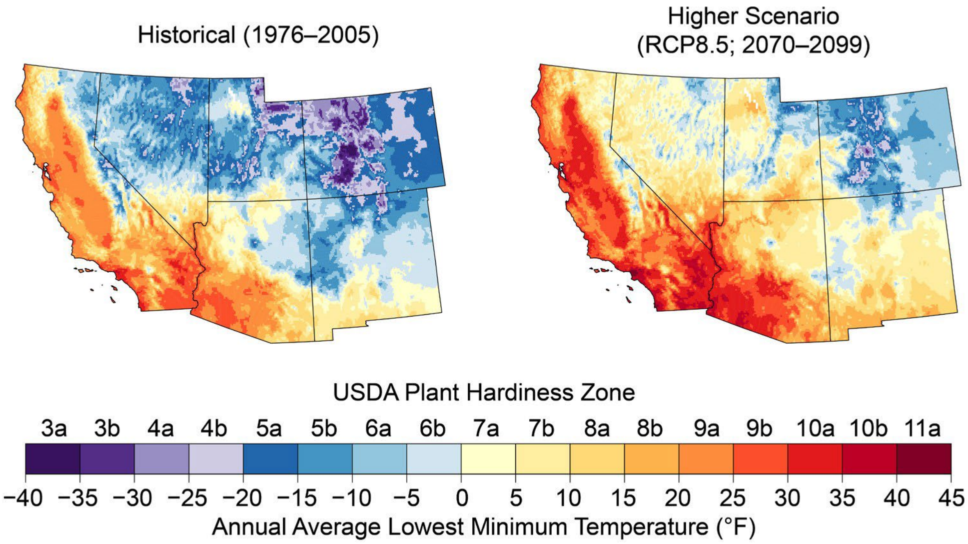

Figure 25.9: The U.S. Department of Agriculture plant hardiness zones indicate the cold temperature requirements of crops. Increases in temperature under the higher scenario (RCP8.5), would shift these zones northward and upslope, from the period 1976—2005 (left, modeled historical) compared to projections for 2070—2099 (right, average of 32 general circulation models). Sources: NOAA NCEI and CICS-NC.

Climate-related vulnerabilities of the Southwest region's livestock industry include reduced long-term livestock grazing capacity, reduced feed supply, increased heat stress (Ch. 10: Ag & Rural, KM 3), and reduced forage quality.[383] Water-intensive forage crops are especially vulnerable to water shortages.[15] Although livestock production systems persist in highly variable conditions, projected high temperatures may decrease production of rangeland vegetation and livestock forage.[384] In response to drought (1999–2004), 75% of Utah ranch operations reported major reductions in water supply, forage, and cattle productivity.[385] Only 14% felt they were adequately prepared for the drought, which may be reflected in the high use of federal relief programs.

One potential adaptation of agriculture to drought is water banking, the storage of excess surface water in groundwater aquifers.[386,387] For example, streamflows from the Sierra Nevada in high-precipitation years could provide substantial groundwater recharge in the California Central Valley.[388] Additional options include expanding surface reservoir storage or relying upon groundwater pumping, although this further depletes limited groundwater stores.[389]

Flexible livestock management strategies, such as stocking rates, grazing management practices, employing livestock bred for arid environments, erosion control, and identification of alternate forage supplies can help reduce vulnerability in an increasingly arid and variable climate.[390,391] Criollo cattle appear well-suited for the arid Southwest because they are more heat tolerant and adaptive than traditional breeds.[392]

In urban areas across the Southwest, such as Tucson, Arizona, and Sacramento, California, community food banks that grow food in community gardens can help maintain food security in a drier and more variable climate. Urban gardens and local food organizations provide fresh produce, foster community education, and support networks of local growers. These organizations build food systems capacity, which helps to mitigate impacts of urban heat, reduces food transportation costs and emissions, and supports provision of fresh local food to low-income urban dwellers.

Additional emerging issues that increase risks to food production include invasive nonnative or alien insect pests (introduced into the region intentionally or unintentionally) that are more adapted to hotter temperatures.[393] Global trade and efficient transportation also increase risks of invasion by alien insect pests. A mismatch in timing between plant flowering and the arrival of insect pollinators would reduce crop production and pollinator survival.[393] In addition, some subsistence foods, such as fish, upon which some Indigenous and other subsistence and urban communities depend,[309,394,395,396,397] and spiritually, socially, and culturally important tribal traditional foods[298] would be vulnerable in a drier and more variable climate (Key Message 4).

Key Message 7

Human Health

Heat-associated deaths and illnesses, vulnerabilities to chronic disease, and other health risks to people in the Southwest result from increases in extreme heat, poor air quality, and conditions that foster pathogen growth and spread. Improving public health systems, community infrastructure, and personal health can reduce serious health risks under future climate change.

Exposure to hotter temperatures and heat waves has led to heat-associated deaths and illnesses in Arizona and California.[398,399,400,401,402,403] In the unprecedented 2006 California heat wave, which affected much of the state and part of Nevada, extremely high temperatures occurred day and night for more than two weeks.[404] Compared to non-heat wave summer days, it is estimated that the event led to an additional 600 deaths, 16,000 emergency room visits, 1,100 hospitalizations in California,[399,405,406] and economic costs of $5.4 billion (in 2008 dollars).[405] Parts of the Southwest region experienced record-breaking heat in five of the six years from 2012 to 2017.[25,26,27,28,29] Assessments of the health impacts associated with record high temperatures in parts of the Southwest since 2010 are not yet available in the scientific literature.

Under continued climate change, projected increases in hot days and extreme heat events in the Southwest (Figure 25.10)[23,24,404,407] will increase the risk of heat-associated deaths.[30] Under the higher scenario (RCP8.5), the Southwest would experience the highest increase in annual premature deaths due to extreme heat in the country, with an estimated 850 additional deaths per year and an economic loss of $11 billion (in 2015 dollars) by 2050.[178] Under a lower scenario (RCP4.5), deaths and costs would be reduced by half compared to the higher scenario (RCP8.5).[178] By 2090, deaths and economic losses would more than double from 2050 under all emissions scenarios.[178] Heat and other environmental exposures particularly affect outdoor workers.[178] Under the higher scenario (RCP8.5), extreme heat in the Southwest (Figure 25.10) would also lead to high labor losses, including losses of high-risk labor hours of up to 6.5% for some counties by 2090 and of $23 billion per year in regionwide wages (in 2015 dollars).[178] It is projected that the lower scenario (RCP4.5) would reduce those wage losses by half.[178]

The risk of illness or death associated with extreme temperatures can be reduced through targeted public health and clinical interventions.[30,32] The main factors that put individuals and populations at increased risk in a heat wave are age (children and older adults are most at risk), hydration status, and presence of a chronic disease such as obesity, cardiovascular or respiratory disease, or psychiatric illness.[400,408,409,410,411,412,413,414,415] Psychosocial stresses and socioeconomic conditions, such as hot and poorly ventilated homes or lack of access to public emergency cooling centers can elevate these risks.[31,33,416]

Without adoption and implementation of strategies to minimize exposures to extended periods of extreme heat, the public health impacts of future heat waves may be as serious as those observed in California in 2006. The technological and behavioral adaptations to heat developed by populations in the Southwest are based on the observed historical range of nighttime minimum temperatures.[404] Projected increases in minimum temperatures and decreases in the number of cool nights[23] may diminish the efficacy of these adaptations.

Climate change and variability can also increase communicable and chronic disease burdens.[417,418,419] While infectious diseases like plague and hantavirus pulmonary syndrome disproportionately affect the Southwest region,[158] new research to support estimating future climate-associated risk for these diseases is sparse.[420] Therefore, this assessment focuses on recent developments in the understanding of heat, air quality, mosquito-borne diseases, and Valley fever and vulnerabilities that influence them.

In addition to extreme heat, the environmental conditions of greatest concern for human health are ground-level ozone air pollution, dust storms, particulate air pollution (such as from wildfires and dust storms), aeroallergens (airborne substances that trigger allergic reactions), and low water quality and availability.[30,178] In addition, alternating episodes of drought and extreme precipitation coupled with increasing temperatures promote the growth and transmission of pathogens.[30,421] The risk of onset or exacerbation of respiratory and cardiovascular disease is associated with a single or a combined exposure to ground-level ozone pollution, particulate air pollution, respiratory allergens, and extreme heat. Ground-level ozone is produced by chemical reactions of combustion-related chemicals (for example, from vehicles or wildfires) in a reaction that is dependent on ultraviolet radiation (that is, from the sun) and amplified by higher temperatures. Once formed, ozone can travel great distances and persist in high concentrations overnight in rural areas. Among many health impacts, ozone can promote or aggravate asthma and respiratory allergies.[422,423,424,425]

Projected Increases in Extreme Heat

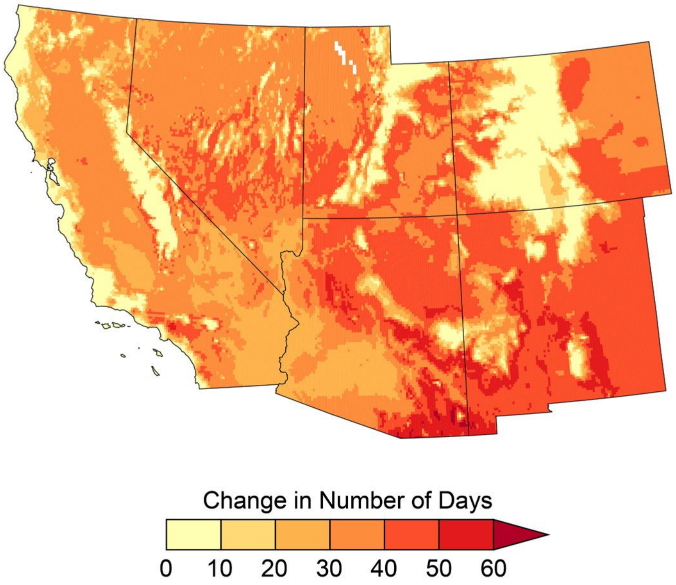

Figure 25.10: Under the higher scenario (RCP8.5), extreme heat would increase across the Southwest, shown here as the increase in the average number of days per year when the temperature exceeds 90°F (32°C) by the period 2036–2065, compared to the period 1976–2005.[23] Heat waves increase the exposure of people to heat stroke and other illnesses that could cause death.[30] Source: adapted from Vose et al. 2017.[23]

Elevated levels of CO_2 in conjunction with higher temperatures can increase the amount and potency of aeroallergens (Ch. 14: Human Health, KM 1). These conditions may also lead to new cases or exacerbation of allergy and asthma.[426,427,428,429] Mortality risk during a heat wave is amplified on days with high levels of ground-level ozone or particulate air pollution, with the greatest mortality due to cardiovascular causes.[430]

Severe dust storms in the Southwest contribute to respiratory and cardiovascular disease.[431,432] The association between Valley fever, a soilborne fungal respiratory infection of the Southwest, and warmer temperatures and soil dryness varies across the region and by time of year.[189,433,434] The connection between climate change, dust storm frequency and severity, and future public health effects in the region is complex and remains an emerging area of research.[435,436,437,438,439] Heat extremes, warming, and changes in precipitation will also influence the distribution and occurrence of vector-borne diseases like West Nile virus[440,441,442,443] and may lead to the emergence of new disease (Ch. 14: Human Health, KM 1).[30] Without proactive interventions and policies that address the biological, exposure, and socioeconomic factors that influence individual and population vulnerability, adverse health impacts may increase (Ch. 14: Human Health, KM 2). Those increases may disproportionately affect people with the lowest incomes, which hinders adaptive capacity (Ch. 14: Human Health, KM 1).[416,444]

Climate-related hazards such as heat waves, flooding, wildfires, or large disease outbreaks require emergency responses. Prolonged droughts can affect drinking water availability, reduce water quality,[445] and send more people seeking medical treatment.[446,447] The increased burden of disease can outpace the resources and adaptive capacity of public health and clinical infrastructures. The region may not be prepared to absorb the additional patient load that could accompany climate change,[448] but integrating risk reduction strategies into emergency response plans and recognizing and addressing vulnerability factors can appreciably reduce risks of future adverse health consequences (Ch. 14: Human Health, KM 3). This approach is embodied in the Centers for Disease Control and Prevention's (CDC) Building Resilience Against Climate Effects framework for adaptation planning.[449] Adaptation planning is already yielding health protection benefits.[450]

Local government agencies are preparing for extreme events by developing and updating emergency response plans and improving public warning and response systems. In 2014, California updated its Contingency Plan for Excessive Heat Emergencies,[451] Arizona released its Heat Emergency Response Plan,[452] and Salt Lake City, San Francisco, and Sonoma County were recognized in the first cohort of U.S. Department of Energy Climate Action Champions. Integrated and participatory planning for extreme heat,[453] such as the Capital Region Climate Readiness Collaborative in Sacramento, California, can help overcome institutional and governance barriers to implementing adaptation actions (Ch. 28: Adaptation).[454]

Policies and interventions related to one health factor can positively affect other factors and yield co-benefits[455,456,457,458,459] For example, research shows that heat-associated deaths and illnesses are preventable[460] and that healthier individuals are less susceptible to adverse effects of extreme heat exposure. Obesity, which affects about 30% of adults and 15% of school-age children and teens nationwide, increases the risk for many chronic diseases, such as asthma and diabetes, and increases the risk for serious heat-related adverse health outcomes.[32,461,462,463] Access to healthcare, social isolation, housing quality, and neighborhood poverty are also key risk factors for heat-related health impacts.[31,33,412]

Urban design strategies to address these risk factors include increasing walkability and bicycle safety and maintaining and planting trees and green space.[464] These strategies can achieve multiple health benefits, including increasing physical activity, thereby helping residents maintain a healthy weight,[465,466] reducing the urban heat island effect,[467] and reducing exposure to harmful air pollutants from vehicles. Reducing the urban heat island effect also reduces energy demand and risks of power outages, which can contribute to health risks, such as patients losing access to electricity-dependent medical devices.

Climate change may weigh heavily on mental health in the general population and those already struggling with mental health disorders.[468,469,470,471,472] One impact of rising temperatures, especially in combination with environmental and socioeconomic stresses, is violence towards others and towards self.[473,474,475] Slow-moving disasters, such as drought, may affect mental health over many years.[470] Studies of chronic stress indicate a potentially diminished ability to cope with subsequent exposures to stress.[476,477,478]

Populations under chronic social and economic stresses in urban and rural areas possess lower psychological, physical, and economic resilience (Ch. 10: Ag & Rural, KM 3). Communities that rely especially on well-functioning natural and agricultural systems in specific locations may be especially vulnerable to mental health effects when those systems fail. In the Southwest, the loss of stability and certainty in natural systems may affect physical, mental, and spiritual health of Indigenous peoples with close ties to the land.[42,316] For example, extended drought raises concerns about maintaining Navajo Nation water-based ceremonies essential for spiritual health, livelihoods, cultural values, and overall well-being.[301]

Acknowledgments

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Opening Image Credit

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Traceable Accounts

Process Description

The authors examined the scientific literature in their areas of expertise. The team placed the highest weight on scientific articles published in refereed peer-reviewed journals. Other sources included published books, government technical reports, and, for data, government websites. The U.S. Global Change Research Program issued a public call for technical input and provided the authors with the submissions. The University of Arizona Center for Climate Adaptation Science and Solutions organized the Southwest Regional Stakeholder Engagement Workshop on January 28, 2017, with over 70 participants at the main location in Tucson, AZ, and dozens of participants in Albuquerque, NM, Boulder, CO, Davis, CA, Los Angeles, CA, Reno, NV, and Salt Lake City, UT, all connected by video. Participants included scientists and managers. The author team met the following day for their only meeting in person. Subsequently, authors held discussions in regular teleconferences. Many chapter authors met at the all-author meeting March 26–28, 2018, in Bethesda, MD.

Key Message 1

Water Resources

Water for people and nature in the Southwest has declined during droughts, due in part to human-caused climate change (*very high confidence*). Intensifying droughts (*very high confidence*) and occasional large floods (*medium confidence*), combined with critical water demands from a growing population, deteriorating infrastructure, and groundwater depletion, suggest the need for flexible water management techniques that address changing risks over time (*high confidence*), balancing declining supplies with greater demands.

Description of evidence base

Research has found that hotter temperatures can make hydrologic droughts more severe. The unprecedented droughts in the Colorado River Basin and California showed that increased temperatures from climate change intensified the severity of the drought.[13,14,56,59] Climate change, more than natural cycles, has reduced snowpack.[46,49] Models project more drought under climate change,[13,56,62] snowpack and streamflow decline in parts of the Southwest, and decreasing surface water supply reliability for cities, agriculture, and ecosystems.[479]

Major uncertainties

Projecting future streamflow and hydrologic characteristics in a basin contains many uncertainties. These differences arise because of uncertainty in temperature and precipitation projections due to differences among global climate models (GCMs), uncertainty in regional downscaling, uncertainty in hydrological modeling, and differences in emissions, aerosols, and other forcing factors. Another important uncertainty is differences in the hemispheric and regional-scale atmospheric circulation patterns produced by different GCMs, which generate different levels of snow loss in different model simulations. A key uncertainty is the wide range in projections of future precipitation across the Southwest;[105] some projections of higher-than-average precipitation in the northern parts of the Southwest could roughly offset declines in warm-season runoff associated with warming.[105]

Detection is the finding of statistically significant changes different from natural cycles. Attribution is the analysis of the relative contribution of different causes and whether greenhouse gas emissions from human sources outweigh other factors. Attribution of extreme events, such as the recent California drought to climate change, is an area of emerging science. On the one hand, Seager et al. (2015)[58] concluded that the California drought was primarily driven by natural precipitation variability. Sea surface temperature anomalies helped set up the high-pressure ridge over California that blocked moisture from moving inland. On the other hand, Diffenbaugh et al. (2015),[56] Williams et al. (2015),[14] and Berg and Hall (2017)[55] concluded that high temperatures from climate change drove record-setting surface soil moisture deficits that made the drought more severe than it would have been without climate change. Storage of increased precipitation in soils may partially offset increased evaporation, possibly making drought less likely.[480]

In addition to the uncertainties in regional climate and hydrology projections and attribution studies, other uncertainties include potential changes in water management strategies and responses to accommodate the new changing baseline. Additionally, external uncertainties can impact water use in the region via legal, economic, and institutional options for augmenting existing supplies, adding underground storage and recovery infrastructure, and fostering further water conservation, changes in unresolved water rights, and changes to local, state, tribal, regional and national policies related to the balance of agricultural, ecosystem, and urban water use.

Description of confidence and likelihood

The *very high confidence* in historical droughts derives from the detection and attribution analyses of temperature increases, snow decreases, and soil moisture decreases that have documented hydrologic droughts in California and the Colorado River Basin due to anthropogenic climate change and the conclusions of the *Climate Science Special Report* (CSSR), Volume I of the Fourth National Climate Assessment.[74] The *very high confidence* in drought projections derives from the multitude of analyses projecting drought in the Southwest under a range of emissions scenarios and the conclusions of the CSSR.[74] Only *medium confidence* is found for flood projections due to lack of consensus in the model projections of precipitation. Increasingly arid conditions and the potential for increased water use by people lead to an assessment of *high confidence* in the need for new ways to address increasing risks of water scarcity. The actual frequency and duration of water supply disruptions will depend on the preparation of water resource managers with drought and flood plans, the flexibility of water resource managers to implement or change those plans in response to altered circumstances,[481] the availability of funding to make infrastructure more resilient, and the magnitude and frequency of climate extremes.

Key Message 2

Ecosystems and Ecosystem Services

> The integrity of Southwest forests and other ecosystems and their ability to provide natural habitat, clean water, and economic livelihoods have declined as a result of recent droughts and wildfire due in part to human-caused climate change (*high confidence*). Greenhouse gas emissions reductions, fire management, and other actions can help reduce future vulnerabilities of ecosystems and human well-being (*high confidence*).

Description of evidence base

Scientific research in the Southwest has provided many cases of detection and attribution of historical climate change impacts. Detection is the finding of statistically significant changes different from natural cycles. Attribution is the analysis of the relative contribution of different causes and whether greenhouse gas emissions from human sources outweigh other factors. Published field research has detected ecological changes in the Southwest and attributed much of the causes of the changes to climate change. Wildfire across the western United States doubled from 1984 to 2015, compared to what would have burned without climate change, based on analyses of eight fuel aridity metrics calculated from observed data, historical observed temperature, and historical modeled temperature from global climate models.[7] The increased heat has intensified droughts in the Southwest,[13,14] reduced snowpack,[49,156] and advanced spring warmth.[101] These changes have dried forests,[154,155] driving the wildfire increase.[7,153] Tree death across the western United States doubled from 1955 to 2007[146] likely due to increased heat,[21] wildfire,[7] and bark beetle infestations,[148,149] all of which are mainly attributable to climate change[7,148,149] more than to other factors such as fire exclusion or competition for light and water.[146] In the Yosemite National Park biome shift,[209] the research analyzed the relative contributions of temperature, precipitation, and the Pacific Decadal Oscillation. The researchers found that "Minimum temperature was the main effect related to accelerating annual branch growth in krummholz whitebark pine and initiation of pine invasion into formerly persistent snowfield openings." In the Yosemite National Park small mammal range shift,[210] the locations of the monitoring sites allowed relative isolation of climate change factors. Moritz et al. (2008)[210] state, "The transect spans YNP [Yosemite National Park], a protected landscape since 1890, and allowed us to examine long-term responses to climate change without confounding effects of land-use change, although at low to mid-elevations there has been localized vegetation change relating to seral dynamics, climate change, or both."

Cutting emissions through energy conservation and renewable energy can reduce ecological vulnerabilities. Under high emissions, projected climate change could triple burned area in the Sierra Nevada, but under low emissions, fire could increase just slightly.[173] Projections of biome shifts[213,215] and wildlife range shifts[217,218,219,220,221] consistently show lower vulnerabilities with lower emissions. Extensive research on, and practice of, fire management show that allowing naturally ignited fires to burn in wilderness and using low-severity prescribed burns can reduce fuels and the risk of high-severity fires under climate change.[181,182,183] Proactive use of fire in Yosemite, Sequoia, and Kings Canyon National Parks has improved the resilience of giant sequoias and other trees to severe fires.[187,188,190,191] Numerous research results have identified climate change refugia for plants and animals.[207,482,483]

Major uncertainties

Because climate model projections often diverge on whether precipitation may increase or decrease, two broad types of fire futures[152] could be 1) dry-fire future—hotter and drier climate, increased fire frequency, fire limited by vegetation, potential biome change of forest to grassland after a fire due to low natural regeneration, and high carbon emissions; or 2) intense-fire future—hotter and wetter climate, more vegetation, increased fire frequency and intensity, fire limited by climate, and higher carbon emissions. These two broad categories each encompass a range of fire conditions. On the ground, gradients of temperature, precipitation, and climate water deficit (difference between precipitation and actual evapotranspiration) generate gradients of fire regimes. Because climate change, vegetation, and ignitions vary across the landscape, potential fire frequency shows high spatial variability. Therefore, future fire types could appear in patches across the landscape, with different fire future types manifesting themselves in adjacent forest patches. Changes in aridity may shift some plant and animal species ranges downslope to favorable combinations of available moisture and suitable temperature, rather than upslope.[484] Plants and animals may respond to changing climate, and have been shown to do so, through range shifts, phenology shifts, biological evolution, or local extirpation. Thus, no single expected response pattern exists.[224]

Description of confidence and likelihood

Field evidence provides *high confidence* that human-caused climate change has increased wildfire, tree death, and species range shifts. Projections consistently indicate that continued climate change under higher emissions could increase the future vulnerability of ecosystems, but that reducing emissions and increasing fire management would reduce the vulnerability, providing *high confidence* in positive benefits of these actions.

Key Message 3

The Coast

Many coastal resources in the Southwest have been affected by sea level rise, ocean warming, and reduced ocean oxygen—all impacts of human-caused climate change (*high confidence*)—and ocean acidification resulting from human emissions of carbon dioxide (*high confidence*). Homes and other coastal infrastructure, marine flora and fauna, and people who depend on coastal resources face increased risks under continued climate change (*high confidence*).

Description of evidence base

At the Golden Gate Bridge, San Francisco, sea level rose 9 ± 0.4 inches (22 ± 1 cm) from 1854 to 2016,[236] and at San Diego, 9 ± 0.8 inches (24 ± 2 cm) from 1906 to 2016.[237] Analyses of these gauges and hundreds around the world show a statistically significant increase in global mean sea level[238,239] due to melting of land ice and expansion of warming water caused by climate change.[21,240] Measurements of sea surface temperatures from buoys off the California coast and around the world, combined with remote sensing data, have found warming of the top 75 m of ocean water at a rate of 2 ± 0.4°F (1.1 ± 0.2°C) per century from 1971 to 2010,[252] caused by climate change.[21] Measurements and modeling of ocean acidity found an increase of acidity in the Pacific Ocean off San Diego of 25% to 40% (0.1 to 0.15 pH units) since 1750,[485] caused by the increase of carbon dioxide in the atmosphere from cars, power plants, deforestation, and other human activities.[21] Measurements along the California coast have found ocean acidity during the core upwelling season (April to October) increasing by as much as four times (0.7 pH units) to some of the most acidic values in the world.[274] Griggs et al. (2017)[242] project a median sea level rise of 19 inches (49 cm) and a range of 12–29 inches (30–73 cm; 67% probability) for the very low scenario (RCP2.6) and a median of 30 inches (76 cm) and a range of 19–41 inches (49–104 cm; 67% probability) for the higher scenario (RCP8.5) by the end of the century. On a similar timescale, Sweet et al. (2017)[241] provide one map showing sea level rise projections for San Francisco, which shows a 39–47 inch (1–1.2 m) rise for the Intermediate scenario (approximately RCP8.5); the range for all of their scenarios is 0.3–2.5 m. Jevrejeva et al. (2016)[486] project a sea level rise of 73 cm and a range of 12–74 inches (37–187 cm; 5% probability) for the higher scenario (RCP8.5) by 2100.

Major uncertainties

Catastrophic rapid loss of Antarctic and Greenland ice sheets could increase sea level more rapidly. Sea level rise at individual locations depends on the form of the seafloor (bathymetry) and other local conditions. Climate change impacts compound overfishing and make fish populations more vulnerable. Potential economic changes in California's coastal and marine-based economies are subject to many different environmental and socioeconomic factors.

The full complexity of ecological responses to ocean acidification in combination with other stresses in California marine waters is currently unknown. Food supply for marine species,[487] natural variation in resilience,[488,489] and other environmental factors can affect the sensitivity of organisms to acidic conditions.

Description of confidence and likelihood

Field measurements at numerous locations have detected sea level rise, ocean warming, ocean acidification, and ocean hypoxia. Multiple model-based analyses have attributed these changes to human-caused climate change, giving *high confidence* to these impacts of climate change.

Key Message 4

Indigenous Peoples

Traditional foods, natural resource-based livelihoods, cultural resources, and spiritual well-being of Indigenous peoples in the Southwest are increasingly affected by drought, wildfire, and changing ocean conditions (*very likely, high confidence*). Because future changes would further disrupt the ecosystems on which Indigenous peoples depend (*likely, high confidence*), tribes are implementing adaptation measures and emissions reduction actions (*very likely, very high confidence*).

Description of evidence base

Abundant evidence and strong agreement among sources exist regarding current impacts of climate change in the region. Impacts of climate change on the food sources, natural resources-based livelihoods, cultural resources and practices, and spiritual health and well-being of Southwest Indigenous peoples are supported, in part, by evidence of regional temperature increases,[23,24] drought,[14,56,58,480] declines in snow,[46,49,156] and streamflow,[11,13,60,110] which have affected ecological processes, such as tree death,[146] fire occurrence,[7,152] and species ranges.[211]

Impacts specific to Indigenous peoples include: 1) declining surface soil moisture, higher temperatures, and evaporation converge with oak trees' decreased resilience,[285] diminished acorn production, and fire and pest threat to reduce the availability and quality of acorns for tribal food consumption and cultural purposes;[306] and 2) declining vegetation, higher temperatures, diminished snow, and soil desiccation have caused dust storms and more mobile dunes on some Navajo and Hopi lands, resulting in damaged infrastructure and grazing lands and loss of valued native plant habitat.[44,301,490] Evidence and agreement among evidence exist on the effects of climate-related environmental changes on culturally important foods,[318,319] practices, and mental and spiritual health.[42]

Multiple projections of climate and hydrological changes show potential future change and disruption to the ecosystems on which Indigenous peoples depend for their natural resources-based livelihoods, health, cultural practices, and traditions. These include projections of increased temperatures and heat extremes;[24] longer, more severe, and more frequent drought;[13,65] expanded forest mortality;[197,198] increased wildfire;[172] and ocean temperature increases, ocean acidification, and inundation of coastal areas.[242,273]

Evidence of specific future disruptions to traditional food sources from forests and oceans mostly relies upon inferences, based on projections of changing seasonality and associated phenological or ecosystem responses[298,307] or potential changes to biophysical factors, such as salinity of freshwater lakes, and associated impacts to culturally important fish species.[310]

Abundant evidence exists of autonomous adaptation strategies, projects, and actions, rooted in traditional environmental knowledge and practices or integration of diverse knowledge systems to inform ecological management to support adaptation and ecosystem resilience.[490,491,492,493]

In response to the current and future projected climate changes and ecosystem disruptions, a number of tribes in the Southwest are planning and implementing energy efficient and renewable energy projects.[327,361,494,495] These include installation of or planning for photovoltaic systems,[361] solar arrays, biofuels, microgrids, utility-scale wind, biogas, geothermal heating and cooling systems,[327] increased building insulation,[495] and carbon offsets.[334] Several Southwest tribes, such as the Ramona Band of Cahuilla and the Santa Ynez Band of Chumash Indians, have established or are in the process of establishing energy independence.[495] A well-recognized example is that of the Blue Lake Rancheria Tribe, in California, which was named a Climate Action Champion in 2015–2016 for implementing innovative climate actions, such as an all-of-the-above renewable strategy of transportation, residential, and municipal renewable energy projects, which includes a biogas project. A number of these projects (Ch. 15: Tribes, Figure 15.1) aim to simultaneously meet mitigation and adaptation objectives, such as the Yurok Tribe and the Round Valley Indian Tribe, which have developed carbon offset projects under California's cap-and-trade program to support tribally led restoration and stewardship.[496]

Several tribes in the Southwest are developing climate change adaptation plans to address the current climate-related impacts and prepare for future projected climate changes. The Santa Ynez Band of Chumash Indians, which is working towards an integrated energy and climate action plan, the Yurok Tribe, the Gila River Indian Community, and the Tohono O'odham Nation are among the first tribes in the region to develop climate adaptation and resilience plans, which reflects a nationwide gap or need for further tribal adaptation plan development. Lack of capacity and funds has hindered progress in moving from planning to implementation, which is similar to the situation for U.S. cities.[497]

Major uncertainties

Uncertainties in the climate and hydrologic drivers of regional changes affecting Indigenous peoples in the Southwest include 1) differences in projections from multiple GCMs and associated uncertainties related to regional downscaling methods, 2) the way snow is treated in regional modeling,[498] 3) variability in projections of extreme precipitation, and, in particular, 4) uncertainties in summer and fall precipitation projections for the region.[88] Additional uncertainties exist in sea level rise projections[242] and, for the California coast, ocean process model projections of acidification, deoxygenation, and warming coastal zone temperatures.[499] For the most part, Native lands lack instrumental monitoring for weather and climate, which is a barrier for long-term climate-related planning.[493]

Complexities arising from the multiple factors affecting ecosystem processes, including tree mortality and fire, often preclude formal detection and attribution studies. Much evidence and agreement among evidence exist regarding the role of hotter temperatures in fire and tree mortality.[7,146] Detection and attribution studies seldom focus explicitly on tribal lands.

Other uncertainties relate to estimating future vulnerabilities and impacts, which depend, in part, on adjudication of unresolved water rights and the potential development of local, state, regional, tribal, and national policies that may promote or inhibit the development and deployment of adaptation and mitigation strategies.

Description of confidence and likelihood

The documented human-caused increase in temperature is a key driver of regional impacts to snow, soil moisture, forests, and wildfire, which affect Indigenous peoples, other frontline communities, and all of civil society. Case study evidence, using Indigenous and Western scientific observations, oral histories, traditional knowledge and wisdom (e.g., Ferguson et al. 2016[493]), suggests that climate change is affecting the health, livelihoods, natural and cultural resources, practices, and spiritual well-being of Indigenous communities and peoples in the Southwest (e.g., Redsteer et al. 2011, 2013; Wotkyns 2011; Cozzetto et al. 2013; Gautam et al. 2013; Navajo Nation Department of Fish and Wildlife 2013; Nania and Cozzetto et al. 2014; Sloan and Hostler 2014; Redsteer and Fordham 2017[44,302,305,307,310,311,490,500,501]). Abundant evidence gives *high confidence* that hotter temperatures, tree mortality, and increased wildfire and drought, due to climate change, would disrupt the ecosystems on which Indigenous people depend; the likelihood of these impacts affecting individual tribes will depend in large part on the non-climatic stresses (such as historical legacies and resource management practices) interacting with the climatic stresses. *Very high confidence* exists that tribes are developing adaptation measures and emissions reductions to address current and future climate change, based on abundant ongoing initiatives and associated documentation.

Key Message 5

Energy

The ability of hydropower and fossil fuel electricity generation to meet growing energy use in the Southwest is decreasing as a result of drought and rising temperatures (*very likely, very high confidence*). Many renewable energy sources offer increased electricity reliability, lower water intensity of energy generation, reduced greenhouse gas emissions, and new economic opportunities (*likely, high confidence*).

Description of evidence base

Numerous studies link Southwest hydrologic drought with a decline in renewable hydroelectricity generation in the region. Hydroelectric generation depends on runoff to fill reservoirs to maximize generation capacity.[336,337] During the California drought, which was intensified by climate change,[14,56] hydroelectric generation in California fell from 43 trillion watt-hours (TWh) in 2011 before the drought to 14 TWh in 2015 during the drought.[335] Climate change also reduced the snowpack[46,47,48,49] and river runoff on which hydroelectric generation depends.[336,337]

Similarly, low reservoir levels in Lake Mead—which is formed by damming the Colorado River—driven by reduced Colorado River runoff[13,59] can reduce the efficiency and production levels of hydropower at Hoover Dam.

Fossil fuel generation efficiency depends on the temperature and availability of the external cooling water. Warming could reduce energy efficiency up to 15% across the Southwest by 2100.[91] Higher temperatures also increase electric resistance in transmission lines, causing transmission losses of 7% under higher emissions.[344] Replacing fossil fuel generation with solar power renewables reduces greenhouse gas emissions and water use per unit of electricity generated.[90] This supports the assertion that increasing solar energy generation in the Southwest could meet the energy demand no longer being met by hydropower and fossil fuel as well as the expected increase in energy use in the future.

Solar energy production is also an economic opportunity for the region. The energy potential for renewable energy is estimated to range from one-third to over ten times 2013 generation levels from all sources.[502] The lower range assumes capacity requirements remain at 2013 levels,[502] but recent data show an upward trend in Southwest energy use.[89]

The high potential for solar energy projects in the Southwest and the extent of federally owned land in the Southwest (well over half the total surface area for the six-state region) prompted the Bureau of Land Management (BLM) and the U.S. Department of Energy to conduct a programmatic environmental impact analysis of a new Solar Energy Program to further support utility-scale solar energy development on BLM-administered lands.[502,503] This potential capacity, combined with the increasingly competitive cost of solar and wind,[504] presents economic opportunities for the region and an opportunity to reduce overall greenhouse gas emissions.

Solar and renewable energy jobs are increasing. The solar workforce increased 25% in 2016, while wind employment increased 32%.[505] Jobs in low-carbon-emission generation systems, including renewables, nuclear, and advanced low-emission natural gas, comprise 45% of all the jobs in the electric power generation and fuels technologies.[505] Growing Southwest energy use, competitive prices for renewables, and the renewable energy potential of the Southwest favor the replacement of fossil-fuel-generated energy by renewable solar and wind energy.

Major uncertainties

Climate model projections of the future diverge on whether precipitation may increase or decrease for much of the region, so hydroelectric power changes may exhibit spatial variation. The amount of runoff is a key factor driving the generation potential for hydroelectric power. A key uncertainty is how much hydroelectricity generation will decline. Some projections of higher-than-average precipitation in the northern parts of the Southwest could roughly offset declines in warm-season runoff associated with warming.[105]

Energy demand in the Southwest is increasing, but the rate of growth is uncertain.[506] Changes in energy market prices cause future uncertainty in the future mix of energy sources for the Southwest.[502] The low cost of natural gas and the competitive cost of solar and wind renewables make it somewhat certain the proportion of the energy generated from these sources will continue to increase and offset reductions in traditional fossil-fuel-generated energy, reducing overall greenhouse gas emissions.[504] Renewable energy job growth potential is also uncertain and depends on the factors mentioned above.[505]

Additionally, daily to multiyear variation in coastal cloud cover affects solar electricity generation potential along the California coast.[507,508,509,510]

Description of confidence and likelihood

Hydrological drought in California reduced hydroelectric generation[335] and fossil fuel electricity generation efficiencies. Drought and rising temperatures under climate change can reduce the ability of hydropower and fossil fuel electricity generation to meet growing energy use in the Southwest (*very likely, very high confidence*). Renewable solar and wind energy offers increased electricity reliability, lower water intensity for energy generation, reduced greenhouse gas emissions, and new economic opportunities (*likely, high confidence*).

Key Message 6

Food

> Food production in the Southwest is vulnerable to water shortages (*medium confidence*). Increased drought, heat waves, and reduction of winter chill hours can harm crops (*medium confidence*) and livestock (*high confidence*); exacerbate competition for water among agriculture, energy generation, and municipal uses (*medium confidence*); and increase future food insecurity (*medium confidence*).

Description of evidence base

Climate change has altered climate factors fundamental to food production and rural livelihoods in the Southwest. Abundant evidence and good agreement in evidence exist regarding regionally increasing temperatures, reduced soil moisture, and effects on regional snowpack and surface water sources.[13,23,67,74,79] The heat of climate change has intensified severe droughts in California[14,56] and the Colorado River Basin.[13] Hotter temperatures and aridity in the Southwest affected agricultural productivity from 1981 to 2010.[366]

Elevated temperatures can be associated with failure of some crops, such as warm-season vegetable crops, and reduced yields and/or quality in others.[374] Temperatures in California, Nevada, and Arizona are already at the upper threshold for corn[372] and rice.[373] While crops grown in some areas might not be viable under hotter conditions, other crops such as olives, cotton, kiwi, and oranges may replace them.[375] In the Southwest, climate change may cause a northward shift in crop production, potentially displacing existing growers and affecting rural communities.[376] Quality of specialty crops, both nutritive and sensory, declines because of increased temperatures and other changes associated with a changing climate,[393,511] which is particularly important in a region producing a majority of the Nation's specialty crops. Decreases in winter chill hours may reduce fruit and tree nut yields, though the magnitude may vary considerably.[380,381]

High ambient temperatures associated with climate change could decrease production of rangeland vegetation across the Southwest,[384] reducing available forage for livestock. Ranching enterprises across the region have vastly different characteristics that will influence their adaptive capacities.[390]

Local-scale impacts can vary considerably across the region depending upon surface and groundwater availability. Drought causes altered water management, with heavy reliance on a limited groundwater to sustain regional food production.[130] Despite severe localized impacts, losses in total agricultural revenue are buffered by groundwater reliance to offset surface water shortage.[369] Parts of the Southwest have exhausted sustainable use of groundwater resources. When surface water supplies are reduced, farmers shift to increased groundwater pumping, even when pumping raises production costs[371]—declining groundwater tables significantly increase pumping costs and require drilling of deeper wells.[130] Continued climate change may reduce aquifer recharge in the southern part of the region 10%–20%.[370] Climate change is projected to cause longer and more severe drought periods that will intensify the uncertainty associated with Southwest water supply and demand. Water-intensive forage crops and the livestock industry are especially vulnerable to climate-related water shortages.[15]

Major uncertainties

The impacts of climate change on food production depend upon microclimatology and local-scale environmental, social, and economic resources. While the scientific community relies upon computer models and generalized information to project likely future conditions, unforeseen consequences of warming temperatures, such as those related to pests, pollinators, and pathogens, may be more detrimental than some of the well-documented projections, such as temperature impacts on reduced yields. The effects of increased precipitation supplying the deep root zone may somewhat offset the increase in temperature, so agricultural drought may be less frequent for trees and other crops dependent on deeper soil moisture.[480] Scientists are producing more drought- and heat-tolerant cultivars, which may be suitable to production in the projected warmer and more arid climate of the Southwest.

Since food security relies on complex national and international trade networks, how regional climate change may affect local food security is uncertain. Many adaptation options, such as using alternate breeds, crops, planting and harvest dates, and new (sometimes untested) chemicals, may work in certain situations but not others. Thus, predicting impacts to food production in a hotter/drier land is likely to vary by crop and location, necessitating flexibility and adaptive management. Of paramount uncertainty is the impact of water shortage on regional food production as other uses may outcompete producers for limited supplies.

Description of confidence and likelihood

Since the availability of affordable food around the world depends upon complex trade and transportation networks, the effects of climate change on Southwest food availability, production, and affordability remain highly complex and thereby uncertain and classified with *medium confidence*. While the viability of rural livelihoods is vulnerable to water shortages and other climate-related risks, rural livelihoods may be supplemented by other nonagricultural income, such as recreation and hunting. The viability of rural livelihoods is highly complex, and risk is, therefore, classified with *medium confidence*. Crop impacts related to hotter and drier conditions and reduced winter chill periods, caused by climate change, are classified with *medium confidence*. Not all crops are directly harmed by warming temperatures, and the simulation impacts of reduced chilling hours can produce a fairly wide range of results depending upon model assumptions. Hotter and drier conditions can directly harm livestock via reduced forage quantity and quality and exposure to higher temperatures, conferring a *high confidence* classification. Projections of future drought and water scarcity portend increased competition for water from other beneficial uses with *medium confidence*.

Key Message 7

Human Health

Heat-associated deaths and illnesses, vulnerabilities to chronic disease, and other health risks to people in the Southwest result from increases in extreme heat, poor air quality, and conditions that foster pathogen growth and spread (*high confidence*). Improving public health systems, community infrastructure, and personal health can reduce serious health risks under future climate change (*medium confidence*).

Description of evidence base

Strong evidence and good agreement among multiple sources and lines of evidence exist, indicating that the Southwest regional temperature may increase, snowpack may decline, soil moisture may decrease, and drought may be prolonged.[14,23,24,56,58,62,68,74,480]

Exposure to hotter temperatures and extreme heat events, partly a manifestation of human-caused climate change, already led to heat-associated deaths and illnesses in heat waves in Arizona and California in the early and mid-2000s.[398,399,400,401,402,406,444,450,512]

Good agreement exists among models that most of the Southwest may become more arid, due to the effect of increasing temperatures on snow, evaporation, and soil moisture.[58,65,70,80] Projections also indicate that flood-causing atmospheric rivers may become more moist, frequent, and intense[84,85,86] and that intense daily precipitation may increase in frequency.[88,513] Models project declines in future runoff of key Southwest rivers, such as the Colorado, due chiefly to the effects of increased temperature on soil moisture and snowpack.[13,71,110]

Strong evidence exists of the effects of extreme heat on public health in the region (e.g., Knowlton et al. 2009, Oleson et al. 2015, Wilhelmi et al. 2004[400,514,515]) and for reasonable projections of future deaths and costs of lost labor productivity due to enhanced future episodes of extreme heat. Factors that predict a person will be at increased risk include being confined to bed, not leaving home daily, and being unable to care for oneself;[516] various general indicators of being socially isolated (such as living alone, the presence of or frequency of social contacts, or being isolated linguistically);[516,517,518,519] and persons who are socioeconomically disadvantaged.[516,517,518,519] Dehydration in general and dehydration associated with medications (neurological and non-neurological) that impair thermoregulation or thirst regulation were also associated with elevated risk of mortality during the 2003 heat wave in France.[520] The role of prescription medications in altering the risk for heat-associated illness or death is of growing interest and concern.[521] This issue is more important as chronic diseases become more prevalent and more people take prescription drugs.

Given the proportion of the U.S. population in the Southwest, a disproportionate number of West Nile virus, plague, hantavirus pulmonary syndrome, and Valley fever cases occur in the region.[158,420] West Nile virus transmission is projected to shift to the north under climate change, and areas where the mosquitoes that carry this virus are present may see increased abundances.[441,442,443] The mosquito species that carry Zika and chikungunya are established in parts of the region, but mosquito-borne transmission has only been observed in Puerto Rico, the U.S. Virgin Islands, Florida, and Texas (Ch. 14: Human Health).

Overall, the Southwest is ill-prepared to absorb the additional patient load that would accompany climate change associated disasters.[448] The American College of Emergency Physicians assigned an overall emergency care grade of C or C+ to three of the six Southwest states, with the others receiving poorer grades, and four of the six states received an F grade for access to emergency care.[448]

Major uncertainties

Uncertainties in the climate and hydrologic drivers of regional changes affecting public health include 1) differences in projections from multiple GCMs and associated uncertainties related to regional downscaling methods, 2) variability in projections of extreme precipitation, 3) uncertainties in summer and fall precipitation projections for the region,[88] and 4) uncertainties in models that project occurrence and levels of climate-sensitive exposures that are known to impact public health, such as local and regional ozone air pollution, particulate air pollution (for example, increases from wildfire emissions or reductions from advancements in vehicle emissions control technology), or occurrence and exposure to toxins or pathogens.

Studies of non-fatal illnesses using healthcare services data can yield critical insights different from those one can derive from death data. Most studies of heat impacts on health have focused on deaths rather than nonfatal illnesses. This is primarily because hospitalization and emergency department data, compared with death certificate data, are not as available or uniform across locations, and when they are available it can be difficult to access them due to concerns for patient confidentiality. Ongoing enhancements to electronic medical records technology and adoption across the healthcare services sector will potentially address those limitations in the near future and will provide invaluable data resources to identify and adopt prevention strategies that reduce the vulnerability of patients and populations to the adverse effects of climate-sensitive exposures.

More recent work focusing on the more deadly neuroinvasive West Nile virus indicates that regionally, the central and southern parts of the country may experience increasing cost from this vector-borne disease in the future.[178,440] The lack of a statistical association between temperature and West Nile virus diagnoses in the Southwest may be because extreme temperatures in some locations rise above the survival thresholds for vectors, thereby reducing mosquito abundance[522,523] and disease transmission.[419] Additionally, because the data for diseases like Valley fever are limited to cases, rather than exposures, the link to climate change is not clear.[435,436]

While improvements to individual health and to clinical and community infrastructure are highly likely to 1) improve physical capacity to adapt to climate effects, 2) diminish the overall impacts on population health, and 3) increase societal capacity to respond quickly to dampen the effects of long-term and emergency responses,[446,447,524] other factors also influence adaptive capacity, adding considerable uncertainty. For example, many factors influence the observed number of West Nile virus cases including available habitat, human prevention and control efforts, and recent history of cases in a given area.[442,525,526,527]

Description of confidence and likelihood

Evaluation of confidence levels for the assessment of the type and magnitude of observed or projected public health and clinical impacts was based on the strength of evidence underlying the answers to three primary questions:

1. What characteristics of the region’s historical climate and weather patterns translate directly (for example, extreme heat) or indirectly (for example, higher temperatures fostering ozone formation or the growth and spread of pathogens and vectors) to exposures associated with observed human health risks that are unique to or overrepresented in the Southwest?
2. Does recent historical evidence indicate that climate and weather patterns have changed, or do climate models project changes over the 21st century, thereby increasing the risk of human exposures and health impacts evaluated under question 1?
3. What are the determinants of individual and population vulnerability that increase or decrease the risk of an adverse health outcome or affect adaptive capacity? These include factors that affect a) biological susceptibility, b) physical environment and exposure characteristics, and c) social, behavioral, or economic factors.

To the extent possible, the evaluation recognized and accounted for the complex interconnections among these factors, the fact that their relative importance may differ across geographic and temporal scales, and the combined uncertainties of evidence from multiple disciplines (for example, health sciences, climatology, and social or behavioral sciences) that can vary substantially.

The information revealed by answering those questions, gives *high confidence* that extreme heat will be the dominant driver of exposures that pose the greatest health risks in the

Southwest—including direct effects of heat on individuals and indirect effects of heat on air pollution levels. Due to the uncertainties related to the frequency and intensity of human exposures and related to impacts on essential ecosystem services under projected climate change, the statement "Improving public health systems, community infrastructure, and personal health can reduce serious health risks under future climate change" is made with *medium confidence*. Nevertheless, clinical and public health policy effectiveness assessments show that such improvements can reduce the burden of disease and health risks associated with environmental exposures.

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American Lung Association.

State of the Air

2023 Report

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Acknowledgments

The American Lung Association "State of the Air" 2023 is the result of the hard work of many.

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"State of the Air" 2023 would not have been possible but for the twenty years of inspiration, dedication and hard work of the late Janice E. Nolen. We still miss her every day.

The American Lung Association assumes sole responsibility for the content of "State of the Air" 2023.

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Why “State of the Air”?

The Clean Air Act requires the U.S. Environmental Protection Agency (EPA) to set health-based limits, called National Ambient Air Quality Standards (NAAQS), for six dangerous outdoor air pollutants: particulate matter, ozone, nitrogen oxides, sulfur dioxide, carbon monoxide and lead. “State of the Air” looks at two of the most widespread and dangerous pollutants from this group, fine particulate matter and ozone.

The NAAQS identify what is considered a safe level of each pollutant to breathe, based on the most recent health and medical science, including an adequate margin of safety for those most at risk. These standards alert the public when pollution levels place Americans’ health at risk and require states and local governments to take steps to reduce emissions to attain the standards. The standards are also used to inform families with children, seniors, people with lung or heart disease and others when air pollution levels are dangerous through color-coded air quality alerts, so they can take steps to limit their exposure. Under the Clean Air Act, the standards must be based solely on what is needed to protect health, and must be periodically updated as the science evolves. EPA is currently reviewing both the particulate matter and ozone standards; future editions of “State of the Air” will reflect any revisions to the standards.

Setting national health-based standards and requiring states that violate the standards to enact plans to clean up their air pollution problems have been a great benefit to the public health of the nation. Since the Clean Air Act was passed in 1970, emissions of these outdoor air pollutants, including ozone and particle pollution, have fallen by 78%, according to EPA. But as “State of the Air” 2023 shows, millions of Americans are still breathing unhealthy air.

Purpose and history of “State of the Air”

In the year 2000, the American Lung Association launched its annual “State of the Air” report to provide the public with easy-to-understand information about the quality of the air in their local communities based on the credible data and sound science that EPA is required to use to set the air quality standards.

For the first several years, “State of the Air” focused solely on ozone pollution and included data for five populations at increased risk—children, older adults, children with asthma, adults with asthma and people with emphysema. In 2004, changes to the air quality standards and the deployment of air pollution monitoring enabled the addition of short-term and year-round fine particle pollution to the report. Over time, accumulating scientific evidence has shown significant health harms from both ozone and particle pollution among other groups of vulnerable individuals. “State of the Air” has accommodated this new information by gradually adding populations-at-risk categories to its reporting. “State of the Air” 2023 now includes data for 10 vulnerable groups.

Since its inception, “State of the Air” has been tremendously successful in raising awareness about particle pollution and ozone, two of the most dangerous and pervasive air pollutants nationwide. The American Lung Association is proud and grateful that the public, the media, clean air advocates and decision-makers have used this report every day, year after year, to call attention to the work that remains to be done to protect the health of all Americans from the threat of air pollution.

How “State of the Air” can be used

We write and release “State of the Air” every year to make information on air quality and health clear and accessible to everyone. We show the progress each community has made and how much more needs to be done to achieve healthy air. In this report, you’ll find information on local air quality nationwide. You’ll also find the latest roundup of the research on how air pollution affects health. With these tools, you can help keep your lungs and your family’s lungs safer from unhealthy air.

This report also includes ideas for how you can become a champion for clean air. First, we have suggestions for concrete actions you can take to reduce your own contributions to air pollution and climate change. And second, we invite you to take advocacy action with the American Lung Association. Our report includes policy recommendations for every level of government. Your voice is powerful, and when you tell your leaders that your lungs depend on stronger limits on air pollution, you make a compelling case. Please share your story and add your name to our petition—and then, take the next step. Reach out to your representatives at every level of government, share the “State of the Air” results for your community, and call on them to take action to protect public health.

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State of the Air 2023 Methodology

Statistical Methodology: The Air Quality Data

Data Sources

Ozone and short-term particle pollution. The data on air quality throughout the United States were obtained from the U.S. Environmental Protection Agency's Air Quality System (AQS). The American Lung Association contracted with Dr. Allen S. Lefohn, A.S.L. & Associates, Montana, to characterize the hourly averaged ozone concentration information and the 24-hour averaged $PM_{2.5}$ concentration information for the three-year period for 2019-2021 for each monitoring site.

Year-round particle pollution. Design values for the annual $PM_{2.5}$ concentrations by county for the period 2019-2021 were retrieved November 21, 2022 from data posted on May 24, 2022, at the U.S. Environmental Protection Agency's website at https://www.epa.gov/air-trends/air-quality-design-values.

The Lung Association received critical assistance from members of the National Association of Clean Air Agencies and the Association of Air Pollution Control Agencies. With their assistance, all state and local agencies were provided the opportunity to review and comment on the data in draft tabular form. The Lung Association reviewed all discrepancies with the agencies and, if needed, with Dr. Lefohn at A.S.L. & Associates. The Lung Association wishes to express its continued appreciation to the state and local air directors for their willingness to assist in ensuring that the characterized data used in this report are correct.

Ozone Data Analysis

The 2019, 2020 and 2021 AQS hourly ozone data were used to calculate the daily 8-hour maximum concentration for each ozone-monitoring site. The hourly averaged ozone data were downloaded on June 22, 2022, following the close of the authorized period for quality review and assurance certification of data. Only the hourly average ozone concentrations derived from FRM and FEM monitors were used in the analysis. The data were considered for a three-year period for the same reason that EPA uses three years of data to determine compliance with the ozone standard: to prevent a situation in any single year, where anomalies of weather or other factors create air pollution levels, which inaccurately reflect the normal conditions. The highest 8-hour daily maximum concentration in each county for 2019, 2020 and 2021, based on EPA-defined ozone season, was identified.

The current national ambient air quality standard for ozone is 70 parts per billion (ppb) measured over eight hours. The EPA's Air Quality Index reflects the 70 ppb standard. A.S.L. & Associates prepared a table by county that summarized, for each of the three years, the number of days the ozone level was within the ranges identified by EPA based on the EPA Air Quality Index:

8-hour Ozone Concentration	Air Quality Index Levels
0-54 ppb	🟩 Good (Green)
55-70 ppb	🟨 Moderate (Yellow)
71-85 ppb	🟧 Unhealthy for Sensitive Groups (Orange)
86-105 ppb	🟥 Unhealthy (Red)
106-200 ppb	🟪 Very Unhealthy (Purple)
>200 ppb	🟫 Hazardous (Maroon)

The goal of this report was to identify the number of days that 8-hour daily maximum concentrations in each county occurred within the defined ranges. This approach provided an indication of the level of pollution for all monitored days, not just those days that fell under the requirements for attaining the national ambient air quality standards. Therefore, no data capture criteria were applied to eliminate monitoring sites or to require a number of valid days for the ozone season.

The daily maximum 8-hour average concentration for a given day is derived from the highest of the 17 consecutive 8-hour averages beginning with the 8-hour period from 7:00 a.m. to 3:00 p.m. and ending with the 8-hour period from 11:00 p.m. to 7:00 a.m. the following day. This follows the process EPA uses for the current ozone standard adopted in 2015 but differs from the form used under the previous 0.075 ppm 8-hour average ozone standard that was established in 2008. All valid days of data within the ozone season were used in the analysis. However, for computing an 8-hour average, at least 75 percent of the hourly concentrations (i.e., 6-8 hours) had to be available for the 8-hour period. In addition, an 8-hour daily maximum average was identified if valid 8-hour averages were available for at least 75 percent of possible hours in the day (i.e., at least 13 of the possible 17 8-hour averages). Because EPA includes days with inadequate data (i.e., not 75 percent complete) if the standard value is exceeded, our data capture methodology also included the site's 8-hour value if at least one valid 8-hour period were available, and it was 71 ppb or higher.

As instructed by the Lung Association, A.S.L. & Associates included the exceptional (e.g., wildfires) and natural events (e.g., stratospheric intrusions) that were identified in the database and identified for the Lung Association the dates and monitoring sites that experienced such events. Some data have been flagged by the state or local air pollution control agency to indicate that they had raised issues with EPA about those data. For each day across all sites within a specific county, the highest daily maximum 8-hour average ozone concentration was recorded and then the results were summarized by county for the number of days the ozone levels were within the ranges identified above.

Following receipt of the above information, the American Lung Association identified the number of days each county, with at least one ozone monitor, experienced air quality designated as orange (Unhealthy for Sensitive Groups), red (Unhealthy) or purple (Very Unhealthy). When insufficient data were available in any year, an "incomplete" was identified for the 3-year period. Insufficient data exist for various reasons. For example, when a specific monitor was used for a special study and the monitor was then discontinued in other years, an "incomplete" is assigned.

Short-Term Particle Pollution Data Analysis

A.S.L. & Associates identified the maximum daily 24-hour AQS $PM_{2.5}$ concentration for each county in 2019, 2020 and 2021 with monitoring information. The 24-hour $PM_{2.5}$ data were downloaded on August 4, 2022, following the close of the authorized period for quality review and assurance certification of data. In addition, on August 4, 2022, hourly averaged $PM_{2.5}$ concentration data were characterized into 24-hour average $PM_{2.5}$ values by EPA and provided to A.S.L. & Associates. Using these results, A.S.L. & Associates prepared a table by county that summarized, for each of the three years, the number of days the maximum of the daily $PM_{2.5}$ concentration was within the ranges identified by EPA based on the EPA Air Quality Index, as adopted by the EPA on December 14, 2012:

24-hour $PM_{2.5}$ Concentration	Air Quality Index Levels
0.0 µg/m³ to 12.0 µg/m³	🟩 Good (Green)
12.1 µg/m³ to 35.4 µg/m³	🟨 Moderate (Yellow)
35.5 µg/m³ to 55.4 µg/m³	🟧 Unhealthy for Sensitive Groups (Orange)
55.5 µg/m³ to 150.4 µg/m³	🟥 Unhealthy (Red)
150.5 µg/m³ to 250.4 µg/m³	🟪 Very Unhealthy (Purple)
greater than or equal to 250.5 µg/m³	🟫 Hazardous (Maroon)

All previous data collected for 24-hour average $PM_{2.5}$ were characterized using the AQI thresholds listed above.

The goal of this report was to identify the number of days that the maximum in each county of the daily $PM_{2.5}$ concentration occurred within the defined ranges. This approach provided an indication of the level of pollution for all monitored days, not just those days that fell under the requirements for attaining the national ambient air quality standards. Therefore, no data capture criteria were used to eliminate monitoring sites. Both 24-hour averaged PM data, as well as hourly averaged PM data averaged over 24 hours were used. Included in the analysis are data collected using only FRM and FEM methods, which reported hourly and 24-hour averaged data. As instructed by the Lung Association, A.S.L. & Associates included the exceptional and natural events that were identified in the database and identified for the Lung Association the dates and monitoring sites that experienced such events. Some data have been flagged by the state or local air pollution control agency to indicate that they had raised issues with EPA about those data. For each day across all sites within a specific county, the highest daily maximum 24-h $PM_{2.5}$ concentration was recorded and then the results were summarized by county for the number of days the concentration levels were within the ranges identified above.

Following receipt of the above information, the American Lung Association identified the number of days each county, with at least one $PM_{2.5}$ monitor, experienced air quality designated as orange (Unhealthy for Sensitive Groups), red (Unhealthy), purple (Very Unhealthy) or maroon (Hazardous).

Description of County Grading System.

Ozone and Short-Term Particle Pollution (24-hour $PM_{2.5}$)

The grades for ozone and short-term particle pollution (24-hour $PM_{2.5}$) were based on a weighted average calculation. To determine weighted averages, the Lung Association followed these four steps separately for each pollutant in each county:

1. Assigned weighting factors to each category of the Air Quality Index. Days of poor air quality were given the following weighting factors:

Orange days	**1.0**
Red days	**1.5**
Purple days	**2.0**
Maroon days	**2.5**

This ensured that days when the air pollution levels were worse received appropriately greater weight.

2. Multiplied the total number of days within each AQI category by their assigned factor, and added all the categories to calculate a total:

**Total = [Orange days x 1] + [Red days x 1.5] + [Purple days x 2] +
[Maroon days x 2.5]**

3. Divided the total by three to determine the weighted average, since the monitoring data were collected over a three-year period:

Weighted Average = Total ÷ 3

Weighted average was then used to determine each county's grades for ozone and 24-hour PM2 5 according to the following table:

Weighted Average	Grade
0.0	A
0.3 to 0.9	B
1.0 to 2.0	C
2.1 to 3.2	D
3.3 or higher	F

All counties with a weighted average of zero (corresponding to no exceedances of the standard over the three-year period) were given a grade of "A."

For ozone, an "F" grade was set to generally correlate with the number of unhealthy air days that would place a county in nonattainment for the ozone standard.

For short-term particle pollution, fewer unhealthy air days are required for an F than for nonattainment under the $PM_{2.5}$ standard. The national air quality standard is set to allow two percent of the days during the three years to exceed 35 micrograms per cubic meter ($\mu g/m^3$) (called a "98th percentile" form) before violating the standard. That would be roughly 21 unhealthy days in three years. The grading used in this report would allow only about one percent of the days to be over 35 $\mu g/m^3$ (called a "99th percentile" form) of the $PM_{2.5}$. The American Lung Association supports using the tighter limits in a 99th percentile form as a more appropriate standard that is intended to protect the public from short-term episodes or spikes in pollution.

Weighted averages allow comparisons to be drawn based on severity of air pollution. For example, if one county had nine orange days and no red days, it would earn a weighted average of 3.0 and a D grade. However, another county that had only eight orange days but also two red days, which signify days with more serious air pollution, would receive an F. That second county would have a weighted average of 3.7.

Note that this system differs significantly from the methodology EPA uses to determine violations of both the ozone and the 24-hour $PM_{2.5}$ standards. EPA determines whether a county violates the standard based on the fourth maximum daily 8-hour ozone reading each year averaged over three years. Multiple days of unhealthy air beyond the highest four in each year are not considered. By contrast, the system used in this report recognizes when a community's air quality repeatedly results in unhealthy air throughout the three years. Consequently, some counties will receive grades of "F" in this report, showing repeated instances of unhealthy air, while still meeting the EPA's 2015 ozone standard. The American Lung Association's position is that the evidence shows that the 2015 ozone standard, although stronger than the 2008 standard, still fails to adequately protect public health.

Counties were ranked by weighted average. Metropolitan areas were ranked by the highest weighted average among the counties within a given Metropolitan Statistical Area as of 2020 as defined by the White House Office of Management and Budget (OMB).

Year-Round Particle Pollution (Annual $PM_{2.5}$)

Since no comparable Air Quality Index exists for year-round particle pollution (annual $PM_{2.5}$), the grading was based on the 2012 National Ambient Air Quality Standard for annual $PM_{2.5}$ of 12 µg/m^3. Counties that EPA listed as being at or below 12 µg/m^3 were given grades of “Pass.” Counties that EPA listed as being at or above 12.1 µg/m^3 were given grades of “Fail.” Where insufficient data existed for EPA to determine a design value, those counties received a grade of “Incomplete.”

A design value is the calculated concentration of a pollutant based on the form of the national ambient air quality standard and is used by EPA to determine whether the air quality in a county meets the standard. Counties were ranked by design value. Metropolitan areas were ranked by the highest design value among the counties within a given Metropolitan Statistical Area as of 2020 as defined by the OMB.

Statistical Methodology: Population Data

The Lung Association calculates the county population at risk from these pollutants based on the population from the entire county where the monitor is located. The Lung Association then calculates the metropolitan population at risk based upon the largest metropolitan area that contains that county. Not only do people from that county or metropolitan area circulate within the county and the metropolitan area, but the air pollution also circulates to that monitor from throughout the county and metropolitan area.

Details about how the populations-at-risk numbers are derived can be found in Understanding Grades and Tables.

Key Findings

The "State of the Air" 2023 report finds that after decades of progress on cleaning up sources of air pollution, nearly 36% of Americans—119.6 million people—still live in places with failing grades for unhealthy levels of ozone or particle pollution. Overall, this is 17.6 million fewer people breathing unhealthy air compared to last year's report. The improvement was seen in falling levels of ozone in many places around the country, the continuation of a positive trend that reflects the success of the Clean Air Act. However, the number of people living in counties with failing grades for daily spikes in deadly particle pollution was 63.7 million, the most reported in the last ten years.

More than **1 in 3** Americans live in places with unhealthy levels of air pollution.

The "State of the Air" report looks at two of the most widespread and dangerous air pollutants, fine particles and ozone. The air quality data used in the report are collected at official monitoring sites across the United States by the federal, state, local and Tribal governments. The Lung Association calculates values reflecting the air pollution problem and assigns grades for daily and long-term measures of particle pollution and daily measures of ozone. Those values are also used to rank cities (metropolitan areas) and counties. This year's report presents data from 2019, 2020 and 2021, the most recent quality-assured nationwide air pollution data publicly available. See ***About This Report*** for more detail about the methodology for data collection and analysis.

"State of the Air" 2023 is the 24th edition of this annual report, which was first published in 2000. From the beginning, the findings in "State of the Air" have reflected the successes of the Clean Air Act, as emissions from transportation, power plants and manufacturing have been reduced. In recent years, however, the findings of the report have added to the evidence that a changing climate is making it harder to protect human health. The three years covered by "State of the Air" 2023 ranked among the seven hottest years on record globally. High ozone days and spikes in particle pollution related to heat, drought and wildfires are putting millions of people at risk and adding challenges to the work that states and cities are doing across the nation to clean up air pollution.

Climate change is making the job of cleaning up the air more difficult.

The combination of policy-driven reductions in emissions on the one hand and climate change-fueled increases in pollution on the other hand is driving a widening disparity between air quality in eastern and western states, especially for particle pollution. When particle pollution was first added to the "State of the Air" report in 2004, 106 counties in 30 states got failing grades for daily spikes in particle pollution. Forty-four of those counties—fewer than half—were in 8 states west of the Rocky Mountains. In this year's report, 111 counties in 19 states got Fs for this measure. All but 8 counties in Indiana, Michigan, Minnesota and Pennsylvania are in the West. A number of historically urban, industrialized eastern and midwestern states such as New Jersey, New York and Ohio, which dominated the list in the early years, are now getting all passing grades. A similar story can be told for annual particle pollution. In 2004, 20 of the 22 states with counties that got a failing grade were east of the Rockies. In 2023, all of the 17 failing counties were in 6 western states.

3.7X

People of color were 3.7 times as likely as white people to live in a county with 3 failing grades.

Again this year, "State of the Air" finds that the burden of living with unhealthy air is not shared equally. Although people of color are 41% of the overall population of the U.S., they are 54% of the nearly 120 million people living in counties with at least one failing grade. And in the counties with the worst air quality that get failing grades for all three pollution measures, 72% of the 18 million residents affected are people of color, compared to the 28% who are white.

In “State of the Air” 2023, Bakersfield, California displaced Fresno, California as the metropolitan area with the worst short-term particle pollution while Bakersfield continued in the most-polluted slot for year-round particle pollution, tied this year with Visalia, California. Los Angeles remains the city with the worst ozone pollution in the nation, as it has for all but one of the 24 years tracked by the “State of the Air” report.

Short-term Particle Pollution Trends

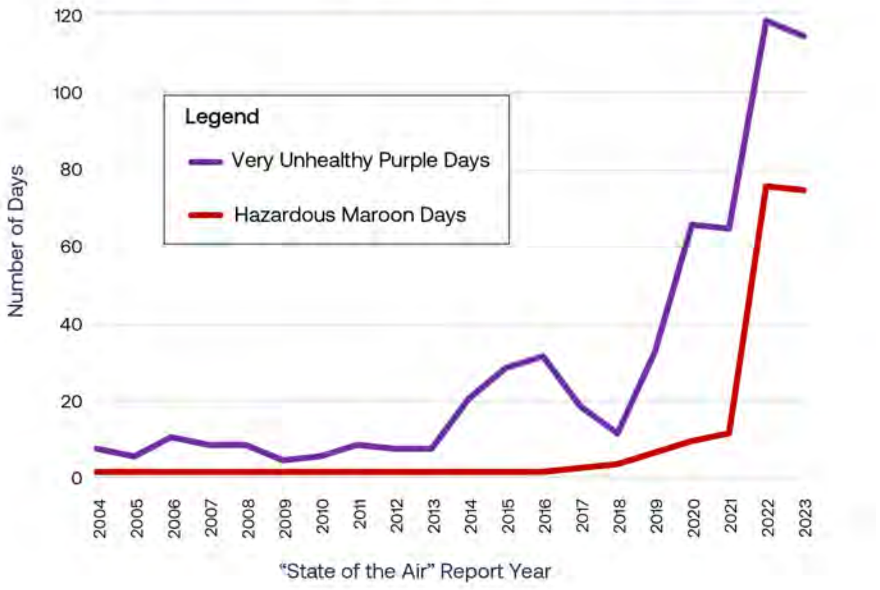
Nearly 64 million Americans live in counties with **F grades** for daily particle pollution.

In the years 2019, 2020 and 2021, some 63.7 million people lived in the 111 counties that earned an F for unhealthy spikes in particulate matter air pollution. This represents close to half a million more people than in last year’s “State of the Air” report, and more people in total than in any of the last ten reports.

Even compared with the past three years of “State of the Air” reports—in which many cities and counties experienced their highest weighted average number of days ever reported for fine particle pollution—results this year were again worse throughout much of the western U.S. Among those cities ranked the worst 25, the average number of days residents were exposed to high levels of fine particle pollution increased by almost two days, to a weighted average of 18.3 days, up from 16.5 days in last year’s report.

Wildfires in the western U.S. are a major contributing factor to the increasing number of days and places with unhealthy levels of particle pollution. They are also increasing the severity of pollution, resulting in a sharp rise in the number of days designated as either purple or maroon. These are the levels on the Air Quality Index that carry the strongest health warnings. On purple very unhealthy days, “the risk of health effects is increased for everyone.” On maroon hazardous days, a health warning of emergency conditions is issued, saying, “Everyone is more likely to be affected.”

Worst Levels of Daily Particle Pollution Remain High



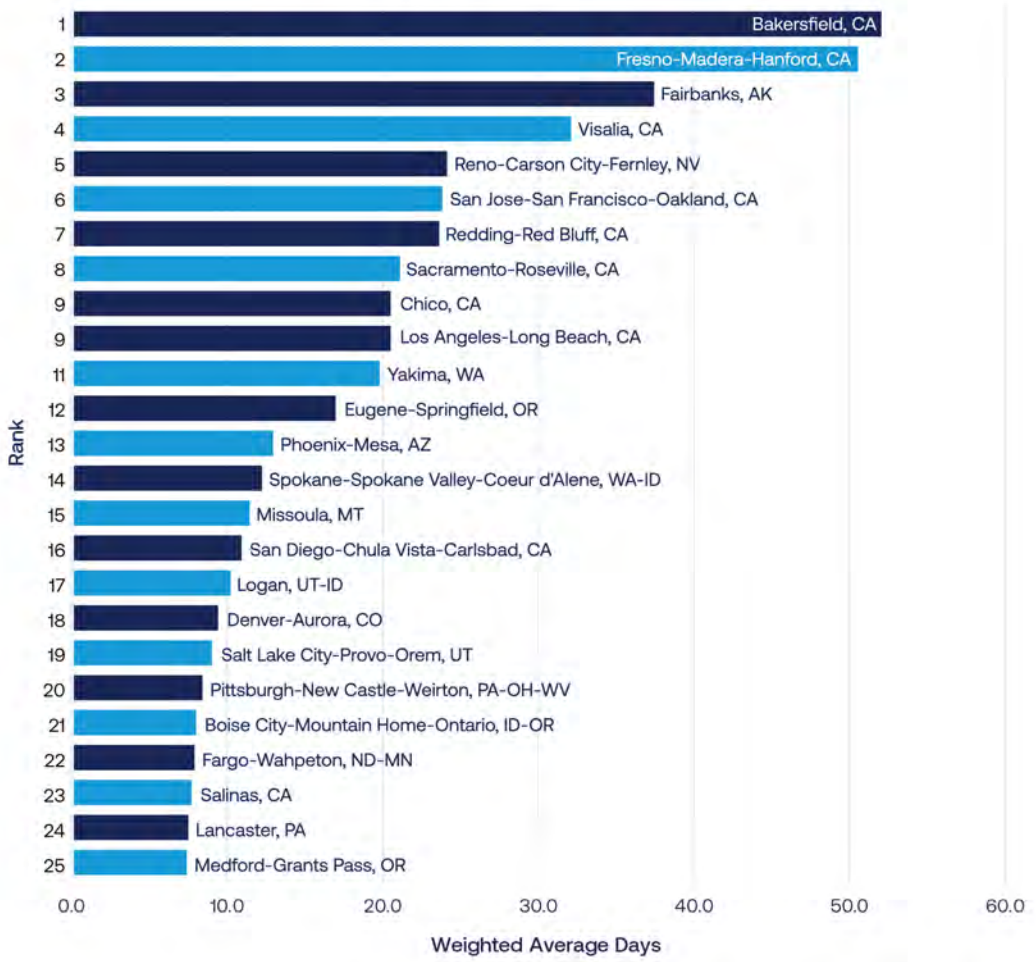
All but two of the 25 worst cities for short-term particle pollution are in the western U.S.

In the years 2019, 2020 and 2021, the health of nearly 32 million people across 56 counties in ten states was put at risk on “purple” or “maroon” days for fine particle pollution. This is very similar to the findings in last year’s “State of the Air” and a worrisome sign of a trend that is likely to continue as climate change worsens.

Seven of the 25 most polluted cities for this measure posted their highest-ever weighted average number of days with unhealthy levels of particle pollution. Two of those, Denver, Colorado and Fargo, North Dakota, are new on the list. The remaining five are Visalia, California; Reno, Nevada; Yakima and Spokane, Washington; and Boise, Idaho.

Twenty-one of last year’s worst 25 cities remained listed among the worst 25 in this year’s report, though their relative ranks often shifted by several places. Missoula, Montana and Lancaster, Pennsylvania both rejoined the ranks of the worst 25 cities after a short hiatus in 2022. San Luis Obispo, California; Portland, Oregon; and Seattle and Bellingham, Washington all moved off the list of worst 25 cities.

25 Cities Most Polluted by Daily PM



In “State of the Air” 2023, only two cities among the 25 worst for short-term particle pollution were not in the western U.S. Both of the eastern cities, Pittsburgh and Lancaster, Pennsylvania, posted more days high in fine particle pollution in this year’s report, and remained the two worst metro areas in the country east of the Mississippi River for this pollutant measure.

Year-round Particle Pollution Trends

Nearly 18.8 million people live in the 17 counties where year-round particle pollution levels do not meet the national air quality standard, and that receive a failing grade in “State of the Air” 2023. This is 1.5 million fewer people living in counties with unhealthy levels of year-round particle pollution compared to last year’s report, continuing a slight downward trend over the past four years.

By its nature, the year-round measure of average particle pollution is not as volatile as the daily measure. Changes over time may look smaller, but because they represent recurring exposures over many days and weeks, seemingly minor differences can have a big impact on public health. The 25 most polluted cities for year-round particle pollution continued the worsening trend of recent years, but only slightly, by an average of less than 0.1 micrograms per cubic meter (from 12.2 to 12.3 $\mu g/m^3$).

Fourteen cities suffered worse year-round levels during 2019-2021 than in last year’s report, with two reporting their worst ever: Sacramento, California and Yakima, Washington for its second consecutive year. In contrast, nine of the 25 most polluted cities had lower year-round levels this year. Although none of the cities with improved levels achieved their best ever in “State of the Air” 2023, Fresno and San Jose-San Francisco-Oakland, California did post their second-best results.

New on the worst 25 list this year were Birmingham, Alabama; Louisville, Kentucky; and Laredo, Texas. Philadelphia, Pennsylvania; Redding-Red Bluff, California; Shreveport, Louisiana; and St. Louis, Missouri all improved enough to leave the list.

When Rev. Jenny Wynn wakes up in the morning, she checks two things—the weather and the air quality. As someone with asthma, high air pollution days force her to limit the time she spends outdoors.

Wynn says she often has to consider whether eating a meal outside or running errands on a day with poor air quality might trigger an asthma attack.

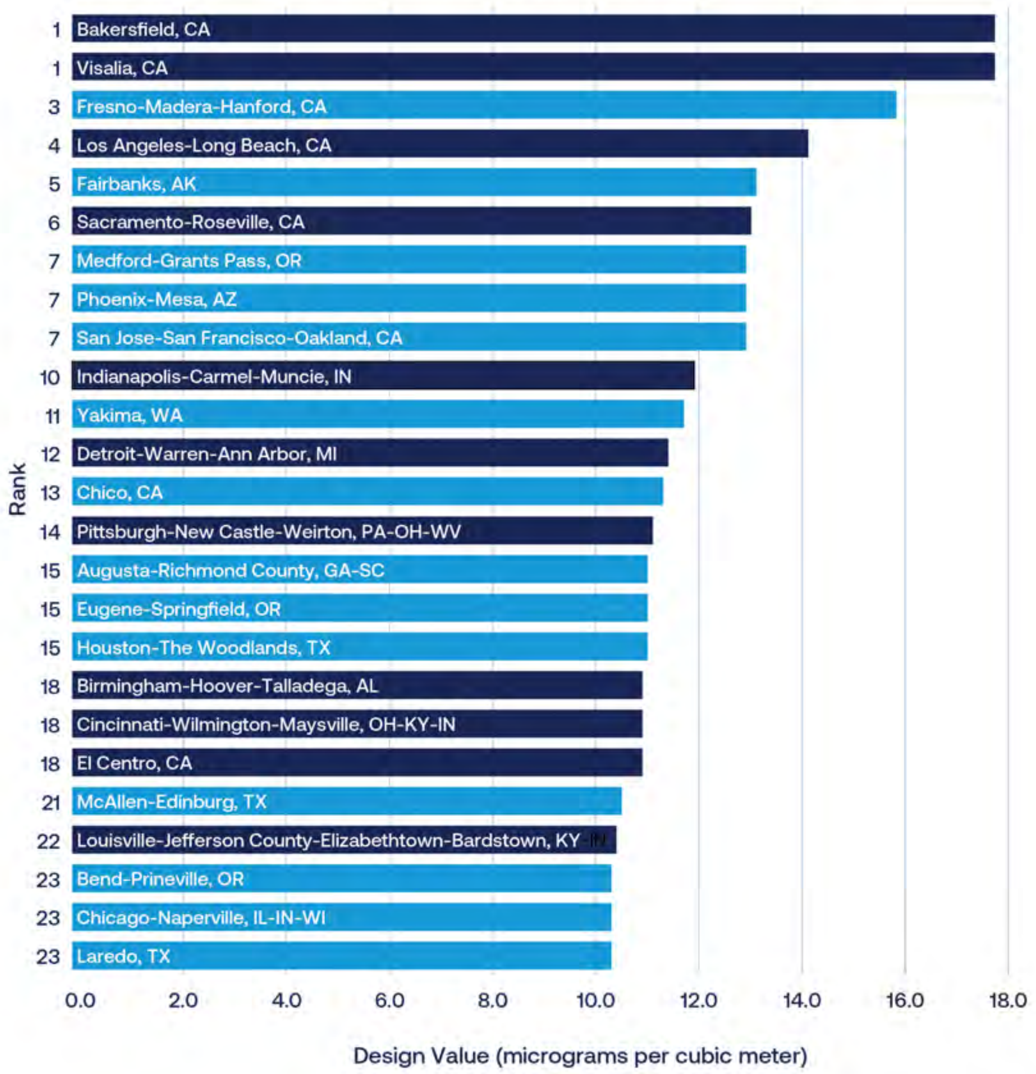
“In Phoenix, it seems there are more days than not with bad air quality,” said Wynn, Senior Minister at First Christian Church in Scottsdale, Arizona.

To help improve air quality in the community over the long term, she would like to see greater investments in public transportation and green-energy vehicles.

“As a preacher,” Wynn says, “I’m always preaching to people that when you’re voting or making decisions, you shouldn’t be doing it for your immediate future but thinking generationally, thinking 50+ years out.”

Rev. Jenny Wynn
First Christian Church Scottsdale

25 Cities Most Polluted by Annual PM



Unlike the worst 25 cities for the daily measure of particle pollution, the worst 25 cities for annual particle pollution were more distributed around the country. Although cities most affected by western drought and wildfires, including eight in California, three in Oregon, and three others in Alaska, Arizona, and Washington, still represented the largest share, cities with high power plant emissions as well as local industrial and mobile sources of year-round particle pollution continued to show up on this list. These included Indianapolis, Detroit, Pittsburgh, Augusta, Houston, Cincinnati, Birmingham, McAllen, Louisville, Chicago and Laredo.

For the year-round average levels of fine particles, all but nine of the cities on the worst 25 list met the current national air quality standard and got a passing grade in "State of the Air." However, evidence shows that no threshold exists for harmful effects from particle pollution, even below the official standard. Until the standard is strengthened, a passing grade does not mean that the air is safe to breathe. See ***Recommendations for Action.***

National Air Quality Standards and the Air Quality Index: Sending the Wrong Message

The Air Quality Index, or AQI, is a well-designed, easy-to-understand resource to communicate air quality information to the public. Since its inception in 1999, the AQI has become embedded in weather and air quality forecasting. It is used every day to help people plan their outdoor activities and make decisions about when they need to take measures to protect themselves from air pollution that could put their health at risk. It is also the basis of the methodology for grading used in "State of the Air."

The AQI's familiar color categories are set according to the levels of air pollution regulated by the National Ambient Air Quality Standards. The breakpoint between the Moderate (code yellow) and Unhealthy for Sensitive Groups (code orange) levels of concern is tied to the national standard. Air quality at levels above the standard is considered unhealthy and triggers increasingly strong health warnings in the AQI. Anything below the standard is considered moderate or good, and the corresponding AQI messages say that the air quality is acceptable.

The AQI only works as the public health tool it is intended to be if the standards accurately reflect what is known about the health harm of ozone and particle pollution. Regrettably, both of these standards are currently inadequate, and the AQI is therefore presenting a misleading picture of health risks. Research has shown that on code yellow days, when all but "unusually sensitive individuals" are told it's a good day to be active outside, millions of people, including children and the elderly, are at risk of a range of health harms from air pollution, including death.

Setting more protective national standards for ozone and fine particles will not only drive pollution cleanup, but also result in an updated air quality index that will provide more accurate information so families, teachers, coaches and others can make decisions to reduce or prevent exposures to pollution levels that threaten health. See *Recommendations for Action* for more information.

Ozone Pollution Trends

Exposure to unhealthy levels of ozone air pollution makes breathing difficult for more Americans all across the country than any other single pollutant. In the years 2019, 2020 and 2021, some 103 million people lived in the 124 counties that earned an F for ozone. More than 30% of the nation's population, including 23.6 million children, 15.4 million people age 65 or older, and millions in other groups at high risk of health harm, are exposed to high levels of ozone on enough days to earn the air they breathe a failing grade.

More than 100 million Americans live in counties with **F grades** for ozone smog.

Although ozone air pollution remains a serious threat to public health, the trend in this year's "State of the Air" report is continuing in a positive direction. The number of people living in counties with a failing grade for ozone declined by more than 19 million this year. Thirty-nine counties in 23 states dropped off the "F" list, including 8 states that left the list completely, some for the first time in the history of the report. At the same time, the number of counties that got an "A" increased by 26%.

Ambient ozone levels are influenced by a complex interaction of factors that can vary from year to year. Some fluctuation is to be expected and does not necessarily represent lasting change. However, at least some of the significant improvement in ozone levels in this year's report can be attributed to the fact that the Clean Air Act has been working. Controls placed on emissions have increasingly resulted in the replacement of more polluting engines, fuels, and processes nationwide. The transition of the economy away from the coal, the dirtiest fossil fuel, has unquestionably had an impact, especially in parts of the eastern United States. It is also possible that

124 counties — fewer than ever in the history of State of the Air — **got an F for ozone smog.**

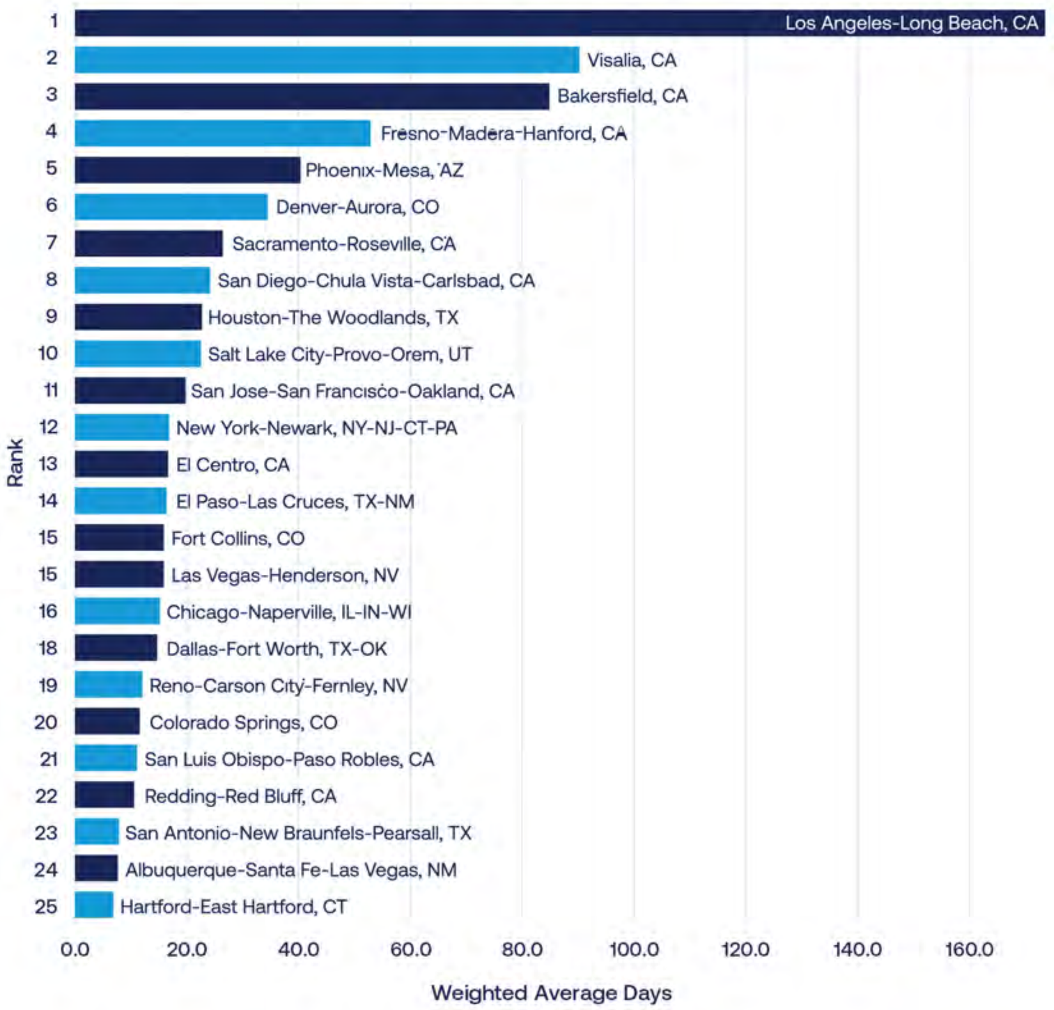
pandemic-related changes in activity patterns in 2020 and 2021, such as increased telework, have made a difference, but that is still being studied and characterized.

The list of 25 cities with the worst ozone pollution in “State of the Air” 2023 and their order of ranking remained relatively stable compared with last year’s report. Only two cities improved enough to move off the list: Chico, California and Detroit, Michigan. They were replaced by Colorado Springs, Colorado and Hartford, Connecticut.

Cities in the West and the Southwest continue to dominate the list of most ozone-polluted. California retains its historic record of being the state with the most places on the list, with 10 of the 25 most-polluted cities. Cities in the Southwest fill most of the remaining slots, with twelve cities spread across six states in this year’s report. New York, Chicago and Hartford were the only three of the worst 25 cities for ozone east of the Mississippi River.

Of the cities on the worst 25 list, 13 saw an increase in the weighted average number of high ozone days and 12 had a decrease compared with last year’s report. Bakersfield, Fresno, San Diego and El Centro, California, along with Las Vegas and New York, all recorded their fewest days of high ozone in the report’s 24-year history. New York did so for the third year in a row.

25 Cities Most Polluted by Ozone



The geographical distribution of cities with the worst ozone problems confirms a pattern seen over the past seven reports: nearly all are western cities and only a few lie in the East. Although cleanup of ozone precursor pollutants has been working to reduce ozone concentrations, the impact of climate change in the West has meant higher temperatures, dry, sunny skies and more frequent stagnation events that are contributing to the number of unhealthy ozone days being higher than it would otherwise be. Simply, climate change is undercutting the progress we would have made.

Monitoring the State of the Air in Indian Country

EPA's National Ambient Air Quality Monitoring System is a network of more than 4,300 sites in over 900 counties across the country measuring air pollutants such as ozone and fine particle pollution. The information these monitors gather is essential for the functioning of the Clean Air Act and protecting public health and welfare. Many of these monitors are maintained and operated by state and local governments with funding and direction from EPA. Tribes across the U.S. also act as partners, conducting programs to monitor and improve air quality on Tribal lands.

As sovereign nations, Tribes have express authority under the Clean Air Act and the Tribal Authority Rule to manage air quality in Indian country. Unlike requirements applying to state agencies, there are no mandates for Tribes to conduct air quality monitoring. However, many Tribes recognize the value in doing so and for decades have been active participants in the nationwide monitoring program, following EPA's specific requirements to assure the quality of the data gathered.

In the years 2019-2021, 38 Tribes collected and submitted air quality data to EPA from monitors in 37 counties across 14 states. In most of those counties, state and local governments also contributed data from their monitoring networks. However, in some cases the Tribal monitors were the sole source of air quality information available to the residents of that county.

Indian Country covers a wide diversity of environments, from frontier (which is less population-dense than rural) to semi-urban. In many places, the air quality on Tribal lands suffers from the same threats as elsewhere in the U.S. Of the 37 counties with data from Tribal monitors in this year's "State of the Air" report, 15 of them, covering a population of more than 12 million people, received at least one failing grade. They included some of the most polluted counties in the country, including Riverside (ranked 2nd worst for ozone), Fresno (2nd worst for short-term particle pollution), and Kings (5th worst for annual particle pollution), all in California.

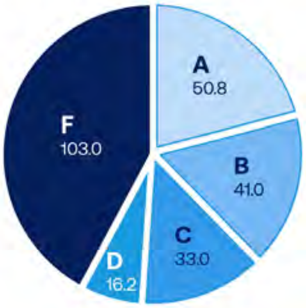
At least 46 tribes that had been active in monitoring ozone and fine particle pollution at some time in the past were not identified as having collected data during the 2019-2021 period. Resources are often spread very thin in Indian country, and that can have a negative impact on the sustainability of air quality and other environmental programs. Considering how important these programs are to protecting the health and well-being of people living on Tribal lands and in the surrounding communities, expanding and sustaining adequate investment needs to be a priority for the nation. In particular, Congress should increase funding for Tribes' air quality work.

For more information about Tribal air quality programs, see the Status of Tribal Air report published annually by the National Tribal Air Association.

Populations at Risk

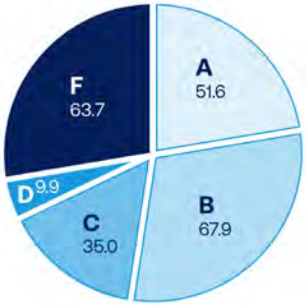
Nearly 264 million people live in the 922 counties for which there is monitored data for at least one pollutant in this year's report. The proportion of the population in those counties varies by pollutant. The majority of U.S. counties actually don't have monitors—which means that many communities, especially rural ones, don't have official monitored information on their air quality. It is important to note that the population numbers included in this section are only for those places that collect air pollution data, and do not reflect the entire population of these groups in the U.S.

Population (millions) by County Ozone Grade



Population (millions) by County Annual PM Grade

Population (millions) by County 24-hour PM Grade



All of the 119.6 million Americans living in places with failing grades for unhealthy levels of ozone or particle pollution are at risk of harm to their health. But some groups of people are especially vulnerable to illness and death from their exposure. *See **People at Risk** for more detail about the factors that contribute to increased risk.*

The number of people in these high-risk groups in "State of the Air" 2023 are as follows:

- **People of color**—Some 64 million people of color live in counties that received at least one failing grade for ozone and/or particle pollution. Over 13 million people of color live in counties that received failing grades on all three measures, including over 9 million Hispanics.
- **People experiencing poverty**—More than 14.6 million people with incomes meeting the federal poverty definition live in counties that received an F for at least one pollutant. Nearly 2.6 million people in poverty live in counties failing all three measures.
- **Children and older adults**—More than 27 million children under age 18 and some 18 million adults age 65 and over live in counties that received an F for at least one pollutant. Almost 4.3 million children and 2.6 million seniors live in counties failing all three measures.
- People with underlying health conditions
  - **Asthma**—1.7 million children and nearly 8.7 million adults with asthma live in counties that received an F for at least one pollutant. More than 217,000 children and 1.2 million adults with asthma live in counties failing all three measures.
  - **Chronic Obstructive Pulmonary Disease (COPD)**—Over 5 million people with COPD live in counties that received an F for at least one pollutant. Almost 630,000 people with COPD live in counties failing all three measures.
  - **Lung Cancer**—More than 55,000 people diagnosed with lung cancer in 2019 live in counties that received an F for at least one pollutant. And nearly 6,900 people diagnosed with lung cancer live in counties failing all three measures.

- **Cardiovascular Disease**—More than 6.6 million people with cardiovascular disease live in counties that received an F for at least one pollutant. Some 864,000 people live in counties failing all three measures.
- **Pregnancy**—Adverse impacts from air pollution have been shown both for those who are pregnant as well as for the developing fetus. More than 1.3 million pregnancies were recorded in 2021 in counties that received at least one F for particle pollution. Of those, nearly 198,000 are in counties that received failing grades for all three measures.

For more detail about the number of people at risk by grade and by pollutant, see ***Data Table 1****. The populations at risk are also included by county in the* ***State Data Tables****.*

Most Polluted Places to Live

In addition to the 25 worst cities for each pollutant listed above, the 25 most polluted counties for ozone and particle pollution are ranked in the tables below:

Daily PM Ranking	State	County
1	CA	Kern
2	CA	Fresno
3	CA	Mono
4	CA	Kings
4	OR	Klamath
6	CA	Inyo
7	AK	Fairbanks North Star
8	CA	Tulare
9	CA	Siskiyou
10	NV	Douglas
11	CA	Stanislaus
12	CA	Tehama
13	CA	Plumas
14	NV	Washoe
15	CA	Carson City
15	CA	Madera
17	CA	Nevada
18	CA	Butte
18	CA	Los Angeles
20	CA	Colusa
20	WA	Yakima
22	CA	Sutter
23	CA	Scramento
24	CA	Placer
25	CA	San Joaquin

Annual PM Ranking	State	County
1	CA	Kern
2	CA	Tulare
3	CA	Plumas
4	0R	Klamath
5	CA	Kings
6	CA	Fresno
7	CA	San Barnadino
8	CA	Riverside
9	MT	Lincoln
10	AK	Fairbanks Norh Star
11	CA	Sutter
12	OR	Jackson
12	CA	Los Angeles
12	CA	Madera
12	AZ	Pinal
16	CA	Stanislaus
17	WA	Okanogan
18	IN	Marion
19	CA	Merced
20	CA	San Joaguin
21	WA	Yakima
22	MI	Wayne
23	CA	Butte
24	OR	Josephine
25	PA	Allegheny

Ozone Ranking	State	County
1	CA	San Bernadino
2	CA	Riverside
3	CA	Los Angeles
4	CA	Tulare
5	CA	Kern
6	CA	Fresno
7	AZ	Maricopa
8	CO	Jefferson
9	CA	Placer
10	CA	San Diego
11	CO	Douglas
12	TX	Harris
13	UT	Salt Lake
14	CA	Madera
15	CA	Nevada
16	CA	Stanislaus
17	CA	Orange
18	CA	Kings
18	NM	Eddy
20	CO	Arapahoe
21	CA	Mariposa
22	AZ	Pinal
23	CA	Sacramento
24	CT	Fairfield
25	CA	Imperial

Eleven counties received failing grades for all 3 measures of pollution: Fresno, Kern, Kings, Los Angeles, Madera, Riverside, San Bernardino, Stanislaus, Sutter, and Tulare in California and Pinal in Arizona.

Cleanest Places to Live

Many cities in the U.S. enjoy air that is considered clean for one or more of the pollution measures tracked in "State of the Air." In this year's report, 59 of the cities for which there is monitoring data had zero high short-term particle days and 80 cities had zero ozone days. Because year-round particle pollution is scored differently, the cleanest cities for this measure can be ranked, and the best 25 are considered cleanest. *See* ***Data Tables 3a-c***.

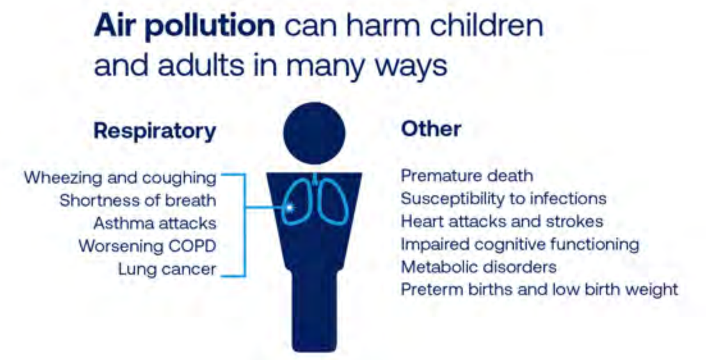
Seven cities rank on all three cleanest cities lists for particle pollution and ozone. They had zero days high in particle pollution or ozone and are among the 25 cities with the lowest year-round particle levels. Added to the list this year are Asheville and Greenville, NC and Rochester NY. The other four repeat their appearance on the list this year. Elmira NY, Burlington VT and Charlottesville, Harrisonburg, Roanoke and Virginia Beach, VA all lost their place on this year's cleanest list because of increases in either short-term or annual particle pollution.

Listed alphabetically, the cleanest cities are:

- Asheville-Marion-Brevard, NC
- Bangor, ME
- Greenville-Kinston-Washington, NC
- Lincoln-Beatrice, NE
- Rochester-Batavia-Seneca Falls, NY
- Urban Honolulu, HI
- Wilmington, NC

Health Effects of Air Pollution

Years of scientific research have clearly established that particle pollution and ozone are a threat to human health at every stage of life, increasing the risk of premature birth, causing or worsening lung and heart disease, and shortening lives. Some groups of people are more at risk of illness and death than others, because they are more likely to be exposed, or are more vulnerable to health harm, or often both.



Health Effects of Particle Pollution

Particle pollution—also known as particulate matter—is a deadly and growing threat to public health in communities around the country. The more researchers learn about the health effects of particle pollution, the more dangerous it is recognized to be.

What is particle pollution?

Particle pollution refers to a mixture of tiny bits of solids and liquids in the air we breathe. Particle pollution comes from many sources. Factories, power plants, and diesel- and gasoline-powered motor vehicles (cars, trucks and buses) and equipment either directly emit fine particles or generate other pollutants such as nitrogen oxides (NOx), known as precursors because they can then form into fine particles in the atmosphere. Other sources of particle pollution include wildfires, burning wood in wood stoves or residential fireplaces and burning biomass for electricity.

Individual particles may be too small as to be visible, but when pollution levels are high, they can make the air appear thick and hazy. Researchers and regulators categorize particles according to size, grouping them as coarse, fine and ultrafine. Coarse particles, called PM10, can include wind-blown dust, ash, pollen and smoke. Fine particles, $PM_{2.5}$, are most often a by-product of burning wood or fossil fuels. The tiniest are called ultrafine particles, or PM0.1, which are also produced by combustion.

The differences in size make a big difference in how particles affect our health. Our bodies' natural defenses help us to keep the coarse particles we inhale out of the deepest parts of our lungs, although these particles do deposit in the larger airways. However, those defenses do not keep smaller fine or ultrafine particles from penetrating all the way into the air sacs of the lungs. Many of these particles get trapped in the air sacs, while the smallest are so tiny that they can pass from the air sacs into the bloodstream and disperse to other organs of the body.

What can particles do to your health?

Particle pollution can be very dangerous to breathe, especially at higher concentrations. It can trigger illness, hospitalization and premature death. Researchers estimate that $PM_{2.5}$ is responsible for nearly 48,000 premature deaths in the United States every year.[1]

Short-Term Exposure

Short-term spikes in particle pollution that last from a few hours to a few days can kill. Premature deaths from breathing these particles can occur on the very day that particle levels are high, or up to a month or two afterward. Most premature deaths are from respiratory and cardiovascular causes. Particle pollution does not just make people die a few days earlier than they might otherwise—in many cases these deaths would not have occurred for years if the air were cleaner.[2]

Studies linking short-term exposure to $PM_{2.5}$ to death from all causes have been accumulating for a number of years. Taken together, this body of research provides consistent evidence of positive associations between particle pollution and mortality across diverse geographic locations and in populations with a wide range of demographic characteristics. In 2019, an international study in 499 cities across the globe reinforced these consistent findings.[3]

Even low daily levels of fine particles can be deadly. Looking nationwide in a 2017 study, researchers found that older adults faced a higher risk of premature death even when levels of short-term particle pollution remained well within the current national standards. This was consistent whether the older adults lived in cities, suburbs or rural areas.[4] Another study published in 2018 analyzed mortality data from 135 U.S. cities and found a causal relationship with exposure to $PM_{2.5}$ at concentrations below the federal standard.[5]

Particle pollution also has many other harmful effects, ranging from decreased lung function to heart attacks. Extensive research has linked short-term increases in particle pollution to:

- increased mortality in infants;[6]
- increased hospital admissions for cardiovascular disease, including heart attacks and strokes;[7]
- increased hospital admissions and emergency department visits for chronic obstructive pulmonary disease (COPD);[8]
- increased severity of asthma attacks and hospitalization for asthma among children.[9,10]

Year-Round Exposure

Decades of research have firmly established that breathing particle pollution day in and day out can also be deadly. Across numerous seminal studies that looked at different groups of people living in different parts of the country, the results consistently showed a clear relationship between long-term exposure to particulate matter and mortality.[11]

Recent research using publicly available data on a cohort of more than million adults in the U.S. reconfirmed that long-term exposure to $PM_{2.5}$ was associated with elevated risks of early death. The increased risk was primarily associated with death from cardiovascular and respiratory causes, including heart disease, stroke, influenza and pneumonia. Researchers also found a similar association between exposure to fine particle pollution and an increased risk of death from lung cancer among never-smokers.[12] Another study of 68.5 million Medicare-enrolled adults in the United States between 2000 and 2016 found a 6-8% increase in risk of all-cause mortality for every 10µg/m3 increase in $PM_{2.5}$.[13]

Research has also linked year-round exposure to particle pollution to a wide array of serious health effects at every stage of life, from conception through old age. Among pregnant people, fetuses and children, long-term particle pollution exposure is linked to:

- Increased risk of preterm birth and low birth weight;[14]
- Increased fetal and infant mortality;[15]
- Impaired neurological development and cognition;[16]
- Reduced lung development and impaired lung function in children;[17]
- Higher likelihood of children developing asthma.[18]

In adults, long-term particle pollution exposure is linked to:

- Increased risk from existing cardiovascular and respiratory disease, including a worsening of heart disease, atherosclerosis and COPD;[19,20]
- Higher likelihood of developing diabetes and subsequent complications;[21,22]
- Higher likelihood of getting lung cancer and of dying from it;[23]
- Impaired cognitive functioning and an increased risk of Parkinson's disease, Alzheimer's disease and other dementias later in life.[24,25]

The good news is, cleaning up particle pollution makes a difference. Research has shown a consistent relationship between decreasing $PM_{2.5}$ concentrations and improving respiratory health in children and adults in communities that have reduced their levels of year-round particle pollution.[26]

Who is most at risk from particle pollution?

Anyone who lives where particle pollution levels are high is at risk. Some people face greater risk, however, based on their underlying health and other characteristics. [See the ***People at Risk*** section for more information about vulnerable groups] Research has shown that the groups at the greatest risk from particle pollution include:

- Pregnant people and fetuses;[27]
- Infants, children and older people (>65 years of age);[28]
- People with lung disease, especially asthma, but also people with COPD;[29]
- People with cardiovascular disease;[30]
- People with lung cancer;[31]
- People of color;[32]
- Current or former smokers;[33]
- People with low incomes;[34] and
- People who are obese or have diabetes.[35]

Health Effects of Ozone Pollution

Ozone air pollution, sometimes known as smog, is one of the most widespread pollutants in the United States. It is also one of the most dangerous. Scientists have studied the effects of ozone on human health for decades. Hundreds of studies have confirmed that ozone harms people at levels currently found in many parts of the United States.

What is Ozone?

Ozone is a gas composed of molecules with three oxygen atoms. (The oxygen we need for life is made up of molecules with two oxygen atoms). Ozone forms in the lower atmosphere when a combination of other pollutants, usually nitrogen oxides (NOx) and volatile organic compounds (VOCs), “cook” together in sunlight through a series of chemical reactions. NOx and VOCs are produced primarily when fossil fuels such as gasoline, diesel, oil, natural gas or coal are burned or when solvents and some other chemicals evaporate. NOx is emitted from power plants, motor vehicles and other sources of high-heat combustion. VOCs are emitted from motor vehicles, oil and gas operations, chemical plants, refineries, factories, gas stations, paint, consumer products and other sources.

If these ingredients are present under the right conditions, they react to form ozone. Sunlight is key, with higher temperatures increasing ozone production. Because the reactions take place in the atmosphere, ozone often shows up downwind of the sources of the original emissions, sometimes many miles from where it formed.

Ozone air pollution is sometimes called ground-level ozone, to distinguish it from the much higher-altitude stratospheric ozone layer that protects the Earth from damaging ultraviolet rays from the sun.

What Can Ozone Pollution Do to Your Health?

Ozone gas is a powerful lung irritant. When it is inhaled into the lungs, it reacts with the delicate lining of the airways, causing inflammation and other damage that can impact multiple body systems. Ozone exposure can also shorten lives.

Ozone has a serious effect on the respiratory system, both in the short term and over the course of years of exposure. When ozone levels are high, many people experience breathing problems such as chest tightness, coughing and shortness of breath, often within hours of exposure. Even healthy young adults may experience respiratory symptoms and decreased lung function.[36]

Other breathing problems that have been tied to short-term exposure to ozone include:

- Worsening of symptoms, increased medication use, and increased emergency department visits and hospital admissions for people with asthma and COPD;[37]
- Susceptibility to respiratory infections such as pneumonia, resulting in an increased likelihood of emergency department visits and hospitalizations.[38]

Living with ozone pollution long term may cause lasting damage to respiratory health, including:

- Development of new cases of asthma in children;[39]
- Damage to the airways, leading to development of COPD;[40]
- Increased allergic response.[41]

The inflammation and systemic stress caused by short- and long-term exposure to ozone can also do damage to tissues, DNA and proteins throughout the body, which can cause or worsen other disease conditions over time. These include:

- Increased risk of metabolic disorders, including glucose intolerance, hyperglycemia and diabetes;[42]
- Impact on the central nervous system, including brain inflammation, structural changes and increased risk of cognitive decline;[43,44]
- Increased likelihood of reproductive and developmental harm, including reduced fertility, preterm birth, stillbirth and low birth weight;[45,46]
- Possible cardiovascular effects.[47]

The damage ozone does to the body can be deadly. Recent research has affirmed earlier findings that short-term exposure to ozone, even at levels below the current standard, likely increases the risk of premature death, particularly for older adults.[48] There is also a growing body of evidence that long-term exposures to ambient ozone may be associated with an increased risk of cardiovascular and respiratory disease mortality.[49]

Who is Most at Risk from Ozone Pollution?

Anyone who spends time outdoors where ozone pollution levels are high may be at risk. Some people face a higher-than-average risk, however, because of their underlying health and other characteristics. [See the ***People at Risk*** section for more information about vulnerable groups.] Research has shown that the groups at greatest risk from ozone pollution include:

- Pregnant people and fetuses;[50]
- Children;
- Anyone 65 and older;
- People with existing lung disease such as asthma and COPD;
- People who work or exercise outdoors.[51]

Air Pollution and COVID-19

Both ozone and particle pollution can impact the functioning of the immune system and increase susceptibility to respiratory infections. Air pollution also increases the risk of chronic lung and cardiovascular diseases that put people at higher risk of poor outcomes from COVID-19. It should come as no surprise then, that since the pandemic began, a growing body of research has found an association between exposure to air pollution and an increased risk of severe illness and death from COVID-19. Short-term exposure to both ozone and $PM_{2.5}$ has been shown to increase the risk of death among infected individuals.[52] Long-term exposure to air pollution also appears to leave people more vulnerable to severe disease outcomes. A 2022 study in California found that people living in the most polluted areas of the state had a 20% higher risk of infection and a 51% higher risk of death than residents in the least polluted areas.[53]

People at Risk

The health burden of air pollution is not evenly shared. Some people are more at risk of illness and death from air pollution than others. Several key factors affect an individual's level of risk:

- Exposure—Where someone lives, where they go to school and where they work make a big difference in how much air pollution they breathe. In general, the higher the exposure, the greater the risk of harm.
- Susceptibility—Pregnant people and their fetuses, children, older adults and people living with chronic conditions, especially heart and lung disease, may be physically more susceptible to the health impacts of air pollution than other adults.
- Access to healthcare—Whether or not a person has health coverage, a healthcare provider, and access to linguistically and culturally appropriate health information may influence their overall health status and how they are impacted by environmental stressors like air pollution.
- Psychosocial stress—There is increasing evidence that non-physical stressors such as poverty, racial/ethnic discrimination and fear of deportation can amplify the harmful effects of air pollution.

These risk factors are not mutually exclusive and often interact in ways that lead to significant health inequities among subgroups of the population. Taken all together, these high risk categories account for a large proportion of the U.S. population.

People of color

Research has shown that people of color are more likely to be exposed to air pollution and more likely to suffer harm to their health from air pollution than white people.[54,55] Much of this inequity can be traced to the long history of systemic racism in the United States. Practices such as redlining, the discriminatory outlining of so-called "riskier" neighborhoods by mortgage lenders, institutionalized residential segregation in the 20th century, impairing the ability of many people of color to build wealth and limiting their mobility and political power. Over the years, decision-makers have found it easier to place sources of pollution, such as power plants, industrial facilities, landfills and highways, in economically disadvantaged communities of color than in more affluent, predominantly white neighborhoods. The resulting disproportionate exposure to air pollution has contributed to high rates of emergency department visits for asthma and other diseases.[56,57]

People of color are also more likely than white people to be living with one or more chronic conditions that make them more susceptible to the health impact of air pollution, including asthma, diabetes and heart disease.[58]

People experiencing poverty

There is evidence that having low income or living in lower income areas puts people at increased risk from air pollution, although the correlation is not as strong as with race and ethnicity.[59,60] People living in poverty are more likely to live in close proximity to sources of pollution and have fewer resources to relocate than people with more financial security.[61] Poverty itself, along with the problems that beset many low-income communities, such as lack of safety, green space, and high-quality food access, have been associated with increased psychosocial distress and chronic stress, which in turn make people more vulnerable to pollution-related health effects.[62] People with low income also have lower rates of health coverage and less access to quality and affordable health care to provide relief to them when they get sick.

Children

Children are both more susceptible to harm from air pollution and more likely to be exposed than adults. The growth and development of a child's lungs and breathing ability start in utero and continue into early adulthood. Long-term exposure to particle pollution during pregnancy and early childhood has been linked to reduced lung growth and long-term exposure to ozone has been linked to increased potential for the development of asthma. The developing brain and heart may also be affected, with life-long consequences.[63] In addition, the body's defenses that help adults fight off infections are still developing in children. Children have more respiratory infections than adults, which also seems to increase their susceptibility to air pollution.[64]

Children breathe more rapidly and inhale more air relative to their size than do adults. They are more likely to spend time outdoors, running around, being active and breathing hard. Consequently, they are more exposed to polluted outdoor air than adults typically are.

Older adults

Much of the illness and premature death caused by air pollution occurs in older adults, who are at increased risk of harm for several reasons. As a person ages, the normal process of thinning and weakening of the lung tissue and the supporting muscle and bones of the ribcage results in diminishing lung function over time. The impairment that results from exposure to air pollutants then has an add-on effect, putting stress on the lungs and heart. Older people are also more likely to be living with chronic diseases, and there is evidence that co-existing chronic lung, heart or circulatory conditions may worsen following exposure to environmental pollutants.[65]

The strength of the immune system also declines with age, leaving older people at greater risk of contracting infections and less able to get them under control before they become serious. Because exposure to air pollution increases susceptibility to respiratory infections, it also increases the risk of severe illness and death in older adults.

People with underlying health conditions

For the millions of people in the U.S. living with illnesses such as asthma, COPD, diabetes, heart disease and lung cancer, exposure to air pollution places them at greater risk of harm to their health than those without disease. The cellular injury and systemic inflammation triggered by breathing ozone and particle pollution put additional stress on people's lungs, heart and other organs already compromised by disease. This can result in a worsening of symptoms, increased medication use, more frequent emergency department visits and hospitalizations, an overall reduced quality of life and far too often premature death.

Pregnant people and fetuses

Pregnancy is always a susceptible time for both the mother and the developing fetus. The pregnant body undergoes dramatic physiological changes in hormone levels, metabolism and circulation throughout months of gestation. The rapid and complex development of the fetus is a precisely timed and sequenced process. The inflammation and oxidative stress resulting from exposure to air pollution during pregnancy can increase the risk of hypertensive disorders, including preeclampsia, in the mother and lead to intrauterine inflammation and damage to the placenta that can disrupt the growth and development of the fetus. Fetal health may also be impacted in a number of ways by environmental contaminants that have been shown to cross the placenta.[66]

Exposure to both ozone and particle pollution during pregnancy is strongly associated with premature birth, low birth weight and stillbirth. These risks are amplified in pregnancies where the mother is already at higher risk, such as people of color and those chronic conditions, especially asthma.[67]

People with a smoking history

There is some recent evidence suggesting that current and former smokers are at greater risk of health harm from exposure to fine particle pollution compared with never-smokers. They are more likely to develop lung cancer and to die prematurely.[68] Smoking damages the lungs, heart, blood vessels and other organs.[69] This impairment leaves the person with a smoking history more vulnerable to the health impact of air pollution than a never-smoker.

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Recommendations for Action

We need action at every level to clean up air pollution and address climate change.

Individuals

You can take action to protect yourself and your family from the dangers of air pollution. Regardless of its grade or ranking in this report, any community can experience days with unhealthy levels of air pollution. Some simple precautions will reduce your risk:

- **Check daily air pollution forecasts in your area at airnow.gov.** The color-coded forecasts let you know when the air is unhealthy in your community. When the air is bad, move your exercise plans and other activities indoors. If you live in a fire-prone area, learn more about using N-95 masks and creating a clean room inside your home with our wildfire resources at Lung.org/wildfire.
- **Reduce your own contributions to air pollution.** Prioritize walking, biking and public transit over diesel or gasoline-powered vehicles. Conserve electricity and purchase your power from clean, non-combustion sources if you can. Don't burn leaves or trash and avoid burning wood whenever possible.
- **Consider taking advantage of tax incentives to reduce emissions from your home and vehicle.** One of the best ways to reduce pollution is to switch from vehicles and appliances that burn fuel—like gasoline-powered cars and natural gas stoves and furnaces—to zero-emission versions that run on electricity. Under the Inflation Reduction Act passed in 2022, you may be able to get tax credits for buying a new or used electric vehicle or for upgrading your home with efficient, zero-emissions appliances like induction stoves or heat pumps.

Poor air quality is often associated with public health impacts, such as asthma and heart disease. Joanne Kilgour says while protecting people's health must be a priority, it's important to not overlook the economic effects of air pollution.

"It's hard to attract new industry to a place where you can't promise employees their children will be free of asthma or enjoy the outdoors without the threat of an air quality action day," says Kilgour, executive director of the Ohio River Valley Institute, a nonprofit focused on the greater Ohio Valley and Western Pennsylvania.

Her region has some of the country's worst air quality year after year, she says. That limits the time people spend outdoors in an area where recreation can be a powerful economic driver, she adds.

Kilgour says decarbonization is key to reducing emissions and air pollution, with opportunities to leverage investments in fossil-free steel production as an example of strategies that can make a difference.

"There's a broad understanding that the status quo isn't serving families and residents in the community," she says.

Joanne Kilgour
Executive Director, Ohio River Valley Institute

Local Governments

Local governments have the power to help ensure that city and county operations are zero-emission and that residents have the ability to choose zero-emission forms of transportation and electricity. These actions must benefit the communities most impacted by unhealthy air.

- **Adopt a climate action plan.** Reduce city- and county-wide emissions by supporting walking, biking and transit and zero-emission-vehicle infrastructure and ensuring that building and parking policies support these goals. Include measures to address the impacts of climate change on residents, including health impacts. Under the Inflation Reduction Act, municipalities can opt in to get planning grant funding to reduce climate pollution.
- **Purchase zero-emission fleet vehicles.** Commit to purchasing zero-emission garbage and recycling trucks, transit buses, school buses and other vehicles.
- **Establish purchasing goals for renewable, non-combustion electricity.** Power city and county operations with truly clean sources of electricity like wind, solar, geothermal or tidal.

Providing more options for transit can help reduce traffic and air pollution. As part of the Metro’s Silver Line extension in Virginia last year, Fairfax County added about 4,000 parking spaces in two garages to make the rapid transit line more convenient.

Martha Coello, Special Projects Division Chief at the Fairfax County Department of Transportation, says Park and Rides are a convenient way for people to use public transportation for more than just commuting to work.

“People are looking at these facilities to make transit more accessible and allow them to avoid driving to downtown D.C. for a show or a nice dinner on a Friday,” Coello says. “There’s a good, interconnected impact in that it does take cars off the road which helps air quality.”

The Silver Line extension included three new stations, enhanced bus service, and pedestrian and bicycle improvements. Coello says having infrastructure that makes it comfortable for people to access different modes is key to encouraging public transportation use.

“It’s all about giving people options,” she says.

Martha Coello
Special Projects Division Chief, Fairfax County Department of Transportation

State, Territorial and Tribal Governments

- **Set a clean or renewable electricity standard or clean peak standard** that phases out the use of coal, oil, methane gas (often called natural gas) and other combustion energy sources and replaces it with wind, solar, geothermal and tidal and other non-combustion forms of electricity. Do not allow for the increased use of biomass or municipal solid waste for electricity because of their contributions to particle pollution.
- **Leverage Inflation Reduction Act funding** available to state, territorial and Tribal governments to reduce emissions, including reducing air pollution at ports, investing in zero-emission heavy-duty vehicles and infrastructure and improving air quality monitoring. Ensure that environmental justice communities that have long borne the brunt of pollution impacts are prioritized.
- **States: Use Clean Air Act authority to adopt the California zero-emissions standards for cars and trucks.** These include California's Low-Emission Vehicle criteria pollutant and greenhouse gas regulations; Zero-Emission Vehicle regulations; and Advanced Clean Trucks regulations.

Federal Government

The passage of the 2022 Inflation Reduction Act was a major victory, providing major investments to reduce air pollution and address climate change that federal agencies are now dolling out. However, these investments are only half the battle. Federal agencies must also finalize strong limits on air pollution to truly protect public health and advance environmental justice.

The Biden administration is behind on its clean air to-do list and must urgently pick up the pace by moving on key clean air regulatory priorities. Go to Lung.org/sota to ***take action now.*** Key priorities include:

- EPA must finalize strong new emissions standards that transition the nation's cars and trucks to zero-emission vehicles. EPA has already strengthened emissions standards for the next few years of new cars and trucks. Now, EPA must finalize stronger standards for emissions for light-duty and medium-duty vehicles beginning in Model Year 2027. EPA must also finalize a proposed rule to limit pollution from heavy-duty vehicles beginning in Model Year 2027.
- EPA must set stronger national standards for particulate matter and ozone. For particulate matter, the research shows that the new standard should be set at 8 micrograms per cubic meter annually, and 25 micrograms per cubic meter daily, to protect those at greatest risk of harm. For ozone, the research shows that a standard of no higher than 60 parts per billion would protect health. Not only will stronger standards drive cleanup of polluting sources nationwide, they will also mean that families across the country are better informed about when their local air quality may put their health at risk.

- EPA must clean up power plant pollution. EPA has proposed tighter limits on mercury and air toxics from power plants and must see them across the finish line. This action is critical for communities with a coal- or oil-fired plant nearby that emit dangerous pollutants, harming health. EPA must also propose and finalize rules to limit carbon emissions from the power sector, including for coal, oil and natural gas-fired power plants.
- Federal agencies must further limit pollution from the oil and gas industry. EPA must finalize strong rules that dramatically limit emissions of methane and other harmful air pollutants from the oil and gas industry. Additionally, burning methane gas in appliances in homes contributes to outdoor air pollution and has harmful health impacts indoors, especially for kids with asthma. EPA, the Consumer Product Safety Commission and the Department of Energy must set standards improving the efficiency of these appliances and continue to foster a transition to zero-emission, electric appliances wherever possible.
- The U.S. Congress must pass funding bills that adequately invest in clean air protections, including increased funding for EPA to set and enforce these lifesaving rules and to pass along to state, local and Tribal air agencies to monitor and clean up harmful air pollution.

Understanding Grades and Tables

*See **Methodology** for a full explanation of data sources and calculations made for state grades.*

Notes for state grades tables

1. Not all counties have monitors for either ozone or particle pollution. If a county does not have any monitors for either pollutant, that county's name is not on the list in these tables. The decision about monitors in the county is made by the state and the U.S. Environmental Protection Agency, not by the American Lung Association.
2. **INC** (Incomplete) indicates that monitoring data is available for at least one year in that county, but not all three years.
3. **DNC** (Data Not Collected) indicates that data on that particular pollutant is not collected in that county.
4. The **Weighted Average (Wgt. Avg)** was derived by adding the three years of individual level data (2019-2021), multiplying the sums of each level by the assigned standard weights (i.e. 1=orange, 1.5=red, 2.0=purple and 2.5=maroon) and calculating the average. Grades are assigned based on the weighted averages as follows: A=0.0, B=0.3-0.9, C=1.0-2.0, D=2.1-3.2, F=3.3+.
5. The **Design Value** is the calculated concentration of a pollutant based on the National Ambient Air Quality Standard for $PM_{2.5}$, which is 12 $\mu g/m^3$. Counties with design values of 12 or lower received a grade of "Pass" for Annual $PM_{2.5}$. Counties with design values of 12.1 or higher received a grade of "Fail."

Notes for at-risk groups tables

1. **Total Population** is based on 2021 U.S. Census and represents the at-risk populations in counties with ozone or $PM_{2.5}$ pollution monitors; it does not represent the entire state's sensitive populations.
2. Those **18 & under** and **65 & over** are vulnerable to ozone and $PM_{2.5}$. Do not use them as population denominators for disease estimates—that will lead to incorrect estimates.
3. **Pediatric asthma** estimates are for those under 18 years of age and represent the estimated number of people who had asthma in 2021 based on the state rates when available or national rates when not (Behavioral Risk Factor Surveillance System, or BRFSS), applied to county population estimates (U.S. Census).
4. **Adult asthma** estimates are for those 18 years and older and represent the estimated number of people who had asthma during 2021 based on state rates (BRFSS) applied to county population estimates (U.S. Census).
5. **COPD** estimates are for adults 18 and over who had ever been diagnosed with chronic obstructive pulmonary disease, which includes chronic bronchitis and emphysema, based on state rates (BRFSS) applied to county population estimates (U.S. Census).
6. **Lung cancer** estimates are for all ages and represent the estimated number of people diagnosed with lung cancer in 2019 based on state rates (StateCancerProfiles.gov) applied to county population estimates (U.S. Census).
7. **Cardiovascular disease** estimates are for adults 18 and over who have been diagnosed within their lifetime, based on state rates (BRFSS) applied to county population estimates (U.S. Census). CV disease includes coronary heart disease, stroke and heart attack.
8. **Pregnancy** estimates are for females 18-49 and based on state rates of pregnancies resulting in live births applied to population estimates (U.S. Census).
9. **Poverty** estimates include all ages and come from the U.S. Census Bureau's Small Area Income and Poverty Estimates program. The estimates are derived from a model using estimates of income or poverty from the Annual Social and Economic Supplement and the Current Population Survey, 2021. Puerto Rico poverty estimates come from the U.S. Census Bureau's American Community Survey, 2017-2021.
10. **People of color** are defined as anyone Hispanic or non-Hispanic black, Asian, American Indian/Alaska Native, Native Hawaiian and Other Pacific Islander, or two or more races and are based on 2021 county population estimates (U.S. Census).
11. Adding across rows does not produce valid estimates. Adding the at-risk categories (asthma, COPD, poverty, etc.) will double-count people who fall into more than one category.

Table 1 Populations at Risk by Grade and by Pollutant

People at Risk from Short-Term Particle Pollution (Daily $PM_{2.5}$)

	Chronic Diseases					Age Groups						
In Counties Where the Grades Were:	**Adult Asthma**	**Pediatric Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Under 18**	**65 and Over**	**Pregnancies**	**Poverty**	**People of Color**	**Total Population**	**Number of Counties**
Grade A (0.0)	3,894,015	792,057	2,807,694	29,095	3,628,440	10,837,393	9,154,039	565,400	6,646,761	20,912,987	51,591,902	201
Grade B (0.3-0.9)	5,116,583	1,078,252	3,419,289	37,373	4,272,816	15,139,596	10,708,528	767,317	8,606,513	31,296,133	67,897,198	181
Grade C (1.0-2.0)	2,585,150	564,739	1,728,708	19,539	2,209,878	7,926,089	5,307,917	408,543	4,658,924	16,617,212	35,012,717	87
Grade D (2.1-3.2)	729,612	157,009	445,360	4,931	588,034	2,337,256	1,529,864	112,989	1,340,205	4,488,927	9,866,872	33
Grade F (3.3+)	4,619,925	841,181	2,473,889	26,117	3,309,609	14,383,225	9,700,045	700,286	7,570,747	34,646,678	63,737,389	111
National Population in Counties with $PM_{2.5}$ Monitors	17,228,739	3,496,135	11,063,041	119,108	14,245,688	51,507,725	37,004,318	2,596,848	29,278,409	109,299,287	231,900,896	641

People at Risk from Year-Round Particle Pollution (Annual $PM_{2.5}$)

	Chronic Diseases					Age Groups						
In Counties Where the Grades Were:	**Adult Asthma**	**Pediatric Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Under 18**	**65 and Over**	**Pregnancies**	**Poverty**	**People of Color**	**Total Population**	**Number of Counties**
Pass	13,629,195	2,803,936	8,917,431	95,471	11,389,424	40,222,940	29,281,942	2,047,656	22,652,092	82,843,833	182,014,307	500
Fail	1,280,081	224,268	652,230	7,115	895,089	4,398,997	2,678,240	202,060	2,635,394	13,301,972	18,777,994	17
National Population in Counties with $PM_{2.5}$ Monitors	17,228,739	3,496,135	11,063,041	119,108	14,245,688	51,507,725	37,004,318	2,596,848	29,278,409	109,299,287	231,900,896	641

People at Risk from Ozone

	Chronic Diseases				Age Groups						
In Counties Where the Grades Were:	**Adult Asthma**	**Pediatric Asthma**	**COPD**	**CV Disease**	**Under 18**	**65 and Over**	**Pregnancies**	**Poverty**	**People of Color**	**Total Population**	**Number of Counties**
Grade A (0.0)	3,724,203	792,445	2,845,405	3,672,420	10,712,467	9,381,259	540,232	6,327,648	17,412,682	50,782,442	302
Grade B (0.3-0.9)	3,124,597	639,568	2,159,751	2,730,778	8,927,874	6,907,495	452,681	4,949,087	15,649,867	41,003,492	170
Grade C (1.0-2.0)	2,624,418	508,597	1,628,445	2,101,592	7,271,049	5,474,479	361,246	3,617,690	12,040,309	33,049,011	117
Grade D (2.1-3.2)	1,251,042	255,556	842,334	1,070,194	3,498,280	2,579,481	186,076	2,008,450	7,710,616	16,189,161	40
Grade F (3.3+)	7,409,618	1,477,630	4,369,962	5,685,100	23,640,266	15,377,344	1,158,834	12,847,236	57,655,731	103,024,220	124
National Population in Counties with Ozone Monitors	18,265,858	3,702,154	11,937,305	15,378,430	54,420,489	40,027,698	2,717,094	29,973,254	110,838,705	245,723,508	782

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Table 2a People at Risk in 25 U.S. Cities Most Polluted by Short-Term Particle Pollution (Daily PM$_{2.5}$)

2023 Rank	Metropolitan Statistical Areas	Total Population	Under 18	65 and Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	People of Color	Poverty
1	Bakersfield, CA	917,673	263,402	104,638	13,139	57,795	27,903	346	37,178	9,412	632,525	164,169
2	Fresno-Madera-Hanford, CA	1,326,434	370,656	166,947	18,488	84,458	41,730	499	56,129	13,906	954,184	248,788
3	Fairbanks, AK	95,593	22,506	11,366	1,485	6,595	3,866	49	4,450	1,261	29,724	7,247
4	Visalia, CA	477,054	144,196	55,572	7,193	29,409	14,362	179	19,237	4,989	351,235	88,367
5	Reno-Carson City-Fernley, NV	667,301	137,452	127,206	10,813	48,769	37,703	330	44,392	6,657	241,209	69,983
6	San Jose-San Francisco-Oakland, CA	9,545,921	2,028,372	1,520,400	101,177	665,484	346,398	3,589	482,268	101,021	6,071,450	909,294
7	Redding-Red Bluff, CA	247,637	55,298	51,533	2,759	17,057	9,749	93	14,037	2,248	62,837	35,248
8	Sacramento-Roseville, CA	2,697,399	608,540	445,410	30,355	184,931	97,656	1,013	136,361	28,177	1,325,731	317,925
9	Chico, CA	208,309	42,437	37,992	2,117	14,671	7,834	78	10,807	2,243	64,260	33,874
9	Los Angeles-Long Beach, CA	18,490,242	4,112,015	2,705,866	205,110	1,272,354	648,442	6,949	895,585	200,022	13,071,213	2,316,720
11	Yakima, WA	256,035	75,344	36,193	5,508	19,003	9,052	124	12,015	2,605	151,594	37,078
12	Eugene-Springfield, OR	383,189	68,642	78,561	4,771	35,390	19,103	180	25,578	3,785	74,138	53,989
13	Phoenix-Mesa, AZ	4,999,734	1,145,926	819,746	92,379	366,150	211,696	1,970	305,529	54,708	2,317,167	556,754
14	Spokane-Spokane Valley-Coeur d'Alene, WA-ID	773,255	169,457	138,509	12,097	62,288	32,986	367	44,834	8,216	117,315	83,167
15	Missoula, MT	119,533	21,817	19,996	1,095	9,688	5,096	56	6,475	1,479	13,804	15,043
16	San Diego-Chula Vista-Carlsbad, CA	3,286,069	698,371	489,101	34,835	228,821	115,946	1,237	158,242	35,582	1,848,397	340,522
17	Logan, UT-ID	152,083	45,387	15,795	2,542	10,555	4,465	43	5,738	2,254	24,513	15,911
18	Denver-Aurora, CO	3,642,145	785,279	504,471	51,802	299,680	139,933	1,383	154,061	40,646	1,297,572	316,593
19	Salt Lake City-Provo-Orem, UT	2,746,164	785,045	292,153	43,095	192,994	82,907	732	107,164	38,839	659,527	220,391
20	Pittsburgh-New Castle-Weirton, PA-OH-WV	2,637,506	499,377	554,715	32,720	221,020	153,253	1,559	216,368	26,029	386,787	293,775
21	Boise City-Mountain Home-Ontario, ID-OR	882,138	212,229	137,555	14,028	65,772	38,024	393	51,454	10,529	192,123	86,651
22	Fargo-Wahpeton, ND-MN	275,091	63,863	37,384	4,048	18,275	9,322	144	14,154	3,965	42,472	29,475
23	Salinas, CA	437,325	113,236	63,337	5,648	28,668	14,691	165	20,181	4,378	313,287	50,725
24	Lancaster, PA	553,652	129,256	104,237	8,421	44,025	28,838	325	40,807	5,542	108,092	47,460
25	Medford-Grants Pass, OR	312,080	63,156	74,256	4,389	27,924	16,607	146	22,984	2,601	59,577	44,396

Notes:

Cities are ranked using the highest weighted average for any county within that Combined Metropolitan Statistical Area or Metropolitan Statistical Area.

Adding across rows does not produce valid estimates. Adding the disease categories (asthma, COPD, etc.) will double-count people who fall into more than one category.

Table 2b People at Risk in 25 U.S. Cities Most Polluted by Year-Round Particle Pollution (Annual $PM_{2.5}$)

2023 Rank	Metropolitan Statistical Areas	Total Population	Under 18	65 and Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	People of Color	Poverty
1	Bakersfield, CA	917,673	263,402	104,638	13,139	57,795	27,903	346	37,178	9,412	632,525	164,169
1	Visalia, CA	477,054	144,196	55,572	7,193	29,409	14,362	179	19,237	4,989	351,235	88,367
3	Fresno-Madera-Hanford, CA	1,326,434	370,656	166,947	18,488	84,458	41,730	499	56,129	13,906	954,184	248,788
4	Los Angeles-Long Beach, CA	18,490,242	4,112,015	2,705,866	205,110	1,272,354	648,442	6,949	895,585	200,022	13,071,213	2,316,720
5	Fairbanks, AK	95,593	22,506	11,366	1,485	6,595	3,866	49	4,450	1,261	29,724	7,247
6	Sacramento-Roseville, CA	2,697,399	608,540	445,410	30,355	184,931	97,656	1,013	136,361	28,177	1,325,731	317,925
7	San Jose-San Francisco-Oakland, CA	9,545,921	2,028,372	1,520,400	101,177	665,484	346,398	3,589	482,268	101,021	6,071,450	909,294
7	Phoenix-Mesa, AZ	4,999,734	1,145,926	819,746	92,379	366,150	211,696	1,970	305,529	54,708	2,317,167	556,754
7	Medford-Grants Pass, OR	312,080	63,156	74,256	4,389	27,924	16,607	146	22,984	2,601	59,577	44,396
10	Indianapolis-Carmel-Muncie, IN	2,507,944	600,785	371,608	42,254	197,689	157,460	1,556	163,232	30,309	680,691	272,410
11	Yakima, WA	256,035	75,344	36,193	5,508	19,003	9,052	124	12,015	2,605	151,594	37,078
12	Detroit-Warren-Ann Arbor, MI	5,393,033	1,164,730	935,955	81,511	493,567	329,752	3,195	400,142	56,884	1,764,417	713,268
13	Chico, CA	208,309	42,437	37,992	2,117	14,671	7,834	78	10,807	2,243	64,260	33,874
14	Pittsburgh-New Castle-Weirton, PA-OH-WV	2,637,506	499,377	554,715	32,720	221,020	153,253	1,559	216,368	26,029	386,787	293,775
15	Eugene-Springfield, OR	383,189	68,642	78,561	4,771	35,390	19,103	180	25,578	3,785	74,138	53,989
15	Augusta-Richmond County, GA-SC	615,933	140,717	104,050	12,390	44,319	33,368	351	43,817	6,694	289,250	93,326
15	Houston-The Woodlands, TX	7,398,774	1,927,208	894,440	122,452	460,317	325,709	3,366	385,518	93,373	4,839,676	1,036,292
18	El Centro, CA	179,851	51,197	24,033	2,554	11,371	5,719	68	7,739	1,715	163,246	29,738
18	Cincinnati-Wilmington-Maysville, OH-KY-IN	2,318,870	538,113	373,954	30,908	192,950	158,476	1,591	182,639	26,076	496,399	273,458
18	Birmingham-Hoover-Talladega, AL	1,350,100	306,036	232,702	29,496	105,400	98,489	819	121,624	15,467	479,199	196,969
21	McAllen-Edinburg, TX	946,405	299,852	107,413	19,052	53,940	37,526	430	44,585	11,595	894,220	271,830
22	Louisville-Jefferson County--Elizabethtown--Bardstown, KY-IN	1,512,785	339,875	251,417	18,500	134,917	122,682	1,209	131,898	17,569	371,818	184,842
23	Bend-Prineville, OR	230,540	44,762	48,596	3,111	20,980	11,841	108	15,935	2,053	31,515	20,737
23	Laredo, TX	267,945	85,427	26,695	5,428	15,224	10,370	122	12,044	3,287	258,388	59,771
23	Chicago-Naperville, IL-IN-WI	9,876,339	2,202,143	1,552,155	154,670	680,535	440,098	5,694	620,403	105,565	4,679,774	1,117,401

Notes:

Cities are ranked using the highest design value for any county within that Combined Metropolitan Statistical Area or Metropolitan Statistical Area.

Adding across rows does not produce valid estimates. Adding the disease categories (asthma, COPD, etc.) will double-count people who have been diagnosed with more than one disease.

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Table 2c People at Risk in 25 Most Ozone-Polluted Cities

2023 Rank	Metropolitan Statistical Areas	Total Population	Under 18	65 and Over	Pediatric Asthma	Adult Asthma	COPD	CV Disease	Pregnancies	People of Color	Poverty
1	Los Angeles-Long Beach, CA	18,490,242	4,112,015	2,705,866	205,110	1,272,354	648,442	895,585	200,022	13,071,213	2,316,720
2	Visalia, CA	477,054	144,196	55,572	7,193	29,409	14,362	19,237	4,989	351,235	88,367
3	Bakersfield, CA	917,673	263,402	104,638	13,139	57,795	27,903	37,178	9,412	632,525	164,169
4	Fresno-Madera-Hanford, CA	1,326,434	370,656	166,947	18,488	84,458	41,730	56,129	13,906	954,184	248,788
5	Phoenix-Mesa, AZ	4,999,734	1,145,926	819,746	92,379	366,150	211,696	305,529	54,708	2,317,167	556,754
6	Denver-Aurora, CO	3,642,145	785,279	504,471	51,802	299,680	139,933	154,061	40,646	1,297,572	316,593
7	Sacramento-Roseville, CA	2,697,399	608,540	445,410	30,355	184,931	97,656	136,361	28,177	1,325,731	317,925
8	San Diego-Chula Vista-Carlsbad, CA	3,286,069	698,371	489,101	34,835	228,821	115,946	158,242	35,582	1,848,397	340,522
9	Houston-The Woodlands, TX	7,398,774	1,927,208	894,440	122,452	460,317	325,709	385,518	93,373	4,839,676	1,036,292
10	Salt Lake City-Provo-Orem, UT	2,746,164	785,045	292,153	43,095	192,994	82,907	107,164	38,839	659,527	220,391
11	San Jose-San Francisco-Oakland, CA	9,545,921	2,028,372	1,520,400	101,177	665,484	346,398	482,268	101,021	6,071,450	909,294
12	New York-Newark, NY-NJ-CT-PA	23,216,685	4,946,442	3,913,804	314,901	1,788,239	1,000,958	1,337,984	250,084	12,213,038	2,870,717
13	El Centro, CA	179,851	51,197	24,033	2,554	11,371	5,719	7,739	1,715	163,246	29,738
14	El Paso-Las Cruces, TX-NM	1,092,742	283,266	147,908	17,962	71,440	46,479	56,620	13,159	935,784	214,015
15	Las Vegas-Henderson, NV	2,345,926	529,254	370,191	41,638	168,013	121,877	141,494	25,489	1,395,591	349,176
15	Fort Collins, CO	362,533	68,005	61,379	4,486	30,662	14,940	16,910	4,105	67,328	39,476
17	Chicago-Naperville, IL-IN-WI	9,876,339	2,202,143	1,552,155	154,670	680,535	440,098	620,403	105,565	4,679,774	1,117,401
18	Dallas-Fort Worth, TX-OK	8,255,035	2,083,340	1,018,460	132,756	521,173	370,988	440,083	105,121	4,500,196	906,907
19	Reno-Carson City-Fernley, NV	667,301	137,452	127,206	10,813	48,769	37,703	44,392	6,657	241,209	69,983
20	Colorado Springs, CO	762,793	176,921	105,976	11,671	61,320	28,699	31,692	8,086	242,008	70,686
21	San Luis Obispo-Paso Robles, CA	283,159	49,467	60,618	2,467	20,693	11,570	16,302	2,799	92,156	35,120
22	Redding-Red Bluff, CA	247,637	55,298	51,533	2,759	17,057	9,749	14,037	2,248	62,837	35,248
23	San Antonio-New Braunfels-Pearsall, TX	2,620,224	646,677	354,220	41,090	165,851	118,941	143,217	32,782	1,774,924	349,662
24	Albuquerque-Santa Fe-Las Vegas, NM	1,164,315	240,933	224,610	15,143	97,051	51,622	68,194	11,668	727,810	166,601
25	Hartford-East Hartford, CT	1,480,711	291,345	271,448	25,974	126,841	62,083	85,370	14,582	496,015	141,220

Notes:

Cities are ranked using the highest weighted average for any county within that Combined Metropolitan Statistical Area or Metropolitan Statistical Area.

Adding across rows does not produce valid estimates. Adding the disease categories (asthma, COPD, etc.) will double-count people who have been diagnosed with more than one disease.

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Table 3a Cleanest U.S. Cities for Short-Term Particle Pollution (Daily PM$_{2.5}$)

Metropolitan Statistical Area	Population
Amarillo-Pampa-Borger, TX	312,025
Asheville-Marion-Brevard, NC	550,223
Bangor, ME	152,765
Baton Rouge, LA	871,905
Bloomington-Bedford, IN	206,391
Brunswick, GA	113,963
Burlington-Fort Madison-Keokuk, IA-IL-MO	102,154
Cape Coral-Fort Myers-Naples, FL	1,214,269
Cedar Rapids-Iowa City, IA	452,674
Champaign-Urbana, IL	222,696
Charlottesville, VA	222,688
Cleveland-Indianola, MS	55,710
Dayton-Springfield-Kettering, OH	1,087,422
Erie-Meadville, PA	352,362
Fayetteville-Springdale-Rogers, AR	560,709
Florence, SC	199,259
Gadsden, AL	103,162
Greenville-Kinston-Washington, NC	271,343
Gulfport-Biloxi, MS	418,082
Harrisonburg-Staunton, VA	261,598
Hattiesburg-Laurel, MS	256,113
Hickory-Lenoir-Morganton, NC	366,441
Hot Springs-Malvern, AR	133,478
Houma-Thibodaux, LA	206,212
Huntsville-Decatur, AL	659,486
Johnson City-Kingsport-Bristol, TN-VA	516,729
Kokomo-Peru, IN	119,768
Lafayette-West Lafayette-Frankfort, IN	257,774
Lake Charles-Jennings, LA	242,707
Lansing-East Lansing, MI	540,281
Lexington-Fayette--Richmond--Frankfort, KY	749,512
Lima-Van Wert-Celina, OH	218,852
Lincoln-Beatrice, NE	363,733
Lynchburg, VA	262,258
Midland-Odessa, TX	334,271
Mobile-Daphne-Fairhope, AL	667,514
Montgomery-Selma-Alexander City, AL	474,890
Morgantown-Fairmont, WV	196,746
New Orleans-Metairie-Hammond, LA-MS	1,498,579
North Port-Sarasota, FL	1,089,011
Orlando-Lakeland-Deltona, FL	4,291,852
Owensboro, KY	121,227
Palm Bay-Melbourne-Titusville, FL	616,628
Parkersburg-Marietta-Vienna, WV-OH	148,110
Pensacola-Ferry Pass, FL-AL	553,087
Ponce-Yauco-Coamo, PR	361,201
Portland-Lewiston-South Portland, ME	667,927
Rochester-Batavia-Seneca Falls, NY	1,176,514
Rocky Mount-Wilson-Roanoke Rapids, NC	287,305
Saginaw-Midland-Bay City, MI	376,033
Salisbury-Cambridge, MD-DE	461,712
San Juan-Bayamón, PR	2,344,305
Scottsboro-Fort Payne, AL	124,586
Springfield-Jacksonville-Lincoln, IL	305,994
Tuscaloosa, AL	268,191
Urban Honolulu, HI	1,000,890
Virginia Beach-Norfolk, VA-NC	1,895,105
Waterloo-Cedar Falls, IA	167,796
Wilmington, NC	291,833

Note:

Monitors in these cities reported no days when PM$_{2.5}$ levels reached the unhealthful range using the Air Quality Index based on the 2012 NAAQS.

Table 3b Top 25 Cleanest U.S. Cities for Year-Round Particle Pollution (Annual $PM_{2.5}$)

2023 Rank	Design Value	Metropolitan Statistical Area	Population
1	3.7	Urban Honolulu, HI	1,000,890
1	3.7	Kahului-Wailuku-Lahaina, HI	164,221
3	4.1	Cheyenne, WY	100,863
3	4.1	Wilmington, NC	291,833
5	4.4	Bangor, ME	152,765
6	4.7	Bellingham, WA	228,831
7	5.3	St. George, UT	191,226
8	5.4	Duluth, MN-WI	290,780
9	5.6	Amarillo-Pampa-Borger, TX	312,025
9	5.6	Colorado Springs, CO	762,793
9	5.6	Salisbury-Cambridge, MD-DE	461,712
12	5.8	Grand Junction, CO	157,335
12	5.8	Elmira-Corning, NY	175,993
14	5.9	Asheville-Marion-Brevard, NC	550,223
14	5.9	Saginaw-Midland-Bay City, MI	376,033
16	6.0	Lubbock-Plainview-Levelland, TX	378,828
17	6.1	Lynchburg, VA	262,258
18	6.2	Syracuse-Auburn, NY	734,161
19	6.3	Greenville-Kinston-Washington, NC	271,343
19	6.3	Rochester-Austin, MN	267,309
21	6.5	Bismarck, ND	134,417
22	6.6	Johnson City-Kingsport-Bristol, TN-VA	516,729
22	6.6	Lima-Van Wert-Celina, OH	218,852
22	6.6	Lincoln-Beatrice, NE	363,733
22	6.6	Rochester-Batavia-Seneca Falls, NY	1,176,514

Notes:
Cities are ranked by using the highest design value for any county within that metropolitan area.

Table 3c Cleanest U.S. Cities for Ozone Air Pollution

Metropolitan Statistical Area	Population
Albany-Schenectady, NY	1,190,312
Asheville-Marion-Brevard, NC	550,223
Bangor, ME	152,765
Bellingham, WA	228,831
Blacksburg-Christiansburg, VA	165,293
Bowling Green-Glasgow, KY	237,487
Brownsville-Harlingen-Raymondville, TX	443,345
Brunswick, GA	113,963
Burlington-South Burlington-Barre, VT	286,580
Charleston-Huntington-Ashland, WV-OH-KY	771,171
Charlottesville, VA	222,688
Clarksville, TN-KY	328,304
Cleveland-Indianola, MS	55,710
Columbia-Moberly-Mexico, MO	262,865
Columbus-Auburn-Opelika, GA-AL	504,754
Crestview-Fort Walton Beach-Destin, FL	293,324
Decatur, IL	102,432
Des Moines-Ames-West Des Moines, IA	900,705
Duluth, MN-WI	290,780
Eau Claire-Menomonie, WI	218,864
Elmira-Corning, NY	175,993
Erie-Meadville, PA	352,362
Fairbanks, AK	95,593
Fayetteville-Sanford-Lumberton, NC	842,044
Flagstaff, AZ	145,052
Florence, SC	199,259
Gadsden, AL	103,162
Gainesville-Lake City, FL	412,141
Greensboro--Winston-Salem--High Point, NC	1,705,315
Greenville-Kinston-Washington, NC	271,343
Harrisonburg-Staunton, VA	261,598
Hickory-Lenoir-Morganton, NC	366,441
Jackson-Vicksburg-Brookhaven, MS	665,724
Jacksonville-St. Marys-Palatka, FL-GA	1,767,497
Jefferson City, MO	150,706
Johnstown-Somerset, PA	205,794
La Crosse-Onalaska, WI-MN	139,211
Lafayette-Opelousas-Morgan City, LA	609,515
Lansing-East Lansing, MI	540,281
Laredo, TX	267,945
Lawton, OK	127,543
Lincoln-Beatrice, NE	363,733
Mayagüez-San Germán, PR	220,914
Mobile-Daphne-Fairhope, AL	667,514
Monroe-Ruston, LA	253,036
Morgantown-Fairmont, WV	196,746
Myrtle Beach-Conway, SC-NC	573,715
New Bern-Morehead City, NC	190,814
Palm Bay-Melbourne-Titusville, FL	616,628
Panama City, FL	179,168
Pittsfield, MA	128,657
Quincy-Hannibal, IL-MO	113,833
Raleigh-Durham-Cary, NC	2,144,608
Roanoke, VA	314,496
Rochester-Austin, MN	267,309
Rochester-Batavia-Seneca Falls, NY	1,176,514
Rocky Mount-Wilson-Roanoke Rapids, NC	287,305
Salinas, CA	437,325
San Juan-Bayamón, PR	2,344,305
Savannah-Hinesville-Statesboro, GA	605,693
Scottsboro-Fort Payne, AL	124,586
Scranton--Wilkes-Barre, PA	567,750
Sebring-Avon Park, FL	103,296
Shreveport-Bossier City-Minden, LA	425,339
Springfield, MO	481,483
Springfield-Jacksonville-Lincoln, IL	305,994
State College-DuBois, PA	237,609
Syracuse-Auburn, NY	734,161
Terre Haute, IN	184,910
Tupelo-Corinth, MS	197,511
Tuscaloosa, AL	268,191
Urban Honolulu, HI	1,000,890
Victoria-Port Lavaca, TX	117,854
Virginia Beach-Norfolk, VA-NC	1,895,105
Waco, TX	280,428
Waterloo-Cedar Falls, IA	167,796
Watertown-Fort Drum, NY	116,295
Wausau-Stevens Point-Wisconsin Rapids, WI	310,727
Williamsport-Lock Haven, PA	151,070
Wilmington, NC	291,833

Notes:
This list represents cities with no monitored ozone air pollution in unhealthful ranges using the Air Quality Index based on 2015 NAAQS.

Table 4a Cleanest Counties for Short-Term Particle Pollution (Daily $PM_{2.5}$)

County	State	Metropolitan Statistical Area
Baldwin	AL	Mobile-Daphne-Fairhope, AL
Clay	AL	
DeKalb	AL	Scottsboro-Fort Payne, AL
Etowah	AL	Gadsden, AL
Madison	AL	Huntsville-Decatur, AL
Mobile	AL	Mobile-Daphne-Fairhope, AL
Montgomery	AL	Montgomery-Selma-Alexander City, AL
Morgan	AL	Huntsville-Decatur, AL
Tuscaloosa	AL	Tuscaloosa, AL
Arkansas	AR	
Ashley	AR	
Crittenden	AR	Memphis-Forrest City, TN-MS-AR
Garland	AR	Hot Springs-Malvern, AR
Jackson	AR	
Polk	AR	
Union	AR	
Washington	AR	Fayetteville-Springdale-Rogers, AR
Apache	AZ	
Pima	AZ	Tucson-Nogales, AZ
Kent	DE	Philadelphia-Reading-Camden, PA-NJ-DE-MD
Sussex	DE	Salisbury-Cambridge, MD-DE
Brevard	FL	Palm Bay-Melbourne-Titusville, FL
Escambia	FL	Pensacola-Ferry Pass, FL-AL
Lee	FL	Cape Coral-Fort Myers-Naples, FL
Orange	FL	Orlando-Lakeland-Deltona, FL
Palm Beach	FL	Miami-Port St. Lucie-Fort Lauderdale, FL
Pinellas	FL	Tampa-St. Petersburg-Clearwater, FL
Polk	FL	Orlando-Lakeland-Deltona, FL
Sarasota	FL	North Port-Sarasota, FL
Seminole	FL	Orlando-Lakeland-Deltona, FL
Volusia	FL	Orlando-Lakeland-Deltona, FL
Clayton	GA	Atlanta--Athens-Clarke County--Sandy Springs, GA-AL
Cobb	GA	Atlanta--Athens-Clarke County--Sandy Springs, GA-AL
Fulton	GA	Atlanta--Athens-Clarke County--Sandy Springs, GA-AL
Glynn	GA	Brunswick, GA
Hall	GA	Atlanta--Athens-Clarke County--Sandy Springs, GA-AL
Hawaii	HI	
Honolulu	HI	Urban Honolulu, HI
Kauai	HI	
Black Hawk	IA	Waterloo-Cedar Falls, IA
Clinton	IA	Davenport-Moline, IA-IL
Johnson	IA	Cedar Rapids-Iowa City, IA
Lee	IA	Burlington-Fort Madison-Keokuk, IA-IL-MO
Linn	IA	Cedar Rapids-Iowa City, IA
Montgomery	IA	
Van Buren	IA	
Champaign	IL	Champaign-Urbana, IL
DuPage	IL	Chicago-Naperville, IL-IN-WI
Jersey	IL	St. Louis-St. Charles-Farmington, MO-IL
Madison	IL	St. Louis-St. Charles-Farmington, MO-IL
McHenry	IL	Chicago-Naperville, IL-IN-WI
Sangamon	IL	Springfield-Jacksonville-Lincoln, IL
St. Clair	IL	St. Louis-St. Charles-Farmington, MO-IL
Bartholomew	IN	Indianapolis-Carmel-Muncie, IN
Clark	IN	Louisville-Jefferson County--Elizabethtown--Bardstown, KY-IN
Delaware	IN	Indianapolis-Carmel-Muncie, IN
Dubois	IN	
Greene	IN	
Hamilton	IN	Indianapolis-Carmel-Muncie, IN
Henry	IN	Indianapolis-Carmel-Muncie, IN
Howard	IN	Kokomo-Peru, IN
Madison	IN	Indianapolis-Carmel-Muncie, IN
Monroe	IN	Bloomington-Bedford, IN
Spencer	IN	
Tippecanoe	IN	Lafayette-West Lafayette-Frankfort, IN
Whitley	IN	Fort Wayne-Huntington-Auburn, IN
Campbell	KY	Cincinnati-Wilmington-Maysville, OH-KY-IN
Carter	KY	Charleston-Huntington-Ashland, WV-OH-KY
Christian	KY	Clarksville, TN-KY
Daviess	KY	Owensboro, KY
Fayette	KY	Lexington-Fayette--Richmond--Frankfort, KY
Hardin	KY	Louisville-Jefferson County--Elizabethtown--Bardstown, KY-IN
Perry	KY	
Calcasieu Parish	LA	Lake Charles-Jennings, LA
East Baton Rouge Parish	LA	Baton Rouge, LA
Iberville Parish	LA	Baton Rouge, LA
Jefferson Parish	LA	New Orleans-Metairie-Hammond, LA-MS
Orleans Parish	LA	New Orleans-Metairie-Hammond, LA-MS
St. Bernard Parish	LA	New Orleans-Metairie-Hammond, LA-MS
Tangipahoa Parish	LA	New Orleans-Metairie-Hammond, LA-MS
Terrebonne Parish	LA	Houma-Thibodaux, LA
West Baton Rouge Parish	LA	Baton Rouge, LA
Bristol	MA	Boston-Worcester-Providence, MA-RI-NH-CT
Franklin	MA	Springfield, MA
Hampshire	MA	Springfield, MA
Dorchester	MD	Salisbury-Cambridge, MD-DE
Garrett	MD	
Harford	MD	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Howard	MD	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Kent	MD	

Notes:

Monitors in these counties reported no days when $PM_{2.5}$ levels reached the unhealthful range using the Air Quality Index based on the 2012 NAAQS.

Table 4a Cleanest Counties for Short-Term Particle Pollution (24-hour $PM_{2.5}$) (cont.)

County	State	Metropolitan Statistical Area
Montgomery	MD	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Prince George's	MD	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Washington	MD	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Androscoggin	ME	Portland-Lewiston-South Portland, ME
Cumberland	ME	Portland-Lewiston-South Portland, ME
Hancock	ME	
Kennebec	ME	
Penobscot	ME	Bangor, ME
Allegan	MI	Grand Rapids-Kentwood-Muskegon, MI
Bay	MI	Saginaw-Midland-Bay City, MI
Genesee	MI	Detroit-Warren-Ann Arbor, MI
Ingham	MI	Lansing-East Lansing, MI
Lenawee	MI	Detroit-Warren-Ann Arbor, MI
Macomb	MI	Detroit-Warren-Ann Arbor, MI
Manistee	MI	
Missaukee	MI	
Oakland	MI	Detroit-Warren-Ann Arbor, MI
Cedar	MO	
Clay	MO	Kansas City-Overland Park-Kansas City, MO-KS
Bolivar	MS	Cleveland-Indianola, MS
DeSoto	MS	Memphis-Forrest City, TN-MS-AR
Forrest	MS	Hattiesburg-Laurel, MS
Hancock	MS	Gulfport-Biloxi, MS
Harrison	MS	Gulfport-Biloxi, MS
Jackson	MS	Gulfport-Biloxi, MS
Buncombe	NC	Asheville-Marion-Brevard, NC
Catawba	NC	Hickory-Lenoir-Morganton, NC
Davidson	NC	Greensboro--Winston-Salem--High Point, NC
Durham	NC	Raleigh-Durham-Cary, NC
Guilford	NC	Greensboro--Winston-Salem--High Point, NC
Jackson	NC	
Johnston	NC	Raleigh-Durham-Cary, NC
New Hanover	NC	Wilmington, NC
Northampton	NC	Rocky Mount-Wilson-Roanoke Rapids, NC
Pitt	NC	Greenville-Kinston-Washington, NC
Rowan	NC	Charlotte-Concord, NC-SC
Lancaster	NE	Lincoln-Beatrice, NE
Atlantic	NJ	Philadelphia-Reading-Camden, PA-NJ-DE-MD
Cumberland	NJ	Philadelphia-Reading-Camden, PA-NJ-DE-MD
Gloucester	NJ	Philadelphia-Reading-Camden, PA-NJ-DE-MD
Hudson	NJ	New York-Newark, NY-NJ-CT-PA
Hunterdon	NJ	New York-Newark, NY-NJ-CT-PA
Morris	NJ	New York-Newark, NY-NJ-CT-PA
Chautauqua	NY	
Essex	NY	
Kings	NY	New York-Newark, NY-NJ-CT-PA
Monroe	NY	Rochester-Batavia-Seneca Falls, NY
New York	NY	New York-Newark, NY-NJ-CT-PA
Orange	NY	New York-Newark, NY-NJ-CT-PA
Richmond	NY	New York-Newark, NY-NJ-CT-PA
Suffolk	NY	New York-Newark, NY-NJ-CT-PA
Allen	OH	Lima-Van Wert-Celina, OH
Athens	OH	
Belmont	OH	Wheeling, WV-OH
Clark	OH	Dayton-Springfield-Kettering, OH
Harrison	OH	
Lake	OH	Cleveland-Akron-Canton, OH
Lawrence	OH	Charleston-Huntington-Ashland, WV-OH-KY
Medina	OH	Cleveland-Akron-Canton, OH
Montgomery	OH	Dayton-Springfield-Kettering, OH
Portage	OH	Cleveland-Akron-Canton, OH
Preble	OH	
Scioto	OH	Charleston-Huntington-Ashland, WV-OH-KY
Erie	PA	Erie-Meadville, PA
Adjuntas	PR	Ponce-Yauco-Coamo, PR
Bayamón	PR	San Juan-Bayamón, PR
Caguas	PR	San Juan-Bayamón, PR
Fajardo	PR	San Juan-Bayamón, PR
Guaynabo	PR	San Juan-Bayamón, PR
Ponce	PR	Ponce-Yauco-Coamo, PR
Washington	RI	Boston-Worcester-Providence, MA-RI-NH-CT
Chesterfield	SC	
Edgefield	SC	Augusta-Richmond County, GA-SC
Florence	SC	Florence, SC
Richland	SC	Columbia-Orangeburg-Newberry, SC
Spartanburg	SC	Greenville-Spartanburg-Anderson, SC
York	SC	Charlotte-Concord, NC-SC
Lawrence	TN	Nashville-Davidson--Murfreesboro, TN
Loudon	TN	Knoxville-Morristown-Sevierville, TN
McMinn	TN	Chattanooga-Cleveland-Dalton, TN-GA
Roane	TN	Knoxville-Morristown-Sevierville, TN
Sullivan	TN	Johnson City-Kingsport-Bristol, TN-VA
Ector	TX	Midland-Odessa, TX
Ellis	TX	Dallas-Fort Worth, TX-OK
Potter	TX	Amarillo-Pampa-Borger, TX
Albemarle	VA	Charlottesville, VA
Arlington	VA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Bristol City	VA	Johnson City-Kingsport-Bristol, TN-VA
Charles City	VA	Richmond, VA
Chesterfield	VA	Richmond, VA
Frederick	VA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Hampton City	VA	Virginia Beach-Norfolk, VA-NC
Loudoun	VA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Lynchburg City	VA	Lynchburg, VA

Notes:

Monitors in these counties reported no days when $PM_{2.5}$ levels reached the unhealthful range using the Air Quality Index based on the 2012 NAAQS.

Table 4a Cleanest Counties for Short-Term Particle Pollution (24-hour $PM_{2.5}$) (cont.)

County	State	Metropolitan Statistical Area
Norfolk City	VA	Virginia Beach-Norfolk, VA-NC
Rockingham	VA	Harrisonburg-Staunton, VA
Salem City	VA	Roanoke, VA
Virginia Beach City	VA	Virginia Beach-Norfolk, VA-NC
Skagit	WA	Seattle-Tacoma, WA
Dane	WI	Madison-Janesville-Beloit, WI
Dodge	WI	Milwaukee-Racine-Waukesha, WI
Ozaukee	WI	Milwaukee-Racine-Waukesha, WI
Cabell	WV	Charleston-Huntington-Ashland, WV-OH-KY
Hancock	WV	Pittsburgh-New Castle-Weirton, PA-OH-WV
Harrison	WV	
Kanawha	WV	Charleston-Huntington-Ashland, WV-OH-KY
Marion	WV	Morgantown-Fairmont, WV
Monongalia	WV	Morgantown-Fairmont, WV
Ohio	WV	Wheeling, WV-OH
Wood	WV	Parkersburg-Marietta-Vienna, WV-OH
Sheridan	WY	

Notes:

Monitors in these counties reported no days when $PM_{2.5}$ levels reached the unhealthful range using the Air Quality Index based on the 2012 NAAQS.

Table 4b Top 25 Cleanest Counties for Year-Round Particle Pollution (Annual $PM_{2.5}$)

2023 Rank	County	State	Design Value	Metropolitan Statistical Area
1	Fremont	WY	2.4	
2	Hawaii	HI	2.7	
3	Carlton	MN	2.8	Duluth, MN-WI
4	Gallatin	MT	3.0	
5	Kauai	HI	3.1	
6	Hancock	ME	3.2	
6	Essex	NY	3.2	
8	Cook	MN	3.3	
9	Sublette	WY	3.5	
9	Hillsborough	NH	3.5	Boston-Worcester-Providence, MA-RI-NH-CT
11	Custer	SD	3.6	
12	Honolulu	HI	3.7	Urban Honolulu, HI
12	Maui	HI	3.7	Kahului-Wailuku-Lahaina, HI
12	Hughes	SD	3.7	
15	La Paz	AZ	3.8	
16	New Hanover	NC	4.1	Wilmington, NC
16	Laramie	WY	4.1	Cheyenne, WY
18	Billings	ND	4.2	
18	Belknap	NH	4.2	Boston-Worcester-Providence, MA-RI-NH-CT
20	Park	WY	4.3	
20	Santa Fe	NM	4.3	Albuquerque-Santa Fe-Las Vegas, NM
22	Penobscot	ME	4.4	Bangor, ME
22	Teton	WY	4.4	
22	Aroostook	ME	4.4	
25	Washington	RI	4.5	Boston-Worcester-Providence, MA-RI-NH-CT

Notes:
Counties are ranked by Design Value.

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Table 4c Cleanest Counties for Ozone Air Pollution

County	State	Metropolitan Statistical Area
Denali Borough	AK	
Fairbanks North Star Borough	AK	Fairbanks, AK
Baldwin	AL	Mobile-Daphne-Fairhope, AL
DeKalb	AL	Scottsboro-Fort Payne, AL
Elmore	AL	Montgomery-Selma-Alexander City, AL
Etowah	AL	Gadsden, AL
Mobile	AL	Mobile-Daphne-Fairhope, AL
Morgan	AL	Huntsville-Decatur, AL
Russell	AL	Columbus-Auburn-Opelika, GA-AL
Sumter	AL	
Tuscaloosa	AL	Tuscaloosa, AL
Clark	AR	
Newton	AR	
Coconino	AZ	Flagstaff, AZ
Colusa	CA	
Glenn	CA	
Humboldt	CA	
Lake	CA	
Mendocino	CA	
Monterey	CA	Salinas, CA
Santa Cruz	CA	San Jose-San Francisco-Oakland, CA
Siskiyou	CA	
Sonoma	CA	San Jose-San Francisco-Oakland, CA
Archuleta	CO	
Delta	CO	
Sussex	DE	Salisbury-Cambridge, MD-DE
Alachua	FL	Gainesville-Lake City, FL
Baker	FL	Jacksonville-St. Marys-Palatka, FL-GA
Bay	FL	Panama City, FL
Brevard	FL	Palm Bay-Melbourne-Titusville, FL
Broward	FL	Miami-Port St. Lucie-Fort Lauderdale, FL
Collier	FL	Cape Coral-Fort Myers-Naples, FL
Columbia	FL	Gainesville-Lake City, FL
Duval	FL	Jacksonville-St. Marys-Palatka, FL-GA
Flagler	FL	Orlando-Lakeland-Deltona, FL
Highlands	FL	Sebring-Avon Park, FL
Holmes	FL	
Indian River	FL	Miami-Port St. Lucie-Fort Lauderdale, FL
Liberty	FL	
Martin	FL	Miami-Port St. Lucie-Fort Lauderdale, FL
Okaloosa	FL	Crestview-Fort Walton Beach-Destin, FL
Orange	FL	Orlando-Lakeland-Deltona, FL
Palm Beach	FL	Miami-Port St. Lucie-Fort Lauderdale, FL
Pasco	FL	Tampa-St. Petersburg-Clearwater, FL
Pinellas	FL	Tampa-St. Petersburg-Clearwater, FL
Polk	FL	Orlando-Lakeland-Deltona, FL
Santa Rosa	FL	Pensacola-Ferry Pass, FL-AL
Sarasota	FL	North Port-Sarasota, FL
Seminole	FL	Orlando-Lakeland-Deltona, FL
St. Lucie	FL	Miami-Port St. Lucie-Fort Lauderdale, FL
Volusia	FL	Orlando-Lakeland-Deltona, FL
Wakulla	FL	Tallahassee, FL
Chatham	GA	Savannah-Hinesville-Statesboro, GA
Chattooga	GA	Chattanooga-Cleveland-Dalton, TN-GA
Clarke	GA	Atlanta--Athens-Clarke County--Sandy Springs, GA-AL
Columbia	GA	Augusta-Richmond County, GA-SC
Glynn	GA	Brunswick, GA
Murray	GA	Chattanooga-Cleveland-Dalton, TN-GA
Muscogee	GA	Columbus-Auburn-Opelika, GA-AL
Sumter	GA	
Honolulu	HI	Urban Honolulu, HI
Bremer	IA	Waterloo-Cedar Falls, IA
Clinton	IA	Davenport-Moline, IA-IL
Harrison	IA	Omaha-Council Bluffs-Fremont, NE-IA
Montgomery	IA	
Palo Alto	IA	
Polk	IA	Des Moines-Ames-West Des Moines, IA
Van Buren	IA	
Adams	IL	Quincy-Hannibal, IL-MO
Clark	IL	
Effingham	IL	
Jo Daviess	IL	
Macon	IL	Decatur, IL
Macoupin	IL	St. Louis-St. Charles-Farmington, MO-IL
Sangamon	IL	Springfield-Jacksonville-Lincoln, IL
Bartholomew	IN	Indianapolis-Carmel-Muncie, IN
Brown	IN	Indianapolis-Carmel-Muncie, IN
Delaware	IN	Indianapolis-Carmel-Muncie, IN
Elkhart	IN	South Bend-Elkhart-Mishawaka, IN-MI
Greene	IN	
Hendricks	IN	Indianapolis-Carmel-Muncie, IN
Vigo	IN	Terre Haute, IN
Sumner	KS	Wichita-Winfield, KS
Trego	KS	
Bell	KY	
Boone	KY	Cincinnati-Wilmington-Maysville, OH-KY-IN
Boyd	KY	Charleston-Huntington-Ashland, WV-OH-KY
Carter	KY	Charleston-Huntington-Ashland, WV-OH-KY
Christian	KY	Clarksville, TN-KY
Edmonson	KY	Bowling Green-Glasgow, KY

Note:
This list represents counties with no monitored ozone air pollution in unhealthful ranges using the Air Quality Index based on 2015 NAAQS.

Table 4c Cleanest Counties for Ozone Air Pollution (cont.)

County	State	Metropolitan Statistical Area
Fayette	KY	Lexington-Fayette--Richmond--Frankfort, KY
Greenup	KY	Charleston-Huntington-Ashland, WV-OH-KY
Hancock	KY	Owensboro, KY
Morgan	KY	
Perry	KY	
Pike	KY	
Pulaski	KY	
Simpson	KY	
Trigg	KY	Clarksville, TN-KY
Warren	KY	Bowling Green-Glasgow, KY
Washington	KY	
Bossier Parish	LA	Shreveport-Bossier City-Minden, LA
Caddo Parish	LA	Shreveport-Bossier City-Minden, LA
Lafayette Parish	LA	Lafayette-Opelousas-Morgan City, LA
Ouachita Parish	LA	Monroe-Ruston, LA
St. Bernard Parish	LA	New Orleans-Metairie-Hammond, LA-MS
St. James Parish	LA	New Orleans-Metairie-Hammond, LA-MS
St. Martin Parish	LA	Lafayette-Opelousas-Morgan City, LA
St. Tammany Parish	LA	New Orleans-Metairie-Hammond, LA-MS
Berkshire	MA	Pittsfield, MA
Franklin	MA	Springfield, MA
Hampshire	MA	Springfield, MA
Middlesex	MA	Boston-Worcester-Providence, MA-RI-NH-CT
Garrett	MD	
Androscoggin	ME	Portland-Lewiston-South Portland, ME
Aroostook	ME	
Kennebec	ME	
Oxford	ME	
Penobscot	ME	Bangor, ME
Washington	ME	
Clinton	MI	Lansing-East Lansing, MI
Ingham	MI	Lansing-East Lansing, MI
Carlton	MN	Duluth, MN-WI
Goodhue	MN	Minneapolis-St. Paul, MN-WI
Hennepin	MN	Minneapolis-St. Paul, MN-WI
Lake	MN	Duluth, MN-WI
Lyon	MN	
Mille Lacs	MN	Minneapolis-St. Paul, MN-WI
Olmsted	MN	Rochester-Austin, MN
Scott	MN	Minneapolis-St. Paul, MN-WI
St. Louis	MN	Duluth, MN-WI
Stearns	MN	Minneapolis-St. Paul, MN-WI
Andrew	MO	Kansas City-Overland Park-Kansas City, MO-KS
Boone	MO	Columbia-Moberly-Mexico, MO
Callaway	MO	Jefferson City, MO
Cedar	MO	
Clinton	MO	Kansas City-Overland Park-Kansas City, MO-KS
Greene	MO	Springfield, MO
Monroe	MO	
Ste. Genevieve	MO	
Bolivar	MS	Cleveland-Indianola, MS
Hancock	MS	Gulfport-Biloxi, MS
Hinds	MS	Jackson-Vicksburg-Brookhaven, MS
Lauderdale	MS	
Lee	MS	Tupelo-Corinth, MS
Yalobusha	MS	
Flathead	MT	
Rosebud	MT	
Alexander	NC	Hickory-Lenoir-Morganton, NC
Avery	NC	
Buncombe	NC	Asheville-Marion-Brevard, NC
Caldwell	NC	Hickory-Lenoir-Morganton, NC
Carteret	NC	New Bern-Morehead City, NC
Caswell	NC	
Cumberland	NC	Fayetteville-Sanford-Lumberton, NC
Durham	NC	Raleigh-Durham-Cary, NC
Edgecombe	NC	Rocky Mount-Wilson-Roanoke Rapids, NC
Forsyth	NC	Greensboro--Winston-Salem--High Point, NC
Graham	NC	
Granville	NC	Raleigh-Durham-Cary, NC
Guilford	NC	Greensboro--Winston-Salem--High Point, NC
Haywood	NC	Asheville-Marion-Brevard, NC
Johnston	NC	Raleigh-Durham-Cary, NC
Lenoir	NC	Greenville-Kinston-Washington, NC
Lincoln	NC	Charlotte-Concord, NC-SC
Macon	NC	
Martin	NC	
Montgomery	NC	
New Hanover	NC	Wilmington, NC
Person	NC	Raleigh-Durham-Cary, NC
Pitt	NC	Greenville-Kinston-Washington, NC
Rockingham	NC	Greensboro--Winston-Salem--High Point, NC
Rowan	NC	Charlotte-Concord, NC-SC
Swain	NC	
Wake	NC	Raleigh-Durham-Cary, NC
Yancey	NC	
Burke	ND	
Burleigh	ND	Bismarck, ND
McKenzie	ND	
Ward	ND	
Lancaster	NE	Lincoln-Beatrice, NE
Belknap	NH	Boston-Worcester-Providence, MA-RI-NH-CT

Note:
This list represents counties with no monitored ozone air pollution in unhealthful ranges using the Air Quality Index based on 2015 NAAQS.

Table 4c Cleanest Counties for Ozone Air Pollution (cont.)

County	State	Metropolitan Statistical Area
Cheshire	NH	
Grafton	NH	
Hillsborough	NH	Boston-Worcester-Providence, MA-RI-NH-CT
Morris	NJ	New York-Newark, NY-NJ-CT-PA
Warren	NJ	Allentown-Bethlehem-Easton, PA-NJ
Albany	NY	Albany-Schenectady, NY
Hamilton	NY	
Jefferson	NY	Watertown-Fort Drum, NY
Monroe	NY	Rochester-Batavia-Seneca Falls, NY
Onondaga	NY	Syracuse-Auburn, NY
Orange	NY	New York-Newark, NY-NJ-CT-PA
Oswego	NY	Syracuse-Auburn, NY
Saratoga	NY	Albany-Schenectady, NY
Steuben	NY	Elmira-Corning, NY
Wayne	NY	Rochester-Batavia-Seneca Falls, NY
Clinton	OH	Cincinnati-Wilmington-Maysville, OH-KY-IN
Fayette	OH	Columbus-Marion-Zanesville, OH
Greene	OH	Dayton-Springfield-Kettering, OH
Knox	OH	Columbus-Marion-Zanesville, OH
Lawrence	OH	Charleston-Huntington-Ashland, WV-OH-KY
Licking	OH	Columbus-Marion-Zanesville, OH
Lorain	OH	Cleveland-Akron-Canton, OH
Madison	OH	Columbus-Marion-Zanesville, OH
Mahoning	OH	Youngstown-Warren, OH-PA
Medina	OH	Cleveland-Akron-Canton, OH
Miami	OH	Dayton-Springfield-Kettering, OH
Noble	OH	
Wood	OH	Toledo-Findlay-Tiffin, OH
Adair	OK	
Cleveland	OK	Oklahoma City-Shawnee, OK
Comanche	OK	Lawton, OK
Dewey	OK	
Mayes	OK	
Osage	OK	Tulsa-Muskogee-Bartlesville, OK
Columbia	OR	Portland-Vancouver-Salem, OR-WA
Marion	OR	Portland-Vancouver-Salem, OR-WA
Bradford	PA	
Cambria	PA	Johnstown-Somerset, PA
Centre	PA	State College-DuBois, PA
Clearfield	PA	State College-DuBois, PA
Dauphin	PA	Harrisburg-York-Lebanon, PA
Elk	PA	
Erie	PA	Erie-Meadville, PA
Fayette	PA	Pittsburgh-New Castle-Weirton, PA-OH-WV
Franklin	PA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Lackawanna	PA	Scranton--Wilkes-Barre, PA
Lawrence	PA	Pittsburgh-New Castle-Weirton, PA-OH-WV
Lehigh	PA	Allentown-Bethlehem-Easton, PA-NJ
Luzerne	PA	Scranton--Wilkes-Barre, PA
Lycoming	PA	Williamsport-Lock Haven, PA
Monroe	PA	New York-Newark, NY-NJ-CT-PA
Somerset	PA	Johnstown-Somerset, PA
Tioga	PA	
Washington	PA	Pittsburgh-New Castle-Weirton, PA-OH-WV
Westmoreland	PA	Pittsburgh-New Castle-Weirton, PA-OH-WV
York	PA	Harrisburg-York-Lebanon, PA
Bayamón	PR	San Juan-Bayamón, PR
Cataño	PR	San Juan-Bayamón, PR
Mayagüez	PR	Mayagüez-San Germán, PR
Aiken	SC	Augusta-Richmond County, GA-SC
Berkeley	SC	Charleston-North Charleston, SC
Chesterfield	SC	
Darlington	SC	Florence, SC
Edgefield	SC	Augusta-Richmond County, GA-SC
Horry	SC	Myrtle Beach-Conway, SC-NC
Jackson	SD	
Claiborne	TN	
DeKalb	TN	
Jefferson	TN	Knoxville-Morristown-Sevierville, TN
Knox	TN	Knoxville-Morristown-Sevierville, TN
Loudon	TN	Knoxville-Morristown-Sevierville, TN
Sevier	TN	Knoxville-Morristown-Sevierville, TN
Williamson	TN	Nashville-Davidson--Murfreesboro, TN
Wilson	TN	Nashville-Davidson--Murfreesboro, TN
Brewster	TX	
Cameron	TX	Brownsville-Harlingen-Raymondville, TX
Harrison	TX	Longview, TX
Hunt	TX	Dallas-Fort Worth, TX-OK
Kaufman	TX	Dallas-Fort Worth, TX-OK
McLennan	TX	Waco, TX
Navarro	TX	Dallas-Fort Worth, TX-OK
Polk	TX	
Victoria	TX	Victoria-Port Lavaca, TX
Webb	TX	Laredo, TX
Albemarle	VA	Charlottesville, VA
Charles City	VA	Richmond, VA
Fauquier	VA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Frederick	VA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Giles	VA	Blacksburg-Christiansburg, VA
Hampton City	VA	Virginia Beach-Norfolk, VA-NC
Hanover	VA	Richmond, VA
Henrico	VA	Richmond, VA

Note:
This list represents counties with no monitored ozone air pollution in unhealthful ranges using the Air Quality Index based on 2015 NAAQS.

Table 4c Cleanest Counties for Ozone Air Pollution (cont.)

County	State	Metropolitan Statistical Area
Madison	VA	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Prince Edward	VA	
Roanoke	VA	Roanoke, VA
Rockbridge	VA	
Rockingham	VA	Harrisonburg-Staunton, VA
Suffolk City	VA	Virginia Beach-Norfolk, VA-NC
Wythe	VA	
Bennington	VT	
Chittenden	VT	Burlington-South Burlington-Barre, VT
Rutland	VT	
Clallam	WA	
Clark	WA	Portland-Vancouver-Salem, OR-WA
Skagit	WA	Seattle-Tacoma, WA
Whatcom	WA	Bellingham, WA
Eau Claire	WI	Eau Claire-Menomonie, WI
Forest	WI	
La Crosse	WI	La Crosse-Onalaska, WI-MN
Marathon	WI	Wausau-Stevens Point-Wisconsin Rapids, WI
Taylor	WI	
Vilas	WI	
Berkeley	WV	Washington-Baltimore-Arlington, DC-MD-VA-WV-PA
Cabell	WV	Charleston-Huntington-Ashland, WV-OH-KY
Gilmer	WV	
Greenbrier	WV	
Kanawha	WV	Charleston-Huntington-Ashland, WV-OH-KY
Monongalia	WV	Morgantown-Fairmont, WV
Tucker	WV	
Wood	WV	Parkersburg-Marietta-Vienna, WV-OH

Note:
This list represents counties with no monitored ozone air pollution in unhealthful ranges using the Air Quality Index based on 2015 NAAQS.

ALABAMA

American Lung Association in Alabama

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Baldwin	0	0	0	0.0	A	0	0	0	0	0.0	A	7.6	Pass
Clay	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.0	Pass
Colbert	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC
DeKalb	0	0	0	0.0	A	0	0	0	0	0.0	A	7.5	Pass
Elmore	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Etowah	0	0	0	0.0	A	0	0	0	0	0.0	A	8.2	Pass
Houston	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC
Jefferson	13	0	0	4.3	F	1	0	0	0	0.3	B	11.0	Pass
Madison	2	0	0	0.7	B	0	0	0	0	0.0	A	7.3	Pass
Mobile	0	0	0	0.0	A	0	0	0	0	0.0	A	8.0	Pass
Montgomery	1	0	0	0.3	B	0	0	0	0	0.0	A	8.2	Pass
Morgan	0	0	0	0.0	A	0	0	0	0	0.0	A	7.3	Pass
Russell	0	0	0	0.0	A	3	0	0	0	1.0	C	9.3	Pass
Shelby	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Sumter	0	0	0	0.0	A	INC	INC	INC	INC	INC	INC	INC	INC
Tuscaloosa	0	0	0	0.0	A	0	0	0	0	0.0	A	7.7	Pass

ALABAMA

American Lung Association in Alabama

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Baldwin	239,294	50,774	51,376	4,893	19,042	19,008	145	24,205	2,430	25,526	40,324
Clay	14,190	2,908	3,012	280	1,143	1,142	9	1,455	144	2,560	2,780
Colbert	57,474	12,211	11,641	1,177	4,568	4,461	35	5,626	610	9,396	13,055
DeKalb	71,813	17,290	12,694	1,666	5,519	5,268	44	6,567	749	13,783	15,079
Elmore	89,304	19,665	14,554	1,895	7,051	6,528	54	8,016	1,048	10,138	24,278
Etowah	103,162	22,336	19,957	2,153	8,169	7,905	63	9,923	1,117	17,605	23,831
Houston	107,458	24,532	19,938	2,364	8,368	7,993	65	9,978	1,199	20,210	37,262
Jefferson	667,820	153,073	111,386	14,752	51,824	47,597	403	58,326	8,040	110,131	341,184
Madison	395,211	85,610	61,262	8,250	31,350	28,593	241	34,850	4,563	39,316	141,436
Mobile	413,073	96,569	70,330	9,307	31,905	29,652	250	36,537	4,809	74,061	181,944
Montgomery	227,434	54,005	36,348	5,205	17,461	15,889	137	19,380	2,757	47,309	156,663
Morgan	123,668	28,618	22,348	2,758	9,620	9,209	75	11,496	1,284	16,459	31,662
Russell	58,722	14,264	8,889	1,375	4,497	4,099	36	4,996	697	12,620	32,398
Shelby	226,902	51,805	37,385	4,993	17,746	16,577	138	20,442	2,610	17,306	54,330
Sumter	12,164	2,369	2,415	228	978	914	7	1,132	153	4,005	9,085
Tuscaloosa	227,007	47,984	32,306	4,624	17,936	15,403	138	18,247	3,092	31,735	90,707

ALASKA

American Lung Association in Alaska

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Anchorage Municipality	DNC	DNC	DNC	DNC	DNC	6	4	0	0	4.0	F	6.7	Pass
Denali Borough	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Fairbanks North Star Borough	0	0	0	0.0	A	43	39	1	3	37.0	F	13.2	Fail
Juneau City and Borough	DNC	DNC	DNC	DNC	DNC	4	0	0	0	1.3	C	5.4	Pass
Matanuska-Susitna Borough	DNC	DNC	DNC	DNC	DNC	4	1	0	0	1.8	C	5.2	Pass

ALASKA

American Lung Association in Alaska

	AT-RISK GROUPS										
				Lung Diseases							
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Pregnancies**	**Poverty**	**People of Color**
Anchorage Municipality	288,121	68,780	35,974	4,537	19,890	12,277	149	14,192	3,919	26,920	126,653
Denali Borough	1,593	279	204	18	120	76	1	88	21	115	383
Fairbanks North Star Borough	95,593	22,506	11,366	1,485	6,595	3,866	49	4,450	1,261	7,247	29,724
Juneau City and Borough	31,973	6,596	4,863	435	2,306	1,545	17	1,810	421	2,378	11,587
Matanuska-Susitna Borough	110,686	405	175	27	92	60	1	70	17	11,453	24,585

ARIZONA

American Lung Association in Arizona

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Apache	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Cochise	3	0	0	1.0	C	INC	INC	INC	INC	INC	INC	INC	INC
Coconino	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Gila	30	4	0	12.0	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
La Paz	1	0	0	0.3	B	1	0	0	0	0.3	B	3.8	Pass
Maricopa	111	7	1	41.2	F	12	3	1	0	6.2	F	9.8	Pass
Navajo	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Pima	11	0	0	3.7	F	0	0	0	0	0.0	A	5.0	Pass
Pinal	52	1	0	17.8	F	35	2	0	0	12.7	F	13.0	Fail
Santa Cruz	DNC	DNC	DNC	DNC	DNC	7	2	0	0	3.3	F	10.0	Pass
Yavapai	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Yuma	3	0	0	1.0	C	2	0	0	0	0.7	B	8.8	Pass

ARIZONA

American Lung Association in Arizona

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Apache	65,623	17,469	10,706	1,408	4,568	2,710	26	3,947	640	18,422	53,761
Cochise	126,050	26,564	29,889	2,141	9,305	6,244	50	9,468	1,105	20,618	57,472
Coconino	145,052	28,909	20,390	2,331	11,101	5,790	57	8,027	1,927	22,677	67,427
Gila	53,589	10,389	16,017	838	3,991	3,034	21	4,763	406	8,900	20,718
La Paz	16,408	2,664	6,697	215	1,242	1,089	6	1,768	110	3,303	7,303
Maricopa	4,496,588	1,036,370	709,277	83,547	329,205	187,686	1,771	269,474	50,129	502,224	2,094,356
Navajo	108,147	27,876	20,899	2,247	7,564	4,802	43	7,157	974	26,324	62,696
Pima	1,052,030	213,306	217,441	17,196	79,018	49,196	414	72,863	11,223	151,169	523,375
Pinal	449,557	99,167	94,452	7,994	32,954	20,976	178	31,292	4,173	45,630	202,093
Santa Cruz	47,883	12,566	9,175	1,013	3,328	2,101	19	3,126	478	9,723	40,473
Yavapai	242,253	38,015	81,576	3,065	18,772	14,905	95	23,653	1,756	29,766	50,105
Yuma	206,990	51,894	40,569	4,183	14,601	8,993	82	13,272	1,983	34,270	146,493

ARKANSAS

American Lung Association in Arkansas

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Arkansas	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.6	Pass
Ashley	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Benton	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC	INC
Clark	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Craighead	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC	INC
Crittenden	7	0	0	2.3	D	0	0	0	0	0.0	A	8.0	Pass
Garland	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Jackson	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Newton	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Polk	1	0	0	0.3	B	0	0	0	0	0.0	A	8.1	Pass
Pulaski	3	0	0	1.0	C	1	0	0	0	0.3	B	9.0	Pass
Union	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Washington	1	0	0	0.3	B	0	0	0	0	0.0	A	7.7	Pass

ARKANSAS

American Lung Association in Arkansas

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Arkansas	16,722	3,925	3,382	259	1,164	1,340	12	1,585	181	2,923	5,310
Ashley	18,674	4,236	3,961	279	1,311	1,535	14	1,829	196	3,950	5,998
Benton	293,692	75,519	39,888	4,982	20,124	19,800	218	21,975	3,649	22,890	84,247
Clark	21,321	4,176	3,567	275	1,567	1,534	16	1,769	302	3,699	6,776
Craighead	112,218	28,057	15,690	1,851	7,747	7,544	83	8,440	1,472	19,674	29,464
Crittenden	47,525	12,873	6,942	849	3,192	3,313	35	3,718	576	10,706	28,727
Garland	100,330	20,002	24,475	1,319	7,233	8,684	74	10,635	1,032	14,319	18,990
Jackson	16,811	3,451	3,084	228	1,221	1,309	12	1,517	193	3,316	4,010
Newton	7,204	1,389	1,972	92	520	660	5	824	63	1,366	541
Polk	19,353	4,390	4,449	290	1,351	1,624	14	1,971	188	3,697	2,445
Pulaski	397,821	92,461	65,692	6,099	27,998	29,236	293	33,421	4,985	68,564	196,104
Union	38,340	9,180	7,230	606	2,660	2,970	28	3,476	418	6,726	15,206
Washington	250,057	59,699	30,796	3,938	17,587	16,167	186	17,677	3,415	30,035	75,674

CA Exhibit 14

CALIFORNIA

American Lung Association in California

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Alameda	21	2	0	8.0	F	9	10	1	0	8.7	F	8.8	Pass
Amador	8	1	0	3.2	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Butte	17	2	0	6.7	F	21	22	2	1	20.2	F	11.4	Pass
Calaveras	9	1	0	3.5	F	14	16	0	0	12.7	F	8.9	Pass
Colusa	0	0	0	0.0	A	18	27	0	0	19.5	F	10.4	Pass
Contra Costa	13	0	0	4.3	F	9	11	0	0	8.5	F	9.3	Pass
El Dorado	41	6	0	16.7	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Fresno	136	16	1	54.0	F	77	42	5	0	50.0	F	15.3	Fail
Glenn	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Humboldt	0	0	0	0.0	A	2	0	0	0	0.7	B	7.4	Pass
Imperial	45	4	0	17.0	F	8	1	0	0	3.2	D	11.0	Pass
Inyo	19	0	0	6.3	F	32	34	8	6	38.0	F	8.4	Pass
Kern	201	38	1	86.7	F	107	29	2	0	51.5	F	17.8	Fail
Kings	54	3	0	19.5	F	85	23	0	0	39.8	F	15.9	Fail
Lake	0	0	0	0.0	A	1	4	0	0	2.3	D	6.3	Pass
Los Angeles	175	86	16	112.0	F	39	13	1	0	20.2	F	13.0	Fail
Madera	59	6	0	22.7	F	30	21	1	0	21.2	F	13.0	Fail
Marin	1	0	0	0.3	B	4	4	1	0	4.0	F	7.3	Pass
Mariposa	45	7	0	18.5	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Mendocino	0	0	0	0.0	A	15	12	1	2	13.3	F	9.2	Pass
Merced	44	3	0	16.2	F	24	16	0	0	16.0	F	11.9	Pass
Mono	DNC	DNC	DNC	DNC	DNC	23	27	10	18	42.8	F	INC	INC
Monterey	0	0	0	0.0	A	5	9	2	0	7.5	F	7.0	Pass
Napa	3	0	0	1.0	C	6	8	0	0	6.0	F	INC	INC
Nevada	51	7	1	21.2	F	14	27	4	0	20.8	F	9.7	Pass
Orange	42	9	2	19.8	F	24	2	0	0	9.0	F	11.1	Pass
Placer	69	8	0	27.0	F	19	23	0	0	17.8	F	10.4	Pass
Plumas	DNC	DNC	DNC	DNC	DNC	22	28	1	1	22.8	F	16.5	Fail
Riverside	232	89	10	128.5	F	36	7	0	0	15.5	F	13.9	Fail
Sacramento	48	3	0	17.5	F	22	21	0	1	18.7	F	11.1	Pass
San Benito	3	0	0	1.0	C	6	8	0	0	6.0	F	6.5	Pass
San Bernardino	194	176	37	177.3	F	36	9	0	0	16.5	F	14.2	Fail
San Diego	65	6	0	24.7	F	17	10	0	0	10.7	F	9.6	Pass
San Francisco	1	0	0	0.3	B	3	5	0	0	3.5	F	8.5	Pass
San Joaquin	11	0	0	3.7	F	29	16	0	0	17.7	F	11.8	Pass
San Luis Obispo	32	0	1	11.3	F	5	8	2	0	7.0	F	7.7	Pass
San Mateo	3	0	0	1.0	C	4	5	0	0	3.8	F	7.6	Pass
Santa Barbara	7	1	0	2.8	D	7	3	0	0	3.8	F	7.6	Pass
Santa Clara	15	1	0	5.5	F	12	8	0	0	8.0	F	10.3	Pass

CALIFORNIA (cont.)

American Lung Association in California

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Santa Cruz	0	0	0	0.0	A	6	10	2	2	10.0	F	7.1	Pass
Shasta	12	0	0	4.0	F	9	17	2	0	12.8	F	9.5	Pass
Siskiyou	0	0	0	0.0	A	19	35	2	1	26.0	F	10.5	Pass
Solano	7	0	0	2.3	D	6	5	1	0	5.2	F	9.7	Pass
Sonoma	0	0	0	0.0	A	1	6	0	0	3.3	F	INC	INC
Stanislaus	56	3	0	20.2	F	42	19	0	0	23.5	F	13.0	Fail
Sutter	19	3	0	7.8	F	24	19	1	1	19.0	F	13.1	Fail
Tehama	31	1	0	10.8	F	16	36	0	0	23.3	F	9.8	Pass
Tulare	220	35	2	92.2	F	59	21	1	1	31.7	F	17.8	Fail
Tuolumne	9	0	0	3.0	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Ventura	35	3	0	13.2	F	5	2	0	0	2.7	D	7.9	Pass
Yolo	5	0	0	1.7	C	3	1	0	0	1.5	C	INC	INC

CALIFORNIA

American Lung Association in California

AT-RISK GROUPS

				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Alameda	1,648,556	331,885	246,049	16,555	116,489	59,149	619	81,390	18,725	152,654	1,166,367
Amador	41,259	6,274	11,315	313	3,109	1,920	16	2,850	275	4,104	9,918
Butte	208,309	42,437	37,992	2,117	14,671	7,834	78	10,807	2,243	33,874	64,260
Calaveras	46,221	8,019	13,189	400	3,398	2,160	17	3,243	340	6,198	9,996
Colusa	21,917	5,843	3,375	291	1,423	746	8	1,037	216	2,466	14,676
Contra Costa	1,161,413	257,360	193,929	12,837	80,121	42,768	436	60,672	11,808	100,948	687,016
El Dorado	193,221	37,909	43,677	1,891	13,797	8,114	73	11,958	1,637	16,839	46,513
Fresno	1,013,581	285,552	127,785	14,243	64,336	31,839	381	42,872	10,688	193,449	737,794
Glenn	28,805	7,721	4,806	385	1,867	1,006	11	1,413	268	4,397	14,659
Humboldt	136,310	25,812	26,105	1,288	9,779	5,295	51	7,379	1,470	25,781	37,374
Imperial	179,851	51,197	24,033	2,554	11,371	5,719	68	7,739	1,715	29,738	163,246
Inyo	18,970	3,959	4,567	197	1,333	800	7	1,173	158	2,382	7,678
Kern	917,673	263,402	104,638	13,139	57,795	27,903	346	37,178	9,412	164,169	632,525
Kings	153,443	41,404	16,422	2,065	9,887	4,641	58	6,050	1,471	24,295	107,456
Lake	68,766	15,010	15,864	749	4,773	2,839	26	4,162	567	11,196	22,911
Los Angeles	9,829,544	2,071,174	1,436,518	103,311	686,458	348,045	3,693	479,386	109,039	1,365,808	7,341,491
Madera	159,410	43,700	22,740	2,180	10,235	5,250	60	7,207	1,747	31,044	108,934
Marin	260,206	49,948	61,011	2,491	18,693	11,172	98	16,638	2,139	19,734	77,769
Mariposa	17,147	2,926	4,937	146	1,264	803	6	1,199	129	2,387	3,863
Mendocino	91,305	19,251	21,599	960	6,395	3,812	34	5,561	796	14,539	33,860
Merced	286,461	83,121	32,980	4,146	17,962	8,697	108	11,590	3,025	61,359	215,404
Mono	13,247	2,291	2,340	114	971	517	5	731	132	1,278	4,581
Monterey	437,325	113,236	63,337	5,648	28,668	14,691	165	20,181	4,378	50,725	313,287
Napa	136,207	26,875	27,529	1,341	9,695	5,436	51	7,806	1,309	11,814	67,511
Nevada	103,487	17,560	29,469	876	7,639	4,824	39	7,195	826	12,141	16,609
Orange	3,167,809	679,361	498,753	33,887	220,403	115,006	1,190	161,384	33,179	309,402	1,947,681
Placer	412,300	90,599	82,552	4,519	28,538	16,143	155	23,318	3,858	26,816	125,701
Plumas	19,915	3,446	6,029	172	1,465	951	7	1,428	149	2,545	3,557
Riverside	2,458,395	604,518	364,844	30,154	164,045	84,491	925	116,774	25,573	282,068	1,670,925
Sacramento	1,588,921	369,843	234,117	18,448	107,853	55,118	597	75,886	17,210	203,413	920,382
San Benito	66,677	17,076	8,818	852	4,388	2,201	25	3,020	680	5,899	46,310
San Bernardino	2,194,710	570,561	265,519	28,460	143,564	70,097	825	94,581	23,805	285,474	1,637,602
San Diego	3,286,069	698,371	489,101	34,835	228,821	115,946	1,237	158,242	35,582	340,522	1,848,397
San Francisco	815,201	114,402	142,810	5,706	61,981	32,058	307	44,000	9,597	90,898	503,920
San Joaquin	789,410	210,579	103,226	10,504	51,190	25,611	297	34,953	8,246	95,382	566,055
San Luis Obispo	283,159	49,467	60,618	2,467	20,693	11,570	107	16,302	2,799	35,120	92,156
San Mateo	737,888	146,863	128,911	7,326	52,366	28,013	277	39,608	7,561	49,900	461,621
Santa Barbara	446,475	99,487	71,397	4,962	30,669	15,811	168	21,484	4,867	65,029	256,024
Santa Clara	1,885,508	399,419	272,913	19,923	131,500	66,599	710	91,842	20,111	128,955	1,340,823

CALIFORNIA (CONT.)

American Lung Association in California

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Santa Cruz	267,792	49,800	48,935	2,484	19,296	10,318	101	14,397	2,915	27,132	117,215
Shasta	182,139	39,609	38,317	1,976	12,639	7,227	68	10,396	1,672	25,141	40,316
Siskiyou	44,118	8,941	11,872	446	3,126	1,957	17	2,904	341	7,301	11,403
Solano	451,716	99,168	76,314	4,947	31,219	16,588	170	23,259	4,505	44,037	292,229
Sonoma	485,887	92,864	102,618	4,632	34,856	19,779	182	28,486	4,664	43,661	187,104
Stanislaus	552,999	149,012	74,357	7,433	35,728	18,009	208	24,607	5,736	76,921	342,106
Sutter	99,063	25,360	15,896	1,265	6,525	3,454	37	4,821	983	15,224	56,125
Tehama	65,498	15,689	13,216	783	4,418	2,522	25	3,641	576	10,107	22,521
Tulare	477,054	144,196	55,572	7,193	29,409	14,362	179	19,237	4,989	88,367	351,235
Tuolumne	55,810	9,479	15,200	473	4,114	2,538	21	3,735	412	6,848	12,113
Ventura	839,784	186,401	140,232	9,298	57,884	30,803	316	43,460	8,426	73,968	473,514
Yolo	216,986	44,343	28,690	2,212	15,233	7,334	81	9,582	2,801	30,708	120,110

COLORADO

American Lung Association in Colorado

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Adams	31	1	0	10.8	F	5	1	0	0	2.2	D	INC	INC
Arapahoe	49	5	0	18.8	F	1	0	0	0	0.3	B	6.4	Pass
Archuleta	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Boulder	42	2	0	15.0	F	23	3	0	0	9.2	F	9.0	Pass
Clear Creek	16	0	0	5.3	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Delta	0	0	0	0.0	A	2	0	0	0	0.7	B	INC	INC
Denver	38	2	0	13.7	F	19	3	0	0	7.8	F	10.2	Pass
Douglas	55	10	0	23.3	F	8	2	0	0	3.7	F	7.0	Pass
El Paso	34	1	0	11.8	F	1	0	0	0	0.3	B	5.6	Pass
Garfield	3	0	0	1.0	C	2	1	0	0	1.2	C	INC	INC
Gilpin	28	1	0	9.8	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Gunnison	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jefferson	83	15	0	35.2	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
La Plata	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Larimer	44	3	0	16.2	F	15	1	0	0	5.5	F	7.5	Pass
Mesa	3	0	0	1.0	C	2	0	0	0	0.7	B	5.8	Pass
Montezuma	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Pueblo	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	INC	INC
Rio Blanco	5	0	0	1.7	C	4	1	0	0	1.8	C	8.6	Pass
Weld	37	1	0	12.8	F	17	0	0	0	5.7	F	9.5	Pass

COLORADO

American Lung Association in Colorado

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Adams	522,140	131,824	57,667	8,696	41,033	18,148	198	19,350	5,838	51,680	272,817
Arapahoe	654,900	149,417	91,930	9,856	53,064	25,102	249	27,810	7,126	56,744	274,381
Archuleta	13,790	2,411	3,768	159	1,186	721	5	894	104	1,556	3,289
Boulder	329,543	59,649	52,488	3,935	28,249	13,591	125	15,224	3,685	34,103	74,923
Clear Creek	9,446	1,316	2,077	87	857	470	4	556	82	712	1,184
Delta	31,661	6,175	8,628	407	2,642	1,606	12	1,999	241	4,325	6,107
Denver	711,463	132,461	86,480	8,738	60,368	26,094	270	27,648	9,286	82,086	320,102
Douglas	368,990	88,461	48,765	5,835	29,721	14,205	140	15,710	3,770	10,490	73,629
El Paso	737,867	172,817	99,824	11,400	59,131	27,420	280	30,135	7,894	68,718	238,652
Garfield	62,161	15,298	8,980	1,009	4,929	2,391	24	2,679	612	5,667	20,798
Gilpin	5,873	828	1,144	55	537	287	2	335	52	406	833
Gunnison	17,281	2,791	2,470	184	1,516	693	7	756	197	2,016	2,371
Jefferson	579,581	109,740	100,613	7,239	49,233	24,695	220	28,212	5,989	41,422	132,397
La Plata	56,250	10,116	11,179	667	4,826	2,540	21	2,970	560	5,521	12,248
Larimer	362,533	68,005	61,379	4,486	30,662	14,940	138	16,910	4,105	39,476	67,328
Mesa	157,335	32,844	32,236	2,167	12,958	6,945	60	8,213	1,517	16,238	30,760
Montezuma	26,175	5,526	6,270	365	2,148	1,242	10	1,516	221	3,957	7,395
Pueblo	169,622	37,569	32,384	2,478	13,776	7,242	64	8,479	1,649	26,839	83,171
Rio Blanco	6,476	1,518	1,183	100	518	270	2	315	59	632	1,060
Weld	340,036	87,313	42,986	5,760	26,516	12,224	129	13,364	3,641	32,543	122,743

CONNECTICUT

American Lung Association in Connecticut

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Fairfield	38	9	0	17.2	F	6	0	0	0	2.0	C	8.1	Pass
Hartford	6	0	0	2.0	C	2	0	0	0	0.7	B	7.5	Pass
Litchfield	1	0	0	0.3	B	2	0	0	0	0.7	B	5.1	Pass
Middlesex	18	2	0	7.0	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
New Haven	32	5	0	13.2	F	4	0	0	0	1.3	C	8.2	Pass
New London	16	1	0	5.8	F	1	0	0	0	0.3	B	6.9	Pass
Tolland	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Windham	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC

CA Exhibit 14

CONNECTICUT

American Lung Association in Connecticut

	AT-RISK GROUPS										
				Lung Diseases							
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Pregnancies**	**Poverty**	**People of Color**
Fairfield	959,768	210,680	158,603	18,782	80,138	38,463	533	52,573	9,356	85,452	386,212
Hartford	896,854	186,592	158,512	16,635	75,878	36,692	498	50,405	8,927	92,542	371,285
Litchfield	185,000	32,664	42,169	2,912	15,915	8,942	103	12,359	1,542	15,713	25,753
Middlesex	164,759	27,712	35,695	2,471	14,418	7,744	91	10,686	1,509	10,537	29,067
New Haven	863,700	172,492	156,201	15,378	73,777	35,898	479	49,344	8,832	100,433	345,820
New London	268,805	51,417	51,843	4,584	23,099	11,596	149	15,974	2,497	23,102	69,656
Tolland	150,293	25,624	25,398	2,284	13,446	6,051	84	8,305	1,649	15,039	26,007
Windham	116,418	22,529	20,814	2,008	10,020	4,886	65	6,700	1,132	13,043	21,471

DELAWARE

American Lung Association in Delaware

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Kent	2	0	0	0.7	B	0	0	0	0	0.0	A	INC	INC
New Castle	7	0	0	2.3	D	2	0	0	0	0.7	B	INC	INC
Sussex	0	0	0	0.0	A	0	0	0	0	0.0	A	INC	INC

DELAWARE

American Lung Association in Delaware

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Kent	184,149	42,116	33,033	2,778	14,216	8,563	98	13,358	2,027	21,961	75,860
New Castle	571,708	121,570	94,971	8,019	45,331	26,572	304	41,232	6,410	63,059	258,618
Sussex	247,527	44,608	73,642	2,943	19,557	15,165	132	24,267	1,954	28,006	60,853

DISTRICT OF COLUMBIA

American Lung Association in the District of Columbia

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
District of Columbia	10	0	0	3.3	F	1	3	0	0	1.8	C	8.8	Pass

DISTRICT OF COLUMBIA

American Lung Association in the District of Columbia

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
District of Columbia	670,050	125,835	85,838	12,162	62,995	25,184	302	29,575	8,591	107,307	420,299

FLORIDA

American Lung Association in Florida

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Alachua	0	0	0	0.0	A	1	0	0	0	0.3	B	7.2	Pass
Baker	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Bay	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Brevard	0	0	0	0.0	A	0	0	0	0	0.0	A	7.5	Pass
Broward	0	0	0	0.0	A	3	0	0	0	1.0	C	9.2	Pass
Collier	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Columbia	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Duval	0	0	0	0.0	A	1	0	0	0	0.3	B	8.6	Pass
Escambia	1	0	0	0.3	B	0	0	0	0	0.0	A	9.2	Pass
Flagler	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Highlands	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hillsborough	8	0	0	2.7	D	1	0	0	0	0.3	B	INC	INC
Holmes	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Indian River	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lake	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lee	1	0	0	0.3	B	0	0	0	0	0.0	A	7.4	Pass
Leon	1	0	0	0.3	B	1	0	0	0	0.3	B	7.4	Pass
Liberty	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Manatee	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Marion	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Martin	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Miami-Dade	1	0	0	0.3	B	1	0	0	0	0.3	B	7.1	Pass
Okaloosa	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Orange	0	0	0	0.0	A	0	0	0	0	0.0	A	INC	INC
Osceola	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Palm Beach	0	0	0	0.0	A	0	0	0	0	0.0	A	6.8	Pass
Pasco	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Pinellas	0	0	0	0.0	A	0	0	0	0	0.0	A	7.8	Pass
Polk	0	0	0	0.0	A	0	0	0	0	0.0	A	8.2	Pass
St. Lucie	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Santa Rosa	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Sarasota	0	0	0	0.0	A	0	0	0	0	0.0	A	7.6	Pass
Seminole	0	0	0	0.0	A	0	0	0	0	0.0	A	7.3	Pass
Volusia	0	0	0	0.0	A	0	0	0	0	0.0	A	8.1	Pass
Wakulla	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC

FLORIDA

American Lung Association in Florida

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Alachua	279,238	50,734	42,493	3,382	16,695	13,655	148	17,790	3,722	50,668	111,555
Baker	28,715	6,822	4,179	455	1,615	1,445	15	1,857	270	4,187	5,975
Bay	179,168	37,257	33,098	2,483	10,465	10,232	95	13,367	1,741	24,383	43,941
Brevard	616,628	112,182	149,343	7,478	37,097	40,242	328	53,770	5,364	68,879	167,351
Broward	1,930,983	404,724	338,380	26,978	112,602	107,885	1,025	140,272	20,030	244,519	1,283,111
Collier	385,980	63,943	127,681	4,262	23,483	28,874	205	39,894	2,879	39,843	147,665
Columbia	70,385	15,292	13,850	1,019	4,049	4,009	38	5,296	610	10,722	20,147
Duval	999,935	225,827	149,041	15,053	56,983	50,379	531	65,001	11,179	146,090	491,477
Escambia	322,390	67,752	56,000	4,516	18,705	17,291	171	22,617	3,360	56,350	117,082
Flagler	120,932	19,834	37,642	1,322	7,405	8,968	64	12,257	934	12,373	31,372
Highlands	103,296	17,538	36,883	1,169	6,228	7,912	55	11,055	744	15,428	36,333
Hillsborough	1,478,194	325,550	219,177	21,700	84,933	75,284	785	96,889	16,716	208,765	790,956
Holmes	19,784	4,104	3,951	274	1,154	1,158	11	1,526	161	3,613	2,866
Indian River	163,662	25,084	56,134	1,672	10,112	12,657	87	17,495	1,186	18,938	41,911
Lake	395,804	76,020	104,866	5,067	23,417	26,219	210	35,526	3,491	39,022	132,091
Lee	787,976	136,094	228,930	9,072	47,668	55,147	419	75,252	6,631	95,012	277,671
Leon	292,817	54,936	42,438	3,662	17,397	14,088	155	18,263	4,028	45,137	131,225
Liberty	7,900	1,345	1,260	90	483	427	4	551	56	1,391	2,343
Manatee	412,703	72,883	117,219	4,858	24,895	28,802	219	39,144	3,426	40,642	122,748
Marion	385,915	72,422	110,887	4,827	22,904	26,484	205	36,203	3,284	50,984	123,301
Martin	159,942	25,753	51,121	1,717	9,817	11,981	85	16,430	1,130	17,768	36,345
Miami-Dade	2,662,777	537,115	448,951	35,803	156,874	147,358	1,414	190,773	28,191	398,855	2,301,562
Okaloosa	213,255	47,896	34,873	3,193	12,153	11,052	114	14,398	2,131	20,091	59,200
Orange	1,422,746	307,342	182,193	20,487	82,184	68,405	756	87,009	17,215	208,064	870,854
Osceola	403,282	97,524	53,935	6,501	22,536	19,397	214	24,807	4,574	53,195	286,609
Palm Beach	1,497,987	284,075	367,614	18,936	89,021	96,065	795	129,121	13,765	171,280	709,479
Pasco	584,067	119,378	128,954	7,957	34,160	35,693	310	47,485	5,573	67,129	174,217
Pinellas	956,615	150,259	247,356	10,016	59,258	65,267	507	87,533	8,660	115,468	257,365
Polk	753,520	166,777	149,543	11,117	43,042	42,396	400	56,215	7,651	115,547	347,066
St. Lucie	343,579	67,814	83,980	4,520	20,229	21,944	182	29,492	3,088	38,819	158,382
Santa Rosa	193,998	42,530	31,824	2,835	11,177	10,467	103	13,547	1,864	16,609	36,643
Sarasota	447,057	62,639	166,393	4,175	28,009	36,345	237	50,564	3,105	37,895	80,356
Seminole	470,093	97,789	77,037	6,518	27,435	25,248	249	32,707	5,173	43,726	200,067
Volusia	564,412	99,330	141,305	6,621	34,136	37,109	300	49,824	5,045	75,803	173,318
Wakulla	34,690	7,182	5,586	479	2,033	1,897	19	2,444	309	3,164	7,416

GEORGIA

American Lung Association in Georgia

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Bibb	2	0	0	0.7	B	3	0	0	0	1.0	C	9.0	Pass
Chatham	0	0	0	0.0	A	1	0	0	0	0.3	B	9.3	Pass
Chattooga	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clarke	0	0	0	0.0	A	1	0	0	0	0.3	B	9.4	Pass
Clayton	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	8.6	Pass
Cobb	1	0	0	0.3	B	0	0	0	0	0.0	A	8.6	Pass
Coffee	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	6.9	Pass
Columbia	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Dawson	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
DeKalb	5	1	0	2.2	D	1	0	0	0	0.3	B	8.8	Pass
Dougherty	DNC	DNC	DNC	DNC	DNC	8	0	0	0	2.7	D	9.5	Pass
Douglas	7	0	0	2.3	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Fulton	8	1	0	3.2	D	0	0	0	0	0.0	A	9.6	Pass
Glynn	0	0	0	0.0	A	0	0	0	0	0.0	A	7.7	Pass
Gwinnett	3	0	0	1.0	C	2	0	0	0	0.7	B	INC	INC
Hall	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	9.0	Pass
Henry	8	0	0	2.7	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Houston	DNC	DNC	DNC	DNC	DNC	6	1	0	0	2.5	D	9.4	Pass
Lowndes	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	8.0	Pass
Murray	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Muscogee	0	0	0	0.0	A	0	1	0	0	0.5	B	8.6	Pass
Pike	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Richmond	2	0	0	0.7	B	8	0	0	0	2.7	D	11.1	Pass
Rockdale	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Sumter	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Walker	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	INC	INC
Washington	DNC	DNC	DNC	DNC	DNC	6	0	0	0	2.0	C	9.2	Pass

GEORGIA

American Lung Association in Georgia

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Bibb	156,762	37,774	25,410	3,669	11,096	8,046	88	11,191	1,804	36,780	100,015
Chatham	296,329	61,197	48,992	5,944	22,071	15,583	168	21,604	3,542	43,618	156,167
Chattooga	24,932	5,517	4,600	536	1,779	1,382	14	1,951	229	4,768	4,456
Clarke	128,711	21,671	15,512	2,105	10,517	6,061	73	7,968	2,020	25,418	57,574
Clayton	297,100	80,878	30,968	7,855	20,612	13,636	167	17,924	3,721	55,143	272,109
Cobb	766,802	173,944	102,037	16,894	55,740	39,095	434	52,658	9,038	72,765	381,797
Coffee	43,386	10,516	6,126	1,021	3,088	2,172	25	2,959	441	10,440	18,766
Columbia	159,639	39,977	23,038	3,883	11,202	7,998	91	10,947	1,775	11,580	55,183
Dawson	28,497	5,750	5,787	558	2,065	1,663	16	2,373	276	2,556	2,973
DeKalb	757,718	171,248	102,893	16,632	55,413	38,071	428	51,429	9,393	108,081	534,270
Dougherty	84,844	20,156	14,263	1,958	6,032	4,376	48	6,119	1,004	21,155	64,969
Douglas	145,814	37,128	17,814	3,606	10,194	7,221	82	9,660	1,708	18,540	95,967
Fulton	1,065,334	223,838	131,928	21,739	80,097	53,333	603	70,935	13,702	142,028	650,233
Glynn	84,739	17,781	18,144	1,727	6,065	4,923	48	7,102	862	13,760	30,811
Gwinnett	964,546	253,649	106,230	24,635	67,109	46,283	547	61,183	11,138	102,953	644,227
Hall	207,369	50,165	32,873	4,872	14,585	10,796	118	14,956	2,179	24,666	84,380
Henry	245,235	61,677	30,050	5,990	17,192	12,250	138	16,386	2,890	23,188	157,996
Houston	166,829	42,832	22,191	4,160	11,678	8,132	94	11,015	1,914	19,058	77,190
Lowndes	119,276	29,193	15,320	2,835	8,653	5,536	67	7,449	1,506	27,652	57,043
Murray	39,951	9,532	6,168	926	2,813	2,108	23	2,906	422	6,208	7,555
Muscogee	205,617	51,098	29,153	4,963	14,612	10,003	116	13,661	2,369	40,496	125,582
Pike	19,477	4,582	3,127	445	1,370	1,050	11	1,454	207	1,859	2,509
Richmond	205,673	46,802	30,764	4,545	14,998	10,341	116	14,178	2,382	41,249	138,402
Rockdale	94,082	22,564	14,447	2,191	6,594	5,001	53	6,887	1,029	12,697	69,794
Sumter	29,283	6,668	5,124	648	2,103	1,542	17	2,165	331	7,727	17,899
Walker	68,510	14,789	13,068	1,436	4,911	3,850	39	5,457	686	9,524	6,878
Washington	19,785	4,297	3,538	417	1,424	1,093	11	1,534	177	4,057	11,430

HAWAII

American Lung Association in Hawaii

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Hawaii	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	2.7	Pass
Honolulu	0	0	0	0.0	A	0	0	0	0	0.0	A	3.7	Pass
Kauai	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	3.1	Pass
Maui	DNC	DNC	DNC	DNC	DNC	2	1	0	0	1.2	C	3.7	Pass

HAWAII

American Lung Association in Hawaii

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Hawaii	202,906	43,074	46,047	2,204	13,063	6,075	83	11,583	2,050	29,361	141,490
Honolulu	1,000,890	210,112	187,935	10,753	64,603	26,936	411	50,829	10,998	96,646	824,798
Kauai	73,454	15,866	15,755	812	4,706	2,140	30	4,067	748	8,101	51,891
Maui	164,221	35,347	32,525	1,809	10,532	4,662	67	8,811	1,730	18,548	115,119

IDAHO

American Lung Association in Idaho

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Ada	12	0	0	4.0	F	5	1	0	0	2.2	D	7.3	Pass
Bannock	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Benewah	DNC	DNC	DNC	DNC	DNC	13	12	0	1	11.2	F	10.2	Pass
Butte	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Canyon	DNC	DNC	DNC	DNC	DNC	13	7	0	0	7.8	F	INC	INC
Franklin	DNC	DNC	DNC	DNC	DNC	11	1	0	0	4.2	F	6.5	Pass
Idaho	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jerome	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC	INC
Lemhi	DNC	DNC	DNC	DNC	DNC	9	0	0	0	3.0	D	9.8	Pass
Shoshone	DNC	DNC	DNC	DNC	DNC	11	9	3	1	11.0	F	10.6	Pass

IDAHO

American Lung Association in Idaho

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Ada	511,931	115,384	79,691	7,611	38,743	22,435	227	30,293	6,308	43,285	84,020
Bannock	88,263	22,550	13,344	1,488	6,390	3,609	39	4,904	1,102	11,121	15,423
Benewah	9,931	2,218	2,317	146	756	520	4	745	92	1,348	1,599
Butte	2,654	608	667	40	200	140	1	204	24	417	255
Canyon	243,115	65,926	34,527	4,349	17,276	9,774	108	13,162	2,970	26,280	73,878
Franklin	14,666	4,532	2,144	299	990	582	6	792	159	1,192	1,398
Idaho	17,040	3,341	4,920	220	1,336	976	8	1,447	135	2,232	1,667
Jerome	24,662	7,309	3,287	482	1,694	959	11	1,283	273	3,088	10,074
Lemhi	8,162	1,467	2,564	97	652	488	4	731	69	974	555
Shoshone	13,612	2,862	3,159	189	1,052	714	6	1,020	130	2,404	1,248

ILLINOIS

American Lung Association in Illinois

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Adams	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Champaign	2	0	0	0.7	B	0	0	0	0	0.0	A	7.8	Pass
Clark	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cook	39	5	0	15.5	F	4	0	0	0	1.3	C	10.4	Pass
DuPage	7	2	0	3.3	F	0	0	0	0	0.0	A	INC	INC
Effingham	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hamilton	2	0	0	0.7	B	2	0	0	0	0.7	B	8.8	Pass
Jersey	5	0	0	1.7	C	0	0	0	0	0.0	A	8.0	Pass
Jo Daviess	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Kane	10	1	0	3.8	F	1	0	0	0	0.3	B	8.9	Pass
Lake	21	1	0	7.5	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
McHenry	12	0	0	4.0	F	0	0	0	0	0.0	A	8.4	Pass
McLean	3	0	0	1.0	C	1	0	0	0	0.3	B	9.0	Pass
Macon	0	0	0	0.0	A	3	0	0	0	1.0	C	9.4	Pass
Macoupin	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Madison	10	2	0	4.3	F	0	0	0	0	0.0	A	10.2	Pass
Peoria	4	0	0	1.3	C	1	0	0	0	0.3	B	8.7	Pass
Randolph	1	0	0	0.3	B	2	0	0	0	0.7	B	INC	INC
Rock Island	4	0	0	1.3	C	2	0	0	0	0.7	B	8.7	Pass
St. Clair	2	1	0	1.2	C	0	0	0	0	0.0	A	9.7	Pass
Sangamon	0	0	0	0.0	A	0	0	0	0	0.0	A	8.2	Pass
Will	4	0	0	1.3	C	1	1	0	0	0.8	B	9.9	Pass
Winnebago	1	0	0	0.3	B	1	0	0	0	0.3	B	INC	INC

CA Exhibit 14

ILLINOIS

American Lung Association in Illinois

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Adams	64,954	14,712	13,463	1,035	4,316	3,137	37	4,711	590	7,424	5,877
Champaign	205,943	39,315	28,273	2,767	14,910	7,918	118	11,011	2,641	28,582	70,591
Clark	15,300	3,475	3,077	245	1,010	740	9	1,115	135	1,533	586
Cook	5,173,146	1,111,446	807,186	78,216	354,509	218,829	2,959	318,460	57,451	703,874	3,027,779
DuPage	924,885	206,835	155,352	14,556	61,984	40,994	530	60,688	9,197	62,952	323,625
Effingham	34,430	8,255	6,396	581	2,253	1,571	20	2,344	307	3,158	1,606
Hamilton	7,911	1,743	1,753	123	527	400	5	605	69	1,032	394
Jersey	21,333	4,319	4,280	304	1,456	1,046	12	1,572	197	1,914	1,005
Jo Daviess	21,939	4,020	6,417	283	1,508	1,317	13	2,034	159	1,877	1,289
Kane	515,588	125,987	76,629	8,866	33,686	21,462	295	31,585	5,141	43,982	226,500
Lake	711,239	167,217	109,313	11,768	46,972	30,287	408	44,687	6,926	58,626	289,459
McHenry	311,122	71,178	49,322	5,009	20,607	13,645	178	20,274	2,963	18,456	65,299
McLean	170,889	36,154	24,260	2,544	11,903	6,790	98	9,669	2,070	21,514	36,526
Macon	102,432	23,011	21,285	1,619	6,833	4,940	59	7,406	1,003	16,893	25,821
Macoupin	44,406	9,252	9,422	651	3,001	2,227	25	3,363	403	6,702	1,889
Madison	264,490	57,401	47,890	4,040	17,853	12,139	151	18,048	2,639	29,596	42,541
Peoria	179,432	42,902	32,182	3,019	11,838	7,942	103	11,743	1,813	28,357	56,304
Randolph	30,142	5,779	5,816	407	2,103	1,441	17	2,142	227	3,909	5,065
Rock Island	142,909	32,070	28,843	2,257	9,559	6,778	82	10,124	1,341	22,803	43,467
St. Clair	254,796	59,630	43,039	4,196	16,858	11,197	146	16,578	2,572	33,300	99,924
Sangamon	194,734	42,966	36,600	3,024	13,067	9,061	111	13,514	1,931	27,610	40,620
Will	697,252	167,087	97,936	11,759	45,832	28,649	399	42,060	7,120	54,149	271,606
Winnebago	283,119	66,417	51,801	4,674	18,675	12,867	162	19,164	2,749	39,659	95,369

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CA Exhibit 14
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INDIANA

American Lung Association in Indiana

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Allen	1	0	0	0.3	B	2	0	0	0	0.7	B	INC	INC
Bartholomew	0	0	0	0.0	A	0	0	0	0	0.0	A	7.1	Pass
Boone	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Brown	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Carroll	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clark	1	0	0	0.3	B	0	0	0	0	0.0	A	7.5	Pass
Delaware	0	0	0	0.0	A	0	0	0	0	0.0	A	8.4	Pass
Dubois	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	8.8	Pass
Elkhart	0	0	0	0.0	A	0	2	0	0	1.0	C	8.3	Pass
Floyd	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Greene	0	0	0	0.0	A	0	0	0	0	0.0	A	7.9	Pass
Hamilton	2	0	0	0.7	B	0	0	0	0	0.0	A	9.8	Pass
Hendricks	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Henry	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.7	Pass
Howard	4	0	0	1.3	C	0	0	0	0	0.0	A	7.3	Pass
Huntington	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jackson	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Knox	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lake	10	0	0	3.3	F	2	1	0	0	1.2	C	9.7	Pass
LaPorte	14	1	0	5.2	F	1	0	0	0	0.3	B	8.1	Pass
Madison	1	0	0	0.3	B	0	0	0	0	0.0	A	8.8	Pass
Marion	4	0	0	1.3	C	12	0	0	0	4.0	F	12.0	Pass
Monroe	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.9	Pass
Morgan	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Perry	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Porter	13	1	0	4.8	F	1	0	0	0	0.3	B	8.2	Pass
Posey	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. Joseph	4	0	0	1.3	C	1	1	0	0	0.8	B	9.2	Pass
Shelby	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Spencer	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	8.2	Pass
Sullivan	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC	INC
Tippecanoe	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	8.9	Pass
Vanderburgh	1	0	0	0.3	B	2	0	0	0	0.7	B	9.1	Pass
Vigo	0	0	0	0.0	A	2	0	0	0	0.7	B	9.1	Pass
Wabash	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Warrick	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Whitley	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	8.0	Pass

INDIANA

American Lung Association in Indiana

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Allen	388,608	99,204	59,043	6,977	29,992	23,994	241	25,043	4,614	50,086	108,774
Bartholomew	82,475	19,928	13,666	1,402	6,460	5,337	51	5,642	913	6,624	16,599
Boone	73,052	18,850	10,392	1,326	5,605	4,551	45	4,718	841	3,980	8,597
Brown	15,552	2,673	4,005	188	1,300	1,304	10	1,471	137	1,670	757
Carroll	20,444	4,502	4,079	317	1,629	1,476	13	1,608	206	1,730	1,443
Clark	122,738	27,277	19,985	1,918	9,854	8,159	76	8,575	1,445	12,668	22,464
Delaware	111,871	20,266	19,288	1,425	9,521	7,438	69	7,779	1,527	19,056	15,460
Dubois	43,549	10,606	8,065	746	3,375	2,995	27	3,237	431	3,187	4,926
Elkhart	206,921	56,653	31,560	3,984	15,544	12,648	129	13,277	2,307	22,950	55,536
Floyd	80,454	18,316	13,589	1,288	6,401	5,404	50	5,725	920	7,237	10,721
Greene	30,786	6,665	6,167	469	2,465	2,237	19	2,438	311	4,349	1,276
Hamilton	356,650	91,973	47,301	6,469	27,422	21,843	221	22,392	4,292	13,447	65,880
Hendricks	179,355	43,719	26,056	3,075	14,042	11,296	112	11,701	2,075	9,294	35,093
Henry	48,935	9,924	9,454	698	4,002	3,511	31	3,786	471	6,831	3,431
Howard	83,687	19,222	16,501	1,352	6,609	5,849	52	6,364	905	9,771	13,611
Huntington	36,717	7,997	6,551	562	2,954	2,529	23	2,698	403	3,758	2,161
Jackson	46,067	11,308	7,800	795	3,575	3,061	29	3,258	487	6,443	6,366
Knox	35,956	7,734	6,673	544	2,910	2,449	22	2,623	383	5,092	3,005
Lake	498,558	116,192	86,040	8,172	39,384	33,327	309	35,456	5,707	68,461	234,549
LaPorte	112,390	23,966	21,047	1,686	9,091	7,831	70	8,412	1,109	12,934	24,698
Madison	130,782	27,875	24,339	1,960	10,582	9,101	81	9,765	1,417	19,464	20,939
Marion	971,102	240,146	127,538	16,890	76,236	57,218	601	58,033	12,711	143,143	459,565
Monroe	139,875	21,809	19,577	1,534	12,444	8,437	87	8,374	2,179	26,549	24,029
Morgan	72,206	16,148	12,862	1,136	5,745	5,064	45	5,420	761	7,344	3,429
Perry	19,316	4,042	3,667	284	1,571	1,351	12	1,453	176	2,271	1,300
Porter	174,243	37,647	30,441	2,648	14,071	11,890	108	12,631	2,003	16,533	32,562
Posey	25,116	5,603	5,077	394	1,994	1,813	16	1,981	249	2,268	1,132
St. Joseph	272,212	63,777	44,824	4,485	21,584	17,432	169	18,347	3,294	37,269	78,993
Shelby	45,039	10,140	8,125	713	3,580	3,138	28	3,364	474	4,382	3,992
Spencer	19,798	4,292	4,045	302	1,582	1,454	12	1,590	195	1,582	1,132
Sullivan	20,758	3,910	3,839	275	1,736	1,466	13	1,562	196	2,998	1,834
Tippecanoe	187,076	37,975	22,636	2,671	15,735	10,486	117	10,255	2,635	30,391	48,027
Vanderburgh	179,987	38,959	31,728	2,740	14,568	12,038	112	12,781	2,141	24,050	31,888
Vigo	105,994	21,684	17,752	1,525	8,756	6,889	66	7,210	1,263	19,709	15,974
Wabash	30,816	6,440	6,450	453	2,496	2,233	19	2,444	330	3,253	1,927
Warrick	64,514	15,076	11,578	1,060	5,076	4,414	40	4,734	699	4,311	5,693
Whitley	34,430	7,889	6,509	555	2,719	2,411	21	2,606	354	2,494	1,836

IOWA

American Lung Association in Iowa

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Black Hawk	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	8.1	Pass
Bremer	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clinton	0	0	0	0.0	A	0	0	0	0	0.0	A	8.9	Pass
Harrison	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Johnson	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.9	Pass
Lee	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	8.3	Pass
Linn	1	0	0	0.3	B	0	0	0	0	0.0	A	8.3	Pass
Montgomery	0	0	0	0.0	A	0	0	0	0	0.0	A	6.9	Pass
Muscatine	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	8.3	Pass
Palo Alto	0	0	0	0.0	A	0	1	0	0	0.5	B	7.1	Pass
Polk	0	0	0	0.0	A	1	2	0	0	1.3	C	7.6	Pass
Pottawattamie	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	8.3	Pass
Scott	1	0	0	0.3	B	1	1	0	0	0.8	B	8.7	Pass
Van Buren	0	0	0	0.0	A	0	0	0	0	0.0	A	7.3	Pass
Woodbury	DNC	DNC	DNC	DNC	DNC	0	1	0	0	0.5	B	8.1	Pass

IOWA

American Lung Association in Iowa

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Black Hawk	130,368	28,669	22,667	1,650	9,411	6,375	80	7,291	1,659	17,005	26,534
Bremer	25,081	5,690	4,886	328	1,774	1,299	15	1,521	289	1,681	1,455
Clinton	46,463	10,640	9,367	612	3,258	2,527	29	2,977	485	5,261	4,545
Harrison	14,669	3,461	2,865	199	1,020	796	9	933	146	1,491	679
Johnson	154,748	30,510	19,936	1,756	11,764	6,725	95	7,191	2,361	21,477	35,587
Lee	33,215	7,094	7,101	408	2,368	1,860	21	2,209	330	4,511	3,256
Linn	228,939	52,191	38,163	3,004	16,348	11,414	141	12,964	2,742	21,754	36,027
Montgomery	10,322	2,355	2,274	136	719	580	6	696	102	1,179	734
Muscatine	42,688	10,386	7,549	598	2,968	2,165	26	2,497	464	4,666	10,297
Palo Alto	8,906	2,073	2,000	119	616	492	6	594	86	1,024	658
Polk	496,844	121,504	67,875	6,994	35,142	22,700	307	24,916	6,263	49,300	120,633
Pottawattamie	93,304	21,857	17,045	1,258	6,552	4,840	58	5,603	1,028	11,207	12,947
Scott	174,170	41,016	29,754	2,361	12,281	8,737	107	9,989	2,033	22,074	37,282
Van Buren	7,243	1,701	1,609	98	499	408	4	490	67	917	286
Woodbury	105,607	27,657	16,110	1,592	7,235	4,928	65	5,550	1,229	15,992	32,659

CA Exhibit 14

KANSAS

American Lung Association in Kansas

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Johnson	1	0	0	0.3	B	4	0	0	0	1.3	C	INC	INC
Leavenworth	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Neosho	1	0	0	0.3	B	4	0	0	0	1.3	C	9.3	Pass
Sedgwick	2	0	0	0.7	B	5	0	0	0	1.7	C	INC	INC
Shawnee	0	1	0	0.5	B	5	3	0	0	3.2	D	INC	INC
Sumner	0	0	0	0.0	A	5	0	0	0	1.7	C	9.2	Pass
Trego	0	0	0	0.0	A	3	0	0	0	1.0	C	INC	INC
Wyandotte	4	0	0	1.3	C	9	0	0	0	3.0	D	INC	INC

CA Exhibit 14

KANSAS

American Lung Association in Kansas

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Johnson	613,219	145,167	95,115	10,752	49,814	29,414	331	40,413	7,482	36,111	130,693
Leavenworth	82,184	19,346	12,673	1,433	6,690	3,936	45	5,404	861	6,637	17,886
Neosho	15,784	3,900	3,170	289	1,243	831	9	1,172	162	2,288	1,813
Sedgwick	523,828	132,197	80,926	9,792	41,601	24,401	283	33,584	6,326	68,690	173,524
Shawnee	178,264	41,503	34,100	3,074	14,371	9,246	96	12,953	2,028	25,426	48,389
Sumner	22,385	5,409	4,435	401	1,780	1,188	12	1,670	228	2,694	2,623
Trego	2,793	522	738	39	234	177	2	254	24	286	176
Wyandotte	167,046	46,014	21,918	3,408	12,949	7,240	90	9,842	2,027	27,959	100,928

KENTUCKY

American Lung Association in Kentucky

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Bell	0	0	0	0.0	A	2	0	0	0	0.7	B	8.5	Pass
Boone	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Boyd	0	0	0	0.0	A	1	0	0	0	0.3	B	7.9	Pass
Bullitt	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Campbell	2	0	0	0.7	B	0	0	0	0	0.0	A	7.8	Pass
Carter	0	0	0	0.0	A	0	0	0	0	0.0	A	5.9	Pass
Christian	0	0	0	0.0	A	0	0	0	0	0.0	A	8.9	Pass
Daviess	2	0	0	0.7	B	0	0	0	0	0.0	A	INC	INC
Edmonson	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Fayette	0	0	0	0.0	A	0	0	0	0	0.0	A	8.1	Pass
Greenup	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hancock	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hardin	1	0	0	0.3	B	0	0	0	0	0.0	A	7.7	Pass
Henderson	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC	INC
Jefferson	11	0	0	3.7	F	4	0	0	0	1.3	C	10.5	Pass
Jessamine	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Livingston	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
McCracken	1	0	0	0.3	B	2	0	0	0	0.7	B	9.2	Pass
Morgan	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Oldham	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Perry	0	0	0	0.0	A	0	0	0	0	0.0	A	7.2	Pass
Pike	0	0	0	0.0	A	0	1	0	0	0.5	B	6.9	Pass
Pulaski	0	0	0	0.0	A	1	0	0	0	0.3	B	7.8	Pass
Simpson	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Trigg	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Warren	0	0	0	0.0	A	2	0	0	0	0.7	B	8.3	Pass
Washington	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC

KENTUCKY

American Lung Association in Kentucky

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Bell	23,858	5,099	4,713	258	2,210	2,147	20	2,405	251	7,388	1,600
Boone	137,412	35,293	19,746	1,785	12,134	11,078	116	11,707	1,562	8,664	19,179
Boyd	47,899	10,369	9,772	525	4,417	4,332	40	4,893	483	9,672	3,379
Bullitt	82,918	17,624	13,968	892	7,761	7,306	70	7,896	941	9,146	5,646
Campbell	93,050	19,132	15,671	968	8,700	7,966	79	8,572	1,117	10,009	7,663
Carter	26,412	5,940	5,151	300	2,415	2,353	22	2,636	278	6,592	967
Christian	72,357	19,967	9,127	1,010	6,039	4,917	62	5,009	806	11,046	25,472
Daviess	103,063	25,200	18,018	1,275	9,162	8,622	87	9,470	1,137	13,621	13,324
Edmonson	12,291	2,220	2,583	112	1,188	1,164	10	1,310	134	2,237	725
Fayette	321,793	66,736	46,434	3,376	29,819	25,620	271	26,550	4,372	45,319	97,083
Greenup	35,649	7,676	7,745	388	3,289	3,291	30	3,771	363	5,124	1,447
Hancock	9,064	2,216	1,610	112	811	779	8	859	95	1,135	480
Hardin	111,607	27,549	16,414	1,394	9,934	8,969	94	9,483	1,264	12,683	27,241
Henderson	44,329	10,089	8,340	510	4,038	3,889	37	4,325	482	5,388	6,393
Jefferson	777,874	171,542	131,961	8,678	71,247	65,503	655	70,896	9,329	110,325	271,190
Jessamine	53,626	12,650	8,688	640	4,842	4,478	45	4,824	633	7,179	6,643
Livingston	8,959	1,865	1,992	94	839	855	8	983	87	1,283	490
McCracken	67,454	14,974	13,964	757	6,154	6,032	57	6,847	732	11,491	11,790
Morgan	13,820	2,486	2,391	126	1,341	1,243	12	1,338	124	3,138	1,105
Oldham	68,685	17,107	9,734	865	6,165	5,678	58	5,980	705	3,118	8,276
Perry	27,929	6,472	5,018	327	2,544	2,448	24	2,699	298	8,164	1,432
Pike	57,391	11,849	11,416	599	5,390	5,284	48	5,918	604	16,831	1,866
Pulaski	65,423	14,553	12,691	736	6,010	5,860	55	6,554	694	12,339	4,124
Simpson	19,718	4,662	3,320	236	1,783	1,679	17	1,826	217	2,638	2,933
Trigg	14,192	3,087	3,251	156	1,311	1,352	12	1,570	130	2,431	1,809
Warren	137,212	31,827	18,298	1,610	12,334	10,489	116	10,756	1,832	19,324	32,010
Washington	12,072	2,803	2,249	142	1,097	1,064	10	1,183	124	1,532	1,460

LOUISIANA

American Lung Association in Louisiana

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Ascension Parish	2	1	0	1.2	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Bossier Parish	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Caddo Parish	0	0	0	0.0	A	1	0	0	0	0.3	B	9.9	Pass
Calcasieu Parish	0	1	0	0.5	B	0	0	0	0	0.0	A	7.1	Pass
East Baton Rouge Parish	7	1	0	2.8	D	0	0	0	0	0.0	A	8.6	Pass
Iberville Parish	10	0	0	3.3	F	0	0	0	0	0.0	A	7.9	Pass
Jefferson Parish	2	0	0	0.7	B	0	0	0	0	0.0	A	7.6	Pass
Lafayette Parish	0	0	0	0.0	A	1	0	0	0	0.3	B	7.9	Pass
Lafourche Parish	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Livingston Parish	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Orleans Parish	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.7	Pass
Ouachita Parish	0	0	0	0.0	A	1	0	0	0	0.3	B	7.3	Pass
Pointe Coupee Parish	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Rapides Parish	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	7.4	Pass
St. Bernard Parish	0	0	0	0.0	A	0	0	0	0	0.0	A	7.7	Pass
St. James Parish	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. John the Baptist Parish	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. Martin Parish	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. Tammany Parish	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Tangipahoa Parish	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.5	Pass
Terrebonne Parish	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.2	Pass
West Baton Rouge Parish	6	0	0	2.0	C	0	0	0	0	0.0	A	8.8	Pass

LOUISIANA

American Lung Association in Louisiana

County	AT-RISK GROUPS										
				Lung Diseases							
	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Ascension Parish	128,369	33,918	16,504	2,968	9,286	8,044	81	8,710	1,621	14,512	43,036
Bossier Parish	129,144	31,916	19,689	2,793	9,499	8,322	82	9,284	1,607	19,266	45,683
Caddo Parish	233,092	54,738	42,920	4,790	17,256	16,060	146	18,781	2,814	53,728	131,442
Calcasieu Parish	205,282	50,853	32,862	4,450	15,044	13,551	130	15,358	2,446	36,850	67,257
East Baton Rouge Parish	453,301	102,982	69,434	9,011	34,271	29,378	285	32,476	6,212	84,936	256,138
Iberville Parish	29,824	5,945	5,066	520	2,326	2,109	19	2,392	352	5,927	15,631
Jefferson Parish	433,688	96,493	79,658	8,444	32,654	30,516	273	35,573	5,134	75,278	213,095
Lafayette Parish	244,205	58,104	35,003	5,084	18,244	15,770	154	17,294	3,181	42,273	86,806
Lafourche Parish	97,504	22,441	15,958	1,964	7,311	6,673	62	7,582	1,159	15,052	23,042
Livingston Parish	145,830	37,242	19,976	3,259	10,653	9,287	92	10,165	1,847	17,350	22,644
Orleans Parish	376,971	74,460	62,665	6,516	29,519	26,051	236	29,242	5,249	92,262	259,233
Ouachita Parish	158,768	39,073	25,015	3,419	11,673	10,411	100	11,733	2,011	38,985	67,729
Pointe Coupee Parish	20,356	4,391	4,465	384	1,529	1,519	13	1,853	213	3,817	8,025
Rapides Parish	128,654	31,891	21,811	2,791	9,396	8,630	81	9,933	1,499	24,885	50,843
St. Bernard Parish	44,258	11,617	5,586	1,017	3,213	2,743	28	2,948	580	9,531	17,892
St. James Parish	19,742	4,413	3,712	386	1,482	1,405	12	1,650	222	3,327	10,079
St. John the Baptist Parish	42,094	10,235	6,469	896	3,110	2,824	27	3,177	502	6,976	28,846
St. Martin Parish	51,540	12,310	8,535	1,077	3,816	3,513	33	4,016	593	9,377	18,382
St. Tammany Parish	269,388	63,859	48,491	5,588	19,900	18,811	170	21,967	3,077	34,095	63,377
Tangipahoa Parish	135,217	33,209	20,479	2,906	9,969	8,759	85	9,762	1,721	23,496	50,637
Terrebonne Parish	108,708	27,316	16,656	2,390	7,944	7,157	69	8,051	1,284	18,132	37,158
West Baton Rouge Parish	27,792	6,830	4,110	598	2,051	1,804	18	2,002	341	4,127	12,798

MAINE

American Lung Association in Maine

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Androscoggin	0	0	0	0.0	A	0	0	0	0	0.0	A	5. 5	Pass
Aroostook	0	0	0	0.0	A	1	3	0	0	1.8	C	4.4	Pass
Cumberland	3	0	0	1.0	C	0	0	0	0	0.0	A	7.1	Pass
Hancock	5	0	0	1.7	C	0	0	0	0	0.0	A	3.2	Pass
Kennebec	0	0	0	0.0	A	0	0	0	0	0.0	A	INC	INC
Knox	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Oxford	0	0	0	0.0	A	1	0	0	0	0.3	B	5.1	Pass
Penobscot	0	0	0	0.0	A	0	0	0	0	0.0	A	4.4	Pass
Washington	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
York	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC

MAINE

American Lung Association in Maine

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Androscoggin	111,034	23,686	20,318	1,697	11,145	7,465	75	8,394	1,013	15,136	11,544
Aroostook	66,859	12,416	16,754	889	6,807	5,173	45	6,033	505	9,666	4,469
Cumberland	305,231	55,405	59,680	3,969	31,816	21,350	207	24,085	2,918	22,937	31,800
Hancock	56,192	9,331	14,693	668	5,849	4,462	38	5,217	448	6,077	3,308
Kennebec	124,486	23,630	25,774	1,693	12,790	8,931	85	10,166	1,096	13,702	7,471
Knox	41,084	7,083	11,100	507	4,228	3,271	28	3,845	304	4,171	2,159
Oxford	58,629	10,575	13,389	758	6,058	4,459	40	5,133	465	8,728	3,126
Penobscot	152,765	27,168	29,618	1,946	16,010	10,736	104	12,092	1,424	21,301	10,455
Washington	31,121	5,970	7,973	428	3,136	2,413	21	2,825	237	5,602	3,474
York	214,591	38,878	46,398	2,785	22,232	15,753	146	18,007	1,846	17,548	14,082

MARYLAND

American Lung Association in Maryland

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Anne Arundel	10	0	0	3.3	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Baltimore	20	0	0	6.7	F	2	0	0	0	0.7	B	7.9	Pass
Calvert	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Carroll	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cecil	6	0	0	2.0	C	1	0	0	0	0.3	B	6.7	Pass
Charles	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Dorchester	4	0	0	1.3	C	0	0	0	0	0.0	A	5.6	Pass
Frederick	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Garrett	0	0	0	0.0	A	0	0	0	0	0.0	A	5.3	Pass
Harford	19	0	0	6.3	F	0	0	0	0	0.0	A	6.9	Pass
Howard	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.1	Pass
Kent	2	0	0	0.7	B	0	0	0	0	0.0	A	5.4	Pass
Montgomery	3	0	0	1.0	C	0	0	0	0	0.0	A	6.4	Pass
Prince George's	12	0	0	4.0	F	0	0	0	0	0.0	A	6.4	Pass
Washington	1	0	0	0.3	B	0	0	0	0	0.0	A	7.2	Pass
Baltimore City	5	0	0	1.7	C	1	0	0	0	0.3	B	7.5	Pass

MARYLAND

American Lung Association in Maryland

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Anne Arundel	590,336	131,557	91,036	8,941	43,411	21,859	303	32,832	6,412	35,719	206,129
Baltimore	849,316	185,454	151,951	12,603	62,549	33,085	434	50,676	9,416	81,334	389,215
Calvert	93,928	21,789	14,829	1,481	6,850	3,570	48	5,422	944	5,419	22,155
Carroll	173,873	38,015	30,464	2,583	12,866	6,904	89	10,603	1,703	9,212	22,087
Cecil	103,905	23,135	17,309	1,572	7,659	4,043	53	6,172	1,056	11,243	16,926
Charles	168,698	40,457	22,412	2,749	12,228	6,056	86	9,007	1,868	11,263	110,215
Dorchester	32,489	6,838	7,315	465	2,406	1,407	17	2,230	314	4,807	12,300
Frederick	279,835	65,091	42,173	4,424	20,361	10,309	143	15,501	3,016	18,065	85,996
Garrett	28,702	5,225	6,715	355	2,206	1,302	15	2,068	261	3,095	1,143
Harford	262,977	58,596	44,411	3,982	19,341	10,180	135	15,536	2,711	19,813	68,270
Howard	334,529	80,475	49,186	5,469	24,114	12,200	171	18,329	3,670	20,724	171,825
Kent	19,270	2,991	5,198	203	1,514	915	10	1,470	185	2,154	4,272
Montgomery	1,054,827	241,287	175,037	16,398	76,964	40,252	540	61,300	11,386	88,627	609,510
Prince George's	955,306	210,915	138,655	14,334	70,604	34,964	489	52,127	10,884	106,832	842,091
Washington	154,937	33,573	27,331	2,282	11,462	6,083	80	9,318	1,490	21,284	37,453
Baltimore City	576,498	117,030	86,276	7,953	43,312	20,826	294	30,787	7,403	126,488	417,615

MASSACHUSETTS

American Lung Association in Massachusetts

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Barnstable	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Berkshire	0	0	0	0.0	A	1	0	0	0	0.3	B	7.6	Pass
Bristol	5	0	0	1.7	C	0	0	0	0	0.0	A	6.6	Pass
Dukes	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Essex	1	0	0	0.3	B	1	0	0	0	0.3	B	6.0	Pass
Franklin	0	0	0	0.0	A	0	0	0	0	0.0	A	7.6	Pass
Hampden	1	0	0	0.3	B	1	0	0	0	0.3	B	8.5	Pass
Hampshire	0	0	0	0.0	A	0	0	0	0	0.0	A	6.0	Pass
Middlesex	0	0	0	0.0	A	1	1	0	0	0.8	B	6.8	Pass
Norfolk	2	0	0	0.7	B	INC	INC	INC	INC	INC	INC	INC	INC
Plymouth	1	0	0	0.3	B	1	0	0	0	0.3	B	7.5	Pass
Suffolk	1	0	0	0.3	B	2	0	0	0	0.7	B	7.9	Pass
Worcester	1	0	0	0.3	B	2	0	0	0	0.7	B	8.4	Pass

MASSACHUSETTS

American Lung Association in Massachusetts

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Barnstable	232,411	33,438	73,864	3,243	23,296	14,224	135	19,479	1,537	18,293	25,500
Berkshire	128,657	20,956	31,686	2,033	12,698	6,964	75	9,175	1,068	13,454	16,681
Bristol	580,164	119,193	101,390	11,561	54,637	26,925	337	33,826	5,446	67,318	115,665
Dukes	21,097	3,701	5,391	359	2,044	1,157	12	1,537	161	1,601	2,870
Essex	807,074	168,869	144,299	16,379	75,644	37,543	469	47,372	7,494	75,743	261,263
Franklin	71,015	11,950	17,113	1,159	6,962	3,806	41	5,001	588	7,464	7,298
Hampden	462,718	97,909	81,804	9,496	43,362	21,171	269	26,667	4,436	76,268	184,521
Hampshire	161,572	22,958	30,300	2,227	16,621	7,706	94	9,651	1,936	16,221	27,785
Middlesex	1,614,742	316,295	257,427	30,678	154,771	72,218	938	89,158	16,422	120,205	487,544
Norfolk	724,505	149,057	125,480	14,457	68,253	33,445	421	41,955	6,938	48,469	203,314
Plymouth	533,003	111,004	101,907	10,767	49,825	25,644	309	32,714	4,614	39,035	105,743
Suffolk	771,245	125,596	99,444	12,182	78,054	31,818	448	37,579	9,899	133,563	427,452
Worcester	862,029	178,225	142,282	17,286	81,111	39,271	501	48,903	8,111	83,218	220,141

MICHIGAN

American Lung Association in Michigan

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Allegan	19	0	0	6.3	F	0	0	0	0	0.0	A	6.7	Pass
Bay	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	5.9	Pass
Benzie	1	1	0	0.8	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Berrien	12	0	0	4.0	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cass	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Chippewa	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC	INC
Clinton	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Genesee	4	0	0	1.3	C	0	0	0	0	0.0	A	6.8	Pass
Huron	9	0	0	3.0	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Ingham	0	0	0	0.0	A	0	0	0	0	0.0	A	8.0	Pass
Kalamazoo	5	0	0	1.7	C	1	0	0	0	0.3	B	8.5	Pass
Kent	9	0	0	3.0	D	1	0	0	0	0.3	B	8.7	Pass
Lenawee	2	0	0	0.7	B	0	0	0	0	0.0	A	8.4	Pass
Macomb	16	0	0	5.3	F	0	0	0	0	0.0	A	7.7	Pass
Manistee	4	0	0	1.3	C	0	0	0	0	0.0	A	INC	INC
Mason	4	1	0	1.8	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Missaukee	1	0	0	0.3	B	0	0	0	0	0.0	A	7.6	Pass
Muskegon	15	0	0	5.0	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Oakland	9	0	0	3.0	D	0	0	0	0	0.0	A	7.8	Pass
Ottawa	9	0	0	3.0	D	1	0	0	0	0.3	B	8.6	Pass
St. Clair	10	0	0	3.3	F	1	0	0	0	0.3	B	7.9	Pass
Schoolcraft	5	0	0	1.7	C	1	0	0	0	0.3	B	INC	INC
Tuscola	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Washtenaw	5	0	0	1.7	C	0	1	0	0	0.5	B	8.5	Pass
Wayne	11	0	0	3.7	F	11	1	0	0	4.2	F	11.5	Pass
Wexford	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC

MICHIGAN

American Lung Association in Michigan

	AT-RISK GROUPS										
				Lung Diseases							
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Pregnancies**	**Poverty**	**People of Color**
Allegan	120,950	28,566	21,313	1,999	10,741	7,353	72	8,992	1,164	11,306	14,910
Bay	102,985	20,247	22,094	1,417	9,512	6,805	61	8,579	986	12,865	11,021
Benzie	18,223	3,229	4,968	226	1,686	1,323	11	1,746	149	1,673	1,198
Berrien	153,101	32,994	31,806	2,309	13,820	9,840	91	12,385	1,461	24,171	38,764
Cass	51,483	10,583	11,389	741	4,677	3,458	31	4,391	457	5,849	7,245
Chippewa	36,816	6,646	6,959	465	3,519	2,321	22	2,844	325	5,697	11,606
Clinton	79,426	17,338	14,531	1,213	7,214	4,937	47	6,057	799	6,121	8,613
Genesee	404,208	90,299	73,750	6,319	36,467	24,957	239	30,642	4,156	65,045	113,792
Huron	31,252	5,938	8,272	416	2,849	2,238	19	2,942	246	3,655	1,621
Ingham	284,034	55,848	41,014	3,908	27,157	15,783	168	18,419	3,693	42,168	87,741
Kalamazoo	261,108	56,121	41,262	3,928	24,199	14,779	155	17,638	3,138	35,688	61,408
Kent	658,046	155,887	95,764	10,909	59,362	36,632	390	43,214	7,476	64,334	180,614
Lenawee	98,956	20,564	19,516	1,439	9,067	6,315	59	7,847	935	10,508	13,832
Macomb	876,792	182,263	156,609	12,755	80,904	54,846	519	66,771	9,109	100,776	205,454
Manistee	25,350	4,286	6,832	300	2,375	1,840	15	2,418	190	3,139	2,939
Mason	29,383	5,921	7,453	414	2,652	2,031	17	2,657	249	4,010	2,713
Missaukee	15,130	3,383	3,218	237	1,347	979	9	1,240	131	1,773	990
Muskegon	176,511	40,223	31,756	2,815	15,856	10,712	105	13,138	1,759	24,759	42,348
Oakland	1,270,017	259,750	226,572	18,178	117,751	79,521	753	96,716	13,146	98,665	369,309
Ottawa	299,157	70,266	47,583	4,917	26,916	16,986	177	20,388	3,338	21,846	50,744
St. Clair	160,053	32,843	31,756	2,298	14,677	10,501	95	13,032	1,490	17,579	14,778
Schoolcraft	8,030	1,406	2,271	98	740	606	5	803	59	1,103	1,183
Tuscola	52,917	10,680	11,386	747	4,844	3,538	31	4,463	473	6,758	3,884
Washtenaw	369,390	68,042	55,925	4,762	35,764	21,244	219	24,944	4,677	43,132	110,720
Wayne	1,774,816	420,338	287,907	29,417	158,651	103,913	1,050	125,121	19,261	344,903	901,944
Wexford	33,901	7,840	6,792	549	3,001	2,137	20	2,680	310	5,097	2,162

MINNESOTA

American Lung Association in Minnesota

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Anoka	4	0	0	1.3	C	2	2	0	0	1.7	C	6.8	Pass
Becker	2	0	0	0.7	B	6	5	0	0	4.5	F	7.1	Pass
Beltrami	DNC	DNC	DNC	DNC	DNC	6	4	1	0	4.7	F	6.6	Pass
Carlton	0	0	0	0.0	A	4	0	0	0	1.3	C	2.8	Pass
Cass	DNC	DNC	DNC	DNC	DNC	7	4	1	0	5.0	F	7.3	Pass
Cook	DNC	DNC	DNC	DNC	DNC	3	1	0	0	1.5	C	3.3	Pass
Crow Wing	1	0	0	0.3	B	2	2	1	0	2.3	D	5.1	Pass
Dakota	DNC	DNC	DNC	DNC	DNC	2	2	0	0	1.7	C	7.6	Pass
Goodhue	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hennepin	0	0	0	0.0	A	1	4	0	0	2.3	D	8.0	Pass
Lake	0	0	0	0.0	A	3	1	0	0	1.5	C	4.8	Pass
Lyon	0	0	0	0.0	A	3	2	0	0	2.0	C	6.2	Pass
Mille Lacs	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Olmsted	0	0	0	0.0	A	3	0	0	0	1.0	C	6.3	Pass
Ramsey	DNC	DNC	DNC	DNC	DNC	3	1	0	0	1.5	C	7.6	Pass
St. Louis	0	0	0	0.0	A	8	2	0	0	3.7	F	5.4	Pass
Scott	0	0	0	0.0	A	1	0	0	0	0.3	B	6.4	Pass
Stearns	0	0	0	0.0	A	3	2	1	0	2.7	D	6.8	Pass
Washington	1	0	0	0.3	B	INC	INC	INC	INC	INC	INC	INC	INC
Wright	2	0	0	0.7	B	2	2	0	0	1.7	C	6.8	Pass

MINNESOTA

American Lung Association in Minnesota

	AT-RISK GROUPS										
				Lung Diseases							
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Pregnancies**	**Poverty**	**People of Color**
Anoka	367,018	87,315	54,698	5,156	24,658	12,775	187	19,613	4,065	24,537	83,818
Becker	35,219	8,449	7,722	499	2,326	1,412	18	2,297	329	3,929	4,943
Beltrami	46,380	11,755	7,773	694	3,055	1,581	24	2,486	523	6,816	13,305
Carlton	36,409	8,107	6,547	479	2,480	1,375	19	2,163	348	3,605	4,426
Cass	30,639	6,355	8,165	375	2,089	1,393	16	2,314	249	3,566	5,310
Cook	5,617	831	1,678	49	411	278	3	466	49	540	869
Crow Wing	67,270	14,124	15,719	834	4,610	2,842	34	4,639	629	7,114	3,704
Dakota	442,038	106,797	67,549	6,307	29,548	15,362	224	23,697	4,963	22,043	107,949
Goodhue	47,968	10,602	9,840	626	3,257	1,910	24	3,063	474	3,771	4,170
Hennepin	1,267,416	276,004	190,925	16,299	87,793	43,397	644	66,614	15,617	124,666	409,588
Lake	10,986	2,119	2,964	125	764	504	6	837	95	953	559
Lyon	25,231	6,592	4,280	389	1,640	875	13	1,379	275	2,555	4,482
Mille Lacs	26,867	6,305	4,889	372	1,799	1,013	14	1,600	268	2,869	3,171
Olmsted	163,436	39,802	26,300	2,351	10,906	5,641	83	8,784	1,915	12,458	36,279
Ramsey	543,257	126,318	83,123	7,460	36,930	18,244	276	28,169	6,740	68,409	217,637
St. Louis	199,182	37,587	41,064	2,220	14,159	7,893	101	12,626	2,213	26,441	18,652
Scott	153,268	40,316	18,229	2,381	10,001	4,910	78	7,334	1,768	7,034	33,358
Stearns	158,947	37,474	25,124	2,213	10,741	5,409	81	8,396	1,841	20,682	27,390
Washington	272,256	65,874	43,297	3,890	18,143	9,699	138	15,038	2,931	13,900	55,247
Wright	144,845	39,728	19,335	2,346	9,284	4,707	74	7,164	1,583	7,005	13,545

MISSISSIPPI

American Lung Association in Mississippi

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Bolivar	0	0	0	0.0	A	0	0	0	0	0.0	A	8.6	Pass
DeSoto	2	0	0	0.7	B	0	0	0	0	0.0	A	8.4	Pass
Forrest	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	9.4	Pass
Hancock	0	0	0	0.0	A	0	0	0	0	0.0	A	8.3	Pass
Harrison	1	0	0	0.3	B	0	0	0	0	0.0	A	9.2	Pass
Hinds	0	0	0	0.0	A	1	0	0	0	0.3	B	10.1	Pass
Jackson	1	0	0	0.3	B	0	0	0	0	0.0	A	8.4	Pass
Lauderdale	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lee	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Yalobusha	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC

MISSISSIPPI

American Lung Association in Mississippi

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Bolivar	30,308	7,530	5,171	761	2,302	2,086	21	2,847	359	9,905	20,591
DeSoto	188,633	47,463	25,312	4,796	14,504	12,396	131	16,550	2,378	20,337	77,492
Forrest	77,875	18,354	10,997	1,854	6,004	5,100	54	6,616	1,066	15,097	33,521
Hancock	46,055	9,016	9,838	911	3,775	3,633	32	5,209	476	7,913	7,366
Harrison	209,396	49,718	33,403	5,023	16,244	14,412	146	19,532	2,471	36,796	78,386
Hinds	222,679	52,918	34,980	5,347	17,208	15,156	154	20,339	2,843	54,213	170,357
Jackson	143,987	33,226	23,962	3,357	11,316	10,177	100	13,997	1,661	21,019	47,454
Lauderdale	72,088	16,840	13,057	1,701	5,592	5,144	50	7,107	795	15,632	35,429
Lee	82,883	20,779	12,726	2,099	6,345	5,611	58	7,626	981	12,446	30,296
Yalobusha	12,415	2,710	2,629	274	984	951	9	1,359	131	2,733	5,229

MISSOURI

American Lung Association in Missouri

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Andrew	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Boone	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Buchanan	DNC	DNC	DNC	DNC	DNC	3	0	0	0	1.0	C	8.2	Pass
Callaway	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cass	2	0	0	0.7	B	1	0	0	0	0.3	B	6.5	Pass
Cedar	0	0	0	0.0	A	0	0	0	0	0.0	A	7.2	Pass
Clay	5	0	0	1.7	C	0	0	0	0	0.0	A	6.2	Pass
Clinton	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Greene	0	0	0	0.0	A	1	0	0	0	0.3	B	INC	INC
Jackson	DNC	DNC	DNC	DNC	DNC	7	1	0	0	2.8	D	7.9	Pass
Jasper	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jefferson	7	0	0	2.3	D	1	1	0	0	0.8	B	7.4	Pass
Lincoln	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Monroe	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Perry	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. Charles	9	1	0	3.5	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Ste. Genevieve	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
St. Louis	10	0	0	3.3	F	2	0	0	0	0.7	B	7.9	Pass
St. Louis City	6	1	0	2.5	D	7	1	0	0	2.8	D	9.2	Pass

MISSOURI

American Lung Association in Missouri

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Andrew	18,002	4,133	3,576	294	1,302	1,261	12	1,449	179	1,543	1,197
Boone	185,840	38,206	24,910	2,722	14,477	10,924	125	11,607	2,662	29,264	40,951
Buchanan	83,853	18,858	14,417	1,343	6,203	5,513	57	6,167	882	14,831	14,975
Callaway	44,638	9,271	7,674	660	3,379	3,002	30	3,346	480	4,312	4,676
Cass	109,638	25,984	19,210	1,851	7,938	7,328	74	8,251	1,165	7,893	15,090
Cedar	14,496	3,562	3,284	254	1,011	1,039	10	1,228	127	2,598	887
Clay	255,518	60,831	38,021	4,333	18,763	15,965	172	17,470	3,011	20,470	53,140
Clinton	21,287	4,903	3,906	349	1,547	1,465	14	1,661	211	2,104	1,466
Greene	300,865	62,477	50,876	4,451	22,920	19,339	202	21,462	3,736	38,292	40,420
Jackson	716,862	167,396	112,332	11,925	52,830	45,242	481	49,879	8,512	92,796	273,390
Jasper	123,155	30,413	19,831	2,167	8,889	7,711	83	8,567	1,402	20,272	20,983
Jefferson	227,771	51,849	36,846	3,694	16,802	15,142	153	16,789	2,447	19,654	14,465
Lincoln	61,586	15,660	8,794	1,116	4,423	3,812	41	4,161	676	5,657	4,539
Monroe	8,712	1,923	2,087	137	625	655	6	777	75	1,288	662
Perry	18,922	4,330	3,695	308	1,373	1,314	13	1,506	190	1,890	1,072
St. Charles	409,981	93,314	66,775	6,647	30,293	26,860	276	29,798	4,561	21,239	58,393
Ste. Genevieve	18,588	4,085	3,887	291	1,354	1,346	13	1,558	172	1,885	790
St. Louis	997,187	220,665	187,634	15,720	73,507	67,980	668	77,219	11,079	102,288	352,013
St. Louis City	293,310	54,137	44,145	3,857	23,233	18,697	197	20,225	3,973	60,908	159,847

CA Exhibit 14

MONTANA

American Lung Association in Montana

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Fergus	5	0	0	1.7	C	11	3	0	0	5.2	F	5.0	Pass
Flathead	0	0	0	0.0	A	12	6	0	0	7.0	F	7.1	Pass
Gallatin	DNC	DNC	DNC	DNC	DNC	12	0	0	0	4.0	F	3.0	Pass
Lewis and Clark	1	0	0	0.3	B	16	7	0	0	8.8	F	8.5	Pass
Lincoln	DNC	DNC	DNC	DNC	DNC	14	10	2	1	11.8	F	13.3	Fail
Missoula	INC	INC	INC	INC	INC	20	9	0	0	11.2	F	9.3	Pass
Phillips	1	0	0	0.3	B	4	0	0	0	1.3	C	5.5	Pass
Powder River	2	0	0	0.7	B	13	3	0	0	5.8	F	7.5	Pass
Ravalli	DNC	DNC	DNC	DNC	DNC	21	10	0	0	12.0	F	6.5	Pass
Richland	1	0	0	0.3	B	3	0	0	0	1.0	C	5.0	Pass
Rosebud	0	0	0	0.0	A	14	4	0	0	6.7	F	INC	INC
Silver Bow	DNC	DNC	DNC	DNC	DNC	19	9	0	0	10.8	F	7.0	Pass
Yellowstone	DNC	DNC	DNC	DNC	DNC	11	3	0	0	5.2	F	INC	INC

MONTANA

American Lung Association in Montana

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Fergus	11,617	2,440	2,872	123	876	598	5	803	100	1,359	775
Flathead	108,454	23,532	22,209	1,182	8,211	5,150	51	6,721	1,051	10,183	8,572
Gallatin	122,713	23,646	16,318	1,187	9,946	4,733	57	5,830	1,527	10,517	11,514
Lewis and Clark	72,223	15,359	14,247	771	5,518	3,377	34	4,382	724	6,389	6,747
Lincoln	20,525	3,791	6,133	190	1,566	1,198	10	1,641	156	3,409	1,629
Missoula	119,533	21,817	19,996	1,095	9,688	5,096	56	6,475	1,479	15,043	13,804
Phillips	4,192	1,008	990	51	303	211	2	281	31	600	720
Powder River	1,702	285	512	14	133	101	1	138	12	184	132
Ravalli	45,959	8,560	12,257	430	3,543	2,524	21	3,405	377	4,323	3,694
Richland	11,283	2,840	1,851	143	826	479	5	609	109	1,022	1,298
Rosebud	8,124	2,400	1,372	121	557	336	4	432	74	1,419	3,806
Silver Bow	35,411	7,233	6,852	363	2,746	1,633	17	2,114	353	4,471	3,526
Yellowstone	167,146	38,877	29,349	1,952	12,549	7,265	78	9,317	1,757	18,523	24,740

NEBRASKA

American Lung Association in Nebraska

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Douglas	2	0	0	0.7	B	4	1	0	0	1.8	C	7.6	Pass
Hall	DNC	DNC	DNC	DNC	DNC	2	0	0	0	0.7	B	INC	INC
Knox	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lancaster	0	0	0	0.0	A	0	0	0	0	0.0	A	6.6	Pass
Sarpy	DNC	DNC	DNC	DNC	DNC	4	0	0	0	1.3	C	8.1	Pass
Scotts Bluff	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	INC	INC
Washington	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	6.9	Pass

NEBRASKA

American Lung Association in Nebraska

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Douglas	585,008	148,214	80,663	8,381	36,429	23,217	305	28,214	7,839	67,277	186,815
Hall	61,979	17,037	9,548	963	3,718	2,544	32	3,187	722	7,341	22,573
Knox	8,401	2,114	2,113	120	507	427	4	587	76	1,009	1,370
Lancaster	324,514	72,895	48,228	4,122	21,033	13,222	170	16,140	4,509	37,132	64,683
Sarpy	193,418	51,845	24,105	2,932	11,819	7,429	101	8,899	2,537	10,533	40,691
Scotts Bluff	35,745	8,872	7,035	502	2,203	1,637	19	2,138	408	4,773	10,517
Washington	20,969	5,015	3,883	284	1,306	971	11	1,252	230	1,303	1,236

NEVADA

American Lung Association in Nevada

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Churchill	11	1	0	4.2	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clark	47	1	0	16.2	F	9	5	0	0	5.5	F	10.0	Pass
Douglas	DNC	DNC	DNC	DNC	DNC	13	31	6	0	23.8	F	8.8	Pass
Lyon	9	0	0	3.0	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Washoe	34	2	0	12.3	F	17	27	5	0	22.5	F	9.7	Pass
White Pine	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Carson City	13	0	0	4.3	F	20	21	6	0	21.2	F	8.3	Pass

NEVADA

American Lung Association in Nevada

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Churchill	25,723	5,897	4,916	464	1,821	1,422	13	1,678	242	2,636	7,370
Clark	2,292,476	520,341	353,819	40,937	163,964	117,991	1,131	136,741	25,109	341,367	1,381,272
Douglas	49,870	7,745	15,612	609	3,830	3,698	25	4,526	363	3,991	10,017
Lyon	60,903	12,728	13,026	1,001	4,422	3,615	30	4,302	551	5,682	17,070
Washoe	493,392	104,538	84,784	8,224	35,860	26,559	244	31,002	5,192	53,423	192,770
White Pine	9,182	1,842	1,746	145	676	519	5	611	71	1,042	2,726
Carson City	58,993	11,918	12,411	938	4,327	3,506	29	4,163	521	6,597	20,615

NEW HAMPSHIRE

American Lung Association in New Hampshire

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Belknap	0	0	0	0.0	A	1	0	0	0	0.3	B	4.2	Pass
Cheshire	0	0	0	0.0	A	1	0	0	0	0.3	B	6.2	Pass
Coos	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Grafton	0	0	0	0.0	A	1	0	0	0	0.3	B	5.1	Pass
Hillsborough	0	0	0	0.0	A	2	0	0	0	0.7	B	3.5	Pass
Merrimack	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Rockingham	3	0	0	1.0	C	2	0	0	0	0.7	B	5.7	Pass

NEW HAMPSHIRE

American Lung Association in New Hampshire

	AT-RISK GROUPS										
				Lung Diseases							
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Pregnancies**	**Poverty**	**People of Color**
Belknap	64,460	11,494	14,942	857	6,400	4,076	40	4,579	510	4,840	3,537
Cheshire	77,329	13,769	16,545	1,027	7,754	4,637	47	5,102	706	7,283	5,047
Coos	31,289	5,079	7,764	379	3,157	2,047	19	2,322	222	3,650	1,800
Grafton	92,201	14,505	20,389	1,082	9,485	5,638	57	6,204	872	7,288	9,255
Hillsborough	424,079	84,196	70,614	6,281	41,944	23,427	260	24,715	3,990	30,217	73,147
Merrimack	155,238	28,784	29,979	2,147	15,494	9,047	95	9,790	1,402	12,908	12,893
Rockingham	316,947	59,511	60,938	4,439	31,462	18,749	194	20,360	2,728	14,449	26,591

NEW JERSEY

American Lung Association in New Jersey

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Atlantic	1	0	0	0.3	B	0	0	0	0	0.0	A	6.5	Pass
Bergen	15	0	0	5.0	F	1	0	0	0	0.3	B	INC	INC
Camden	7	0	0	2.3	D	2	0	0	0	0.7	B	9.4	Pass
Cumberland	5	0	0	1.7	C	0	0	0	0	0.0	A	INC	INC
Essex	2	0	0	0.7	B	2	0	0	0	0.7	B	8.6	Pass
Gloucester	4	0	0	1.3	C	0	0	0	0	0.0	A	INC	INC
Hudson	3	0	0	1.0	C	0	0	0	0	0.0	A	INC	INC
Hunterdon	1	0	0	0.3	B	0	0	0	0	0.0	A	7.6	Pass
Mercer	10	0	0	3.3	F	2	0	0	0	0.7	B	7.8	Pass
Middlesex	7	0	0	2.3	D	2	0	0	0	0.7	B	7.9	Pass
Monmouth	3	1	0	1.5	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Morris	0	0	0	0.0	A	0	0	0	0	0.0	A	INC	INC
Ocean	4	0	0	1.3	C	2	0	0	0	0.7	B	6.7	Pass
Passaic	1	0	0	0.3	B	INC	INC	INC	INC	INC	INC	INC	INC
Union	DNC	DNC	DNC	DNC	DNC	2	0	0	0	0.7	B	9.0	Pass
Warren	0	0	0	0.0	A	2	0	0	0	0.7	B	7.5	Pass

NEW JERSEY

American Lung Association in New Jersey

	AT-RISK GROUPS										
				Lung Diseases							
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Pregnancies**	**Poverty**	**People of Color**
Atlantic	274,966	57,527	53,009	3,101	19,507	12,959	140	16,959	2,840	40,786	122,364
Bergen	953,819	200,450	170,005	10,804	67,811	43,732	484	56,603	10,241	70,847	442,450
Camden	523,771	118,921	85,226	6,410	36,704	22,438	266	28,879	5,903	62,053	238,062
Cumberland	153,627	37,252	24,356	2,008	10,562	6,408	78	8,247	1,552	20,814	85,614
Essex	854,917	202,467	121,017	10,913	59,442	34,690	434	43,884	10,070	126,387	600,349
Gloucester	304,477	65,563	50,933	3,534	21,585	13,511	155	17,371	3,337	23,243	71,616
Hudson	702,463	143,110	88,631	7,714	51,714	26,777	357	33,464	9,189	109,996	503,134
Hunterdon	129,924	24,433	26,126	1,317	9,399	6,514	66	8,496	1,236	5,115	21,931
Mercer	385,898	82,001	61,675	4,420	27,585	16,660	196	21,329	4,429	38,024	205,744
Middlesex	860,807	185,765	136,471	10,013	61,287	36,950	438	47,283	9,752	67,146	517,233
Monmouth	645,354	133,923	120,504	7,219	45,809	30,590	328	39,724	6,499	47,491	162,143
Morris	510,981	105,047	90,781	5,662	36,499	23,668	260	30,554	5,325	28,395	156,906
Ocean	648,998	160,695	145,271	8,662	43,459	31,077	329	41,942	5,820	73,139	105,968
Passaic	518,117	122,623	79,154	6,609	35,944	21,500	263	27,491	5,829	71,951	313,494
Union	572,114	134,052	85,188	7,226	39,754	23,930	291	30,406	6,360	52,354	352,959
Warren	110,731	21,226	21,266	1,144	8,015	5,365	56	6,976	1,114	10,140	24,240

NEW MEXICO

American Lung Association in New Mexico

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Bernalillo	22	1	0	7.8	F	4	2	0	0	2.3	D	9.1	Pass
Doña Ana	41	6	0	16.7	F	8	3	0	0	4.2	F	8.4	Pass
Eddy	53	3	0	19.2	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lea	5	1	0	2.2	D	1	0	0	0	0.3	B	6.5	Pass
Rio Arriba	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Sandoval	8	0	0	2.7	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
San Juan	12	0	0	4.0	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Santa Fe	4	0	0	1.3	C	1	0	0	0	0.3	B	4.3	Pass
Taos	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	5.6	Pass
Valencia	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC

NEW MEXICO

American Lung Association in New Mexico

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Bernalillo	674,393	141,116	117,181	8,870	56,103	28,308	211	37,323	7,178	100,775	423,025
Doña Ana	221,508	52,853	36,602	3,322	17,850	8,697	69	11,371	2,419	41,993	163,692
Eddy	60,911	16,182	9,016	1,017	4,708	2,280	19	3,002	599	8,329	34,403
Lea	73,004	21,885	8,320	1,376	5,382	2,380	23	3,127	738	13,332	49,608
Rio Arriba	40,179	9,168	8,381	576	3,251	1,843	13	2,443	361	8,138	35,064
Sandoval	151,369	33,858	28,924	2,128	12,330	6,648	47	8,801	1,468	14,144	88,921
San Juan	120,993	30,930	19,514	1,944	9,464	4,770	38	6,298	1,202	29,043	77,440
Santa Fe	155,201	26,175	41,328	1,645	13,557	8,334	49	11,035	1,351	18,790	88,049
Taos	34,623	5,825	9,930	366	3,025	1,941	11	2,573	277	6,387	22,184
Valencia	77,190	17,960	14,185	1,129	6,215	3,306	24	4,376	727	14,188	53,456

NEW YORK

American Lung Association in New York

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Albany	0	0	0	0.0	A	5	0	0	0	1.7	C	7.4	Pass
Bronx	11	0	0	3.7	F	0	1	0	0	0.5	B	8.3	Pass
Chautauqua	2	0	0	0.7	B	0	0	0	0	0.0	A	6.0	Pass
Dutchess	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Erie	1	0	0	0.3	B	0	1	0	0	0.5	B	7.2	Pass
Essex	1	0	0	0.3	B	0	0	0	0	0.0	A	3.2	Pass
Hamilton	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Herkimer	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jefferson	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Kings	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Monroe	0	0	0	0.0	A	0	0	0	0	0.0	A	6.6	Pass
New York	9	0	0	3.0	D	0	0	0	0	0.0	A	INC	INC
Niagara	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Onondaga	0	0	0	0.0	A	1	0	0	0	0.3	B	6.2	Pass
Orange	0	0	0	0.0	A	0	0	0	0	0.0	A	INC	INC
Oswego	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Putnam	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Queens	15	0	0	5.0	F	0	1	0	0	0.5	B	7.0	Pass
Richmond	7	0	0	2.3	D	0	0	0	0	0.0	A	INC	INC
Rockland	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Saratoga	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Steuben	0	0	0	0.0	A	1	0	0	0	0.3	B	5.8	Pass
Suffolk	25	1	0	8.8	F	0	0	0	0	0.0	A	INC	INC
Tompkins	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Wayne	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Westchester	7	0	0	2.3	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC

NEW YORK

American Lung Association in New York

	AT-RISK GROUPS										
				Lung Diseases							
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Pregnancies**	**Poverty**	**People of Color**
Albany	313,743	56,968	56,130	3,724	25,691	13,712	175	18,612	3,604	35,631	91,250
Bronx	1,424,948	349,664	199,098	22,855	108,299	55,298	792	73,422	16,120	366,448	1,297,316
Chautauqua	126,807	25,769	26,810	1,684	10,073	5,955	71	8,360	1,173	20,925	17,001
Dutchess	297,112	54,596	55,005	3,569	24,342	13,642	166	18,736	2,968	27,106	90,129
Erie	950,683	191,836	178,176	12,539	75,925	42,445	529	58,438	9,716	126,486	243,431
Essex	37,268	5,887	9,263	385	3,118	1,947	21	2,781	299	4,022	3,046
Hamilton	5,119	676	1,695	44	437	312	3	463	35	491	290
Herkimer	59,937	12,231	12,887	799	4,757	2,852	33	4,019	538	7,806	3,788
Jefferson	116,295	28,010	16,962	1,831	8,851	4,435	65	5,883	1,140	13,592	21,753
Kings	2,641,052	599,746	400,082	39,201	204,903	105,060	1,468	140,229	31,101	501,895	1,663,807
Monroe	755,160	154,850	138,000	10,121	60,083	33,218	420	45,565	7,952	96,950	227,993
New York	1,576,876	231,694	288,916	15,144	134,490	70,557	876	95,319	20,124	264,938	854,444
Niagara	211,653	42,114	42,745	2,753	16,954	9,898	118	13,806	2,000	27,106	32,898
Onondaga	473,236	99,935	85,517	6,532	37,382	20,704	263	28,400	4,933	64,695	112,821
Orange	404,525	103,760	58,564	6,782	30,316	16,030	226	21,518	3,963	47,939	157,302
Oswego	117,387	24,557	20,566	1,605	9,328	5,195	65	7,113	1,140	17,710	7,641
Putnam	97,936	18,844	18,213	1,232	7,954	4,564	55	6,300	909	6,398	24,232
Queens	2,331,143	465,509	404,630	30,427	187,325	102,371	1,298	139,458	24,844	312,866	1,759,091
Richmond	493,494	107,326	83,869	7,015	38,817	21,413	275	29,222	5,027	57,909	206,019
Rockland	339,227	99,127	53,162	6,479	24,077	13,192	189	18,011	3,142	50,989	126,426
Saratoga	237,359	45,819	45,926	2,995	19,199	11,033	132	15,286	2,312	18,123	24,220
Steuben	92,948	20,047	18,850	1,310	7,284	4,298	52	6,018	839	12,570	6,272
Suffolk	1,526,344	316,216	269,092	20,669	121,698	68,368	850	93,778	14,801	95,569	522,831
Tompkins	105,162	15,127	16,554	989	9,011	4,336	59	5,679	1,434	14,936	23,787
Wayne	90,923	19,295	18,218	1,261	7,170	4,243	51	5,935	805	8,981	9,650
Westchester	997,895	213,838	177,508	13,977	78,728	44,198	555	60,708	10,050	91,529	475,252

CA Exhibit 14

NORTH CAROLINA

American Lung Association in North Carolina

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Alexander	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Avery	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Buncombe	0	0	0	0.0	A	0	0	0	0	0.0	A	5.9	Pass
Caldwell	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Carteret	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Caswell	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Catawba	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	8.3	Pass
Cumberland	0	0	0	0.0	A	1	0	0	0	0.3	B	7.6	Pass
Davidson	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	8.7	Pass
Durham	0	0	0	0.0	A	0	0	0	0	0.0	A	7.6	Pass
Edgecombe	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Forsyth	0	0	0	0.0	A	3	0	0	0	1.0	C	8.8	Pass
Graham	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Granville	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Guilford	0	0	0	0.0	A	0	0	0	0	0.0	A	7.0	Pass
Haywood	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jackson	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Johnston	0	0	0	0.0	A	0	0	0	0	0.0	A	7.6	Pass
Lenoir	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lincoln	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Macon	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Martin	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Mecklenburg	11	0	0	3.7	F	3	0	0	0	1.0	C	9.1	Pass
Mitchell	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	5.7	Pass
Montgomery	0	0	0	0.0	A	1	0	0	0	0.3	B	7.8	Pass
New Hanover	0	0	0	0.0	A	0	0	0	0	0.0	A	4.1	Pass
Northampton	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Person	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Pitt	0	0	0	0.0	A	0	0	0	0	0.0	A	6.3	Pass
Rockingham	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Rowan	0	0	0	0.0	A	0	0	0	0	0.0	A	INC	INC
Swain	0	0	0	0.0	A	2	0	0	0	0.7	B	6.5	Pass
Union	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Wake	0	0	0	0.0	A	1	0	0	0	0.3	B	8.1	Pass
Yancey	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC

NORTH CAROLINA

American Lung Association in North Carolina

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Alexander	36,644	7,269	7,562	835	2,589	2,430	23	3,199	339	4,443	5,178
Avery	17,864	2,632	4,036	302	1,336	1,256	11	1,663	154	2,630	2,166
Buncombe	271,534	48,562	57,129	5,581	19,485	17,862	168	23,501	3,076	30,954	46,312
Caldwell	80,463	16,076	16,727	1,847	5,683	5,377	50	7,090	777	11,804	11,414
Carteret	68,541	11,729	18,006	1,348	4,977	5,083	43	6,965	592	7,997	9,276
Caswell	22,714	4,184	5,277	481	1,628	1,588	14	2,132	193	4,463	8,886
Catawba	161,723	35,195	29,924	4,044	11,176	10,173	101	13,177	1,677	21,477	41,996
Cumberland	335,508	84,258	42,320	9,683	21,955	16,987	209	20,574	4,050	50,499	198,193
Davidson	170,637	36,955	32,013	4,247	11,829	10,872	106	14,116	1,749	22,945	37,228
Durham	326,126	64,873	46,762	7,455	22,893	18,265	202	22,402	4,398	41,987	184,435
Edgecombe	48,359	10,930	10,202	1,256	3,277	3,106	30	4,136	508	10,671	31,151
Forsyth	385,523	87,513	64,413	10,057	26,237	22,813	239	29,043	4,479	53,575	172,846
Graham	8,043	1,618	1,995	186	560	558	5	763	73	1,361	1,234
Granville	61,986	12,611	11,103	1,449	4,381	3,954	39	5,074	614	8,231	26,813
Guilford	542,410	120,161	86,256	13,808	37,181	31,627	336	39,830	6,613	70,898	282,433
Haywood	62,476	11,152	15,654	1,282	4,486	4,472	39	6,085	591	8,521	5,347
Jackson	43,410	7,136	8,890	820	3,148	2,776	27	3,621	524	7,364	8,672
Johnston	226,504	56,582	31,141	6,502	15,115	12,722	141	15,724	2,552	26,562	80,019
Lenoir	54,706	12,408	11,416	1,426	3,712	3,521	34	4,678	540	11,414	28,388
Lincoln	89,670	18,632	16,864	2,141	6,312	5,841	56	7,572	892	7,830	14,341
Macon	37,564	6,874	10,931	790	2,656	2,811	23	3,948	316	5,289	4,534
Martin	21,754	4,443	5,472	511	1,511	1,527	13	2,093	200	4,336	10,522
Mecklenburg	1,122,276	256,417	133,280	29,466	76,558	59,687	696	71,345	14,757	113,013	614,019
Mitchell	14,963	2,761	3,781	317	1,066	1,071	9	1,462	133	2,223	1,395
Montgomery	25,798	5,510	5,566	633	1,781	1,705	16	2,272	253	4,407	9,592
New Hanover	229,018	40,818	43,236	4,691	16,469	14,443	142	18,601	2,798	26,307	52,066
Northampton	17,129	3,011	4,845	346	1,230	1,292	11	1,800	139	3,962	10,450
Person	39,127	7,998	8,168	919	2,748	2,613	24	3,452	381	6,772	13,538
Pitt	172,169	36,620	24,602	4,208	11,836	9,387	106	11,535	2,382	35,969	80,800
Rockingham	91,266	18,404	19,308	2,115	6,430	6,133	57	8,117	896	16,319	26,070
Rowan	148,150	32,414	26,663	3,725	10,214	9,174	92	11,824	1,546	24,540	43,959
Swain	14,136	3,222	2,677	370	959	876	9	1,142	151	2,427	5,850
Union	243,648	63,171	32,148	7,259	16,161	13,731	152	16,908	2,663	18,556	73,677
Wake	1,150,204	266,436	144,469	30,618	78,373	62,881	714	76,065	14,409	105,694	473,760
Yancey	18,757	3,420	4,956	393	1,336	1,360	12	1,872	169	3,230	1,528

NORTH DAKOTA

American Lung Association in North Dakota

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Billings	1	0	0	0.3	B	3	1	0	0	1.5	C	4.2	Pass
Burke	0	0	0	0.0	A	7	2	0	0	3.3	F	5.4	Pass
Burleigh	0	0	0	0.0	A	11	5	0	0	6.2	F	6.5	Pass
Cass	1	0	0	0.3	B	8	10	0	0	7.7	F	7.9	Pass
Dunn	1	0	0	0.3	B	6	3	0	0	3.5	F	5.3	Pass
McKenzie	0	0	0	0.0	A	6	2	0	0	3.0	D	4.8	Pass
Mercer	1	0	0	0.3	B	5	4	0	0	3.7	F	5.7	Pass
Oliver	2	0	0	0.7	B	9	6	0	0	6.0	F	6.2	Pass
Ward	0	0	0	0.0	A	10	4	0	0	5.3	F	5.9	Pass
Williams	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC

CA Exhibit 14

NORTH DAKOTA

American Lung Association in North Dakota

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Billings	955	198	233	13	62	43	1	74	9	103	84
Burke	2,158	535	467	35	133	91	1	153	21	191	188
Burleigh	98,933	23,395	16,993	1,522	6,340	3,767	52	6,045	1,268	7,923	12,428
Cass	186,562	42,265	23,926	2,750	12,398	6,368	99	9,554	2,855	19,208	30,356
Dunn	4,035	1,049	698	68	249	153	2	248	42	440	828
McKenzie	13,819	4,430	1,354	288	807	408	7	599	174	1,254	3,545
Mercer	8,323	1,942	1,816	126	522	357	4	602	81	655	678
Oliver	1,873	460	443	30	115	82	1	141	17	207	120
Ward	69,071	16,561	9,274	1,078	4,500	2,359	37	3,583	941	6,234	13,083
Williams	38,484	11,693	3,799	761	2,305	1,155	20	1,690	492	3,239	8,837

CA Exhibit 14

OHIO

American Lung Association in Ohio

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Allen	1	0	0	0.3	B	0	0	0	0	0.0	A	6.6	Pass
Ashtabula	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Athens	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	6.2	Pass
Belmont	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Butler	7	0	0	2.3	D	1	0	0	0	0.3	B	INC	INC
Clark	3	0	0	1.0	C	0	0	0	0	0.0	A	9.0	Pass
Clermont	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clinton	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cuyahoga	14	0	0	4.7	F	3	1	0	0	1.5	C	9.5	Pass
Delaware	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Fayette	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Franklin	2	0	0	0.7	B	1	0	0	0	0.3	B	9.1	Pass
Geauga	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Greene	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hamilton	15	0	0	5.0	F	3	0	0	0	1.0	C	11.0	Pass
Harrison	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Jefferson	1	0	0	0.3	B	2	1	0	0	1.2	C	INC	INC
Knox	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lake	18	0	0	6.0	F	0	0	0	0	0.0	A	6.5	Pass
Lawrence	0	0	0	0.0	A	0	0	0	0	0.0	A	7.7	Pass
Licking	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lorain	0	0	0	0.0	A	0	1	0	0	0.5	B	INC	INC
Lucas	13	0	0	4.3	F	1	0	0	0	0.3	B	INC	INC
Madison	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Mahoning	0	0	0	0.0	A	1	0	0	0	0.3	B	INC	INC
Medina	0	0	0	0.0	A	0	0	0	0	0.0	A	7.1	Pass
Miami	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Montgomery	5	0	0	1.7	C	0	0	0	0	0.0	A	9.6	Pass
Noble	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Portage	2	0	0	0.7	B	0	0	0	0	0.0	A	INC	INC
Preble	1	0	0	0.3	B	0	0	0	0	0.0	A	8.2	Pass
Scioto	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Stark	5	0	0	1.7	C	2	0	0	0	0.7	B	9.5	Pass
Summit	4	0	0	1.3	C	5	0	0	0	1.7	C	8.7	Pass
Trumbull	1	0	0	0.3	B	4	1	0	0	1.8	C	7.4	Pass
Warren	9	0	0	3.0	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Washington	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Wood	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC

OHIO

American Lung Association in Ohio

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Allen	101,670	23,580	18,538	1,385	8,206	6,737	66	8,179	1,030	14,686	20,537
Ashtabula	97,337	21,431	19,487	1,258	7,941	6,882	63	8,510	916	14,787	11,055
Athens	62,056	8,988	8,850	528	5,678	3,884	40	4,341	916	11,068	6,326
Belmont	65,849	12,579	14,258	739	5,552	4,857	43	6,051	599	9,903	5,104
Butler	390,234	91,164	60,391	5,353	31,771	24,687	253	29,044	4,483	43,595	84,692
Clark	135,633	30,506	26,868	1,791	10,993	9,382	88	11,573	1,408	21,066	22,653
Clermont	209,642	47,087	37,072	2,765	17,150	14,157	136	17,099	2,194	19,702	15,343
Clinton	42,004	9,547	7,550	561	3,419	2,829	27	3,427	444	4,908	3,062
Cuyahoga	1,249,387	257,093	237,540	15,096	104,219	85,945	807	104,522	14,044	197,374	524,714
Delaware	220,740	55,911	32,199	3,283	17,573	13,921	143	16,363	2,429	9,056	39,348
Fayette	28,906	6,851	5,272	402	2,319	1,951	19	2,378	298	4,622	2,433
Franklin	1,321,414	307,247	167,632	18,041	108,789	77,450	855	87,277	17,026	184,504	518,044
Geauga	95,565	21,467	20,522	1,260	7,709	6,961	62	8,747	849	5,915	4,645
Greene	168,412	34,830	30,239	2,045	14,077	11,245	109	13,503	1,910	16,474	28,402
Hamilton	826,139	189,950	132,980	11,153	67,402	52,440	534	61,999	9,626	126,383	295,187
Harrison	14,477	3,040	3,204	179	1,188	1,074	9	1,351	136	2,008	830
Jefferson	64,789	12,744	14,402	748	5,408	4,787	42	6,003	655	10,783	6,637
Knox	62,897	14,397	11,844	845	5,087	4,233	41	5,170	663	7,421	3,151
Lake	232,023	45,224	48,888	2,655	19,507	16,977	150	21,064	2,332	16,007	31,181
Lawrence	57,445	12,452	11,092	731	4,721	4,026	37	4,939	592	9,767	3,214
Licking	180,401	41,509	30,888	2,437	14,678	11,999	117	14,421	1,925	19,460	22,695
Lorain	315,595	68,738	60,747	4,036	25,900	21,967	204	26,922	3,227	39,308	72,161
Lucas	429,191	99,025	73,312	5,815	34,867	28,074	278	33,657	4,801	73,260	140,009
Madison	44,386	8,990	7,149	528	3,764	2,988	29	3,528	414	5,356	5,573
Mahoning	226,762	45,650	49,529	2,680	18,830	16,461	147	20,574	2,238	42,174	56,883
Medina	183,092	39,676	34,890	2,330	15,071	12,888	119	15,785	1,833	11,016	12,873
Miami	109,264	25,194	20,926	1,479	8,812	7,488	71	9,195	1,100	8,915	9,608
Montgomery	535,840	118,514	98,142	6,959	43,877	35,789	346	43,346	5,968	79,459	163,279
Noble	14,176	2,671	4,069	157	1,168	1,175	9	1,550	103	1,877	827
Portage	162,382	29,736	28,680	1,746	14,027	11,105	105	13,229	1,957	19,241	18,656
Preble	40,867	9,127	8,120	536	3,322	2,883	27	3,564	399	4,448	1,699
Scioto	73,346	15,995	13,770	939	6,025	5,019	48	6,115	759	16,807	5,278
Stark	373,834	80,334	75,216	4,717	30,684	26,235	242	32,381	3,869	46,583	53,862
Summit	537,633	112,034	101,679	6,578	44,733	37,248	348	45,344	5,799	65,938	132,425
Trumbull	201,335	41,532	44,519	2,439	16,597	14,741	130	18,509	1,955	30,583	27,466
Warren	246,553	59,025	37,492	3,466	19,965	15,918	160	18,786	2,572	14,184	39,325
Washington	59,423	11,769	12,998	691	4,958	4,362	38	5,454	595	7,871	3,132
Wood	132,472	26,902	21,289	1,580	11,199	8,449	86	9,886	1,647	13,773	16,782

CA Exhibit 14

OKLAHOMA

American Lung Association in Oklahoma

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Adair	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Canadian	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Carter	INC	INC	INC	INC	INC	2	0	0	0	0.7	B	8.7	Pass
Choctaw	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cleveland	0	0	0	0.0	A	5	0	0	0	1.7	C	10.3	Pass
Comanche	0	0	0	0.0	A	3	0	0	0	1.0	C	8.1	Pass
Creek	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Dewey	0	0	0	0.0	A	1	0	0	0	0.3	B	7.7	Pass
Johnston	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Kay	INC	INC	INC	INC	INC	10	1	0	0	3.8	F	9.7	Pass
Kiowa	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Le Flore	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC	INC
Love	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
McClain	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Mayes	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Nowata	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC
Oklahoma	5	0	0	1.7	C	5	0	0	0	1.7	C	10.1	Pass
Osage	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Ottawa	3	0	0	1.0	C	13	3	0	0	5.8	F	INC	INC
Pittsburg	2	0	0	0.7	B	4	0	0	0	1.3	C	8.7	Pass
Sequoyah	1	0	0	0.3	B	1	0	0	0	0.3	B	7.9	Pass
Tulsa	5	1	0	2.2	D	5	1	0	0	2.2	D	9.1	Pass
Washington	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC

OKLAHOMA

American Lung Association in Oklahoma

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Adair	19,414	5,278	3,052	517	1,550	1,139	13	1,538	215	4,015	11,936
Canadian	161,737	41,717	21,811	4,088	13,210	8,940	107	11,781	2,030	12,976	43,941
Carter	48,291	12,204	8,281	1,196	3,941	2,903	32	3,953	548	6,725	15,620
Choctaw	14,307	3,509	2,977	344	1,170	930	9	1,301	150	2,630	5,992
Cleveland	297,597	62,198	43,181	6,094	25,861	17,148	197	22,601	4,039	35,293	90,690
Comanche	122,063	29,367	16,082	2,877	10,199	6,630	81	8,669	1,481	21,533	54,784
Creek	72,029	16,776	13,210	1,644	6,029	4,559	48	6,245	792	10,191	18,545
Dewey	4,417	1,183	829	116	352	272	3	376	44	715	923
Johnston	10,301	2,491	1,992	244	849	650	7	898	110	2,108	3,410
Kay	43,732	10,981	8,479	1,076	3,555	2,704	29	3,747	465	6,745	12,269
Kiowa	8,410	2,038	1,672	200	693	543	6	754	83	1,701	2,328
Le Flore	48,476	11,842	8,673	1,160	3,996	2,985	32	4,083	520	11,053	14,732
Love	10,216	2,517	1,888	247	838	632	7	868	114	1,551	3,214
McClain	43,516	10,999	6,802	1,078	3,568	2,584	29	3,474	503	3,987	9,940
Mayes	39,159	9,169	7,304	898	3,270	2,485	26	3,413	429	5,656	14,525
Nowata	9,303	2,135	1,806	209	781	608	6	839	96	1,429	3,266
Oklahoma	798,575	202,515	114,342	19,843	65,462	44,761	527	59,408	10,129	127,511	363,617
Osage	45,772	9,756	9,626	956	3,910	3,083	30	4,292	457	5,441	17,075
Ottawa	30,340	7,687	5,479	753	2,467	1,841	20	2,526	338	6,023	11,215
Pittsburg	43,633	9,946	8,702	975	3,659	2,801	29	3,879	441	7,506	14,173
Sequoyah	39,508	9,457	7,292	927	3,278	2,500	26	3,431	434	7,656	15,603
Tulsa	672,858	169,015	101,361	16,561	55,266	38,603	444	51,586	8,314	97,613	269,714
Washington	52,772	12,766	10,368	1,251	4,343	3,317	35	4,598	582	8,693	15,368

OREGON

American Lung Association in Oregon

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Clackamas	4	1	0	1.8	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Columbia	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Crook	DNC	DNC	DNC	DNC	DNC	2	1	0	2	2.8	D	10.4	Pass
Harney	DNC	DNC	DNC	DNC	DNC	12	12	0	1	10.8	F	11.1	Pass
Jackson	3	0	0	1.0	C	5	8	1	1	7.2	F	13.0	Fail
Josephine	DNC	DNC	DNC	DNC	DNC	1	2	0	1	2.2	D	11.3	Pass
Klamath	DNC	DNC	DNC	DNC	DNC	45	45	1	2	39.8	F	16.2	Fail
Lake	DNC	DNC	DNC	DNC	DNC	8	3	0	0	4.2	F	INC	INC
Lane	1	0	0	0.3	B	16	10	2	6	16.7	F	11.1	Pass
Marion	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Multnomah	2	0	0	0.7	B	0	1	0	1	1.3	C	7.9	Pass
Umatilla	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Washington	1	0	0	0.3	B	1	0	1	1	1.8	C	7.8	Pass

OREGON

American Lung Association in Oregon

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Clackamas	422,537	89,411	80,783	6,214	37,768	20,777	198	27,510	3,800	35,044	84,966
Columbia	53,074	10,850	10,583	754	4,791	2,695	25	3,587	447	5,361	6,896
Crook	25,739	5,130	6,490	357	2,314	1,430	12	1,995	198	3,056	3,234
Harney	7,575	1,515	1,898	105	679	415	4	579	57	1,200	1,075
Jackson	223,734	46,008	50,848	3,197	19,960	11,615	105	15,947	1,930	29,803	46,828
Josephine	88,346	17,148	23,408	1,192	7,964	4,992	41	7,037	671	14,593	12,749
Klamath	70,164	15,409	15,399	1,071	6,155	3,557	33	4,865	581	13,193	16,635
Lake	8,276	1,603	2,193	111	747	470	4	662	56	1,232	1,422
Lane	383,189	68,642	78,561	4,771	35,390	19,103	180	25,578	3,785	53,989	74,138
Marion	347,119	83,212	56,436	5,783	29,916	15,351	163	19,875	3,230	44,959	127,030
Multnomah	803,377	144,371	115,272	10,034	74,998	35,540	377	44,234	9,167	97,458	255,966
Umatilla	79,988	19,882	12,871	1,382	6,813	3,497	38	4,528	681	9,968	28,731
Washington	600,811	131,757	85,870	9,157	53,434	26,015	282	32,636	6,196	51,019	221,258

PENNSYLVANIA

American Lung Association in Pennsylvania

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021 24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Adams	1	0	0	0.3	B	2	0	0	0	0.7	B	INC	INC
Allegheny	6	0	0	2.0	C	17	5	0	0	8.2	F	11.2	Pass
Armstrong	3	0	0	1.0	C	1	0	0	0	0.3	B	8.3	Pass
Beaver	1	0	0	0.3	B	4	0	0	0	1.3	C	8.9	Pass
Berks	6	0	0	2.0	C	5	1	0	0	2.2	D	8.3	Pass
Blair	1	0	0	0.3	B	1	0	0	0	0.3	B	8.6	Pass
Bradford	0	0	0	0.0	A	1	0	0	0	0.3	B	7.3	Pass
Bucks	17	0	0	5.7	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cambria	0	0	0	0.0	A	1	0	0	0	0.3	B	9.2	Pass
Centre	0	0	0	0.0	A	1	0	0	0	0.3	B	8.4	Pass
Chester	1	0	0	0.3	B	4	0	0	0	1.3	C	8.9	Pass
Clearfield	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Cumberland	DNC	DNC	DNC	DNC	DNC	8	0	0	0	2.7	D	8.0	Pass
Dauphin	0	0	0	0.0	A	8	1	0	0	3.2	D	9.5	Pass
Delaware	5	0	0	1.7	C	7	0	0	0	2.3	D	8.6	Pass
Elk	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Erie	0	0	0	0.0	A	0	0	0	0	0.0	A	INC	INC
Fayette	0	0	0	0.0	A	1	0	0	0	0.3	B	7.8	Pass
Franklin	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Greene	1	0	0	0.3	B	1	0	0	0	0.3	B	7.0	Pass
Indiana	2	0	0	0.7	B	INC	INC	INC	INC	INC	INC	INC	INC
Lackawanna	0	0	0	0.0	A	1	0	0	0	0.3	B	INC	INC
Lancaster	2	0	0	0.7	B	19	2	0	0	7.3	F	9.5	Pass
Lawrence	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lebanon	INC	INC	INC	INC	INC	6	0	0	0	2.0	C	INC	INC
Lehigh	0	0	0	0.0	A	3	1	0	0	1.5	C	8.8	Pass
Luzerne	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lycoming	0	0	0	0.0	A	2	0	0	0	0.7	B	INC	INC
Mercer	1	0	0	0.3	B	1	0	0	0	0.3	B	INC	INC
Monroe	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Montgomery	5	0	0	1.7	C	2	0	0	0	0.7	B	8.1	Pass
Northampton	4	0	0	1.3	C	4	0	0	0	1.3	C	7.9	Pass
Philadelphia	18	1	0	6.5	F	2	1	0	0	1.2	C	8.9	Pass
Somerset	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Susquehanna	DNC	DNC	DNC	DNC	DNC	2	0	0	0	0.7	B	6.7	Pass
Tioga	0	0	0	0.0	A	1	0	0	0	0.3	B	6.2	Pass
Washington	0	0	0	0.0	A	1	0	0	0	0.3	B	8.6	Pass
Westmoreland	0	0	0	0.0	A	1	0	0	0	0.3	B	7.8	Pass
Wyoming	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	INC	INC
York	0	0	0	0.0	A	2	0	0	0	0.7	B	9.6	Pass

PENNSYLVANIA

American Lung Association in Pennsylvania

	AT-RISK GROUPS										
				Lung Diseases							
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Pregnancies**	**Poverty**	**People of Color**
Adams	104,127	20,561	22,390	1,340	8,544	6,003	61	8,638	965	8,622	12,044
Allegheny	1,238,090	232,418	243,967	15,142	104,584	67,638	726	95,494	13,161	136,011	278,320
Armstrong	65,093	12,493	15,091	814	5,324	3,914	38	5,710	562	7,580	2,125
Beaver	166,624	32,351	37,181	2,108	13,695	9,715	98	14,087	1,528	18,184	19,193
Berks	429,342	95,285	76,104	6,208	34,745	22,572	252	31,374	4,334	53,947	134,239
Blair	121,767	24,788	26,092	1,615	9,934	6,908	71	9,960	1,144	14,059	7,173
Bradford	59,892	13,311	13,229	867	4,734	3,412	35	4,974	520	8,085	2,757
Bucks	646,098	129,748	128,047	8,453	53,027	36,645	379	51,788	6,070	41,492	113,916
Cambria	132,167	25,521	31,020	1,663	10,829	7,824	78	11,474	1,186	16,322	10,716
Centre	157,527	23,261	24,568	1,515	14,398	7,936	93	10,548	1,895	21,124	23,054
Chester	538,649	120,158	92,653	7,828	43,525	28,345	316	39,130	5,408	34,996	118,853
Clearfield	80,082	14,517	16,994	946	6,719	4,679	47	6,681	659	10,556	6,037
Cumberland	262,919	54,039	49,533	3,521	21,722	14,075	155	19,758	2,681	20,156	45,108
Dauphin	287,400	65,000	50,819	4,235	23,163	14,931	169	20,778	2,965	33,359	106,831
Delaware	573,849	126,550	98,430	8,245	46,746	29,646	336	40,921	6,124	55,843	204,908
Elk	30,783	5,965	7,084	389	2,507	1,864	18	2,713	252	3,061	890
Erie	269,011	56,508	51,394	3,682	22,043	14,461	158	20,381	2,695	40,564	45,183
Fayette	126,931	24,387	28,156	1,589	10,454	7,440	75	10,762	1,132	19,633	11,081
Franklin	156,289	34,445	31,410	2,244	12,522	8,591	92	12,264	1,500	14,695	21,040
Greene	35,369	6,755	7,155	440	2,950	1,996	21	2,830	316	4,803	2,486
Indiana	82,886	14,973	16,954	976	7,050	4,592	49	6,527	863	10,735	5,345
Lackawanna	215,663	44,520	43,733	2,901	17,639	11,929	127	17,010	2,134	28,502	38,563
Lancaster	553,652	129,256	104,237	8,421	44,025	28,838	325	40,807	5,542	47,460	108,092
Lawrence	85,497	17,104	19,475	1,114	6,957	4,990	50	7,282	773	10,145	7,636
Lebanon	143,493	32,461	28,506	2,115	11,443	7,737	84	11,046	1,381	12,565	28,839
Lehigh	375,539	85,430	64,265	5,566	30,316	19,227	220	26,581	3,935	40,827	148,669
Luzerne	326,053	65,882	64,903	4,292	26,855	18,051	192	25,596	3,139	40,126	76,346
Lycoming	113,605	23,509	22,834	1,532	9,300	6,243	67	8,889	1,128	11,647	11,808
Mercer	109,972	21,065	24,834	1,372	9,065	6,435	65	9,352	1,000	13,461	11,418
Monroe	169,273	32,940	31,234	2,146	14,099	9,446	100	13,124	1,662	18,697	63,247
Montgomery	860,578	184,327	157,894	12,009	70,154	46,138	505	64,464	8,688	58,621	224,040
Northampton	313,628	61,579	62,047	4,012	26,054	17,396	184	24,598	3,128	29,433	82,377
Philadelphia	1,576,251	340,070	227,367	22,156	131,954	74,821	922	99,512	19,571	341,533	1,044,529
Somerset	73,627	13,326	17,027	868	6,128	4,422	44	6,436	587	8,898	4,470
Susquehanna	38,389	7,210	9,445	470	3,137	2,365	23	3,492	310	4,561	1,669
Tioga	40,929	8,083	9,417	527	3,340	2,399	24	3,506	372	5,266	1,629
Washington	209,470	41,277	44,721	2,689	17,218	12,025	123	17,278	1,957	18,667	17,755
Westmoreland	353,057	64,384	83,505	4,195	29,246	21,384	207	31,280	3,111	38,934	23,983
Wyoming	26,034	5,056	5,843	329	2,137	1,526	15	2,215	238	2,944	1,370
York	458,696	100,560	83,727	6,552	37,115	24,545	270	34,293	4,515	41,594	85,494

PUERTO RICO

American Lung Association in Puerto Rico

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Adjuntas	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Bayamón	0	0	0	0.0	A	0	0	0	0	0.0	A	INC	INC
Caguas	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Cataño	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Fajardo	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Guayama	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC	INC
Guaynabo	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Juncos	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Mayagüez	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Ponce	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC

PUERTO RICO

American Lung Association in Puerto Rico

	AT-RISK GROUPS										
				Lung Diseases							
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Pregnancies**	**Poverty**	**People of Color**
Adjuntas	17,987	3,196	3,979	332	1,690	769	3	1,628	101	12,084	17,980
Bayamón	182,673	28,837	43,441	2,993	17,530	7,932	29	16,819	1,061	61,089	184,839
Caguas	126,756	20,920	27,885	2,171	12,080	5,431	20	11,381	776	47,847	126,545
Cataño	22,861	3,962	5,305	411	2,154	973	4	2,061	134	10,834	23,310
Fajardo	31,590	5,425	7,357	563	2,986	1,362	5	2,905	187	13,758	32,250
Guayama	36,511	6,285	7,423	652	3,446	1,515	6	3,100	212	17,659	37,275
Guaynabo	89,195	12,738	22,197	1,322	8,726	4,009	14	8,619	496	22,468	88,900
Juncos	37,279	6,861	6,578	712	3,472	1,498	6	2,981	252	14,874	37,203
Mayagüez	71,939	11,309	18,723	1,174	6,887	3,129	11	6,717	409	39,204	73,711
Ponce	135,084	23,708	33,075	2,460	12,690	5,808	21	12,483	735	68,951	138,725

RHODE ISLAND

American Lung Association in Rhode Island

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Kent	3	0	0	1.0	C	1	0	0	0	0.3	B	4.6	Pass
Providence	5	0	0	1.7	C	1	0	0	0	0.3	B	8.2	Pass
Washington	5	1	0	2.2	D	0	0	0	0	0.0	A	4.5	Pass

RHODE ISLAND

American Lung Association in Rhode Island

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Kent	170,715	31,451	33,783	2,075	17,602	8,375	109	10,812	1,501	13,635	23,984
Providence	658,221	133,834	105,211	8,828	66,630	29,103	422	35,998	6,572	90,405	270,169
Washington	130,592	20,520	29,158	1,354	13,869	6,743	84	8,882	1,160	11,421	12,499

SOUTH CAROLINA

American Lung Association in South Carolina

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Aiken	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Anderson	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Berkeley	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Charleston	1	0	0	0.3	B	1	0	0	0	0.3	B	7.1	Pass
Chesterfield	0	0	0	0.0	A	0	0	0	0	0.0	A	7.0	Pass
Darlington	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Edgefield	0	0	0	0.0	A	0	0	0	0	0.0	A	7.5	Pass
Florence	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.3	Pass
Greenville	2	0	0	0.7	B	1	0	0	0	0.3	B	8.3	Pass
Horry	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Lexington	DNC	DNC	DNC	DNC	DNC	2	0	0	0	0.7	B	7.8	Pass
Oconee	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC
Pickens	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Richland	3	0	0	1.0	C	0	0	0	0	0.0	A	7.2	Pass
Spartanburg	3	0	0	1.0	C	0	0	0	0	0.0	A	8.1	Pass
York	8	0	0	2.7	D	0	0	0	0	0.0	A	7.2	Pass

SOUTH CAROLINA

American Lung Association in South Carolina

	AT-RISK GROUPS										
				Lung Diseases							
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Pregnancies**	**Poverty**	**People of Color**
Aiken	170,776	36,457	34,894	2,405	12,406	10,426	99	12,535	1,775	26,041	59,289
Anderson	206,908	46,680	38,059	3,079	14,843	12,193	120	14,445	2,207	32,461	48,744
Berkeley	236,701	56,246	34,962	3,710	16,758	12,744	138	14,589	2,669	23,708	88,944
Charleston	413,024	79,967	71,813	5,275	30,826	23,900	239	27,816	4,939	55,612	140,531
Chesterfield	43,268	9,524	8,355	628	3,127	2,635	25	3,145	430	8,658	17,622
Darlington	62,755	13,945	12,520	920	4,512	3,791	36	4,548	670	12,886	28,957
Edgefield	26,153	4,516	5,235	298	2,003	1,654	15	1,965	233	4,047	11,060
Florence	136,504	32,246	24,168	2,127	9,655	7,813	79	9,215	1,530	25,173	67,784
Greenville	533,834	121,953	88,092	8,045	38,193	30,017	310	34,928	6,056	56,924	174,431
Horry	365,579	63,249	95,413	4,172	27,805	25,322	212	31,480	3,409	45,501	81,797
Lexington	300,137	68,695	50,129	4,532	21,485	17,169	174	20,037	3,286	32,988	81,478
Oconee	79,203	15,424	19,070	1,017	5,877	5,259	46	6,477	717	12,882	12,761
Pickens	132,229	24,897	22,588	1,642	9,930	7,577	77	8,777	1,564	21,938	20,057
Richland	418,307	90,089	57,180	5,943	30,454	21,891	242	24,573	5,426	66,286	248,688
Spartanburg	335,864	78,166	54,898	5,156	23,906	18,824	195	21,895	3,751	44,859	111,083
York	288,595	68,801	43,313	4,539	20,452	15,973	167	18,371	3,311	27,670	91,111

SOUTH DAKOTA

American Lung Association in South Dakota

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Brookings	8	0	0	2.7	D	3	1	1	0	2.2	D	5.1	Pass
Brown	DNC	DNC	DNC	DNC	DNC	0	3	0	0	1.5	C	INC	INC
Codington	INC	INC	INC	INC	INC	2	2	1	0	2.3	D	7.4	Pass
Custer	2	0	0	0.7	B	2	1	0	0	1.2	C	3.6	Pass
Hughes	DNC	DNC	DNC	DNC	DNC	1	0	1	0	1.0	C	3.7	Pass
Jackson	0	0	0	0.0	A	0	1	1	0	1.2	C	4.6	Pass
Meade	7	0	0	2.3	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Minnehaha	1	0	0	0.3	B	3	2	0	0	2.0	C	INC	INC
Pennington	DNC	DNC	DNC	DNC	DNC	3	1	0	0	1.5	C	7.0	Pass
Union	1	0	0	0.3	B	2	2	0	0	1.7	C	INC	INC

SOUTH DAKOTA

American Lung Association in South Dakota

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Brookings	34,639	7,336	4,514	484	2,246	1,302	18	1,792	565	3,952	3,808
Brown	38,101	9,068	6,828	598	2,437	1,696	20	2,538	498	4,281	5,764
Codington	28,427	6,725	5,302	444	1,831	1,308	15	1,978	341	2,712	2,607
Custer	8,609	1,255	2,780	83	624	546	4	886	75	822	1,013
Hughes	17,694	4,352	3,153	287	1,126	794	9	1,195	230	1,652	3,501
Jackson	2,878	1,055	384	70	154	104	1	154	33	801	1,850
Meade	30,173	6,616	4,915	436	1,974	1,306	16	1,914	393	2,733	4,116
Minnehaha	199,685	50,571	27,266	3,336	12,542	8,018	103	11,552	2,728	18,377	38,577
Pennington	111,806	25,456	21,583	1,679	7,275	5,227	58	7,924	1,350	12,746	23,631
Union	16,872	4,092	3,175	270	1,080	779	9	1,183	199	1,086	1,621

TENNESSEE

American Lung Association in Tennessee

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Anderson	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Blount	2	0	0	0.7	B	1	0	0	0	0.3	B	6.9	Pass
Claiborne	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Davidson	2	0	0	0.7	B	5	0	0	0	1.7	C	9.1	Pass
DeKalb	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Dyer	DNC	DNC	DNC	DNC	DNC	2	0	0	0	0.7	B	7.0	Pass
Hamilton	1	0	0	0.3	B	0	1	0	0	0.5	B	8.7	Pass
Jefferson	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Knox	0	0	0	0.0	A	5	0	0	0	1.7	C	9.1	Pass
Lawrence	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	6.3	Pass
Loudon	0	0	0	0.0	A	0	0	0	0	0.0	A	6.9	Pass
McMinn	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.3	Pass
Madison	DNC	DNC	DNC	DNC	DNC	2	0	0	0	0.7	B	INC	INC
Maury	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	6.5	Pass
Montgomery	DNC	DNC	DNC	DNC	DNC	3	0	0	0	1.0	C	INC	INC
Putnam	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	6.6	Pass
Roane	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.1	Pass
Sevier	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Shelby	7	0	0	2.3	D	0	1	0	0	0.5	B	8.6	Pass
Sullivan	1	0	0	0.3	B	0	0	0	0	0.0	A	6.6	Pass
Sumner	1	0	0	0.3	B	2	0	0	0	0.7	B	7.3	Pass
Williamson	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Wilson	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC

TENNESSEE

American Lung Association in Tennessee

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Anderson	77,576	16,418	15,764	1,599	6,326	6,825	54	7,817	806	10,945	8,796
Blount	137,605	27,345	28,998	2,663	11,402	12,472	95	14,309	1,426	13,065	13,447
Claiborne	32,267	6,271	6,606	611	2,691	2,890	22	3,304	343	5,291	1,749
Davidson	703,953	142,262	92,397	13,855	58,722	51,500	486	56,188	9,997	101,651	306,953
DeKalb	20,478	4,421	3,864	431	1,668	1,779	14	2,016	210	3,140	2,658
Dyer	36,615	8,735	6,513	851	2,895	3,014	25	3,409	404	5,767	7,865
Hamilton	369,135	76,661	66,898	7,466	30,348	30,758	255	34,783	4,348	45,470	108,366
Jefferson	55,624	10,739	11,341	1,046	4,655	5,081	39	5,790	575	7,962	4,685
Knox	486,677	101,563	79,519	9,891	40,073	38,801	337	43,379	6,026	57,580	89,954
Lawrence	44,828	11,174	7,943	1,088	3,495	3,665	31	4,149	463	5,998	3,184
Loudon	56,690	10,828	15,513	1,055	4,680	5,648	39	6,703	492	5,365	7,676
McMinn	54,059	11,492	10,890	1,119	4,406	4,761	37	5,444	571	7,651	6,289
Madison	98,775	22,110	17,714	2,153	7,955	8,128	68	9,198	1,159	16,124	44,370
Maury	104,760	24,030	17,650	2,340	8,398	8,456	72	9,499	1,207	10,695	22,663
Montgomery	227,900	61,609	22,341	6,000	17,466	14,448	158	15,414	3,015	24,078	89,261
Putnam	81,188	16,960	13,599	1,652	6,672	6,456	56	7,248	959	10,745	10,212
Roane	53,992	10,008	12,700	975	4,532	5,183	37	6,012	526	7,003	4,286
Sevier	99,517	20,247	20,405	1,972	8,210	8,964	69	10,247	1,014	12,973	11,490
Shelby	924,454	231,748	133,989	22,570	72,298	69,280	637	76,751	11,333	163,230	605,437
Sullivan	159,265	30,265	35,409	2,948	13,311	14,766	110	17,040	1,639	26,800	11,696
Sumner	200,557	46,697	32,818	4,548	16,042	16,302	139	18,219	2,267	17,062	36,494
Williamson	255,735	67,005	36,153	6,526	19,799	20,039	177	22,044	2,826	10,137	42,701
Wilson	151,917	35,365	24,251	3,444	12,168	12,324	105	13,725	1,708	11,297	26,021

TEXAS

American Lung Association in Texas

						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Atascosa	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC	INC
Bell	5	0	0	1.7	C	1	0	0	0	0.3	B	INC	INC
Bexar	24	0	0	8.0	F	1	1	0	0	0.8	B	8.7	Pass
Bowie	DNC	DNC	DNC	DNC	DNC	3	0	0	0	1.0	C	9.6	Pass
Brazoria	19	3	0	7.8	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Brazos	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC	INC
Brewster	0	0	0	0.0	A	1	0	0	0	0.3	B	5.4	Pass
Cameron	0	0	0	0.0	A	6	3	0	0	3.5	F	9.7	Pass
Collin	16	3	0	6.8	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Culberson	13	0	0	4.3	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Dallas	20	1	0	7.2	F	1	0	0	0	0.3	B	9.1	Pass
Denton	37	3	0	13.8	F	1	0	0	0	0.3	B	INC	INC
Ector	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.4	Pass
Ellis	1	0	0	0.3	B	0	0	0	0	0.0	A	INC	INC
El Paso	39	1	0	13.5	F	1	0	0	0	0.3	B	8.9	Pass
Galveston	12	0	0	4.0	F	1	0	0	0	0.3	B	7.7	Pass
Gregg	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Harris	51	11	1	23.2	F	3	2	0	0	2.0	C	11.1	Pass
Harrison	0	0	0	0.0	A	0	1	0	0	0.5	B	INC	INC
Hidalgo	1	0	0	0.3	B	6	2	0	0	3.0	D	10.6	Pass
Hood	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hunt	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Jefferson	10	0	0	3.3	F	1	0	0	0	0.3	B	8.3	Pass
Johnson	15	0	0	5.0	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Kaufman	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Kleberg	DNC	DNC	DNC	DNC	DNC	5	2	0	0	2.7	D	INC	INC
Lubbock	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	6.0	Pass
McLennan	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Maverick	DNC	DNC	DNC	DNC	DNC	0	1	0	0	0.5	B	7.8	Pass
Montgomery	13	1	0	4.8	F	INC	INC	INC	INC	INC	INC	INC	INC
Navarro	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Nueces	1	0	0	0.3	B	1	2	0	0	1.3	C	8.6	Pass
Orange	1	0	0	0.3	B	1	0	0	0	0.3	B	8.2	Pass
Parker	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Polk	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Potter	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	5.6	Pass
Randall	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Rockwall	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Smith	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Tarrant	37	4	1	15.0	F	2	0	0	0	0.7	B	9.2	Pass
Travis	2	0	0	0.7	B	1	1	0	0	0.8	B	9.5	Pass
Victoria	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Webb	0	0	0	0.0	A	3	1	0	0	1.5	C	10.4	Pass

TEXAS

American Lung Association in Texas

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Atascosa	49,939	13,575	7,409	863	3,083	2,307	23	2,841	573	8,151	34,363
Bell	379,617	104,738	43,456	6,655	22,804	15,520	173	18,284	4,873	52,868	214,614
Bexar	2,028,236	508,429	254,331	32,305	127,064	88,953	923	105,803	26,238	293,859	1,498,029
Bowie	92,581	21,930	15,842	1,393	6,003	4,600	42	5,769	1,011	15,460	35,252
Brazoria	379,689	98,396	47,141	6,252	23,742	16,994	173	20,197	4,620	33,053	215,814
Brazos	237,032	49,177	23,861	3,125	15,224	9,411	108	10,663	3,698	50,154	107,978
Brewster	9,450	1,691	2,327	107	667	558	4	741	96	1,250	4,804
Cameron	423,029	123,932	59,236	7,875	25,179	18,462	192	22,642	4,963	103,230	387,136
Collin	1,109,462	279,040	126,015	17,730	70,315	49,914	505	58,297	14,253	72,757	524,183
Culberson	2,193	507	457	32	144	117	1	152	21	427	1,717
Dallas	2,586,050	660,039	297,660	41,939	161,276	111,844	1,176	131,129	33,777	368,709	1,881,922
Denton	941,647	223,263	104,586	14,186	60,541	42,240	428	49,004	12,670	68,494	418,018
Ector	161,091	49,640	15,700	3,154	9,244	6,172	74	7,123	1,957	26,375	115,676
Ellis	202,678	53,626	26,437	3,407	12,631	9,210	92	11,053	2,459	17,641	90,495
El Paso	867,947	229,713	110,826	14,596	53,375	37,630	395	45,064	10,701	171,242	769,302
Galveston	355,062	84,994	54,033	5,400	23,003	17,332	161	21,248	4,209	42,174	157,503
Gregg	124,201	32,069	19,580	2,038	7,794	5,856	56	7,273	1,452	19,426	54,649
Harris	4,728,030	1,240,902	537,117	78,846	292,122	202,685	2,152	237,486	61,038	767,505	3,419,691
Harrison	69,150	17,065	12,443	1,084	4,459	3,516	31	4,456	761	10,198	25,753
Hidalgo	880,356	278,386	99,917	17,688	50,219	34,929	400	41,493	10,815	251,220	830,323
Hood	64,222	13,231	16,258	841	4,426	3,830	29	5,128	610	6,484	11,314
Hunt	103,394	24,845	16,524	1,579	6,686	5,078	47	6,286	1,207	13,902	32,431
Jefferson	253,704	61,836	38,049	3,929	16,217	11,998	116	14,707	2,816	45,633	157,260
Johnson	187,280	48,594	26,661	3,088	11,773	8,741	85	10,643	2,167	17,978	60,720
Kaufman	157,768	44,850	17,591	2,850	9,482	6,629	72	7,781	1,997	13,916	72,988
Kleberg	30,635	7,489	4,124	476	1,904	1,297	14	1,564	412	7,233	24,623
Lubbock	314,451	74,448	40,525	4,730	19,843	13,545	143	16,160	4,317	48,593	152,242
McLennan	263,115	64,243	39,346	4,082	16,656	12,070	119	14,816	3,374	37,352	119,229
Maverick	58,056	17,923	6,866	1,139	3,352	2,349	26	2,806	681	11,691	56,500
Montgomery	648,886	168,407	88,311	10,700	40,816	30,111	295	36,356	7,728	67,809	245,536
Navarro	53,591	14,303	9,071	909	3,357	2,619	24	3,298	578	8,469	25,016
Nueces	353,079	85,527	53,930	5,434	22,575	16,692	161	20,532	4,286	62,967	254,286
Orange	84,742	21,359	13,560	1,357	5,401	4,126	39	5,123	958	10,515	17,987
Parker	156,764	38,840	24,590	2,468	10,098	7,753	71	9,569	1,754	12,227	29,291
Polk	51,899	10,516	9,844	668	3,581	2,882	24	3,639	457	8,117	14,987
Potter	116,547	31,375	15,686	1,994	7,167	5,180	53	6,266	1,314	22,716	66,728
Randall	143,854	34,668	22,151	2,203	9,188	6,763	65	8,334	1,776	12,785	46,395
Rockwall	116,381	31,070	14,495	1,974	7,253	5,290	53	6,297	1,392	5,880	39,986
Smith	237,186	57,701	40,558	3,666	15,212	11,617	108	14,600	2,850	30,154	98,518
Tarrant	2,126,477	547,327	254,934	34,777	132,875	93,864	966	110,853	27,418	242,783	1,197,695
Travis	1,305,154	269,709	138,888	17,137	85,918	57,020	596	65,263	18,755	143,340	673,317
Victoria	90,964	23,090	15,235	1,467	5,741	4,360	41	5,475	1,060	14,471	52,336
Webb	267,945	85,427	26,695	5,428	15,224	10,370	122	12,044	3,287	59,771	258,388

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CA Exhibit 14

UTAH

American Lung Association in Utah

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Box Elder	7	0	0	2.3	D	INC	INC	INC	INC	INC	INC	INC	INC
Cache	3	0	0	1.0	C	27	2	0	0	10.0	F	7.6	Pass
Carbon	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Davis	35	1	0	12.2	F	14	1	0	0	5.2	F	7.0	Pass
Duchesne	13	4	0	6.3	F	8	1	0	0	3.2	D	7.0	Pass
Garfield	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Iron	2	0	0	0.7	B	2	1	0	0	1.2	C	5.4	Pass
Salt Lake	57	8	0	23.0	F	19	5	0	0	8.8	F	9.9	Pass
San Juan	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Tooele	11	1	0	4.2	F	11	3	0	0	5.2	F	6.8	Pass
Uintah	21	4	1	9.7	F	4	1	0	0	1.8	C	6.3	Pass
Utah	17	0	0	5.7	F	14	0	0	0	4.7	F	7.2	Pass
Washington	4	1	0	1.8	C	1	1	0	0	0.8	B	5.3	Pass
Weber	17	0	0	5.7	F	8	0	0	0	2.7	D	INC	INC

UTAH

American Lung Association in Utah

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Box Elder	59,688	18,466	7,675	1,014	4,020	1,860	16	2,539	742	4,712	8,081
Cache	137,417	40,855	13,651	2,243	9,565	3,883	37	4,946	2,095	14,719	23,115
Carbon	20,372	5,181	3,786	284	1,463	743	5	1,093	250	3,166	3,636
Davis	367,285	113,162	39,135	6,212	24,957	10,909	98	14,216	4,948	23,286	65,161
Duchesne	19,790	6,498	2,545	357	1,294	606	5	833	236	2,555	3,089
Garfield	5,129	1,156	1,222	63	378	209	1	325	53	490	607
Iron	60,519	16,921	8,219	929	4,267	1,920	16	2,628	848	7,906	9,171
Salt Lake	1,186,421	306,977	138,009	16,851	86,331	37,869	316	49,569	16,946	103,046	360,327
San Juan	14,489	4,144	2,164	227	1,001	491	4	689	173	3,832	8,043
Tooele	76,640	24,168	7,086	1,327	5,166	2,212	20	2,799	1,047	4,289	14,836
Uintah	36,204	11,507	4,345	632	2,415	1,094	10	1,473	460	4,285	6,802
Utah	684,986	220,721	53,903	12,116	46,184	18,037	183	21,954	10,260	54,542	130,573
Washington	191,226	47,707	42,202	2,619	13,732	7,321	51	11,261	2,219	17,782	32,190
Weber	267,066	72,498	32,373	3,980	19,056	8,520	71	11,311	3,646	24,635	65,769

VERMONT

American Lung Association in Vermont

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Bennington	0	0	0	0.0	A	1	0	0	0	0.3	B	5.8	Pass
Chittenden	0	0	0	0.0	A	1	0	0	0	0.3	B	6.9	Pass
Rutland	0	0	0	0.0	A	1	0	0	0	0.3	B	7.6	Pass

VERMONT

American Lung Association in Vermont

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Bennington	37,312	6,992	8,842	309	3,560	2,158	20	2,615	274	4,471	2,544
Chittenden	168,865	29,439	27,292	1,300	16,849	8,265	90	9,206	1,701	15,931	20,789
Rutland	60,591	10,508	14,307	464	5,892	3,526	32	4,254	448	6,135	3,031

VIRGINIA

American Lung Association in Virginia

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Albemarle	0	0	0	0.0	A	0	0	0	0	0.0	A	6.9	Pass
Arlington	4	0	0	1.3	C	0	0	0	0	0.0	A	7.5	Pass
Caroline	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Charles City	0	0	0	0.0	A	0	0	0	0	0.0	A	6.4	Pass
Chesterfield	1	0	0	0.3	B	0	0	0	0	0.0	A	6.4	Pass
Fairfax	5	0	0	1.7	C	1	0	0	0	0.3	B	8.7	Pass
Fauquier	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Frederick	0	0	0	0.0	A	0	0	0	0	0.0	A	7.6	Pass
Giles	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hanover	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Henrico	0	0	0	0.0	A	1	0	0	0	0.3	B	7.4	Pass
Loudoun	3	0	0	1.0	C	0	0	0	0	0.0	A	6.9	Pass
Madison	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Prince Edward	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Prince William	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Roanoke	0	0	0	0.0	A	1	0	0	0	0.3	B	7.1	Pass
Rockbridge	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Rockingham	0	0	0	0.0	A	0	0	0	0	0.0	A	6.8	Pass
Stafford	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Wythe	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Bristol City	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	6.6	Pass
Hampton City	0	0	0	0.0	A	0	0	0	0	0.0	A	6.4	Pass
Lynchburg City	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	6.1	Pass
Norfolk City	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	6.8	Pass
Richmond City	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	7.8	Pass
Salem City	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	6.5	Pass
Suffolk City	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Virginia Beach City	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	6.8	Pass

CA Exhibit 14

VIRGINIA

American Lung Association in Virginia

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Albemarle	113,535	22,352	22,416	1,474	8,898	6,033	58	7,879	1,279	7,465	26,931
Arlington	232,965	42,477	27,006	2,802	18,779	10,632	119	12,703	3,245	18,150	92,160
Caroline	31,332	7,061	5,322	466	2,391	1,585	16	2,060	321	3,357	11,548
Charles City	6,594	941	1,740	62	554	425	3	587	54	753	3,708
Chesterfield	370,688	87,796	58,505	5,792	27,895	18,119	189	23,325	4,103	26,947	151,831
Fairfax	1,139,720	263,571	165,344	17,387	86,612	54,725	583	69,594	12,672	79,572	580,355
Fauquier	73,815	17,043	12,621	1,124	5,609	3,778	38	4,953	718	4,780	16,426
Frederick	93,717	21,346	17,066	1,408	7,115	4,841	48	6,359	926	6,980	18,385
Giles	16,562	3,245	3,665	214	1,305	945	8	1,274	153	1,934	943
Hanover	111,603	24,073	20,835	1,588	8,621	5,923	57	7,822	1,099	7,297	19,167
Henrico	333,554	74,241	54,923	4,897	25,516	16,625	170	21,408	3,751	23,099	163,226
Loudoun	427,592	115,849	43,443	7,642	31,092	18,290	219	22,522	4,942	15,315	200,645
Madison	13,942	2,785	3,221	184	1,092	806	7	1,094	127	1,294	2,142
Prince Edward	21,932	3,522	3,686	232	1,795	1,108	11	1,381	270	3,407	8,456
Prince William	484,472	128,947	52,455	8,506	35,338	20,895	248	25,746	5,508	30,613	290,988
Roanoke	96,589	18,993	21,361	1,253	7,585	5,455	49	7,320	953	7,597	15,280
Rockbridge	22,641	3,959	6,131	261	1,815	1,407	12	1,941	194	2,254	1,937
Rockingham	84,394	18,641	16,704	1,230	6,438	4,476	43	5,924	841	6,848	11,206
Stafford	160,877	41,803	17,528	2,758	11,834	6,988	83	8,602	1,779	8,443	70,043
Wythe	28,178	5,482	6,265	362	2,225	1,616	14	2,182	263	4,727	1,842
Bristol City	17,054	3,453	3,753	228	1,328	953	9	1,276	168	3,098	2,123
Hampton City	137,746	29,506	22,128	1,946	10,611	6,732	70	8,535	1,607	16,442	87,749
Lynchburg City	79,009	15,026	11,305	991	6,233	3,646	40	4,404	1,142	12,216	30,025
Norfolk City	235,089	45,560	28,169	3,005	18,576	10,445	121	12,375	2,864	34,150	133,572
Richmond City	226,604	38,768	31,900	2,557	18,421	10,883	115	13,281	3,192	45,409	129,112
Salem City	25,373	4,806	4,938	317	2,013	1,361	13	1,778	285	2,469	4,181
Suffolk City	96,194	22,771	14,539	1,502	7,249	4,648	49	5,949	1,043	10,069	49,994
Virginia Beach City	457,672	100,780	69,529	6,648	35,092	22,048	234	27,866	5,209	41,912	182,232

WASHINGTON

American Lung Association in Washington

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	Orange	Red	Purple	Wgt. Avg.	Grade	Orange	Red	Purple	Maroon	Wgt. Avg.	Grade	Design Value	Pass/ Fail
Benton	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clallam	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Clark	0	0	0	0.0	A	2	1	2	5	6.7	F	8.9	Pass
Columbia	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
King	2	2	0	1.7	C	5	5	3	0	6.2	F	8.3	Pass
Kitsap	DNC	DNC	DNC	DNC	DNC	4	3	3	0	4.8	F	5.9	Pass
Kittitas	DNC	DNC	DNC	DNC	DNC	7	4	3	1	7.2	F	7.5	Pass
Okanogan	DNC	DNC	DNC	DNC	DNC	13	11	7	2	16.2	F	12.4	Fail
Pierce	1	0	0	0.3	B	6	4	3	0	6.0	F	7.9	Pass
Skagit	0	0	0	0.0	A	0	0	0	0	0.0	A	INC	INC
Snohomish	DNC	DNC	DNC	DNC	DNC	7	6	1	0	6.0	F	8.7	Pass
Spokane	3	0	0	1.0	C	1	9	1	3	8.0	F	INC	INC
Stevens	DNC	DNC	DNC	DNC	DNC	7	13	1	3	12.0	F	INC	INC
Thurston	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Whatcom	0	0	0	0.0	A	3	6	1	0	4.7	F	4.7	Pass
Yakima	DNC	DNC	DNC	DNC	DNC	21	17	1	4	19.5	F	11.8	Pass

WASHINGTON

American Lung Association in Washington

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Benton	210,025	55,177	32,606	4,033	16,257	7,954	102	10,628	2,133	22,043	67,666
Clallam	78,209	12,959	24,237	947	6,694	4,338	38	6,196	611	9,204	14,690
Clark	511,404	117,552	83,476	8,593	41,318	20,591	247	27,595	5,385	45,938	123,174
Columbia	4,042	724	1,156	53	341	215	2	306	34	529	706
King	2,252,305	445,849	309,960	32,591	190,746	85,718	1,091	111,773	26,732	205,784	989,428
Kitsap	274,314	54,566	52,523	3,989	22,979	11,858	133	16,080	2,657	23,100	67,344
Kittitas	45,499	7,659	7,756	560	3,981	1,859	22	2,464	551	6,195	7,644
Okanogan	42,634	9,791	9,722	716	3,404	1,976	21	2,753	367	6,748	15,313
Pierce	925,708	214,751	133,409	15,698	74,885	35,006	448	46,160	10,117	74,284	334,152
Skagit	130,696	27,830	28,464	2,034	10,697	5,946	63	8,209	1,232	15,073	35,339
Snohomish	833,540	185,638	119,706	13,570	68,228	32,277	404	42,603	9,006	59,505	284,840
Spokane	546,040	118,778	91,795	8,682	44,833	22,096	264	29,590	5,837	59,848	92,139
Stevens	47,426	10,087	11,708	737	3,858	2,342	23	3,288	383	6,392	6,570
Thurston	297,977	62,966	54,080	4,603	24,606	12,496	144	16,871	3,189	29,197	81,106
Whatcom	228,831	43,098	41,938	3,150	19,472	9,620	111	12,927	2,618	29,011	51,342
Yakima	256,035	75,344	36,193	5,508	19,003	9,052	124	12,015	2,605	37,078	151,594

CA Exhibit 14

WEST VIRGINIA

American Lung Association in West Virginia

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Berkeley	0	0	0	0.0	A	2	0	0	0	0.7	B	8.4	Pass
Brooke	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	9.1	Pass
Cabell	0	0	0	0.0	A	0	0	0	0	0.0	A	7.2	Pass
Gilmer	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Greenbrier	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Hancock	1	0	0	0.3	B	0	0	0	0	0.0	A	INC	INC
Harrison	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	7.1	Pass
Kanawha	0	0	0	0.0	A	0	0	0	0	0.0	A	7.5	Pass
Marion	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	INC	INC
Marshall	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	9.3	Pass
Monongalia	0	0	0	0.0	A	0	0	0	0	0.0	A	7.0	Pass
Ohio	1	0	0	0.3	B	0	0	0	0	0.0	A	7.8	Pass
Tucker	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Wood	0	0	0	0.0	A	0	0	0	0	0.0	A	7.5	Pass

WEST VIRGINIA

American Lung Association in West Virginia

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Berkeley	126,069	28,915	19,145	2,722	11,929	12,052	93	12,400	1,310	12,365	22,403
Brooke	22,140	3,878	5,433	365	2,201	2,511	16	2,776	193	2,776	1,095
Cabell	93,418	18,612	17,986	1,752	9,079	9,275	69	9,926	1,012	17,022	9,557
Gilmer	7,377	1,117	1,309	105	764	743	6	777	60	1,455	1,421
Greenbrier	32,608	6,365	7,794	599	3,164	3,613	24	3,993	286	6,037	2,464
Hancock	28,656	5,357	6,850	504	2,814	3,236	21	3,563	251	4,223	1,916
Harrison	65,158	14,005	12,994	1,319	6,218	6,760	48	7,259	615	9,405	4,129
Kanawha	177,952	35,421	38,514	3,335	17,257	18,939	130	20,595	1,704	27,810	22,201
Marion	56,001	11,216	11,000	1,056	5,439	5,694	41	6,102	568	8,257	4,142
Marshall	30,115	5,727	7,138	539	2,944	3,363	22	3,703	254	4,826	1,154
Monongalia	106,387	17,578	14,352	1,655	10,895	9,549	79	9,594	1,362	18,293	12,870
Ohio	41,776	8,135	9,428	766	4,060	4,442	31	4,875	402	5,793	3,426
Tucker	6,672	934	1,831	88	690	818	5	914	56	954	196
Wood	83,624	17,611	17,574	1,658	8,008	8,861	61	9,591	773	12,172	4,272

WISCONSIN

American Lung Association in Wisconsin

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Ashland	1	0	0	0.3	B	2	1	0	0	1.2	C	5.6	Pass
Brown	1	0	0	0.3	B	3	0	0	0	1.0	C	7.8	Pass
Columbia	4	0	0	1.3	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Dane	3	0	0	1.0	C	0	0	0	0	0.0	A	8.3	Pass
Dodge	3	0	0	1.0	C	0	0	0	0	0.0	A	8.0	Pass
Door	8	0	0	2.7	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Eau Claire	0	0	0	0.0	A	4	1	0	0	1.8	C	8.2	Pass
Fond du Lac	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Forest	0	0	0	0.0	A	3	1	0	0	1.5	C	5.9	Pass
Grant	DNC	DNC	DNC	DNC	DNC	1	0	0	0	0.3	B	8.8	Pass
Jackson	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC	INC
Jefferson	5	0	0	1.7	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Kenosha	22	1	0	7.8	F	1	0	0	0	0.3	B	7.7	Pass
Kewaunee	2	0	0	0.7	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
La Crosse	0	0	0	0.0	A	1	0	0	0	0.3	B	7.9	Pass
Manitowoc	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Marathon	0	0	0	0.0	A	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Milwaukee	13	1	0	4.8	F	1	0	0	0	0.3	B	8.9	Pass
Monroe	DNC	DNC	DNC	DNC	DNC	INC	INC	INC	INC	INC	INC	INC	INC
Outagamie	3	0	0	1.0	C	4	0	0	0	1.3	C	8.1	Pass
Ozaukee	14	1	0	5.2	F	0	0	0	0	0.0	A	7.0	Pass
Racine	16	1	0	5.8	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Rock	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Sauk	1	0	0	0.3	B	1	0	0	0	0.3	B	7.7	Pass
Sheboygan	11	2	0	4.7	F	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Taylor	0	0	0	0.0	A	2	2	0	0	1.7	C	6.8	Pass
Vilas	0	0	0	0.0	A	3	0	0	0	1.0	C	5.3	Pass
Walworth	6	0	0	2.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Waukesha	6	0	0	2.0	C	1	0	0	0	0.3	B	9.4	Pass

WISCONSIN

American Lung Association in Wisconsin

	AT-RISK GROUPS										
				Lung Diseases							
County	Total Population	Under 18	65 & Over	Pediatric Asthma	Adult Asthma	COPD	Lung Cancer	CV Disease	Pregnancies	Poverty	People of Color
Ashland	16,107	3,507	3,335	219	1,373	749	9	1,034	150	2,266	2,967
Brown	269,591	62,787	42,776	3,914	22,662	11,246	155	14,781	2,891	24,355	56,164
Columbia	58,488	12,198	11,083	760	5,089	2,686	34	3,642	550	4,415	5,065
Dane	563,951	112,552	82,750	7,016	48,951	22,918	324	29,232	7,060	62,409	122,418
Dodge	89,313	17,326	16,392	1,080	7,925	4,105	52	5,511	799	7,043	10,141
Door	30,369	4,891	9,437	305	2,741	1,743	17	2,576	231	2,604	2,167
Eau Claire	106,452	21,475	17,428	1,339	9,165	4,441	61	5,790	1,306	12,739	11,774
Fond du Lac	104,362	22,087	20,106	1,377	8,996	4,759	60	6,470	1,054	8,168	12,438
Forest	9,258	1,773	2,166	111	819	467	5	658	78	1,250	1,940
Grant	52,110	10,941	9,303	682	4,449	2,247	30	2,994	527	6,039	2,892
Jackson	21,121	4,553	4,152	284	1,814	971	12	1,328	175	2,497	3,069
Jefferson	84,943	17,246	15,545	1,075	7,442	3,861	49	5,191	875	6,203	9,619
Kenosha	168,732	37,117	25,585	2,314	14,545	7,132	97	9,286	1,842	17,554	43,765
Kewaunee	20,543	4,293	4,436	268	1,777	987	12	1,373	184	1,567	1,279
La Crosse	120,433	23,505	20,945	1,465	10,474	5,195	69	6,855	1,457	13,944	13,466
Manitowoc	81,505	16,785	17,747	1,046	7,086	3,946	47	5,496	728	8,665	8,988
Marathon	137,648	31,227	25,622	1,947	11,667	6,152	79	8,344	1,335	10,345	17,021
Milwaukee	928,059	222,246	132,643	13,854	76,921	36,585	532	47,022	11,124	161,890	472,561
Monroe	46,193	11,643	8,224	726	3,789	1,989	27	2,691	427	5,119	4,911
Outagamie	191,545	44,488	30,229	2,773	16,163	8,033	110	10,555	2,005	13,789	26,169
Ozaukee	92,497	19,563	19,187	1,220	7,977	4,357	53	6,015	880	4,244	9,041
Racine	196,896	44,950	34,390	2,802	16,702	8,616	113	11,548	1,950	23,827	59,293
Rock	164,381	37,374	28,507	2,330	13,943	7,158	94	9,574	1,693	16,283	30,689
Sauk	65,697	14,838	12,814	925	5,558	2,977	38	4,073	628	6,305	6,659
Sheboygan	117,747	25,658	22,395	1,599	10,092	5,341	68	7,259	1,119	10,013	20,770
Taylor	19,923	4,596	4,063	287	1,688	932	11	1,291	171	2,027	912
Vilas	23,520	3,960	7,271	247	2,120	1,358	14	2,010	154	2,677	3,465
Walworth	106,799	21,162	20,389	1,319	9,357	4,893	61	6,615	1,101	10,644	16,066
Waukesha	408,756	86,561	80,160	5,396	35,384	18,950	235	25,891	3,965	20,035	53,259

WYOMING

American Lung Association in Wyoming

	HIGH OZONE DAYS 2019–2021					HIGH PARTICLE POLLUTION DAYS 2019–2021							
						24-Hour						Annual	
County	**Orange**	**Red**	**Purple**	**Wgt. Avg.**	**Grade**	**Orange**	**Red**	**Purple**	**Maroon**	**Wgt. Avg.**	**Grade**	**Design Value**	**Pass/ Fail**
Albany	12	0	0	4.0	F	4	1	0	0	1.8	C	INC	INC
Big Horn	3	0	0	1.0	C	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Campbell	11	0	0	3.7	F	5	0	0	0	1.7	C	INC	INC
Carbon	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Converse	7	0	0	2.3	D	INC	INC	INC	INC	INC	INC	INC	INC
Fremont	9	0	0	3.0	D	6	1	0	0	2.5	D	2.4	Pass
Johnson	7	0	0	2.3	D	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Laramie	10	0	0	3.3	F	4	2	0	0	2.3	D	4.1	Pass
Lincoln	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC	INC
Natrona	6	0	0	2.0	C	5	0	0	0	1.7	C	INC	INC
Park	INC	INC	INC	INC	INC	2	0	0	0	0.7	B	4.3	Pass
Sheridan	DNC	DNC	DNC	DNC	DNC	0	0	0	0	0.0	A	6.3	Pass
Sublette	18	3	0	7.5	F	4	1	0	0	1.8	C	3.5	Pass
Sweetwater	9	0	0	3.0	D	1	0	0	0	0.3	B	INC	INC
Teton	3	0	0	1.0	C	17	5	0	0	8.2	F	4.4	Pass
Uinta	INC	INC	INC	INC	INC	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC
Weston	1	0	0	0.3	B	DNC	DNC	DNC	DNC	DNC	DNC	DNC	DNC

CA Exhibit 14

WYOMING

American Lung Association in Wyoming

	AT-RISK GROUPS										
				Lung Diseases							
County	**Total Population**	**Under 18**	**65 & Over**	**Pediatric Asthma**	**Adult Asthma**	**COPD**	**Lung Cancer**	**CV Disease**	**Pregnancies**	**Poverty**	**People of Color**
Albany	37,608	5,998	4,884	515	3,099	1,579	17	1,700	556	6,309	6,710
Big Horn	11,632	2,844	2,532	244	860	647	5	768	106	1,440	1,542
Campbell	46,401	12,511	5,669	1,075	3,352	2,011	20	2,161	519	3,882	6,085
Carbon	14,649	3,312	2,606	285	1,114	749	6	855	142	1,706	3,503
Converse	13,672	3,336	2,482	287	1,017	712	6	815	137	1,321	1,608
Fremont	39,336	9,944	7,694	854	2,882	2,062	17	2,408	384	5,683	12,151
Johnson	8,623	1,834	2,297	158	662	542	4	662	75	855	805
Laramie	100,863	22,942	17,183	1,971	7,659	5,017	44	5,689	1,101	9,765	22,344
Lincoln	20,153	5,131	3,901	441	1,476	1,074	9	1,247	189	1,522	1,673
Natrona	79,555	19,108	13,135	1,642	5,946	3,890	35	4,395	873	8,349	11,303
Park	30,108	6,196	7,490	532	2,334	1,827	13	2,204	280	3,372	2,771
Sheridan	31,646	6,654	6,942	572	2,448	1,805	14	2,131	317	2,929	2,824
Sublette	8,697	1,831	1,923	157	673	505	4	595	82	612	1,019
Sweetwater	41,614	10,468	5,886	899	3,072	1,909	18	2,100	471	3,761	8,704
Teton	23,575	4,142	3,984	356	1,914	1,227	10	1,370	281	1,392	4,522
Uinta	20,635	5,729	3,280	492	1,468	977	9	1,104	214	1,917	2,742
Weston	6,745	1,354	1,523	116	529	398	3	470	57	666	687

CA Exhibit 15

United States Environmental Protection Agency

EPA/600/R-20/012
April 2020
www.epa.gov/isa

Integrated Science Assessment for Ozone and Related Photochemical Oxidants

April 2020

Center for Public Health and Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC

CA Exhibit 15

EXECUTIVE SUMMARY

ES.1 Purpose and Scope of the Integrated Science Assessment

This Integrated Science Assessment (ISA)[1] is a comprehensive evaluation and synthesis of the policy-relevant science aimed at characterizing the health and welfare[2] effects caused by ozone. It communicates critical science judgments of the health-based and welfare-based criteria for ozone and related photochemical oxidants in ambient air. In 2015, the U.S. EPA lowered the health- and welfare-based National Ambient Air Quality Standards (NAAQS) for ozone to 0.070 ppm (annual fourth-highest daily max 8-hour concentration averaged over 3 years[3]). The health-based ozone NAAQS is meant to protect public health, including at-risk populations such as children and people with asthma, with an adequate margin of safety. The welfare-based ozone standard is intended to protect the public welfare from known or anticipated adverse effects associated with the presence of ozone in ambient air.

The ISA identifies and critically evaluates the most policy-relevant scientific literature across scientific disciplines, including epidemiology, controlled human exposure studies, animal toxicology, atmospheric science, exposure science, vegetation studies, agricultural science, ecology, and climate-related science. Key scientific conclusions (e.g., causality determinations; Section ES.4) are presented and explained. These conclusions provide the scientific basis for developing risk and exposure analyses, policy evaluations, and policy decisions for the review. This ISA draws conclusions about the causal nature of the relationships between ozone exposure and health and welfare effects by integrating recent evidence across scientific disciplines with the evidence base evaluated in previous reviews. U.S. EPA engages the Clean Air Scientific Advisory Committee (CASAC) as an independent federal advisory committee to conduct peer reviews of draft ISA and other materials. Peer review comments provided by the CASAC and public comments about the external review draft were considered in the development of this ISA (Section 10.4). The ISA thus provides the policy-relevant scientific information necessary to conduct a review of the NAAQS.

This Executive Summary provides an overview of the important conclusions drawn in the ISA across scientific disciplines, beginning with information on sources, concentrations, estimated background concentrations of ozone and ozone exposure, followed by health and welfare effects. A more detailed summary of the evidence is presented in the Integrated Synthesis, and individual Appendices for

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[1] The general process for developing an ISA, including the framework for evaluating weight of evidence and drawing scientific conclusions and causality determinations, is described in a companion document, Preamble to the Integrated Science Assessments (U.S. EPA, 2015), www.epa.gov/isa.

[2] Under Clean Air Act section 302(h), effects on welfare include, but are not limited to, "effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

[3] Final rule signed October 1, 2015, and effective December 28, 2015 (80 FR 65291).

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each topic area include study-level information and an in-depth characterization of the weight-of-evidence conclusions.

ES.2 Ozone in Ambient Air

The general photochemistry of tropospheric ozone is well-established. Ozone is produced in urban areas and downwind of sources mainly by the reaction of volatile organic compounds (VOCs) with oxides of nitrogen (NO_X) in the presence of sunlight, and outside of polluted areas mainly by reactions of carbon monoxide (CO) and methane (CH_4) with NO_X (Section 1.4). Recent developments in understanding ozone chemistry include observations of higher ozone concentrations during the winter in some western U.S. mountain basins (Section 1.4.1) and new research on the role of marine halogen chemistry in suppressing coastal ozone concentrations (Section 1.4.2). Air monitoring data for the period 2015−2017 show that U.S. daily max 8-hour avg concentrations of ozone (MDA8) are higher in spring and summer (median = 46 ppb) than in autumn (median = 38 ppb) and winter (median = 34 ppb). Figure ES-1 shows the highest values of the 3-year avg of annual fourth-highest MDA8 ozone concentrations (design values above 70 ppb) occur in central and southern California, Arizona, Colorado, Utah, Texas, along the shore of Lake Michigan, and in the Northeast Corridor, typically during the ozone season between May and September (Section 1.2.1.1).

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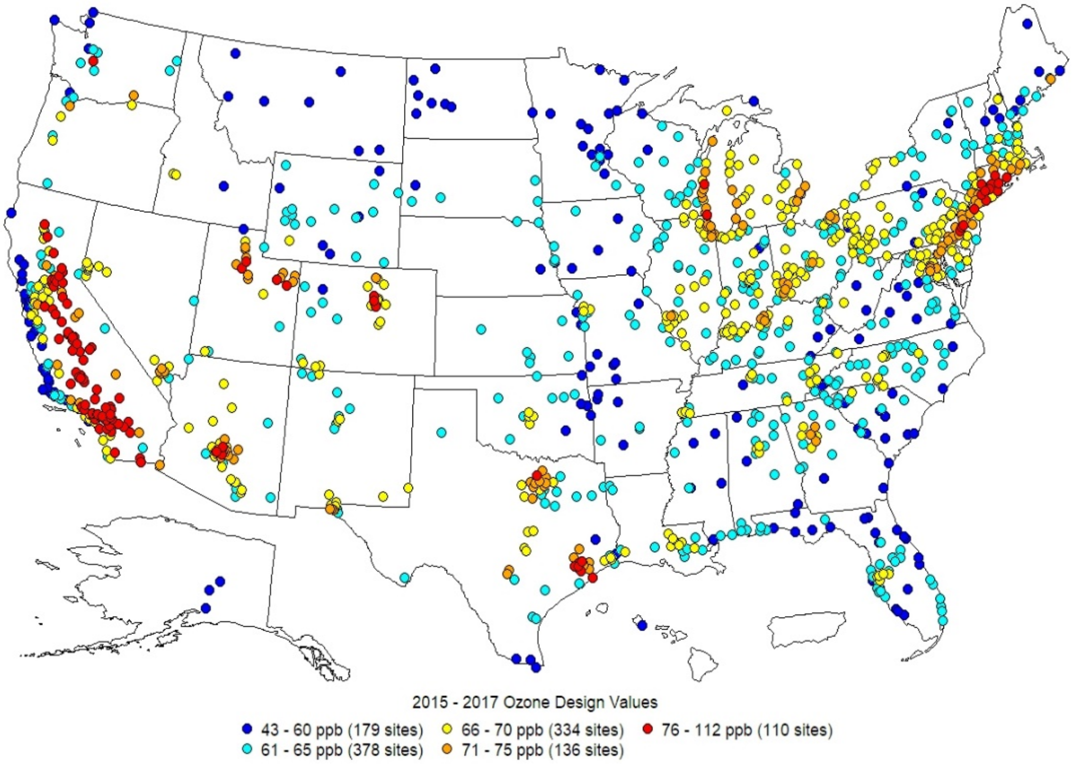

Figure ES-1 **Individual monitor ozone concentrations in terms of design values (i.e., 3-year avg of annual fourth-highest max daily 8-hour avg ozone concentration) for 2015−2017.**

A better understanding of the origins of ground-level U.S. background (USB) ozone and its concentration trends has emerged since the 2013 Ozone ISA. USB ozone concentration is defined as the ozone concentration that would occur if all U.S. anthropogenic ozone precursor emissions were removed (Section IS.2.2). Major contributors to USB ozone concentrations are stratospheric exchange, international transport, wildfires, lightning, global methane emissions, and natural biogenic and geogenic precursor emissions. Ozone monitors cannot discern the portion of ambient ozone concentrations that come from USB. Instead, USB concentrations are estimated using photochemistry and transport models. The estimates of USB ozone concentrations include uncertainties of about 10 ppb for seasonal average concentrations, with higher uncertainty for MDA8 concentrations. Models consistently estimate higher USB ozone concentrations at higher elevations of the western U.S. than in the eastern U.S. or along the Pacific coast. The estimated seasonal pattern in USB ozone concentrations tends to indicate lower USB in the summer than during the rest of the year. Several modeling studies using different approaches indicate that for MDA8 concentrations above 50−60 ppb, USB concentration estimates generally do not increase with increasing total ozone concentration (i.e., USB ozone concentrations are no higher on high ozone days than on low or moderate ozone days). The temporal trend in estimated USB ozone concentrations indicates increasing concentrations at high elevation western U.S. sites through approximately 2010.

Recently, however, this trend has shown signs of slowing or even reversing, possibly due to decreasing East Asian precursor emissions.

ES.3 Exposure to Ozone

Ambient air ozone concentrations, either measured at fixed-site monitors or estimated by models, are often used as surrogates for personal exposure in epidemiologic studies. Exposure measurement error can lead to reduced precision and an underestimation of the association between short-term ambient ozone exposure and a health effect (Section 2.6.1). For studies of long-term exposure, the true effect of exposure to ambient ozone may be underestimated or overestimated when the exposure model respectively overestimates or underestimates ozone exposure. It is much more common for the effect to be underestimated, and bias in the effect estimate is typically small in magnitude (Section 2.6.2). The availability and sophistication of models to predict ambient ozone concentrations to estimate exposure have increased substantially in recent years (Section 2.3.2). For effects elicited by ozone, the use of exposure estimates that do not account for population behavior and mobility (e.g., via use of time-activity data) may result in underestimation of the true effect and reduced precision (Section 2.4.1).

Tropospheric ozone can cause plant damage, which can then have negative impacts on terrestrial ecosystems as shown in observational and controlled exposure studies and in models using experimental data to extrapolate to effects at the community and ecosystem scale. Robust exposure indices that quantify exposure as it relates to measured plant response (e.g., growth) have been in use for decades and are derived from hourly ozone concentrations. Exposure duration influences the degree of plant response, and ozone effects on plants are cumulative. Cumulative indices summarize ozone concentrations over time and provide a consistent metric for reviewing and comparing exposure-response effects obtained from various studies. Cumulative indices of exposure that differentially weight hourly concentrations have been found to be best suited to characterize vegetation exposure to ozone with regard to reductions in vegetation growth and yield (Section 8.1.2.1).

ES.4 Health and Welfare Effects of Ozone Exposure

Broad health and welfare effect categories are evaluated independently in the Appendices of this ISA. Determinations are made about causation by evaluating evidence across scientific disciplines and are based on judgments of consistency, coherence, and biological plausibility of observed effects, as well as related uncertainties. The ISA uses a formal causality framework to classify the weight of evidence using a five-level hierarchy described in Table II of the Preamble (U.S. EPA, 2015). The subsequent sections characterize the evidence that forms the basis of causality determinations for health and welfare effect categories of a "causal relationship" or a "likely to be causal relationship," or describe instances where a causality determination has changed (i.e., "likely to be causal" changed to "suggestive of, but not sufficient to infer, a causal relationship"). Other relationships between ozone and health effects are *"suggestive of, but not sufficient to infer*" and "*inadequate to infer*" a causal relationship. These causality determinations appear in Table ES-1, and are more fully discussed in the respective health effects Appendices.

ES.4.1 Health Effects of Ozone Exposure

Ozone-induced effects can occur through a variety of complex pathways within the body. After inhalation, ozone reacts with lipids, proteins, and antioxidants in the epithelial lining fluid of the respiratory tract, creating secondary oxidation products (Section 5.2.3). Initial ozone exposure leads to physiological reactions that may induce a host of autonomic, endocrine, immune, and inflammatory responses throughout the body at the cellular, tissue, and organ level. Recent evidence continues to support ozone-induced effects on the respiratory system. In addition, recent evidence indicates that short-term exposure to ozone is likely to induce metabolic effects, as shown in Figure ES-2. There is also some evidence that ozone exposure can affect the cardiovascular and nervous systems, reproduction and development, and mortality, although there are more uncertainties associated with interpretation of the evidence for these effects.

Table ES-1 Summary of causality determinations by exposure duration and health outcome.

Health Outcome[a]	Conclusions from 2013 Ozone ISA	Conclusions in the 2020 ISA
Short-term exposure to ozone		
Respiratory effects	Causal relationship	Causal relationship
Cardiovascular effects	Likely to be causal relationship	Suggestive of, but not sufficient to infer, a causal relationship[c]
Metabolic effects	No determination made	Likely to be causal relationship[b]
Total mortality	Likely to be causal relationship	Suggestive of, but not sufficient to infer, a causal relationship[c]
Central nervous system effects	Suggestive of a causal relationship[d]	Suggestive of, but not sufficient to infer, a causal relationship
Long-term exposure to ozone		
Respiratory effects	Likely to be causal relationship	Likely to be causal relationship
Cardiovascular effects	Suggestive of a causal relationship[d]	Suggestive of, but not sufficient to infer, a causal relationship
Metabolic effects	No determination made	Suggestive of, but not sufficient to infer, a causal relationship[b]
Total mortality	Suggestive of a causal relationship[d]	Suggestive of, but not sufficient to infer, a causal relationship
Reproductive effects	Suggestive of a causal relationship[d]	Effects on fertility and reproduction: suggestive of, but not sufficient to infer, a causal relationship[b]
		Effects on pregnancy and birth outcomes: suggestive of, but not sufficient to infer, a causal relationship[b]
Central nervous system effects	Suggestive of a causal relationship[d]	Suggestive of, but not sufficient to infer, a causal relationship
Cancer	Inadequate to infer a causal relationship	Inadequate to infer the presence or absence of a causal relationship[e]

[a] Health effects (e.g., respiratory effects, cardiovascular effects) include the spectrum of outcomes, from measurable subclinical effects (e.g., decrements in lung function, blood pressure) to observable effects (e.g., medication use, hospital admissions) and cause-specific mortality. Total mortality includes all-cause (nonaccidental) mortality, as well as cause-specific mortality.

[b] Denotes new causality determination.

[c] Denotes change in causality determination from 2013 Ozone ISA.

[d] Since the 2013 Ozone ISA, the causality determination language has been updated and this category is now stated as suggestive of, but not sufficient to infer, a causal relationship.

[e] Since the 2013 Ozone ISA, the causality determination language has been updated and this category is now stated as inadequate to infer the presence or absence of a causal relationship.

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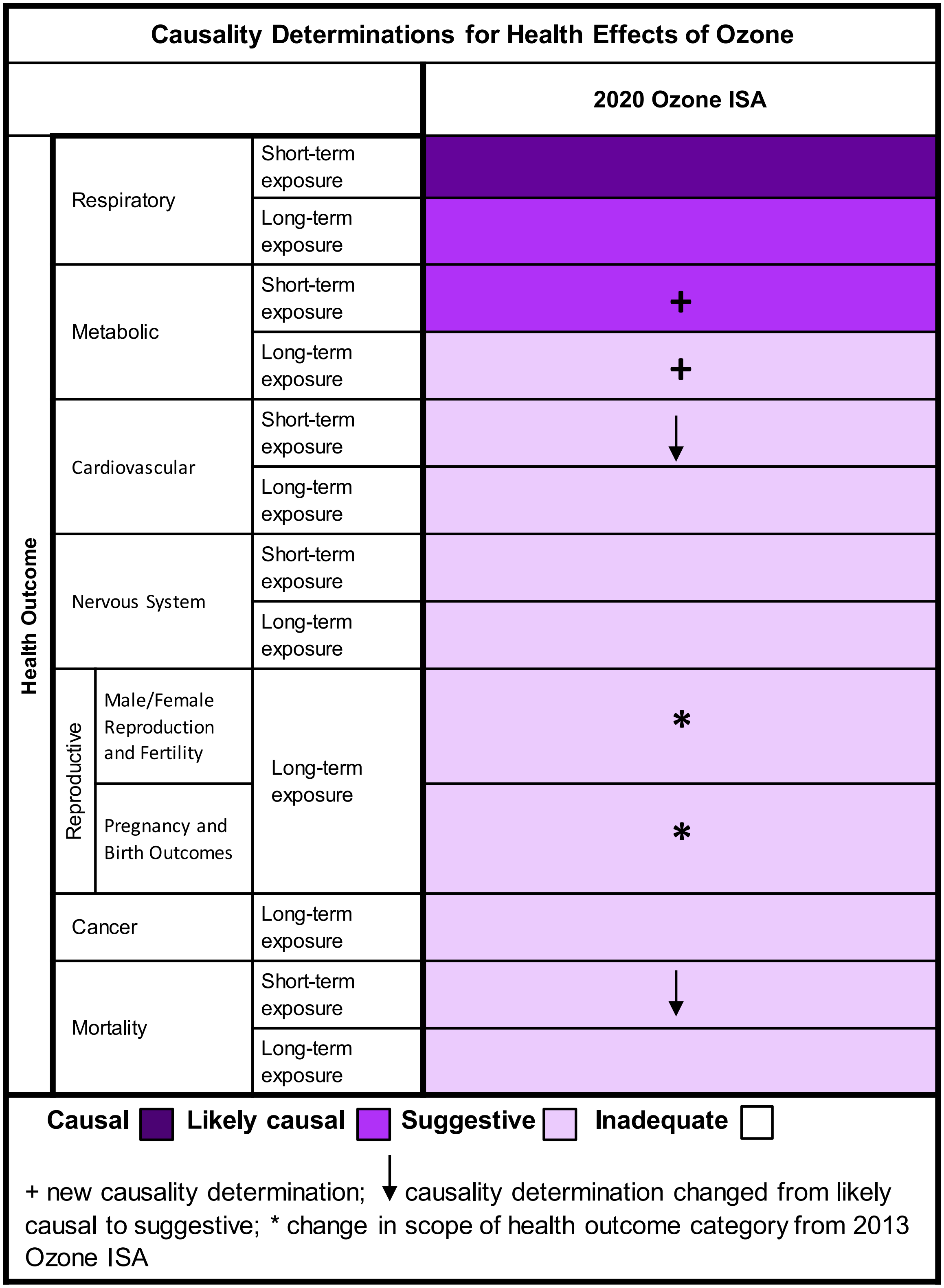


Causality Determinations for Health Effects of Ozone

				2020 Ozone ISA
Health Outcome	Respiratory		Short-term exposure	■
			Long-term exposure	🟪
	Metabolic		Short-term exposure	🟪 +
			Long-term exposure	▨ +
	Cardiovascular		Short-term exposure	▨ ↓
			Long-term exposure	▨
	Nervous System		Short-term exposure	▨
			Long-term exposure	▨
	Reproductive	Male/Female Reproduction and Fertility	Long-term exposure	▨ *
		Pregnancy and Birth Outcomes		▨ *
	Cancer		Long-term exposure	▨
	Mortality		Short-term exposure	▨ ↓
			Long-term exposure	▨

Causal ■ **Likely causal** 🟪 **Suggestive** ▨ **Inadequate** □

+ new causality determination; ↓ causality determination changed from likely causal to suggestive; * change in scope of health outcome category from 2013 Ozone ISA

Figure ES-2 Causality determinations for health effects of short- and long-term exposure to ozone.

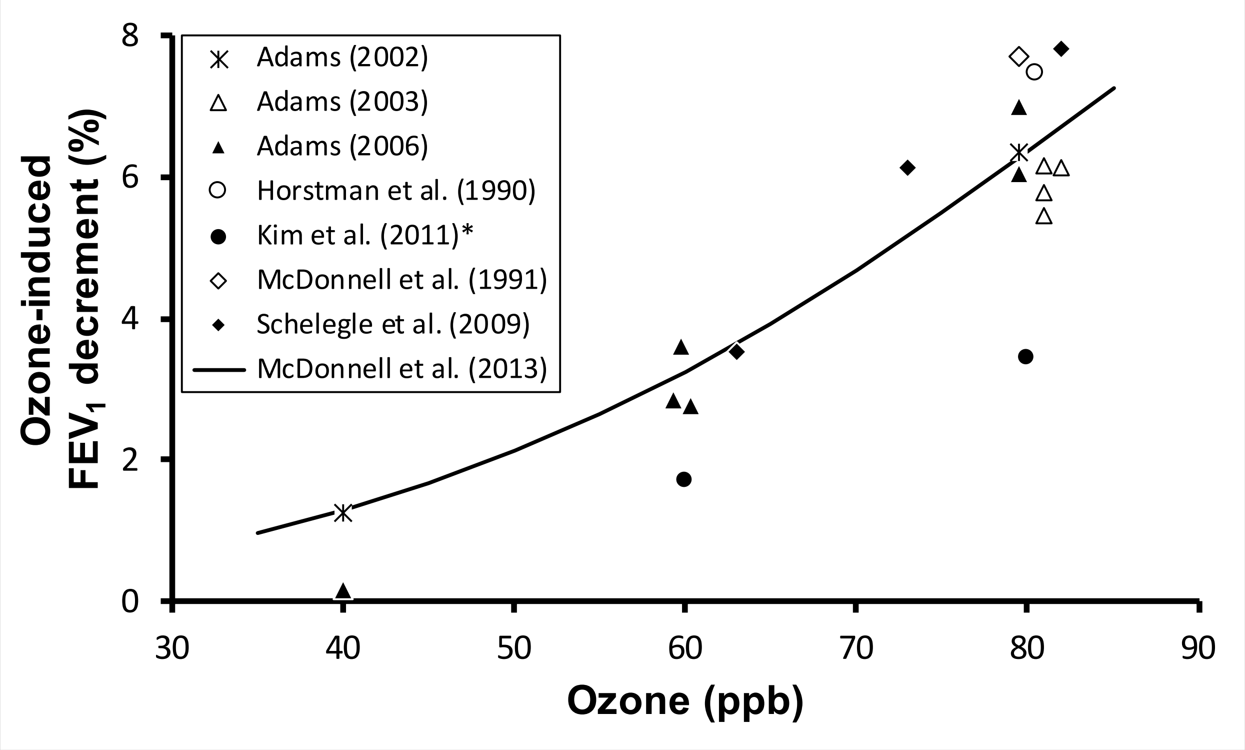
The strongest evidence for health effects due to ozone exposure continues to come from studies of short- and long-term ozone exposure and respiratory health, and this evidence is detailed in Appendix 3. Consistent with conclusions from the 2013 Ozone ISA (Table ES-1), **there is a "causal relationship" between short-term ozone exposure and respiratory effects** (Section 3.1.11), and **there is a "likely to be causal relationship" between long-term ozone exposure and respiratory effects** (Section 3.2.6).

For short-term ozone exposure, controlled human exposure studies conducted over many decades provide experimental evidence for ozone-induced lung function decrements (Figure ES-3), airway responsiveness, respiratory symptoms, and respiratory tract inflammation. Epidemiologic studies continue to provide evidence that ozone concentrations in ambient air are associated with a range of respiratory effects, including asthma exacerbation, chronic obstructive pulmonary disease (COPD) exacerbation, respiratory infection, and hospital admissions and emergency department (ED) visits for combined respiratory diseases.

A large body of animal toxicological studies demonstrate ozone-induced alterations in lung function, inflammation, increased airway responsiveness, and impaired lung host defense. These animal toxicological studies also aid in our understanding of potential mechanisms underlying respiratory effects at the population level and the biological plausibility of epidemiologic associations between short-term ozone exposure and respiratory-related ED visits and hospital admissions.

With respect to long-term ozone exposure, there is strong coherence between animal toxicological studies of changes in lung morphology and epidemiologic studies reporting positive associations between long-term ozone exposure and new-onset asthma, respiratory symptoms in children with asthma, and respiratory mortality. Furthermore, the experimental evidence provides biologically plausible pathways through which long-term ozone exposure could lead to respiratory effects reported in epidemiologic studies.

Metabolic effects related to ozone exposure are evaluated as a separate health endpoint category for the first time in this ISA (Appendix 5). Recent evidence from animal toxicological, controlled human exposure, and epidemiologic studies indicate that **there is a "likely to be causal relationship" between short-term ozone exposure and metabolic effects** (Section 5.1.8). The strongest evidence for this determination is provided by animal toxicological studies that demonstrate impaired glucose tolerance, increased serum triglycerides, fasting hyperglycemia, and increased hepatic gluconeogenesis in various stocks/strains of animals across multiple laboratories. Biological plausibility is provided by results from controlled human exposure and animal toxicological studies that demonstrate activation of sensory nerve pathways following ozone exposure triggers the central neuroendocrine stress response, which includes increased corticosterone, cortisol, and epinephrine production. These findings are coherent with epidemiologic studies that report associations between ozone exposure and perturbations in glucose and insulin homeostasis. In addition, these pathophysiological changes are often accompanied by increased inflammatory markers in peripheral tissues and by activation of the neuroendocrine system.



All responses at and above 70 ppb (targeted concentration) were statistically significant ($p < 0.05$). Adams (2006) found statistically significant responses to square-wave chamber exposures at 60 ppb based on the analysis of Brown et al. (2008) and Kim et al. (2011). During each hour of the exposures, subjects were engaged in moderate quasi-continuous exercise (20 L/minute per m^2 BSA) for 50 minutes and rest for 10 minutes. Following the 3rd hour, subjects had an additional 35-minute rest period for lunch. The data at 60 and 80 ppb have been offset on the *x* axis for illustrative purposes. The solid line illustrates the predicted FEV_1 decrements using Model 3 coefficients at 6.6 hours as a function of ozone concentration for a 23.8-year-old with a BMI of 23.1 kg/m^2 from McDonnell et al. (2013).

*80 ppb data for 30 health subjects were collected as part of the Kim et al. (2011) study, but only published in Figure 5 of McDonnell et al. (2012).

Adapted from Figure 6-1 of 2013 Ozone ISA (U.S. EPA, 2013). Studies appearing in the figure legend are: Adams (2006), Adams (2003), Adams (2002), Horstman et al. (1990), Kim et al. (2011), McDonnell et al. (2013), McDonnell et al. (1991), and Schelegle et al. (2009).

Figure ES-3 Cross-study comparisons of mean decrements in ozone-induced forced expiratory volume in 1 second (FEV_1) in young, healthy adults following 6.6 hours of exposure to ozone.

Notably, there are changes in the causality determinations for short-term ozone exposure and cardiovascular effects (Appendix 4), as well as for total mortality (Appendix 6). In both instances, the evidence synthesized in the 2013 Ozone ISA was sufficient to conclude a “likely to be causal relationship,” but after integrating the previous evidence with recent data, **the collective evidence is “suggestive of, but not sufficient to infer, a causal relationship” between short-term ozone exposure and cardiovascular effects (Section 4.1.17) or total mortality (Section 6.1.8)** in this ISA. The evidence that supports this change in the causality determinations includes: (1) a growing body of controlled human exposure studies providing less consistent evidence for an effect of short-term ozone exposure on

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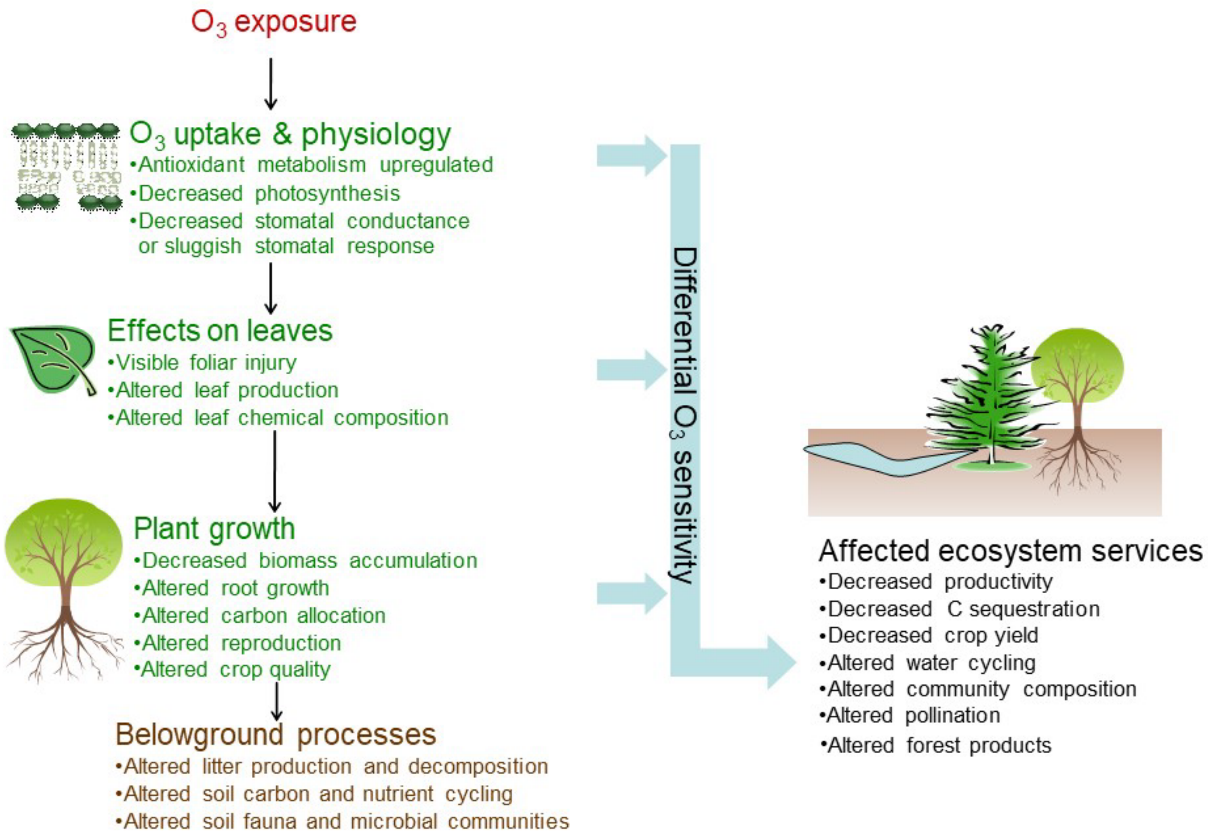
cardiovascular health endpoints; (2) a paucity of positive evidence from epidemiologic studies for more severe cardiovascular morbidity endpoints (i.e., heart failure, ischemic heart disease and myocardial infarction, arrhythmia and cardiac arrest, and stroke); and (3) uncertainties due to a lack of control for potential confounding by copollutants in epidemiologic studies. Although there is generally consistent evidence for a limited number of ozone-induced cardiovascular endpoints in animal toxicological studies and for cardiovascular mortality in epidemiologic studies, these results are not coherent with results from controlled human exposure and epidemiologic studies examining cardiovascular morbidity endpoints. There remains evidence for ozone-induced cardiovascular mortality from epidemiologic studies. However, inconsistent results from a larger number of recent controlled human exposure studies that do not provide evidence of cardiovascular effects in response to short-term ozone exposure introduce additional uncertainties.

ES.4.2 Ozone Exposure and Welfare Effects

The scientific evidence for welfare effects of ozone consists mainly of effects on vegetation and ecosystems (Appendix 8) and effects on climate (Appendix 9). For ecological effects, damage to terrestrial ecosystems as evaluated through controlled exposure studies, observational studies and modeling based on experimental data, is largely a function of uptake of ozone into the leaf via stomata (gas exchange openings on leaves). Subsequent reactions with plant tissues alter whole-plant responses that cascade up to effects at higher levels of biological organization (i.e., from the cellular and subcellular level to the individual organism up to ecosystem level processes and services; Figure ES-4). At the leaf level, ozone uptake produces reactive oxygen species that affect cellular function (Section 8.1.3 and Figure 8-2). Reduced photosynthesis, altered carbon allocation, and impaired stomatal function lead to observable responses in plants. Observed vegetation responses to ozone include visible foliar injury (Section IS.5.1.1), and whole-plant level responses (Section IS.5.1.2), which encompass reduction in aboveground and belowground growth, reproduction and yield. Plant-fauna linkages affected by ozone include herbivores that feed on ozone-damaged vegetation and interactions of ozone with compounds emitted by plants that can alter attraction of pollinators to plants (Section IS.5.1.3). A combination of observational and experimental data, and modeling output provides evidence for broad changes in ecosystems such as decreased productivity and carbon sequestration (Section IS.5.1.4), altered belowground processes (Section IS.5.1.5), terrestrial community composition (Section IS.5.1.6), and water cycling (Section IS.5.1.7).



Source: Adapted from U.S. EPA (2013).

Figure ES-4 **Illustrative diagram of ozone effects cascading from the cellular level to plants and ecosystems.**

There are 12 causality determinations for ecological effects of ozone generally organized from the individual-organism scale to the ecosystem scale in Figure ES-5. Like the findings of the 2013 Ozone ISA (Table ES-2), five are causal relationships (i.e., visible foliar injury, reduced vegetation growth, reduced crop yield, reduced productivity, and altered belowground biogeochemical cycles) and two are likely to be causal relationships (i.e., reduced carbon sequestration, altered ecosystem water cycling). One of the endpoints, alteration of terrestrial community composition, is now concluded to be a causal relationship whereas in the 2013 Ozone ISA this endpoint was classified as a likely to be causal relationship. Three new endpoint categories (i.e., increased tree mortality, alteration of herbivore growth and reproduction, alteration of plant-insect signaling) not evaluated in the 2013 Ozone ISA, are all determined to have a likely to be causal relationship with ozone. Plant reproduction, previously considered as part of the evidence for growth effects, is now a stand-alone causal relationship.

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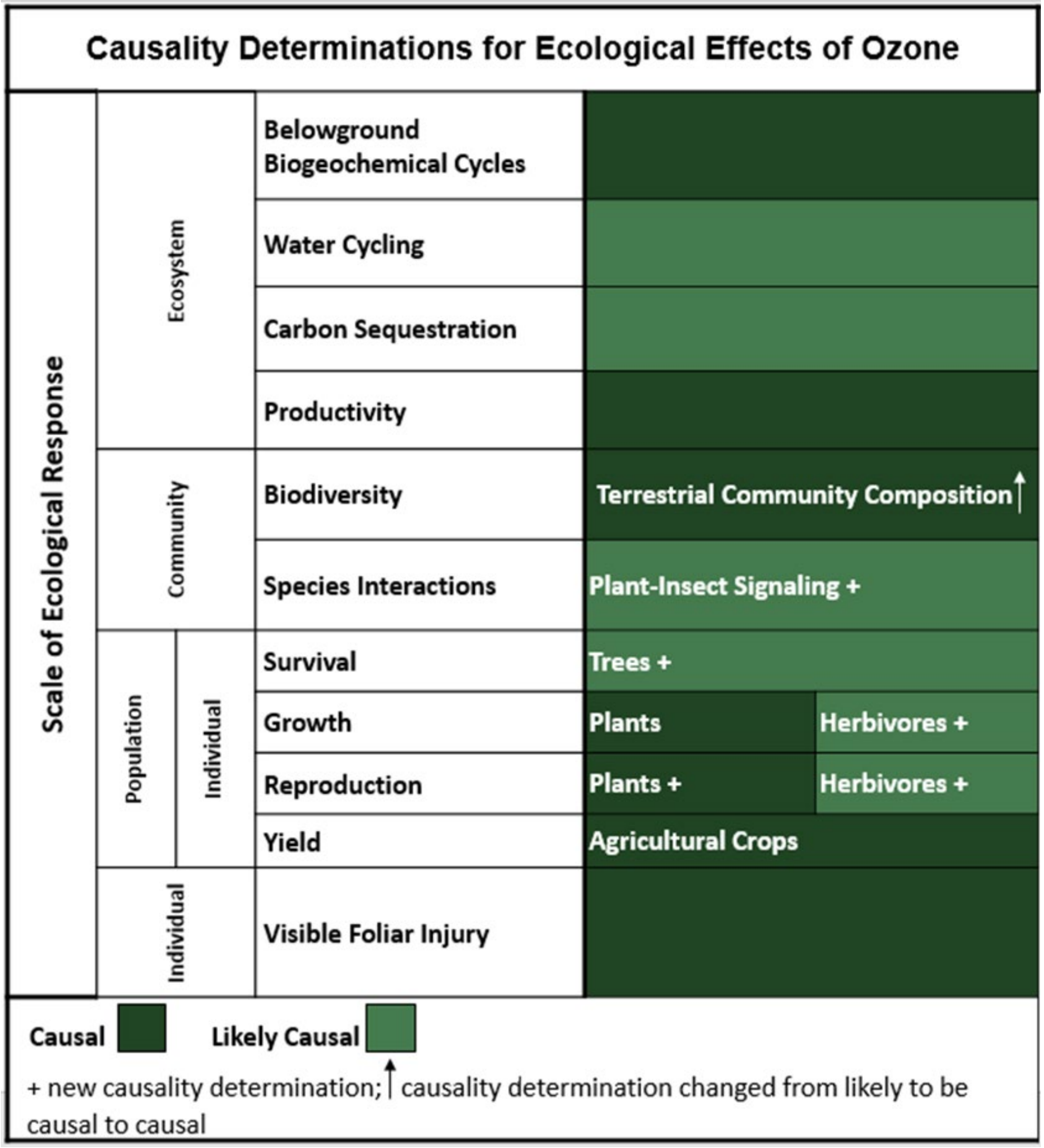

Causality Determinations for Ecological Effects of Ozone

Scale of Ecological Response	Ecosystem		Belowground Biogeochemical Cycles	■	
			Water Cycling	🟩	
			Carbon Sequestration	🟩	
			Productivity	■	
	Community		Biodiversity	■ Terrestrial Community Composition ↑	
			Species Interactions	🟩 Plant-Insect Signaling +	
	Population	Individual	Survival	🟩 Trees +	
			Growth	■ Plants	🟩 Herbivores +
			Reproduction	■ Plants +	🟩 Herbivores +
			Yield	■ Agricultural Crops	
	Individual		Visible Foliar Injury	■	

Causal ■ Likely Causal 🟩

+ new causality determination; ↑ causality determination changed from likely to be causal to causal

Figure ES-5 Causality determinations for ozone across biological scales of organization and taxonomic groups.

Table ES-2 Summary of causality determinations for ecological effects.

Endpoint	Conclusions from 2013 Ozone ISA	Conclusions in the 2020 ISA
Visible foliar injury	Causal relationship	Causal relationship
Reduced vegetation growth	Causal relationship	Causal relationship
Reduced plant reproduction	No separate causality determination; included with plant growth	Causal relationship[a]
Increased tree mortality	Causality not assessed	Likely to be causal relationship[a]
Reduced yield and quality of agricultural crops	Causal relationship	Causal relationship
Alteration of herbivore growth and reproduction	Causality not assessed	Likely to be causal relationship[a]
Alteration of plant-insect signaling	Causality not assessed	Likely to be causal relationship[a]
Reduced productivity in terrestrial ecosystems	Causal relationship	Causal relationship
Reduced carbon sequestration in terrestrial ecosystems	Likely to be causal relationship	Likely to be causal relationship
Alteration of belowground biogeochemical cycles	Causal relationship	Causal relationship
Alteration of terrestrial community composition	Likely to be causal relationship	Causal relationship[b]
Alteration of ecosystem water cycling	Likely to be causal relationship	Likely to be causal relationship

[a] Denotes new causality determination.

[b] Denotes change in causality determination from 2013 Ozone ISA.

Visible foliar injury resulting from exposure to ozone has been well characterized and documented in over six decades of controlled experimental research involving many tree, shrub, herbaceous, and crop species and using both long-term field studies and laboratory approaches. Recent experimental evidence (Section 8.2) continues to show a consistent association between visible injury and ozone exposure supporting the conclusion of the 2013 Ozone ISA that, **there is a "causal relationship" between ozone and visible foliar injury.** Measured changes in photosynthesis and carbon allocation in ozone-exposed plants scale up to reduced growth documented in natural and managed (e.g., agriculture, forestry, landscaping) species (Section 8.3), as well as impaired reproduction in individual plants (Section 8.4.1). Consistent with the conclusions in the 2013 Ozone ISA, there is **a "causal relationship"**

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between ozone and reduced plant growth and **a "causal relationship" between ozone and reduced crop yield and quality**. In the 2013 Ozone ISA, reproduction was considered in the same category with plant growth. Increased information on metrics of plant reproduction (e.g., observed flower number, fruit number, fruit weight, seed number, rate of seed germination) and evidence for direct negative effects on reproductive tissues as well as for indirect negative effects (resulting from decreased photosynthesis and other whole-plant physiological changes) warrants a separate causality determination of **a "causal relationship" between ozone exposure and reduced plant reproduction**. Since the 2013 Ozone ISA, a large-scale multivariate analysis of factors contributing to tree mortality (1971−2005) concluded that county-level ozone concentrations averaged over the study period significantly increased tree mortality in 7 out of 10 plant functional types in the eastern and central U.S. (Section 8.4.3). This evidence, combined with observations of long-term declines of conifer forests in several high ozone regions and new experimental evidence that sensitive genotypes of aspen have increased mortality with ozone exposure, supports **a "likely to be causal relationship" between ozone exposure and tree mortality.**

In addition to effects on plants, ozone can alter ecological interactions between plants and other species including herbivores consuming ozone-exposed vegetation. Studies of insect herbivores in previous ozone assessments and newer experimental studies covering a range of species at varying levels of ozone exposure frequently show statistically significant effects; however, effects on growth and reproduction are highly context- and species-specific, and not all species tested show a response (Section 8.6). **The collective evidence supports "a likely to be causal relationship" between ozone exposure and altered herbivore growth and reproduction.** Many plant-insect interactions are mediated through volatile plant signaling compounds which plants use to signal other community members. In the 2013 Ozone ISA, a few experimental and modeling studies reported altered insect-plant interactions that are mediated through chemical signaling. New evidence from multiple studies show altered/degraded emissions of chemical signals from plants and reduced detection of volatile plant signaling compounds by insects, including pollinators, in the presence of ozone (Section 8.7). **The collective evidence supports "a likely to be causal relationship" between ozone exposure and alteration of plant-insect signaling.**

At the ecosystem scale, ozone-caused decreases in plant photosynthesis can lead to reduced ecosystem carbon content. Changes in patterns of aboveground and belowground carbon allocation associated with ozone effects on plants can alter ecosystem properties of storage (e.g., productivity, carbon sequestration) and cycling (e.g., biogeochemistry) through both experimental and modeling studies. Consistent with the conclusions of the 2013 Ozone ISA, there is **a "causal relationship" between ozone exposure and reduced productivity and a "likely to be causal relationship" between ozone and reduced carbon sequestration** (Section 8.8). As described in the 2013 Ozone ISA and new experimental studies, processes such as carbon and nitrogen cycling and decomposition in soils are indirectly affected via ozone effects on the quality and quantity of carbon supply from plants and leaf litter (Section 8.9). **Recent evidence continues to support a "causal relationship" between ozone exposure and the alteration of belowground biogeochemical cycles**. Ozone can affect water use in plants through several mechanisms including damage to stomatal functioning, loss of leaf area, and changes in wood anatomy (e.g., vessel size and density) that can affect plant and stand evapotranspiration and may lead, in turn, to possible effects on hydrological cycling as shown through a combination of experimental data and modeling (Section 8.11). Evidence continues to support the conclusion of the 2013 Ozone ISA that, **there is a "likely to be causal relationship" between ozone and alteration of ecosystem water cycling.** In terrestrial ecosystems, ozone may alter community composition by uneven effects on co-occurring species, decreasing the abundance of sensitive species, and giving tolerant species a competitive advantage. Alteration of community composition of some ecosystems including conifer forests, broadleaf forests, and grasslands and altered fungal and bacterial communities in soils reported in the 2013 Ozone ISA is augmented by additional experimental and modeling evidence for effects in forest and grassland communities (Section 8.10); collective evidence indicates a change in the causality determination to **a "causal relationship" between ozone exposure and altered terrestrial community composition of some ecosystems.**

For effects on climate, changes in the abundance of tropospheric ozone perturb the radiative balance of the atmosphere by interacting with incoming solar radiation and outgoing longwave radiation. This effect is quantified by radiative forcing.[1] Through this effect on the Earth's radiation balance, tropospheric ozone plays a major role in the climate system and increases in tropospheric ozone abundance contribute to climate change. **Recent evidence continues to support a "causal relationship" between tropospheric ozone and radiative forcing and a "likely to be causal relationship," via radiative forcing, between tropospheric ozone and temperature, precipitation, and related climate variables** (referred to as "climate change" in the 2013 Ozone ISA; the revised title for this causality determination provides a more accurate reflection of the available evidence; Table ES-3). The new evidence comes from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) and its supporting references, as well as a limited number of more recent studies, and builds on evidence presented in the 2013 Ozone ISA. The new studies further support the causality determinations included in the 2013 Ozone ISA.

Table ES-3 Summary of causality determinations for tropospheric ozone effects on climate.

	Conclusions in 2013 Ozone ISA	Conclusions in the 2020 ISA
Radiative forcing	Causal relationship	Causal relationship
Temperature, precipitation, and related climate variables	Likely to be causal relationship	Likely to be causal relationship

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[1] Radiative forcing is the perturbation in net radiative flux at the tropopause (or top of the atmosphere) caused by a change in radiatively active forcing agent(s) after stratospheric temperatures have readjusted to radiative equilibrium [stratospherically adjusted radiative forcing; Myhre et al. (2013)].

ES.5 Key Aspects of Health and Welfare Effects Evidence

There is extensive scientific evidence that demonstrates health and welfare effects from exposure to ozone. As documented by the evaluation of evidence throughout the subsequent Appendices to this ISA, the U.S. EPA carefully considers uncertainties in the evidence, the extent to which recent studies have addressed or reduced uncertainties from previous assessments, and the strengths of the evidence. Uncertainties do not necessarily change the fundamental conclusions of the literature base. In fact, some conclusions are robust to such uncertainties. Where there is clear evidence linking ozone with health and welfare effects—with or despite remaining uncertainties—the U.S. EPA makes a determination of a causal or likely to be causal relationship. The identification of the strengths and limitations in the evidence will help in the prioritization of research efforts to support future ozone NAAQS reviews.

ES.5.1 Health Effects Evidence: Key Findings

A large body of scientific evidence spanning many decades clearly demonstrates there are health effects related to both short- and long-term exposure to ozone. The strongest evidence supports a relationship between ozone exposure and respiratory health effects. The collective body of evidence for each health outcome category evaluated in this ISA is considered systematically and assessed; this assessment includes evaluation of the inherent strengths, limitations, and uncertainties in the overall body of evidence for the health outcome, resulting in the causality determinations detailed in Table ES-1.

An inherent strength of the evidence integration in this ISA is the extensive amount (in both breadth and depth) of available evidence resulting from decades of scientific research that describes the relationship between both short- and long-term ozone exposure and health effects. The breadth of the enormous database is illustrated by the different scientific disciplines that provide evidence (e.g., controlled human exposure, epidemiologic, animal toxicological studies), the range of health outcomes examined (e.g., respiratory, cardiovascular, metabolic, reproductive, and nervous system effects, cancer and mortality), and the large number of studies within several of these outcome categories. The depth of the literature base is exemplified by the examination of effects that range from biomarkers of exposure, to subclinical effects, to overt clinical effects, and even mortality.

There is strong and consistent experimental evidence linking short- and long-term ozone exposure with respiratory effects and short-term ozone exposure with metabolic health effects. However, several uncertainties should be considered when evaluating and synthesizing evidence from these studies. Experimental animal studies are often conducted at ozone concentrations higher than those observed in ambient air (i.e., 250 to >1,000 ppb) to evoke a response within a short time period. These studies are informative and the conduct of studies at these concentrations is commonly used for identifying potential human hazards. There are also substantial differences in exposure concentrations and exposure durations between animal toxicological and controlled human exposure studies. Additionally, a number of animal toxicological studies are performed in rodent models of disease states, while controlled human exposure studies generally are conducted in healthy individuals. Controlled human exposure studies do not typically include unhealthy or diseased individuals for ethical reasons; therefore, this exclusion represents an important uncertainty to consider in interpreting the results of these studies (i.e., that other individuals may be more sensitive and at risk to ozone than those in the study groups). Additional factors that differ between human and experimental animal exposures include: exposure concentration and disease status; differences in physiology (e.g., rodents are obligate nose breathers); differences in the duration and timing of exposure (e.g., rodents are exposed typically during the day, during their resting cycle, while humans are exposed during the day when they are normally active); and differences in the temperature at which the exposure was conducted. These factors may contribute to any lack of coherence between results of experimental animal and human studies. Despite these factors, there is consistent and coherent evidence that spans scientific disciplines for respiratory and metabolic health effects.

Epidemiologic studies contribute important evidence supporting the relationship between short- and long-term ozone exposure with respiratory effects. Although susceptible to chance, bias, and other potential confounding due to their observational nature, epidemiologic studies have the benefit of evaluating real-world exposure scenarios and can include sensitive populations that cannot typically be included in controlled human exposure studies. Innovations in epidemiologic study designs and methods have substantially reduced the role of chance, bias, and other potential confounders in well-designed, well-conducted epidemiologic studies. The most common source of uncertainty in epidemiologic studies of ozone is exposure measurement error. The exposure assignment methods used in short- and long-term ozone exposure epidemiologic studies have inherent strengths and limitations, and exposure measurement errors associated with those methods contribute bias and uncertainty to health effect estimates. For short-term exposure studies, exposure measurement error generally leads to underestimation and reduced precision of the association, whereas in long-term exposure studies exposure measurement error has the potential to bias effect estimates in either direction, although it is more common that they are underestimated. Furthermore, disentangling the effects of short-term ozone exposure from those of long-term ozone exposure (and vice versa) is an inherent uncertainty in the evidence base. When combined with coherent evidence from animal toxicological and controlled human exposure studies, the epidemiologic evidence can support and strengthen determinations of the causal nature of the relationship between health effects and exposure to ozone at relevant ambient air concentrations.

ES.5.2 Welfare Effects Evidence: Key Findings

The collective body of evidence for each welfare endpoint evaluated in this ISA was carefully considered and assessed, including the inherent strengths, limitations, and uncertainties in the overall body of evidence, resulting in the causality determinations for ecological effects detailed in Table ES-2 and effects on climate in Table ES-3. A large body of scientific evidence spanning more than 60 years clearly shows effects on vegetation due to ozone exposure. Decades of research on many plant species confirm effects on visible foliar injury, plant growth, reproduction and yield. The use of visible foliar injury to identify phytotoxic levels of ozone is an established and widely used methodology. There are robust exposure-response functions for reduced growth and yield (i.e., from carefully controlled

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experimental conditions, involving multiple concentrations and based on multiple studies) for about a dozen important tree species and a dozen major commodity crop species. Newer evidence supports a role for ozone in tree mortality and shifts in community composition of forest tree and grassland species. While the effect of ozone on vegetation is well established in general, there are some knowledge gaps regarding precisely which species are sensitive, what exposures elicit adverse responses for many species and how plant response changes with age and size.

There is high certainty in ozone effects on impairment to leaf physiology as mechanisms for effects at higher levels of biological organization (i.e., from the cellular level through individual organisms to the level of communities and ecosystems) and how those can ultimately affect aboveground and belowground processes such as productivity, carbon sequestration, biogeochemical cycling, and hydrology. However, ecosystems are inherently complex, and it is difficult to partition observed responses within a suite of multiple stressors. Scaling ozone effects to the ecosystem level remains a challenge, but there is a large body of knowledge of how ecosystems work through ecological observations and models. Interactive effects in natural ecosystems with multiple stressors (e.g., drought, disease) are difficult to study, but some have been investigated using different statistical methods. Although models and methods for characterizing ecosystem-level responses to ozone are accompanied by inherent uncertainties, more research will strengthen understanding of scaling across different levels of biological organization.

There are multiple pathways in which ozone can affect plant-insect interactions. Studies that characterize volatile plant signaling compounds in ozone-enriched environments and assess insect response to altered chemical signals suggest that ozone alters scent-mediated interactions in ecological communities. A relatively small number of insect species and plant-insect associations have been assessed, and there are knowledge gaps in the mechanisms and consequences of modulation of signaling by ozone. There are multiple studies demonstrating ozone effects on fecundity and growth in insects that feed on ozone-exposed vegetation. However, no consistent directionality of response is observed across studies and uncertainties remain in regard to different plant consumption methods across species and the exposure conditions associated with particular severities of effects.

Changes in the abundance of tropospheric ozone affect radiative forcing, and thus tropospheric ozone is considered an important greenhouse gas. The recent IPCC AR5 estimates global tropospheric ozone radiative forcing to be 0.40 (0.20 to 0.60) W/m^2 and recent studies reinforce the AR5 estimates. Consistent with previous estimates, the effect of global, total tropospheric ozone increases on global mean surface temperature, through its impact on radiative forcing, continues to be estimated at roughly 0.1 to 0.3°C since preindustrial times with larger effects regionally. Some new research has explored certain additional aspects of the climate response to ozone radiative forcing beyond global and regional temperature change. Specifically, ozone changes are understood to have impacts on other climate metrics such as precipitation and atmospheric circulation patterns, and new evidence has continued to support and further quantify this understanding.

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While the warming effect of tropospheric ozone in the climate system is well established in general, precisely quantifying changes in surface temperature due to tropospheric ozone changes, along with related climate effects, requires complex climate simulations that include all relevant feedbacks and interactions. For example, trends in free tropospheric ozone and upper tropospheric ozone (where radiative forcing is particularly sensitive to changes in ozone concentrations) are not captured well by models. In addition, substantial variation exists across models. Such modeling uncertainties make it especially difficult to provide precise quantitative estimates of the climate effects of regional-scale ozone changes. Uncertainties in estimates of preindustrial ozone concentrations represent another important source of uncertainty in climate effects resulting from long-term ozone concentration changes.

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RESEARCH ARTICLE

Association between Air Pollutants and Asthma Emergency Room Visits and Hospital Admissions in Time Series Studies: A Systematic Review and Meta-Analysis

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Abstract

Background

Air pollution constitutes a significant stimulus of asthma exacerbations; however, the impacts of exposure to major air pollutants on asthma-related hospital admissions and emergency room visits (ERVs) have not been fully determined.

Objective

We sought to quantify the associations between short-term exposure to air pollutants [ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and particulate matter $\leq$10μm (PM_{10}) and $PM_{2.5}$] and the asthma-related emergency room visits (ERV) and hospitalizations.

Methods

Systematic computerized searches without language limitation were performed. Pooled relative risks (RRs) and 95% confidence intervals (95%CIs) were estimated using the random-effect models. Sensitivity analyses and subgroup analyses were also performed.

Results

After screening of 246 studies, 87 were included in our analyses. Air pollutants were associated with significantly increased risks of asthma ERVs and hospitalizations [O_3: RR(95%

CI), 1.009 (1.006, 1.011); $I^2 = 87.8\%$, population-attributable fraction (PAF) (95%CI): 0.8 (0.6, 1.1); CO: RR(95%CI), 1.045 (1.029, 1.061); $I^2 = 85.7\%$, PAF (95%CI): 4.3 (2.8, 5.7); NO_2: RR(95%CI), 1.018 (1.014, 1.022); $I^2 = 87.6\%$, PAF (95%CI): 1.8 (1.4, 2.2); SO_2: RR (95%CI), 1.011 (1.007, 1.015); $I^2 = 77.1\%$, PAF (95%CI): 1.1 (0.7, 1.5); PM_{10}: RR(95%CI), 1.010 (1.008, 1.013); $I^2 = 69.1\%$, PAF (95%CI): 1.1 (0.8, 1.3); $PM_{2.5}$: RR(95%CI), 1.023 (1.015, 1.031); $I^2 = 82.8\%$, PAF (95%CI): 2.3 (1.5, 3.1)]. Sensitivity analyses yielded compatible findings as compared with the overall analyses without publication bias. Stronger associations were found in hospitalized males, children and elderly patients in warm seasons with lag of 2 days or greater.

Conclusion

Short-term exposures to air pollutants account for increased risks of asthma-related ERVs and hospitalizations that constitute a considerable healthcare utilization and socioeconomic burden.

Introduction

Asthma is characterized by airway hyperresponsiveness and inflammation, the pivotal components leading to the cascades of pro-inflammatory mediator release and airflow limitation [1] that are associated with allergen exposures, air pollution, cigarette smoking and noxious particle insults [2].

The relationship between air pollution and asthma has been well-established [3–89], particularly in the countries with rapid urbanization and industrialization. Three multi-center studies conducted in Europe [14,51] and Australia [53] reported an overall insignificant association between major air pollutants and the asthma-related emergency room visits (ERVs), except for nitrogen dioxide (NO_2) [14,53] and particulate matter with a diameter of 10 μm or less (PM_{10}) [51]; whereas other multi-city studies conducted in Korea and Europe demonstrated different magnitudes of the associations between asthma exacerbation and ozone (O_3) [5] and sulfur dioxide (SO_2) [5,76] pollution. Moreover, exposure to environmental NO_2 and PM_{10} has recently been associated with worsening of symptoms and lung function decline during asthma exacerbations [90–92].

Whilst the adverse impacts of air pollution on asthma exacerbations have been confirmed, the effect sizes and the extent to which any single pollutant acts as a surrogate of other pollutants are less clear. As epidemiologic evidence regarding the effects of air pollution on asthma accumulates, it is crucial to consider different concentration-response functions (CRFs, defined as the percentage change in any health outcome per unit change in concentration, to different air pollutants [93]), based on the concurrent evidence. Determination of the effect modification across studies may also be challenging because of the underlying geographic diversity, heterogeneous primary outcome indices, the differences in statistical algorithms, the complexity of multiple pollutants and other confounders [4].

Consequently, meticulous risk assessments exploring the influences of multiple air pollutants, calculated as the CRFs [93], are warranted. In view that the quantification between air pollution and asthma-related ERVs or hospitalizations has been well-established and that the majority of population is exposed to air pollution, the relative risks (RRs) and population attributable fractions (PAFs) of individual pollutants on asthma-related ERVs or hospitalizations should be taken into account. Furthermore, investigations of the effect modification may provide further insights into these associations [94]. For instance, there have been the literature reports delineating stronger pollution effects during the warm seasons, despite the culmination of pediatric asthma attacks during cold seasons [1,4,5,17,18,24,52,54,85]. Sex [5,7,37,40,50,68] and age [16,24,30,38,57] differences might also confound the asthma outcomes to air pollutant exposure.

In this study, we sought to conduct a systematic review and meta-analysis on the association between short-term exposure to air pollutants and asthma-related ERVs and hospital admissions based on time-series and case-crossover studies, thus offering rationales to improve public health and environmental protection. We further assessed the impacts of age, sex, season, hospital variance and long lag patterns (lag >2days) on these associations.

Methods

Eligibility criteria and literature searches

Systematic searches were conducted to identify studies focusing on short-term exposures, defined as the duration of up to 7 days to one of the air pollutants associated with asthma exacerbation. These studies involved all age intervals without language limitation. We excluded: (1) animal studies, *ex vivo* and toxicological studies, summaries, commentaries and editorials, case reports and case series; (2) duplicate publications; (3) studies evaluating long-term exposure only; (4) non-peer reviewed articles (a potential source of bias); (5) study duration of less than one year; (6) no original data. Authors were contacted by e-mail in case data were incomplete. Studies were excluded if no reply was obtained despite repeated contacts with corresponding authors.

Time-series studies (including case-crossover studies) were searched comprehensively in EMBASE, PubMed, Cochrane Central Register of Controlled Trials and EBM Reviews–Cochrane Database of Systematic Reviews, Web of Science, Ovid and Highwire up to March 2015 (no start date specified). References were checked for additional data. When the same population was used in several publications, only the largest and the most complete study (i.e. multi-cities study) was included. In addition, single-city study with different time periods from multi-cities study was also accepted. We used a combination of keywords related to the types of exposure (air pollution, CO, PM_{10}, $PM_{2.5}$, SO_2, NO_2 and O_3) and the outcomes of asthma exacerbations (hospital admission and ER visit). (See ***Search Strategies*** in the online supplements for further details)

Quality score assessment

This study complies with the preferred reporting items of PRISMA [95]. Since no validated scales of time-series and case-crossover studies were recommended by New Castle Ottawa and Cochrane risk of bias tool, we evaluated the validity based on Mustafic's study [96]. Three components were assessed, including asthma diagnosis (0 to 1 point), air pollutant measures (0 to 1) and adjustment for confounders (0 to 3). We confirmed asthma exacerbation if coded by *International Classification of Diseases*, *American Thoracic Society*, *National Asthma Education or Prevention Program or International Classification of Primary Care* 2 (0 for no valid criteria). The frequency of measurement and missing data were considered (1 point for measurements performed daily with <25% missing data, otherwise 0 point was assigned). Regarding the potential confounders, 1 point was scored if long-term trends, seasonality and temperature were all adjusted, otherwise 0 point was assigned. Any additional adjustment for the humidity or day-of-week was added for 1 point. Any adjustment made for influenza epidemics and holidays was added for 1 point. Studies fulfilling 5 points were analyzed in sensitivity analyses.

Study selection and data extraction

Two independent reviewers (S.C. and H.D.) screened the abstracts and titles. Full texts were reviewed to determine eligibility for inclusion. Disagreement was resolved by discussion. If consensus was not reached, another reviewer (X.Z.) was consulted to vote for final decisions.

A standardized form was used for data extraction including the main characteristics (author, year of publication, location and period, type of study, age and sex of populations, title and journal), outcome measures (general practitioner's house calls, primary care visits, asthma-related hospitalization and ERV), the quality of measurement methods and adjustments (long-term trend, seasonality, temperature, humidity, days of the week, holidays and influenza epidemics). Data extraction was done by two independent reviewers (W.G. and L.J.) for comparisons. Disagreements were resolved by consultation with the third reviewer (X.Z.).

Statistical analysis

As current evidence suggests a linear association between air pollutants and asthma-related ERVs and hospital admissions, the standardized effect estimates were expressed as the risk ratios (RRs) and 95% confidence intervals (95%CIs), derived from single-pollutant models reporting RRs (95%CIs) or percentage change (95%CIs), and further recalculated to reflect a 10 $\mu g/m^3$ increase in the pollutants by assuming a linear relationship of all pollutants, except for CO (1 mg/m^3 increase) [96]. There was a time lag (measured in days) between short-term air pollution and asthma exacerbations; however, each of the included study varied in lag selection patterns. Some authors recommended the use of the most significant estimate, irrespective of the direction. Given the lack of standardized methods of reporting, we adopted a *priori* lag selection scheme proposed by Atkinson et al [97]. If only one lag estimate for a given pollutant/outcome pair was demonstrated (either the only one was analyzed or reported), it would be included for analyses. If multiple lag estimates were reported, the selection algorithms were: 1) the most frequently used lag in all selected studies; 2) single lags, but not cumulative/distributed lags, were selected as a priority.

Random-effect model is the most conservative tool incorporating within- and between-study heterogeneity in 95%CI, and has been adopted for studies investigating different populations with anticipated significant heterogeneity which is calculated using the I^2 test. The I^2 values of 0 to 30, 30 to 50, and greater than 50 denoted low, moderate and high heterogeneity, respectively [98]. This algorithm is currently recommended by Cochrane collaboration (http://www.cochrane.org) despite concerns of underpowered statistics.

The prevalence of exposure to air pollution in the population was estimated to be 100%, which is imputed from the epidemiological studies reporting effect estimates [99]. Population attributable fractions (PAFs) were calculated from RRs (95%CI) in overall analyses, calculated as PAF = (RR−1)/RR.

To explore the heterogeneity in our pooled analysis, sensitivity analyses of the lag patterns and study quality were applied, based on the studies with the same and most commonly used lag pattern or the studies with 5 scores.

Subgroup analyses of the study characteristics were conducted to combine the effects for evaluating the differences between strata-specific estimates (age, sex, seasons, hospitalization or ERVs). Additional subgroup analyses were performed for short- ($\leq$2 days) and long-lag (>2 days) patterns. The default for short-lag patterns was the most frequently used for individual pollutants; otherwise, lag1 or lag0 or lag 0–1 served as surrogates. For long-lag patterns, single lag was a priority selection compared with the cumulative lag.

Potential publication bias was assessed by using the asymmetric plot and confirmed by the Egger's test [100].

Statistical analyses were conducted using STATA 11.2 (Stata, College Station, TX, USA). All tests were two-sided and statistical significance was defined as $P<0.05$, except for the heterogeneity assessment ($P<0.10$).

The PRISMA checklist for this meta-analysis could be found in **S1 File** in the supporting information.

Results

Eligible studies

We initially identified 1099 literature reports. After screening for the titles and abstracts, 246 full-text articles were assessed for eligibility, of which 87 were included (86 in English and 1 in Spanish, **Fig 1**).

Main characteristics of 87 eligible studies, consisting of 62 time-series and 25 case cross-over studies, are displayed in S1 Table. Databases were extracted from 46 ERVs, 37 hospital admissions and 4 ERVs/hospital admissions. The study cohort consisted of the general population. Lag exposures varied from a specific day (single-lag) to 7 days or less before the onset of asthma exacerbations.

Of the 87 included studies, 50 focused on children, 21 on adults, 13 on elderly population, and 44 on general population. Only 12 studies have conducted sex modification analyses, with

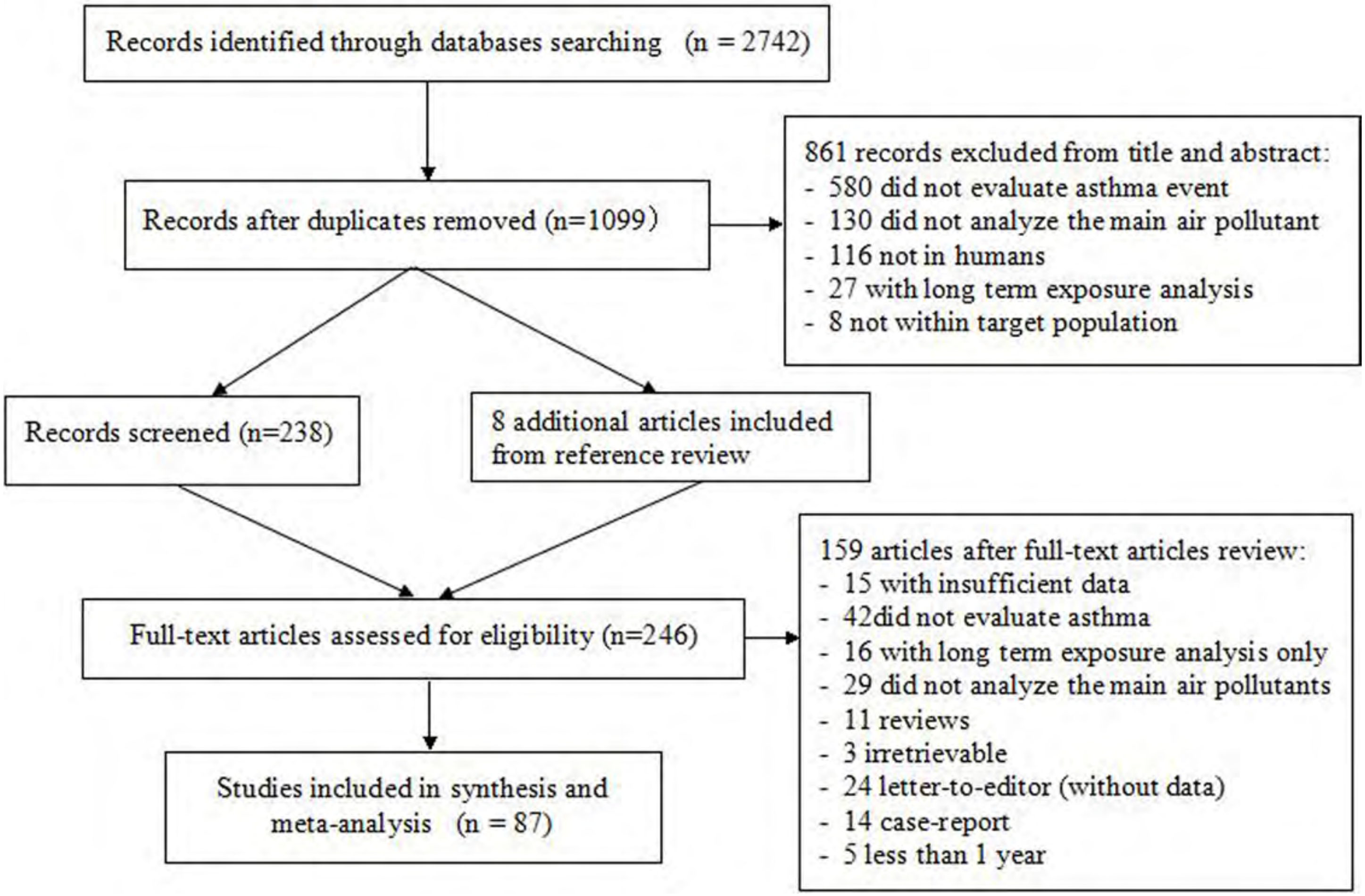

Fig 1. Study flow chart.

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Table 1. Association of six major air pollutants with ERVs and hospital admissions for asthma in overall and sensitivity analyses.

Characteristics	Air pollutant (incremental unit)					
	O_3(10 μg/m^3)	CO (1 mg/m^3)	NO_2 (10 μg/m^3)	SO_2 (10 μg/m^3)	PM_{10} (10 μg/m^3)	$PM_{2.5}$ (10 μg/m^3)
Overall study analyses						
No. of the studies	71	42	66	65	51	37
I^2,%	87.8	85.7	87.6	77.1	69.1	82.8
RR (95%CI)	1.009 (1.006,1.011)	1.045(1.029, 1.061)	1.018 (1.014, 1.022)	1.011 (1.007, 1.015)	1.010 (1.008, 1.013)	1.023(1.015, 1.031)
Egger's test, P value	<0.001	0.01	<0.001	<0.001	<0.001	0.06
PAF, %(95%CI)[a]	0.8 (0.6, 1.1)	4.3 (2.8, 5.7)	1.8 (1.4, 2.2)	1.1 (0.7, 1.5)	1.1 (0.8, 1.3)	2.3 (1.5, 3.1)
Study quality sensitivity analyses						
No. of the studies	12	7	11	13	7	3
I^2,%	55.7	13.6	55.7	57.9	0.0	0.0
RR (95%)	1.005 (1.002,1.008)	1.013 (1.000, 1.028)	1.009 (1.004, 1.015)	1.009 (1.003, 1.015)	1.006 (1.003, 1.009)	1.004 (1.000, 1.009)
Egger's test, P value	0.15	0.16	0.16	0.28	0.53	0.71
Lag exposures sensitivity analyses						
No. of the studies	9	14	11	12	13	13
Lag exposure, d	0	1	0	0	1	1
I^2,%	22.4	0.0	65.9	41.8	0.0	6.6
RR (95%)	1.010 (1.005, 1.014)	1.013 (1.001, 1.025)	1.010 (1.002, 1.018)	1.004 (1.000, 1.008)	1.005 (1.003,1.008)	1.008 (1.003, 1.013)
Egger's test, P value	0.99	0.08	0.93	0.96	0.42	0.49

Abbreviations: PAF, population attributable fraction; PM_{10}, particulate matter of ≤10 μm; $PM_{2.5}$, particulate matter of ≤2.5 μm; RR, relative risk

The PAF was calculated by $\{PAF = P[(RR-1)/P(RR-1)+1]\}$, where P indicates prevalence of exposure to air pollution in the population which was estimated as 100%.

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12 male and 11 female sub-datasets. 31 studies were performed in warm seasons and 25 in cold seasons.

Mean 24-hr or 8-hr maximum concentrations of six pollutants are demonstrated in S1 Table.

Overall analyses

Associations between the six major air pollutants and asthma-related ERVs/hospitalizations were statistically significant [O_3: 71 studies; RR (95%CI), 1.009 (1.006, 1.011); $I^2 = 87.8\%$, PAF (95%CI): 0.8 (0.6, 1.1); CO: 42 studies; RR (95%CI), 1.045 (1.029, 1.061); $I^2 = 85.7\%$, PAF (95% CI): 4.3 (2.8, 5.7); NO_2: 66 studies; RR (95%CI), 1.018 (1.014, 1.022); $I^2 = 87.6\%$, PAF (95%CI): 1.8 (1.4, 2.2); SO_2: 65 studies; RR (95%CI), 1.011 (1.007, 1.015); $I^2 = 77.1\%$, PAF (95%CI): 1.1 (0.7, 1.5); PM_{10}: 51 studies; RR (95%CI), 1.010 (1.008, 1.013); $I^2 = 69.1\%$, PAF (95%CI): 1.1 (0.8, 1.3); $PM_{2.5}$: 37 studies; RR (95%CI), 1.023 (1.015, 1.031); $I^2 = 82.8\%$, PAF (95%CI): 2.3 (1.5, 3.1)]. (**Table 1, Figs 2–7**).

Publication bias was detected in all analyses evaluating all pollutants except for $PM_{2.5}$ ($P = 0.06$). See S1 Fig in the online supplement for the funnel plots of the relative risks of emergency/hospital admissions for asthma in relation to six air pollutants in the overall analyses. The Excel form of our database (S2 File) is also available in the supporting information.

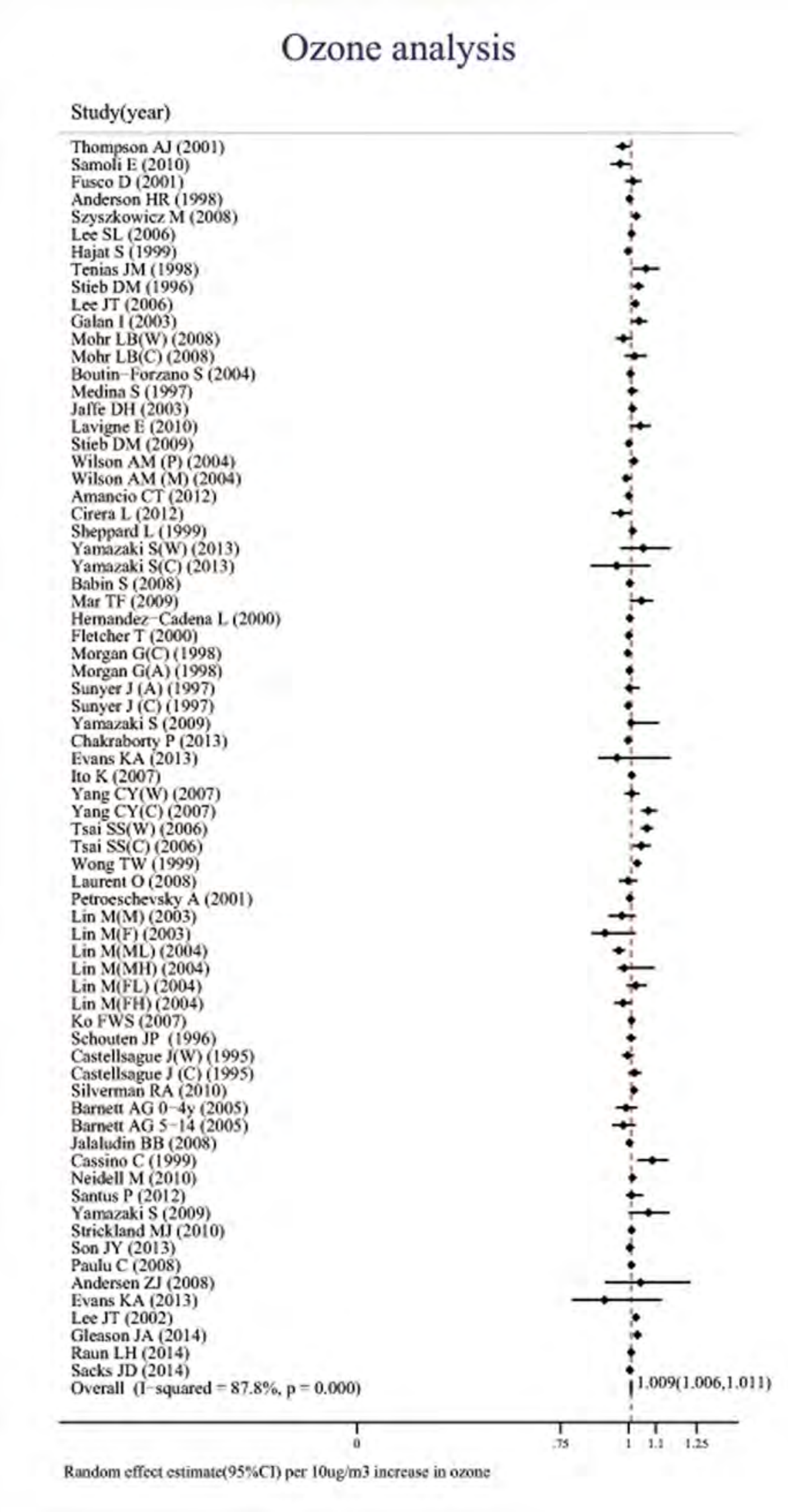

Fig 2. Association between ozone and ERVs/hospital admissions for asthma in the overall analyses.

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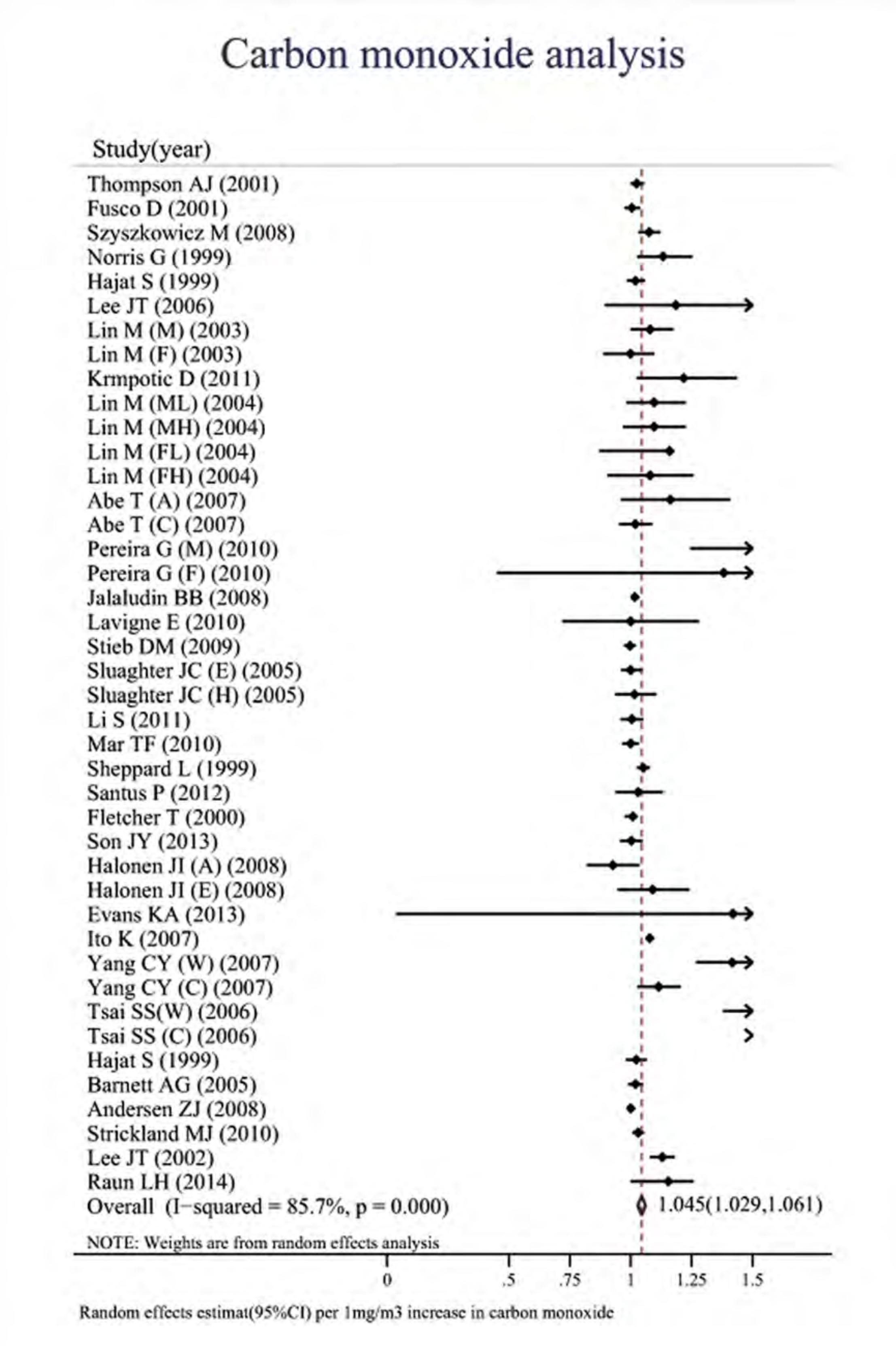

Fig 3. Association between carbon monoxide and ERVs/hospital admissions for asthma in the overall analyses.

doi:10.1371/journal.pone.0138146.g003

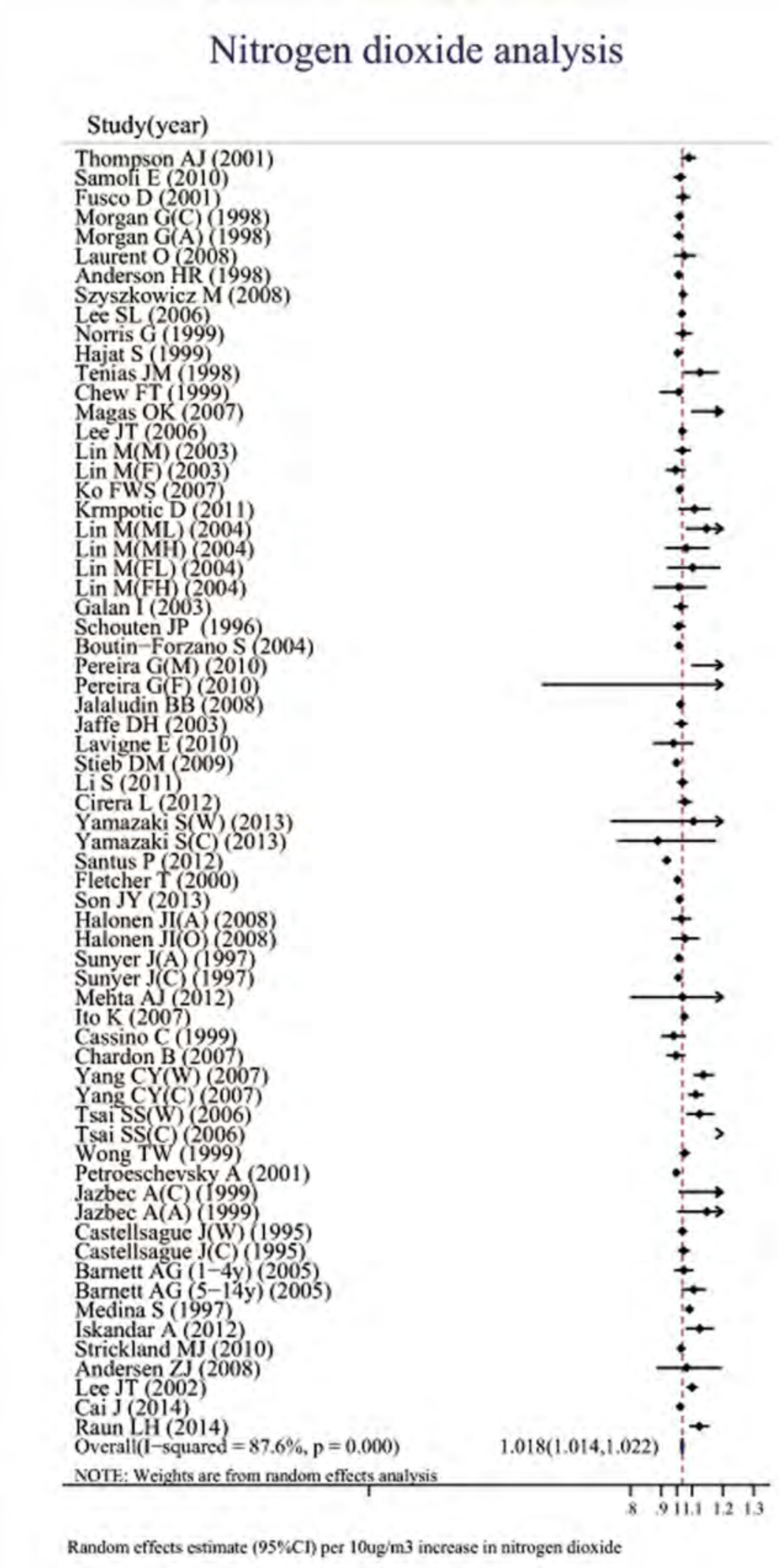

Fig 4. Association between nitrogen dioxide and ERVs/hospital admissions for asthma in the overall analyses.

doi:10.1371/journal.pone.0138146.g004

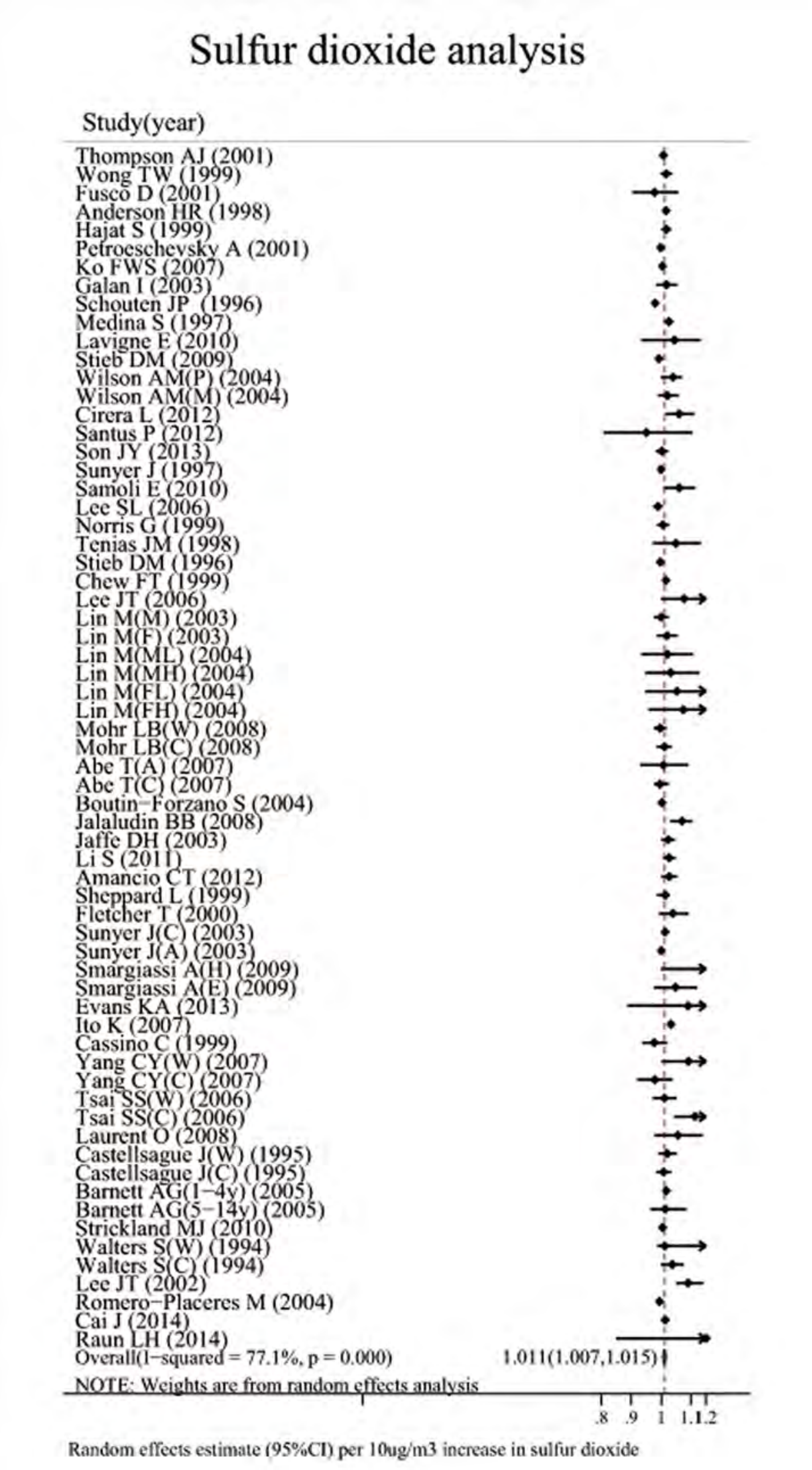

Fig 5. Association between sulfur dioxide and ERVs/hospital admissions for asthma in the overall analyses.

doi:10.1371/journal.pone.0138146.g005

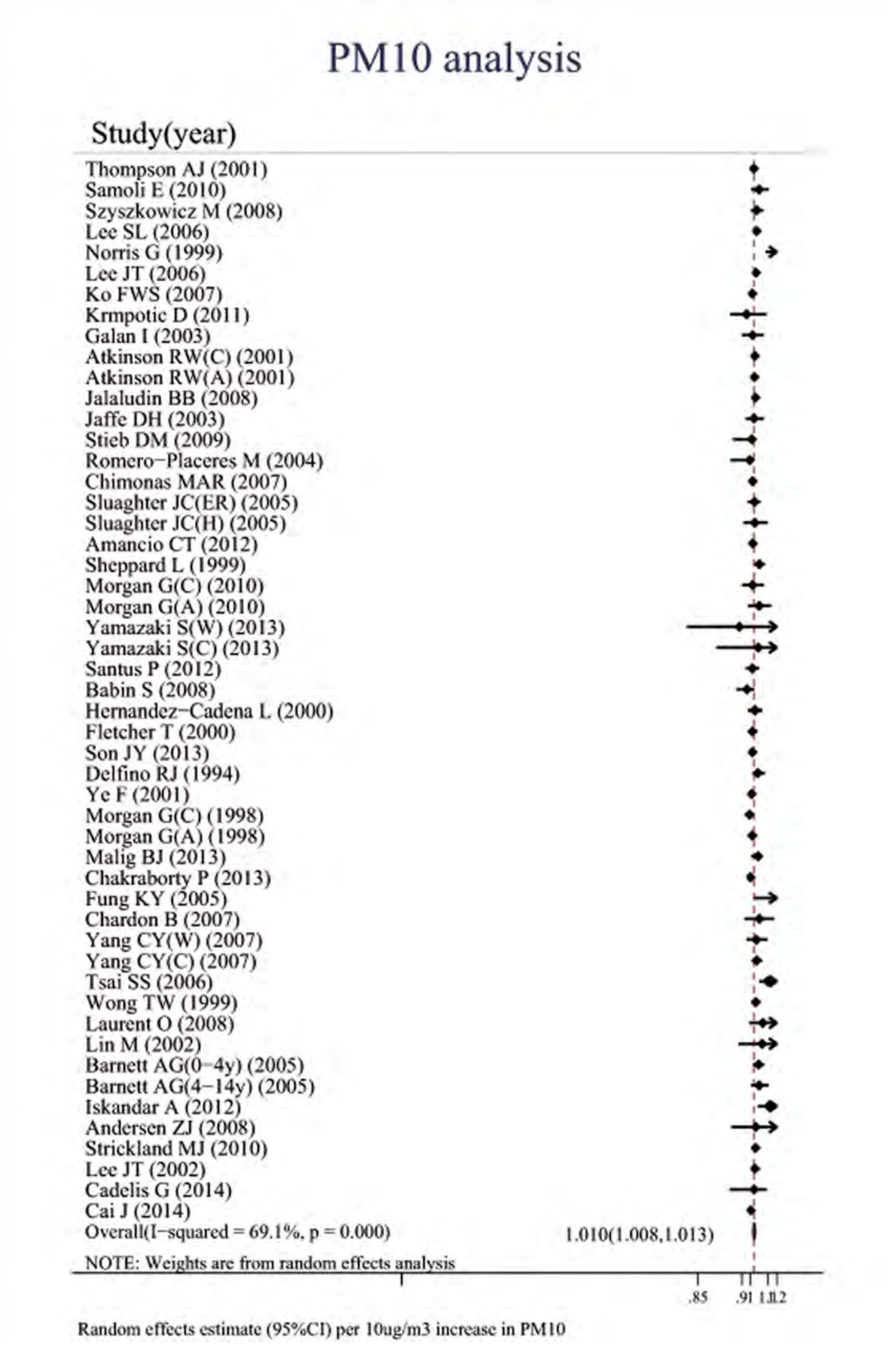

Fig 6. Association between PM_{10} and ERVs/hospital admissions for asthma in the overall analyses.

doi:10.1371/journal.pone.0138146.g006

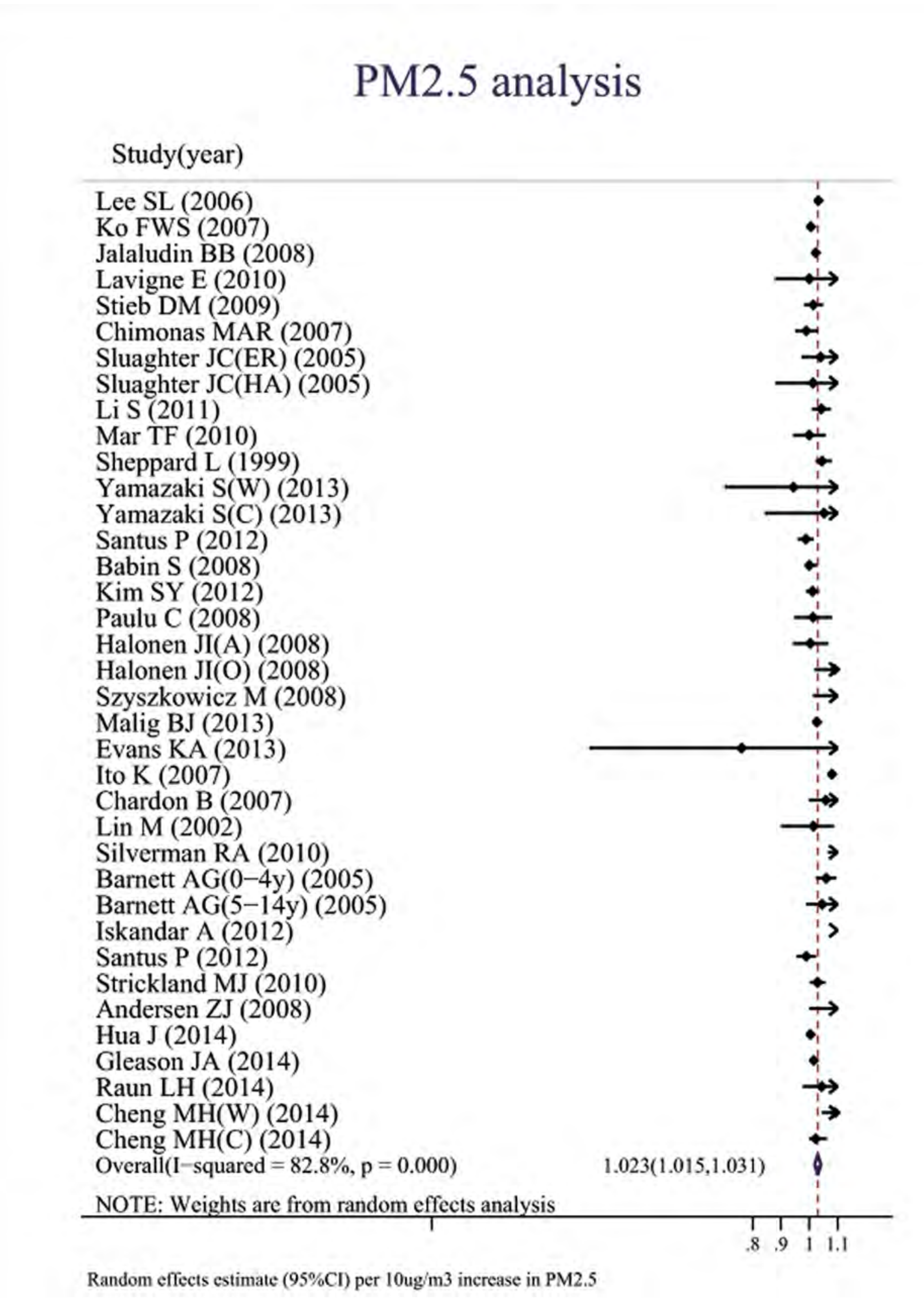

Fig 7. Association between $PM_{2.5}$ and ERVs/hospital admissions for asthma in the overall analyses.

doi:10.1371/journal.pone.0138146.g007

Sensitivity analyses

Study quality. There were significant associations between air pollutants and asthma-related ERVs/hospitalizations in the sensitivity analyses, based on 29 studies fulfilling the quality score of 5 points without significant publication bias [O_3: 12 studies; RR (95%CI), 1.005 (1.002, 1.008); $I^2 = 55.7\%$; Egger's test, $P = 0.15$; CO: 7 studies; RR (95%CI), 1.013 (1.000, 1.028); $I^2 = 13.6\%$; Egger's test, $P = 0.16$; $NO_{2:}$ 11 studies; RR (95%CI), 1.009 (1.004, 1.015); $I^2 = 55.7\%$; Egger's test, $P = 0.16$; $SO_{2:}$ 13 studies; RR (95%CI), 1.009 (1.003, 1.015); $I^2 = 57.9\%$; Egger's test, $P = 0.28$; PM_{10}: 7 studies; RR (95%CI), 1.006 (1.003, 1.009); $I^2 = 0.0\%$; Egger's test, $P = 0.53$; $PM_{2.5}$: 3 studies; RR (95%CI), 1.004 (1.000, 1.009); $I^2 = 0.0\%$; Egger's test, $P = 0.71$] (**Table 1, and S1 Fig** in the online supplement for the funnel plots of the relative risks of emergency/hospital admissions for asthma in relation to six air pollutants regarding studies with a score of 5.)

Lag exposure. Lag exposure was 0 day for O_3, NO_2 and SO_2, and 1 day for CO, PM_{10} and $PM_{2.5}$. Likewise, associations between the six air pollutants and asthma-related ERVs/hospitalizations were statistically significant [O_3: 9 studies; RR (95%CI), 1.010 (1.005, 1.014); $I^2 = 22.4\%$; Egger's test, $P = 0.99$; CO: 14 studies; RR (95%CI), 1.033 (1.001, 1.025); $I^2 = 0.0\%$; Egger's test, $P = 0.37$; $NO_{2:}$ 11 studies; RR (95%CI), 1.010 (1.002, 1.018); $I^2 = 65.9\%$; Egger's test, $P = 0.93$; $SO_{2:}$ 12 studies; RR (95%CI), 1.004 (1.000, 1.008); $I^2 = 41.8\%$; Egger's test, $P = 0.96$; PM_{10}: 12 studies; RR (95%CI), 1.005 (1.003, 1.008); $I^2 = 0.0\%$; Egger's test, $P = 0.42$; $PM_{2.5}$: 13 studies; RR (95%CI), 1.008 (1.003, 1.013); $I^2 = 6.6\%$; Egger's test, $P = 0.49$]. No publication bias was detected. (**Table 1, Fig 8**)

Subgroup analyses

Effect modification of O_3, CO, NO_2, PM_{10} and $PM_{2.5}$ on asthma-related hospital admission and ERVs (stronger association for hospital admissions) was found.

In subgroup analysis of sex, more pronounced associations were demonstrated in males [CO: 1.080 (1.047, 1.113), NO_2:1.028 (1.008, 1.038); PM_{10}: 1.025 (1.011, 1.039); $PM_{2.5}$: 1.013 (1.000, 1.018)]. No significant association was found in females, except for exposure to O_3 [1.023 (1.006, 1.040)].

There was a tendency towards stronger associations between ERVs/hospital admissions and the six air pollutants in children [CO: 1.018 (1.013, 1.023); NO_2: 1.018 (1.013, 1.023); SO_2: 1.016 (1.011, 1.022); PM_{10}: 1.013 (1.008, 1.018); $PM_{2.5}$: 1.025 (1.013, 1.037)] and the elderly [CO: 1.094 (1.002, 1.185); NO_2: 1.019 (1.013, 1.024); SO_2: 1.024 (1.005, 1.044)] as compared with the adults.

Stronger associations can also be observed in warm seasons [CO: 1.166 (1.099, 1.232), NO_2: 1.029 (1.018, 1.040); SO_2: 1.018 (1.010, 1.026); PM_{10}: 1.021 (1.007, 1.023); $PM_{2.5}$: 1.028 (1.011, 1.044)], except for ozone exposure.

Additional subgroup analyses demonstrated that long-lag patterns that were associated with significant heterogeneity yielded a stronger association than short-lag patterns (**Table 2**).

Discussion

Principal findings

We have systematically evaluated and confirmed the associations between short-term exposure to six air pollutants which are closely regulated by the environmental protection agencies and asthma-related ERV/hospitalizations, based on all available time-series and case-crossover studies. Low heterogeneity and no publication bias was observed in the sensitivity analyses.

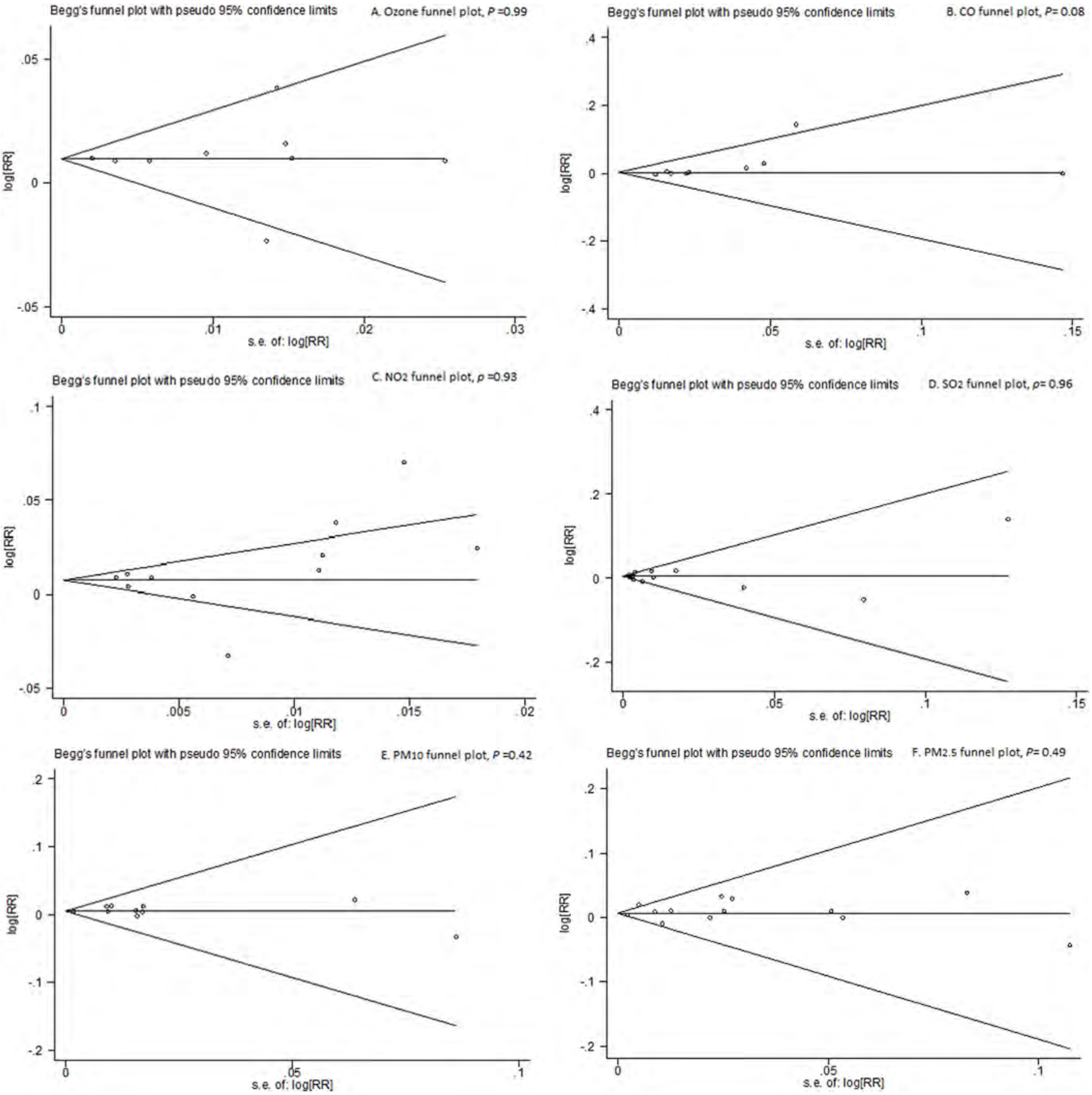

Fig 8. Funnel plots for relative risks of ERVs/hospital admissions for asthma in relation to the six air pollutants in lag pattern sensitivity analyses. A) Funnel plot for ozone; B) Funnel plot for CO; C) Funnel plot for NO_2; D) Funnel plot for SO_2; E) Funnel plot for PM_{10}; F) Funnel plot for $PM_{2.5.}$

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Our findings remained robust, despite potential publication bias resulting from the relatively small sample sizes in sensitivity analyses.

Table 2. Stratum-specific combined estimates of the association of six major air pollutants with ERVs and hospital admissions for asthma.

Stratum	Air pollutant (incremental unit)																	
	O_3(10 μg/m^3)			CO (1 mg/m^3)			NO_2 (10 μg/m^3)			SO_2 (10 μg/m^3)			PM_{10} (10 μg/m^3)			$PM_{2.5}$ (10 μg/m^3)		
	No.	RR (95%CI)	I^2	No.	RR (95%CI)	I^2	No.	RR (95%CI)	I^2	No.	RR (95%CI)	I^2	No.	RR (95%CI)	I^2	No.	RR (95%CI)	I^2
Sex																		
Males	9	1.009 (0.993,1.025)	77	7	1.080 (1.047,1.113)	0	10	1.028 (1.008,1.038)	68	7	1.018 (0.996,1.040)	40	8	1.025 (1.011,1.039)	80	5	1.013 (1.000,1.018)	79
Females	9	1.023 (1.006,1.040)	79	7	1.045 (0.966,1.124)	33	10	1.008 (0.987,1.029)	71	7	1.014 (0.996,1.021)	0	6	1.005 (1.000,1.009)	0	4	1.012 (1.000,1.020)	7
Age																		
Children	42	1.008 (1.005,1.012)	89	29	1.018 (1.013,1.023)	70	39	1.018 (1.013,1.023)	87	37	1.016 (1.011,1.022)	53	25	1.013 (1.008,1.018)	83	20	1.025 (1.013,1.037)	82
Adults	23	1.013 (1.008,1.018)	79	7	1.004 (0.963,1.045)	13	14	1.008 (1.003,1.014)	68	15	1.002 (0.997,1.007)	26	7	1.009 (1.003,1.014)	29	6	1.027 (1.007,1.047)	56
Elderly	10	1.010 (1.002,1.017)	61	5	1.094 (1.002,1.185)	40	9	1.019 (1.013,1.024)	0	9	1.024 (1.005,1.044)	25	6	1.009 (1.004,1.015)	52	5	1.022 (1.014,1.031)	0
Season																		
Cold	22	1.017 (1.007,1.028)	82	10	1.087 (1.020,1.154)	94	21	1.026 (1.016,1.038)	85	19	1.012 (1.002,1.022)	71	11	1.014 (1.006,1.023)	71	13	1.004 (0.997,1.011)	61
Warm	29	1.016 (1.010,1.021)	87	12	1.166 (1.099,1.232)	85	23	1.029 (1.018,1.040)	84	22	1.018 (1.010,1.026)	43	14	1.021 (1.007,1.023)	74	15	1.028 (1.011,1.044)	91
Type of admission																		
ERV	40	1.007 (1.004,1.010)	85	22	1.030 (1.011,1.049)	81	33	1.013 (1.008,1.018)	73	34	1.013 (1.007,1.019)	74	23	1.010 (1.006,1.014)	65	23	1.017 (1.006,1.029)	77
HA	31	1.010 (1.006,1.014)	84	20	1.080 (1.048,1.112)	87	33	1.023 (1.017,1.029)	91	31	1.008 (1.002,1.014)	71	28	1.011 (1.008,1.015)	70	14	1.028 (1.017,1.040)	85
Lag pattern																		
Lag ≤2days	49	1.007 (1.004,1.011)	82	32	1.036 (1.018,1.055)	78	44	1.013 (1.009,1.014)	70	48	1.008 (1.004,1.013)	73	35	1.008 (1.005,1.010)	67	27	1.021 (1.011,1.031)	83
Lag >2days	23	1.010 (1.006,1.013)	90	11	1.082 (1.042,1.122)	92	22	1.028 (1.019,1.036)	92	17	1.022 (1.012,1.032)	79	16	1.016 (1.012,1.020)	4	10	1.031 (1.012,1.050)	78

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Mechanisms of air pollutants on eliciting asthma exacerbations

The observed effects of the six major air pollutants on asthma ERVs/hospitalization are biologically plausible. The major mechanisms of individual air pollutants responsible for triggering asthma exacerbations are as follows:

** NO_2 and ozone have been implicated in eliciting lipid peroxidation of the cell membranes and the generation of various free radicals which collectively impair the structure and function of the asthmatic airways [101]. Furthermore, exposure to ozone and (or) NO_2 can also promote the release of inflammatory mediators (i.e. interleukin-8, granulocyte macrophage-colony stimulating factor [102],

** SO_2, a well-known inorganic chemical irritant, has been demonstrated to promote airway inflammation (increased levels of tumor growth factor-β in bronchoalveolar fluids) and eosinophilia, induce bronchospasm and airway fibrosis (a factor potentially leading to increased airway responsiveness) in asthma [103].

** Particulate matters harbor a more complex impact on asthmatic airways, since their deposition in the airways directly elicited airway inflammation, mucosal edema and cytotoxicity [104]. The convergence of regulatory signals generated by particulate matter-induced oxidative stress in dendritic cells and their interactions may also be responsible for asthma exacerbations [105]. Furthermore, the defective airway macrophage phagocytosis, resulting from increased prostaglandin E_2 levels, could have augmented the adverse effects of inhaled carbonaceous particulate matters on eliciting exacerbations [106].

** The direct association between CO and asthma is unfortunately less clearer [29,107]. It is plausible that CO might act as a surrogate of other noxious gases which are derived from incompletely combusted products. Moreover, CO seemed to confer greater adverse impacts on asthmatic children because of their immature lung development.

Interpretation

Most studies were limited at all age intervals, which constituted an important effect modifier [52]. In keeping with literature reports [16,24,30,38,57], we further confirmed that children and elderly people were more susceptible to asthma exacerbations. A plausible interpretation could be that children harbor immature lung growth and host-defense capacity and that, in elderly individuals, air pollution amplifies inflammatory responses of remodeled airways.

To date, effect modification by sex has not been well established [5,7,37–38,40,50,68]. The higher rate of asthma-related hospitalizations and ERVs in males could not justify the sex-related susceptibility, since the exposures (outdoor occupations, social activities) and biologic characteristics (i.e. hormonal levels, lung size and growth and airway inflammation) are different. Furthermore, greater effects of ozone on females were consistent with those in a previous report [108].

If the additive effects of air pollution were season-independent, then the PAFs and RRs would be higher during warm seasons because of fewer competing pollutants. However, unlike other pollutants, the association of ozone (a component of "photochemical cocktail" which is typically a warm-season pollutant [24,27,31–32,52,54,76,78,82,87]) and asthma exacerbations was similar between the warm and cold seasons. Unfortunately, the variability of temperature adjustment approaches and the lack of information regarding solar radiation and brightness have constrained our analyses in determining the seasonal modifications. Furthermore, limiting the analysis to the above-mentioned confounders might have minimized the number of eligible studies, possibly resulting in inaccurate conclusions.

Clinical significance

Despite the weak associations between air pollution and asthma exacerbations, the effects of air pollution were globally considerable because the RRs and percentage increase were derived from large cohorts in time-series studies, reflecting significant healthcare utilization, immense social and economical burden. Despite that the high PAFs for outdoor air pollution was essentially imputed from the prevalence of exposure of 100%, this assumption may still be reasonable, since epidemiological studies generally assigned outdoor average level to all individuals. Furthermore, we quantified asthma risk according to the changes in air pollution, since asthma-related ERVs/hospitalizations and the changes in air pollutant concentrations would assume a linear correlation, and hence, no positive threshold [109] could be established.

Limitations

First, the differences between ERVs and hospitalizations did have certain impacts on their utility for quantifying the observed associations with air pollution in subgroup analysis. However, a high degree of heterogeneity could be observed in analyses of all strata, including hospital admissions and ERVs. This might be linked to the various study design quality, inclusion criteria, analytic strategies and lag patterns. Heterogeneities were reduced dramatically among studies with a common analytic strategy (most commonly used lag patterns) or standardized protocol (study quality >5), highlighting the importance of standardized study protocol with the most appropriate lag.

Second, we did not analyze the association between air pollutants and other systemic diseases, therefore the multi-faceted adverse effects of air pollution could have been markedly diluted. Lower levels of air pollutants reportedly led to attenuated asthma symptoms [110–111], airway inflammation [112], lung function improvement [112] and less healthcare utilization and access to medications [113], confirming the roles of air pollution on eliciting asthma exacerbations.

Third, the coefficients from "single-pollutant" model were utilized despite potential interactions among different air pollutants. Regarding that the lack of crystal-clear exposure-asthma relationships hampered selection of additive or multiplicative model, and that a large number of complex parameters rendered the ideal 'multivariate' meta-analysis computationally impractical [114], we therefore independently analyzed the effects of individual pollutants [15, 17–18, 115].

Finally, the methodologies of lag selection remain controversial. Any particular lag selection would have excluded a considerable number of studies. In this study, we chose the most frequently used short lags (lag0, lag1 or lag0-1), since longer lags have been less consistently reported in previous literature and harbored a significant heterogeneity in our pooled analysis.

Practical implications

Our findings has called for the implementation of more stringent regulations on the traffic and industry, including the utilization of environmental-friendly fuels (i.e. liquid natural gas, diesel derived from biomass fuels, hydrogen gas), engines or techniques (such as hybrid vehicles, purely electric motors), and the utilization of filters or absorbers of noxious gases before release into the atmosphere, and the upgrading of traditional industrial facilities (i.e. cement production). The development of fine particle separating facial masks or intranasal gel might be useful for the patients who have difficulty in avoiding direct exposure to exposure, particularly at the workplace. The levels of air pollutants should also be incorporated into weather forecasts so as to issue alerts to population at risk, thus facilitating administration of preventative medications.

Conclusion

Short-term exposure to air pollutants confers an increased risk of asthma-related ERVs and hospital admissions. Our findings call for greater awareness of environmental protection and the implementation of effective measures to improve the quality of air, which may reduce the risks of adverse effects on the population's health. However, the effects need to be interpreted cautiously since longer lags are essential in time-series studies to better determine the effects of outdoor air pollution on asthma outcomes.

Supporting Information

S1 Fig. Funnel plots of the relative risks of ERVs/hospital admissions for asthma in relation to six air pollutants in the overall analyses and sensitivity analyses (studies with a score of 5). Fig A. Funnel plot of the relative risks of ERVs/hospital admissions for asthma in relation to CO in the overall analyses; Fig B. Funnel plot of the relative risks of ERVs/hospital admissions for asthma in relation to NO_2 in the overall analyses; Fig C. Funnel plot of the relative risks of ERVs/hospital admissions for asthma in relation to ozone in the overall analyses; Fig D. Funnel plot of the relative risks of ERVs/hospital admissions for asthma in relation to $PM_{2.5}$ in the overall analyses; Fig E. Funnel plot of the relative risks of ERVs/hospital admissions for asthma in relation to PM_{10} in the overall analyses; Fig F. Funnel plot of the relative risks of ERVs/hospital admissions for asthma in relation to SO_2 in the overall analyses; Fig G. Funnel plot of the relative risks of ERVs/hospital admissions for asthma in relation to CO in the sensitivity analyses regarding studies with a score of 5; Fig H. Funnel plot of the relative risks of ERVs/hospital admissions for asthma in relation to NO_2 in the sensitivity analyses regarding studies with a score of 5; Fig I. Funnel plot of the relative risks of ERVs/hospital admissions for asthma in relation to ozone in the sensitivity analyses regarding studies with a score of 5; Fig J. Funnel plot of the relative risks of ERVs/hospital admissions for asthma in relation to $PM_{2.5}$ in the sensitivity analyses regarding studies with a score of 5; Fig K. Funnel plot of the relative risks of ERVs/hospital admissions for asthma in relation to PM_{10} in the sensitivity analyses regarding studies with a score of 5; Fig L. Funnel plot of the relative risks of ERVs/hospital admissions for asthma in relation to SO_2 in the sensitivity analyses regarding studies with a score of 5.
(EPS)

S1 File. PRISMA checklist.
(DOC)

S2 File. The database of the association between six air pollutants and ERVs/hospital admissions for asthma in overall analyses (in Excel form).
(XLS)

S1 Table. Search strategies and main characteristics of all included studies.
(DOC)

Author Contributions

Conceived and designed the experiments: XYZ WJG JPZ QC. Performed the experiments: XYZ HD LNJ SWC. Analyzed the data: XYZ MQ YXZ. Wrote the paper: XYZ WJG. Provided critical review of the manuscript and approved the final submission: WJG QC.

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CA Exhibit 17

6.6-Hour Inhalation of Ozone Concentrations from 60 to 87 Parts per Billion in Healthy Humans

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***Rationale*: Identification of the minimal ozone (O_3) concentration and/or dose that induces measurable lung function decrements in humans is considered in the risk assessment leading to establishing an appropriate National Ambient Air Quality Standard for O_3 that protects public health.**

***Objectives*: To identify and/or predict the minimal mean O_3 concentration that produces a decrement in FEV_1 and symptoms in healthy individuals completing 6.6-hour exposure protocols.**

***Methods*: Pulmonary function and subjective symptoms were measured in 31 healthy adults (18–25 yr, male and female, nonsmokers) who completed five 6.6-hour chamber exposures: filtered air and four variable hourly patterns with mean O_3 concentrations of 60, 70, 80, and 87 parts per billion (ppb).**

***Measurements and Main Results*: Compared with filtered air, statistically significant decrements in FEV_1 and increases in total subjective symptoms scores ($P < 0.05$) were measured after exposure to mean concentrations of 70, 80, and 87 ppb O_3. The mean percent change in FEV_1 ($\pm$standard error) at the end of each protocol was 0.80 ± 0.90, -2.72 ± 1.48, -5.34 ± 1.42, -7.02 ± 1.60, and -11.42 ± 2.20% for exposure to filtered air and 60, 70, 80, and 87 ppb O_3, respectively.**

***Conclusions*: Inhalation of 70 ppb O_3 for 6.6 hours, a concentration below the current 8-hour National Ambient Air Quality Standard of 75 ppb, is sufficient to induce statistically significant decrements in FEV_1 in healthy young adults.**

Keywords: ozone; clinical study; exposure assessment; human

AT A GLANCE COMMENTARY

Scientific Knowledge on the Subject

The acute inhalation of ambient concentrations of ozone induces several health effects including airway irritation and inflammation, decrements in pulmonary function, and symptoms of respiratory discomfort.

What This Study Adds to the Field

This study identifies 70 ppb as the mean concentration of ozone averaged over 6.6 hours that results in a statistically significant decrement in FEV_1 and presents an empirically validated model that predicts the onset of pulmonary responses induced by any combination of ozone concentration, minute ventilation, and exposure duration.

Ozone is the primary oxidant found in photochemical air pollution and is one of the six criteria air pollutants identified in the 1971 United States Clean Air Act as adversely affecting public health. Human clinical exposure studies have played an important role in the risk assessment required to set the National Ambient Air Quality Standard (NAAQS) for ozone. These clinical exposure studies have been designed to expose defined subpopulations of individuals while varying ozone concentrations, exposure duration, and minute ventilations. A central question inherent in these studies has been as follows: What is the minimal mean ozone concentration that produces a statistically significant decrement in FEV_1 and other markers of response?

Early clinical studies focused on manipulating ozone concentration and/or minute ventilation ($\dot{V}\mathrm{E}$) by adjusting exercise workloads, while limiting the duration of exposure to 2.5 hours or less (1–4). The minimal mean ozone concentration that produced a statistically significant decrement in FEV_1 in healthy male subjects in these early studies was shown to be 120 ppb using a 2.5-hour protocol and heavy intermittent exercise (15-min periods of rest and exercise with exercise $\dot{V}\mathrm{E}$ of 65 L/min) (3) and 300 ppb using a 1-hour protocol and heavy continuous exercise (exercise $\dot{V}\mathrm{E}$ of 66 L/min) (4). Subsequently, Schelegle and Adams (5) observed a statistically significant decrement in FEV_1 in endurance athletes who completed a 1-hour competitive simulation (mean $\dot{V}\mathrm{E}$ of 86.6 L/min) while breathing 180 ppb ozone. More recently several investigators have extended exposure duration to 6.6 hours, using a protocol initially described by Folinsbee and colleagues (6). This protocol contains six 50-minute exercise periods with minute ventilation maintained at 8 L/min/L of FVC ($\dot{V}\mathrm{E}$ of approximately 40 L/min). As noted by Folinsbee and colleagues (6) and McDonnell and colleagues (7), this level of exertion was "intended to simulate work performed during a day of heavy to severe manual labor in outdoor laborers." Folinsbee and colleagues (6), Horstman and colleagues (8), and Adams (9, 10) have used this 6.6-hour protocol to examine ozone-induced responses in healthy young adults exposed to ozone concentrations ranging from 40 to 120 ppb. Of these, the studies conducted by Adams (9–11) have played an important role in the 2007 exposure/risk assessment conducted by the United States Environmental Protection Agency and the establishment of a new NAAQS for ozone in 2008. Adams (9) observed statistically significant FEV_1 decrements and respiratory symptoms at 80 ppb. Although lung function decrements and respiratory symptoms in the 60 ppb ozone protocols were not statistically significant, the magnitude of the pulmonary function decrements at 60 ppb ozone at 40 L/minute were consistent with the trend observed at higher levels and some subjects had "notable" FEV_1 decrements (i.e., >10% FEV_1) at 60 ppb.

The current study further examines the minimal mean ozone concentration that produces a statistically significant decrement in FEV_1 and symptoms in healthy individuals completing five 6.6-hour exposure protocols with variable ozone concentration

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profiles. In addition, the variable ozone concentration profiles were specifically designed to examine the relative importance of mean ozone concentration over the entire exposure period versus peak dose rate in determining peak pulmonary function decrements and symptoms during and after exposure. This was accomplished by adjusting the mean and peak ozone concentrations for each exposure protocol. The mean ozone concentrations of the five protocols were 0, 60, 70, 80, and 87 ppb. Each of the four stepwise ozone concentration profiles (60, 70, 80, and 87 ppb ozone) had peak ozone concentrations in the fourth hour of exposure with peaks of 90, 90, 150, and 120 ppb, respectively. The dose of onset (Dos) of ozone-induced decrements in FEV_1 was derived from the combined individual subject FEV_1 and cumulative dose data, using an iterative process involving least-squares linear regression analysis (12). The derived value of Dos that represents the cumulative dose of ozone at which approximately half the subjects have developed pulmonary responses and half have not was then combined with other published (12) values of Dos to predict the onset of ozone-induced pulmonary responses in the healthy young subjects at multiple combinations of ozone concentration, exposure duration, and minute ventilations. The results of this study have been previously reported in the form of an abstract (13).

METHODS

Subject Recruitment

Thirty-one young adults (16 females and 15 males), ages 18–25 years, participated in the study. Subjects were solicited volunteers from the University of California, Davis, or surrounding community. Each subject was informed of study risks and subsequently signed a consent form approved by the Institutional Human Subjects Review Board (IRB) of the University of California, Davis. Individuals with a history of cardiovascular disease or respiratory ailments (i.e., asthma, seasonal allergies) were not allowed to participate in the study. Subjects were nonsmokers and did not live in a high air pollution area 6 months before participation in the study. All subjects were engaged in a regular program of aerobic training to ensure their ability to complete the exercise protocols. All subjects underwent preexperimental screening to determine normal pulmonary function (Table 1) and filled out a general health questionnaire, both of which were reviewed by the project physician before being included in the study. In addition, female subjects were asked to perform a urine pregnancy test to make sure they were not pregnant at the time of enrollment.

Experimental Design

All exposures were performed in a free-standing 9 × 10 × 8 ft stainless steel environmental chamber (model 1328-M; Vista Scientific, Ivyland, PA). The chamber and its operation have been previously described by Adams (9). The five 6.6-hour chamber exposures completed by each subject were composed of six 50-minute exercise bouts at a mean equivalent ventilation rate of 20 L/minute/m^2 body surface area (BSA) (9). The 50-minute exercise bouts were done alternately on a cycle ergometer and treadmill. A 35-minute lunch break took place after completion of Hour 3 and was taken at rest in the chamber at the Hour 3 O_3 concentration. Temperature and relative humidity were maintained between 21 and 25°C and between 40 and 60%, respectively. The exposure regimens were composed of filtered air and four varying hourly O_3 concentrations averaging 60, 70, 80, and 87 ppb. The stepwise patterns of O_3 concentration are given in Table 2. Ozone concentration was monitored continuously with a Dasibi monitor (model 1003H; Dasibi Instruments Inc, Glendale, CA) calibrated according to the ultraviolet absorption photometric method, traceable to a National Institute of Standards and Technology standard photometer, at the Primate Research Center of the University of California, Davis. The protocols were conducted in single-blind fashion and completed by each subject in random order, with a minimum of 7 days intervening between protocols.

Subjects performed two to four forced expiratory maneuvers immediately before and after each experimental exposure, during the last 10 minutes of each hour and at 1 and 4 hours postexposure, using a portable computer-based spirometer (SpiroVision-3; FUTUREMED Inc., Granada Hills, CA). The FVC and FEV_1 values were selected on the basis of American Thoracic Society guidelines (14).

Minute ventilation ($\dot{V}_E$), tidal volume (V_T), breathing frequency (f), expired gas temperature, heart rate, and subjective symptoms were monitored as previously described (9). Subjects were asked to rate the severity of each of four symptoms: throat tickle, cough, shortness of breath, and pain on deep inspiration. Each symptom was rated according to a severity scale (ranging from 0, not present, to 40, severe) as previously described (15). Total subjective symptoms (TSS) score was calculated as the sum of the severity ratings for the four individual symptoms.

Statistical Procedures

The effect of exposure on FVC, FEV_1, and FEV_1/FVC was expressed as the percent change from the preexposure value. Similarly, f, V_T, and $\dot{V}_E$ are presented as percent change from the initial value obtained at 7–10 minutes of the first exercise period. TSS was analyzed as absolute changes from zero. All data are expressed as means (standard error). The effects of gas concentration and exposure time were determined by mixed model two-way analysis of variance (ANOVA) with repeated measures ($P < 0.05$) (SAS software; SAS Institute, Cary, NC), using

TABLE 1. FEMALE AND MALE SUBJECT PHYSICAL CHARACTERISTICS AND BASELINE PULMONARY FUNCTION MEASURES

Characteristic	Females (*n* = *16*)	Males (*n* = *15*)
Age, yr	21.4 (0.6)	21.4 (0.5)
Height, m	1.68 (0.02)	1.82 (0.02)
Weight, kg	65.1 (2.8)	81.0 (2.8)
BSA, m^2	1.73 (0.05)	2.04 (0.04)
FVC, L	4.16 (0.19)	5.72 (0.19)
FEV_1, L	3.43 (0.13)	4.67 (0.18)
FEV_1/FVC, %	82.8 (1.9)	81.7 (1.5)
$FEF_{25–75}$, L/s	3.35 (0.15)	4.48 (0.29)
PEF, L/s	7.04 (0.17)	9.96 (0.46)

Definition of abbreviations: BSA = body surface area; $FEF_{25–75}$ = forced expiratory flow between 25 and 75% FVC; PEF = peak expiratory flow.

Values represent means (SE).

TABLE 2. TARGET AND ACTUAL MEAN OZONE CONCENTRATIONS EXPRESSED AS PARTS PER BILLION FOR THE FIVE 6.6-HOUR EXPOSURE PROTOCOLS

		Exercise Period						
Protocol	Target/ Actual	1	2	3	4	5	6	Mean
FA	Target	0	0	0	0	0	0	0
	Actual	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)
60 ppb[†]	Target	40	70	70	90	50	40	60
	Actual	43 (1)	72 (1)	73 (1)	91 (1)	54 (1)	42 (1)	63 (1)
70 ppb[‡]	Target	50	70	80	90	80	50	70
	Actual	52 (1)	73 (1)	82 (1)	92 (0)	81 (1)	54 (1)	72 (1)
80 ppb[§]	Target	30	70	100	150	80	50	80
	Actual	33 (1)	71 (1)	101 (1)	147 (1)	84 (1)	52 (1)	81 (1)
87 ppb[‖]	Target	40	80	90	120	100	90	87
	Actual	42 (1)	81 (1)	93 (1)	119 (1)	102 (1)	91 (1)	88 (1)

Definition of abbreviation: FA = filtered air.

Actual values represent means (SE); n = 31.

[†] Pattern is modified from Adams (9), with the ozone concentration in the third and fourth exercise period switched.

[‡] Daily pattern observed in Little Rock, Arkansas metropolitan area (A. Lefohn, personal communication).

[§] Pattern is the Adams (9) stepwise 80 ppb protocol and provides a means of direct comparison with previous published findings.

[‖] Daily pattern observed in San Bernardino, California metropolitan area (A. Lefohn, personal communication).

the procedures described by Littell and colleagues (16). There are two steps in performing a mixed model two-way ANOVA with repeated measures (16). In the first step we determined the best fit of the data to one of several within-subject covariance structures using the Akaike information criterion (AIC) and the Schwarz Bayesian criterion (SBC). After fitting the data to unstructured, Toeplitz, compound symmetry, heterogeneous compound symmetry, heterogeneous first-order autoregressive, first-order autoregressive, and heterogeneous covariance structures both the AIC and SBC indicated that the Toeplitz covariance structure provided the best fit to the data. In the second step we analyzed the time and protocol effects by estimating and comparing means, initially using least-squares means and then using a Tukey adjustment (SAS Institute).

Having analyzed the data in a manner that allowed for the evaluation of the time and mean concentration effects we reanalyzed the data, focusing on the effect that each protocol had on the immediate postexposure FEV_1 compared with the filtered air protocol. To make this comparison we used both parametric and nonparametric tests. The parametric analysis followed the same procedures as those used for the whole data set described previously, except that a Dunnett's adjustment was used to compare means. The Dunnett's test limits the number of comparisons to those between the control group (in this case the filtered air protocol) and each experimental protocol. The nonparametric approach used the Friedman test, which is the nonparametric equivalent of a repeated measures ANOVA on ranks, with post hoc comparisons of mean ranks using Dunnett's test (17).

To further examine the time course of the FEV_1 response we identified the dose of onset (Dos), using a regression approach similar to the one we previously described and applied to breathing pattern data (12). In brief, we plotted the percent change in FEV_1, corrected for filtered air (FA) responses, for all the subjects combined against the cumulative dose of O_3 (micrograms) for each exposure protocol. Dos was determined by an iterative process involving least-squares linear regression (Microsoft Excel X; Microsoft Corporation, Redmond, WA). In each iteration step two lines were fit to the percent change in FEV_1 and cumulative dose. In the first iteration the first region (region 1) of the data that was fit included the first 31 data points. The second region (region 2) that was fit began at the 32nd point and included all the cumulative dose points greater than this to the end of the protocol. In the next iteration a point was added to region 1 and subtracted from region 2. This iterative process was continued until region 2 consisted of the data from the last 31 points. With each iteration step the slope, intercept, and correlation coefficient were calculated for each region. In addition, the difference in slope of regions 1 and 2, and the average correlation coefficient of regions 1 and 2, were calculated. The point at which the maximum in the correlation coefficient of region 1, the average correlation coefficient of regions 1 and 2, and the difference in slopes of region 1 and 2 occurred was determined and averaged to obtain the estimated Dos.

RESULTS

A summary of the male and female subjects' characterization data is given in Table 1. All the subjects were engaged in some form of regular aerobic activity. One male subject was a competitive cyclist at the time of the study. All the subjects were healthy and had normal pulmonary functions, with the baseline value of $FEV_1/FVC\%$ ranging from 69.8 to 96.2%.

The group mean exercise $\dot{V}_E$ and estimated overall mean $\dot{V}_E$ (includes estimated resting $\dot{V}_E$ [18]) values for the five 6.6-hour protocols are given in Table 3. Resting $\dot{V}_E$ was estimated using regression equations derived from the data of Aitken and colleagues (18) that relate resting $\dot{V}_E$ to body surface area for college-age males [resting $\dot{V}_E = 7.61(BSA)$] and females [resting $\dot{V}_E = 8.05(BSA)$]. There were no statistically significant differences in exercise $\dot{V}_E$ with regard to time of exposure or protocol. In addition, there was no statistically significant difference in the estimated overall mean $\dot{V}_E$ for the five protocols.

TABLE 3. GROUP MEAN EXERCISE MINUTE VENTILATION AND ESTIMATED OVERALL MINUTE VENTILATION* FOR THE FIVE EXPOSURE PROTOCOLS

	$\dot{V}_E$	
Protocol	Exercise	Estimated Overall
FA	39.3 (0.9)	33.4 (0.8)
60 ppb	38.5 (0.9)	32.8 (0.7)
70 ppb	38.6 (1.0)	32.8 (0.8)
80 ppb	38.9 (1.0)	33.1 (0.8)
87 ppb	38.4 (0.9)	32.7 (0.7)

Definition of abbreviation: $\dot{V}_E$ = minute ventilation.
Values represent means (SE).
* Inclusive of rest and lunch periods.

The group mean ozone concentrations during each exercise period, as well as the average ozone concentration for each protocol, are given in Table 2, whereas the mean cumulative inhaled dose (CD, µg) of ozone is plotted against time of exposure in Figure 1. The ozone concentrations (ppb) during each exercise period for all four ozone protocols were significantly greater than the background levels measured in the FA protocol. Comparing across protocols, whenever the target ozone concentration was set to be different compared with any other protocol the measured values for this comparison were found to be significantly different. The inhaled dose rate (DR, µg/min) during each exercise period for all four ozone protocols was significantly greater than the background levels measured in the FA protocol. In contrast to ozone concentration the DR during each exercise period was significantly different across ozone protocols only when the difference in the target ozone concentration was greater than or equal to 20 ppb. All possible comparisons of CD at the end of each protocol were significant different. However, the time during exposure at which the CD became significantly different between ozone protocols varied (Figure 1). The CD for the 60 ppb exposure protocol became significantly different from the 70, 80, and 87 ppb ozone exposure protocols during the fifth, fourth, and third exercise periods, respectively. The CD for the 70 ppb exposure protocol became significantly different from the 80 and 87 ppb ozone exposure protocols during the fourth exercise period. The CD for the 80 ppb exposure protocol became significantly different from the 87 ppb ozone exposure protocol during the fifth exercise period.

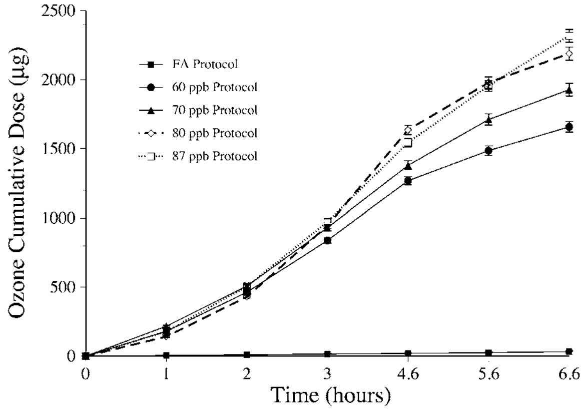

Figure 1. Diagram of mean group values for cumulative dose of ozone (micrograms) against time of exposure for each of the five protocols. Values represent means ± SEM.

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Pulmonary Function and Symptom Responses

The mean responses for the percent change in FVC, percent change in FEV$_1$, percent change in FEV$_1$/FVC%, and TSS are shown in Figure 2. In comparison with the FA protocol statistically significant decrements in the percent change in FVC were present after the fourth and sixth exercise periods of the 80 ppb protocol and after the fifth and sixth exercise periods and 1 hour postexposure of the 87 ppb protocol (Figure 2A). In comparison with the FA protocol the 70, 80, and 87 ppb exposure protocols resulted in statistically significant decrements in the percent change in FEV$_1$ (Figure 2B). These statistically significant differences occurred after the sixth exercise period in the 70 ppb protocol; after the fourth, fifth, and sixth exercise periods and 1 hour postexposure of the 80 ppb protocol; and after the fifth and sixth exercise periods and 1 hour postexposure of the 87 ppb protocol. In comparison with the FA protocol, statistically significant decrements in the percent change in FEV$_1$/FVC% were present only after the fifth and sixth exercise periods of the 87 ppb protocol (Figure 2C). In comparison with the FA protocol the 70, 80, and 87 ppb exposure protocols resulted in statistically significant increases in TSS (Figure 2D). In each of these three exposure protocols the statistically significant increases in TSS occurred after the fifth and sixth exercise periods. In all the protocols pulmonary function and symptoms returned to preexposure levels within 4 hours of the end of exposure.

In comparison with the FA protocol the inhalation of ozone during the 60 ppb protocol did not result in a statistically significant decrement in percent change in FVC, percent change in FEV$_1$, percent change in FEV$_1$/FVC, or TSS at any time point. Examination of the percent change in FEV$_1$ shows that the maximal difference between the FA and 60 ppb protocol occurred after the sixth exercise period (Figure 2B). The magnitude of this difference was 3.52 ± 1.52% (mean ± SE) and was the result of 11 subjects who had FEV$_1$ decrements greater than 5% compared with the FA protocol (11.42 ± 2.62%). To increase the power of our analysis we limited the number of mean comparisons and narrowed the hypothesis being tested by restricting our analysis to immediate postexposure FEV$_1$ data and only comparing each ozone protocol with the filtered air protocol. In addition, we used both parametric and nonparametric tests in this restricted analysis. The distribution of the percent change in FEV$_1$ at 6.6 hours for each protocol is illustrated using histograms in Figure 3. While increasing the power of the analysis both parametric and nonparametric tests provided the same result as the more global two-way ANOVA with repeated measures (Table 4).

Dose at Onset

We were able to obtain reliable estimates of Dos, using the pooled FEV$_1$ from the 80 and 87 ppb ozone exposure protocols and when all of the FEV$_1$ data was combined, but not from the

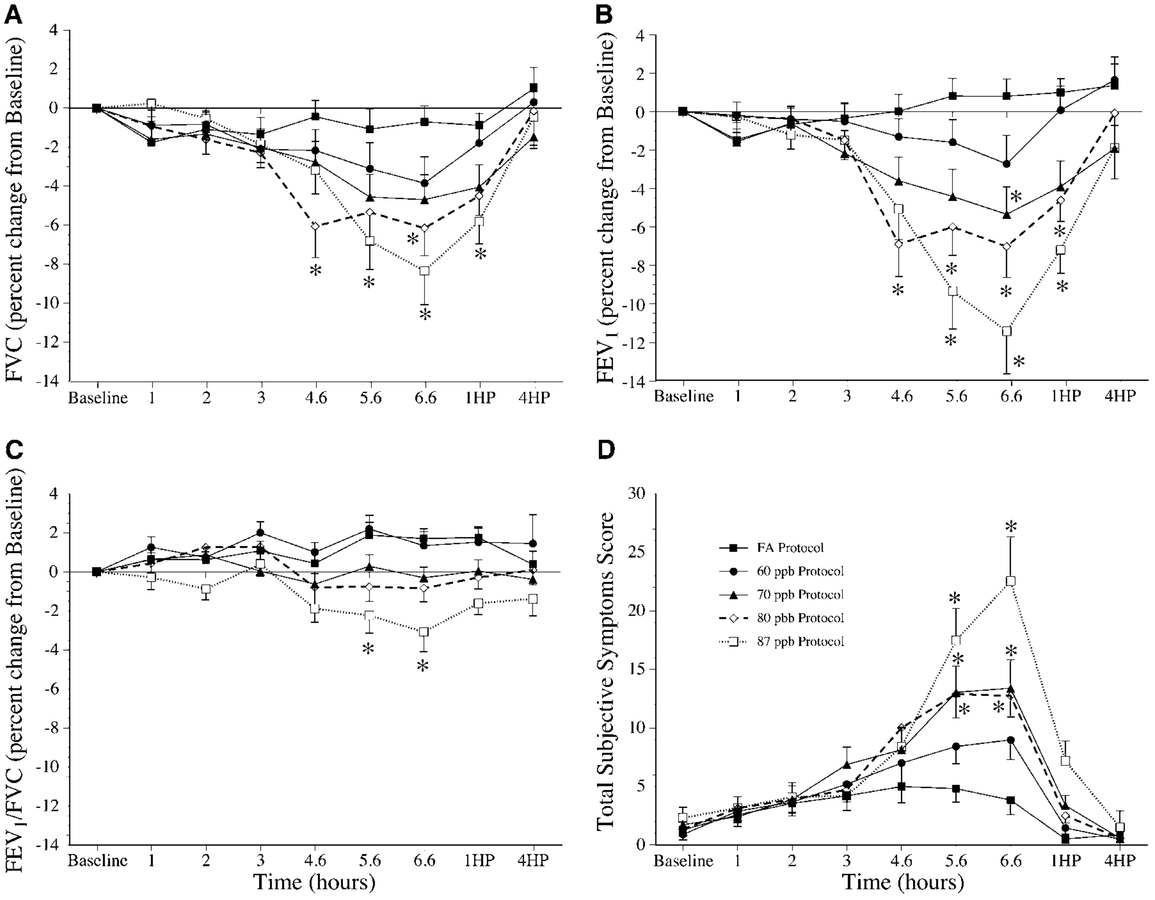

Figure 2. Mean responses of 31 healthy young adult subjects to various time–concentration profiles during, and 1 and 4 hours after, 6.6-hour ozone exposure. (*A*) FVC; (*B*) FEV$_1$; (*C*) FEV$_1$/FVC, all percent change from baseline; and (*D*) total subjective symptoms scores. *Asterisks* indicate a statistically significant difference from filtered air (FA) at the same time point. *Note:* Only a portion of the subjects completed the 4-hour postexposure measurements: FA (n = 17); 60 ppb (n = 15); 70 ppb (n = 15); 80 ppb (n = 15); and 87 ppb (n = 13). Values represent means ± standard error of the mean.

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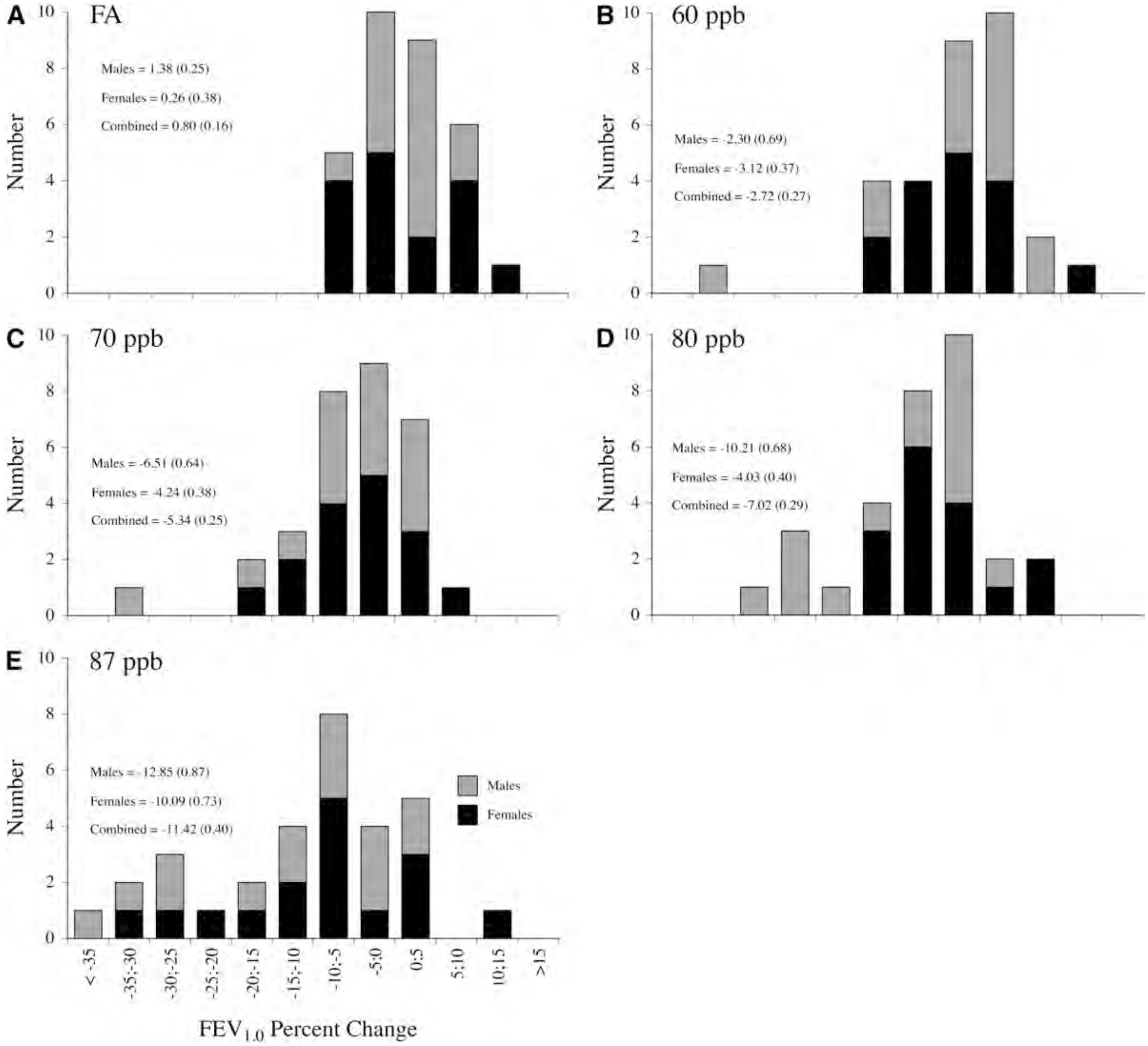

Figure 3. Histograms of percent change in FEV_1 after 6.6-hour exposure to (*A*) filtered air, (*B*) 60 ppb O_3, (*C*) 70 ppb O_3, (*D*) 80 ppb O_3, and (*E*) 87 ppb O_3 for both female subjects (*solid column portions*) and male subjects (*shaded column portions*). Values represent means (SEM).

pooled FEV_1 data from the 60 and 70 ppb ozone exposure protocols. The inability to estimate Dos using the FEV_1 data from the 60 and 70 ppb ozone exposure protocols is most likely because less than one third of the subjects had changes in FEV_1 greater than 5% in either of these protocols. The estimated values of Dos from the 80 and 87 ppb ozone exposure protocols are 1,374 and 1,326 μg of ozone, respectively. The estimated value of Dos from all of the FEV_1 data combined was 1,362 μg of ozone.

TABLE 4. PROBABILITY VALUES OBTAINED BY THREE STATISTICAL APPROACHES TO ANALYZE FEV_1 RESPONSE AFTER FOUR 6.6-HOUR EXPOSURE PROTOCOLS COMPARED WITH FILTERED AIR

	Statistical Test		
Comparison	Two-way ANOVA with Tukey-Kramer	One-way ANOVA with Dunnett's Test	Friedman's Test with Dunnett's Test
FA vs. 60 ppb	0.8	0.2	>0.05
FA vs. 70 ppb	0.0016	0.0023	<0.01
FA vs. 80 ppb	<0.0001	0.0002	<0.001
FA vs. 87 ppb	<0.0001	<0.0001	<0.0001

Definition of abbreviation: ANOVA = analysis of variance.

DISCUSSION

The U.S. Clean Air Act defines a primary air quality standard to protect the public health, while allowing for an adequate margin of safety. An Ozone NAAQS was first established on April 30, 1971 and subsequently reviewed and revised in 1979, 1997, and 2008. The NAAQS for ozone established in 1971 and 1979 were based on a peak 1-hour average. Subsequently, in 1997, in an effort to address the broad multiple-hour elevations seen in ambient ozone concentration in some urban and suburban environments, the NAAQS for ozone was revised to an 8-hour average concentration of 0.08 ppm for the fourth highest average over 3 years. More recently the NAAQS for ozone was revised to an 8-hour average concentration of 0.075 ppm for the fourth highest average over 3 years. In the current study the mean 6.6-hour ozone concentration of the four ozone protocols brackets the current NAAQS. We observed statistically significant decrements in FEV_1 and TSS associated with the 70, 80, and 87 ppb protocols, but not the 60 ppb protocol. In addition, there were statistically significant decrements in FVC in the 80 and 87 ppb protocols and in FEV_1/FVC in the 87 ppb protocol. These findings lower the mean ozone concentration at which statistically significant decrements in FEV_1 have been observed during a 6.6-hour exposure protocol to 70 ppb.

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These findings are consistent with the results of Adams (9), who reported statistically significant decrements in FEV_1 using a 6.6-hour protocol with a mean ozone concentration of 80 ppb, but not 40 or 60 ppb. Adams (9) obtained the same result while using both constant ozone concentrations of either 60 or 80 ppb over the exposure period, and variable stepwise ozone concentration profiles similar but not identical to those used in the current study. There has been some concern expressed in the literature (19) that the univariate two-way ANOVA with repeated measures followed by Scheffé's post hoc test used by Adams in 2006 (9) indicating no statistically significant effect on FEV_1 in the 60 ppb protocols lacked sufficient statistical power to guarantee that this finding did not represent a false negative (type II error). It has been suggested that limiting the analysis to the immediate postexposure FEV_1 data and restricting the mean comparisons to the filtered air control would increase the power of the analysis and allow for the detection of significant differences when differences between means are small (18). We recognize the validity of this suggestion and agree that limiting the scope of the hypothesis being tested can increase the power of the statistical approach; however, we also recognize that when doing so caution should be exercised to ensure that the approach used is consistent with the original study design. In this case the individual subject FEV_1 responses induced by each exposure protocol are not independent and therefore any analysis should consider the effect of multiple comparisons. To address these concerns in the current paper we analyzed our data using a mixed-model two-way ANOVA with repeated measures followed by Tukey's post hoc test and then analyzed the immediate postexposure FEV_1 data using both parametric and nonparametric approaches. The mixed-model two-way ANOVA with repeated measures followed by Tukey's post hoc test provides the ability to directly address the covariance structure of the data and greatly enhances the ability to analyze repeated measures data by providing valid standard errors and efficient and powerful comparisons of means within a global analysis (16). This greatly improves the ability to examine time effects within protocols and protocol effects at multiple time points. Our analysis of the immediate postexposure FEV_1 data using both parametric and nonparametric statistics, while correcting for the inherent multiple comparisons in the original study design, optimized the power of the analysis by limiting the mean comparisons to those between the filtered air protocol and the 60, 70, 80, and 87 ppb exposure protocols. Furthermore, we also used a nonparametric statistic that is appropriate if the within-subject variance is not normally distributed (17). We obtain a similar result regardless of our statistical method, with the 60 ppb exposure protocol not being significantly different from filtered air, whereas the 70, 80, and 87 ppb exposure protocols were significantly different from filtered air. Although recognizing the consistency of our statistical analyses we point out, as did Adams (11), that there is a subset of responsive subjects that did respond to the 60 ppb protocol in excess of a 10% decrement in FEV_1. In addition, it is important to note that the previous study conducted by Adams (11) and the current study use a 6.6-hour protocol, which is 1.4 hours less than the 8-hour NAAQS and that if the 60 ppb ozone protocols were extended greater decrements might be achieved. A counterpoint to this possibility is the fact the mean overall ventilations in Adams (9) and this study are equal to or greater than mean ventilations that might be encountered during a day of heavy to severe manual labor among the construction workers observed by Linn and colleagues (20) and that this represents the higher end of ventilations that might be encountered in the normal population for this prolonged period.

In the current study, the variable stepwise profile of ozone concentration differed from protocol to protocol in such a way that the peak ozone concentration did not correlate with the mean ozone concentration over the entire protocol (Table 2). The clearest example of this and the one with demonstrated consequences are the 80 and 87 ppb protocols in which the peak 1 hour (4.6 to 5.6 h) values were 150 and 120 ppb ozone, respectively. The 80 ppb protocol also started and ended at a lower ozone concentration (30 and 50 ppb ozone) than the 87 ppb protocol (40 and 90 ppb ozone). The net result was that the cumulative dose for these two protocols did not become significantly different from each other until the final hour of exposure (*see* Figure 1), with the dose rate becoming significantly greater in the 80 ppb protocol during the fourth exercise period and then becoming significantly less during the fifth and sixth exercise periods. This pattern of exposure resulted in decrements in FEV_1 becoming statistically significant 1 hour earlier (4.6 vs. 5.6 h) in the 80 ppb protocol compared with the 87 ppb protocol (Figure 2B). This pattern then resulted in a plateau in FEV_1 decrements in the 80 ppb protocol, whereas FEV_1 decrements continued to increase in the 87 ppb protocol (Figure 2B). These observations, in combination with a delay in onset of response of approximately 3 hours (Figure 2) in the face of an increasing cumulative dose, suggest that there exists a complex interaction between time and dose rate at the level of the individual subject and cohort studied.

Several studies support the hypothesis that ozone-induced rapid shallow breathing and decrements in inspiratory capacity and FEV_1 are mediated by lung C-fibers (21–23) and could be expected to have similar time courses. Using breathing pattern data collected from 97 healthy male and female subjects during ozone exposure protocols of shorter duration, higher ozone concentrations, and continuous exercise of greater intensity than those used in the current study, we identified a distinct delay and response phase in the development of ozone-induced tachypnea (12). We found that the delay phase was dependent on reaching a dose of onset (Dos) and that the value of Dos was not influenced by ozone concentration or duration of exposure and only mildly influenced by changing $\dot{V}_E$. The consequence of this relationship is that if $\dot{V}_E$ is held constant the higher the mean ozone concentration the shorter the time to reach the threshold for the onset of response. In addition, we observed that the magnitude of tachypnea that developed after Dos was reached correlated with dose rate and not the cumulative or effective inhaled dose. Also of considerable importance was the observation that the magnitude of Dos was not correlated with the magnitude of tachypnea. We proposed that the development of decrements in FVC and FEV_1 may follow a similar time course and cited previous 6.6-hour exposure protocols to support this possibility. The plot of the group mean decrement in FEV_1 versus cumulative inhaled dose (Figure 4) supports the notion that a Dos is clearly present in the FEV_1 data in the current study. In addition, the plateau of FVC and FEV_1 decrements in the 80 ppb protocol, despite the fact that cumulative inhaled dose continues to increase, supports the notion that after Dos is reached the magnitude of response is a function of dose rate.

Using a similar regression analysis approach for deriving Dos from breathing frequency data, we determined Dos on the basis of the combined individual FEV_1 data. The derived Dos, using all the pooled FEV_1 data, was 1,362 μg of ozone. This value of Dos is greater than the values of Dos derived in our previous analysis (12). This difference may be related to numerous factors, for example, the plot of Dos from this and our previous analysis against $\dot{V}_E$ further suggests that Dos is a function of $\dot{V}_E$ (Figure 5A). Dos is not only useful in providing a better understanding of the kinetics of ozone-induced pulmonary

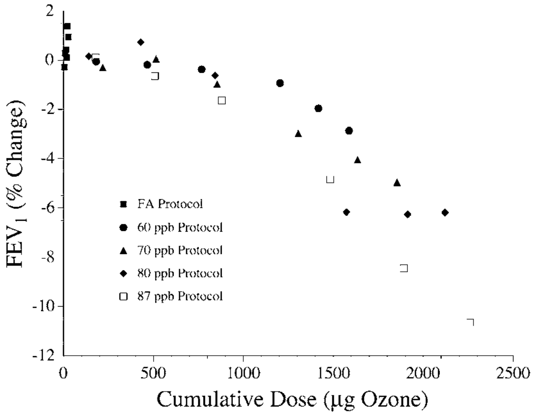

Figure 4. Scatter plot of group mean decrements in FEV$_1$ against the total cumulative dose of ozone (micrograms). Note that there is an inflection in the data between 1,300 and 1,400 µg of ozone. Values represent means ± SEM.

responses but provides insights into a component that contributes to the individual or group responsiveness to ozone. Given the relationship between Dos and $\dot{V}_E$ (Figure 5A) it is possible to predict the average maximal dose of ozone at which there is no pulmonary function decrement for exposures varying greatly in ozone concentration, duration of exposure, and minute ventilation (Figure 5B). The three-dimensional surface defined by this relationship (Figure 5B) provides a tool for predicting the maximal ozone exposure that approximately half of healthy individuals could experience without demonstrating functional responses. However, this relationship needs to be further validated, especially with studies using lower minute ventilations in combination with ambient ozone concentrations. It is also of critical importance to gain a better understanding of how the airway environment changes at the onset of decrements in lung function and subjective symptoms.

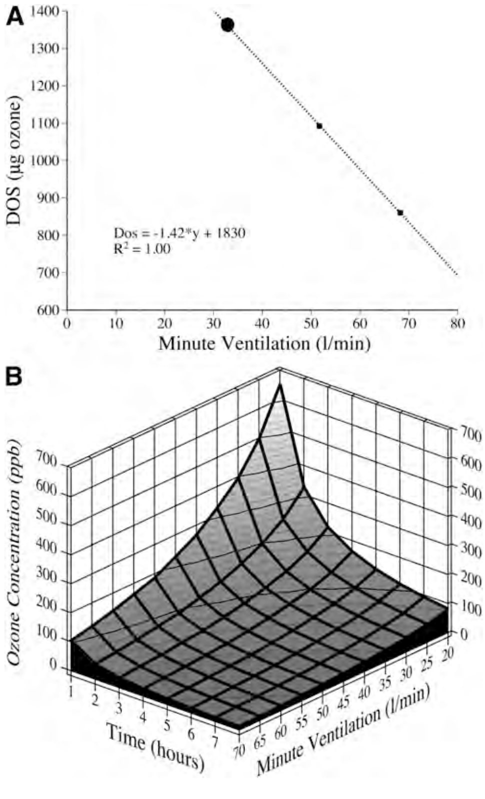

Figure 5. (*A*) Plot of dose of onset (Dos) derived previously by Schelegle and colleagues (12) (*solid squares*) and in the current study (*solid circle*) plotted against mean minute ventilation. (*B*) The three-dimensional surface defined by the relationship between Dos and minute ventilation that predicts the average cumulative dose of ozone in an average young healthy adult, below which no appreciable FEV$_1$ decrement occurs for exposures varying greatly in ozone concentration, duration of exposure, and minute ventilation. Dos is the cumulative dose of ozone at which approximately half the subjects have developed pulmonary responses and half have not.

Conflict of Interest Statement: None of the authors has a financial relationship with a commercial entity that has an interest in the subject of this manuscript

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REPORT

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SEEING THE WHOLE:
USING CUMULATIVE IMPACTS ANALYSIS TO ADVANCE ENVIRONMENTAL JUSTICE


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In 2017, NRDC and its environmental justice (EJ) partner groups in Chicago (the Southeast Environmental Task Force, the Southeast Side Coalition to Ban Petcoke, and the Little Village Environmental Justice Organization) and Newark, New Jersey (the Ironbound Community Corporation) began to explore how describing environmental burdens in a cumulative framework could advance advocacy to protect public health in their respective cities. Our objective was to work in close partnership to develop a method of analyzing cumulative environmental burdens in those two cities that could potentially be used in other cities and states. We wanted to build on existing methods, adapt them as needed, and document the lessons learned for cumulative impacts-based advocacy. This issue brief is intended to be a resource for EJ advocates. It describes some of the history, motivation, and evidence behind the cumulative impacts framework and provides a case study of how a cumulative impacts mapping analysis might be leveraged to promote policies that protect low-income communities and communities of color that are disproportionately burdened by environmental and social stressors. Other audiences, including agencies working on public health and environmental protection, may also find the synthesis of evidence contained in this brief useful in making the case for considering cumulative impacts in their work.

Cover photo top: An aerial view of homes in a residential neighborhood of Newark, New Jersey.

Cover photo bottom left: An industrial site as seen from a bridge over the Calumet River in the South Side of Chicago, Illinois, on October 26, 2020.

Cover photo bottom right: An aerial view of an industrial area near a residential neighborhood in Chicago, Illinois, in 2019.

About NRDC
NRDC is an international nonprofit environmental organization with more than 3 million members and online activists. Since 1970, our lawyers, scientists, and other environmental specialists have worked to protect the planet's wildlife and wild places and to ensure the rights of all people to clean air, clean water, and healthy communities. NRDC has offices in New York City, Washington, D.C., Los Angeles, San Francisco, Chicago, Montana, and Beijing. Visit us at nrdc.org.

About Little Village Environmental Justice Organization (LVEJO)
LVEJO's mission is to organize in the Little Village, Chicago, community to accomplish environmental justice and achieve self-determination of immigrant, low-income, and working-class families. LVEJO envisions building a sustainable community that promotes the healthy development of youth and families, provides economic justice, and practices participatory democracy and self-determination. LVEJO's grassroots organizing model is grounded in three guiding principles: 1) intergenerational leadership that sustains community self-determination; 2) the assumption that those directly affected have the solutions to solve their own problems; and 3) that building on the existing assets and resources of the community is central to social change. Learn more at lvejo.org.

About Southeast Side Coalition to Ban Petcoke (SSCBP)
Residents of the Southeast Side of Chicago came together to form the Southeast Side Coalition to Ban Petcoke and work to rid the neighborhood of the fugitive dust from petroleum coke, or petcoke—a by-product of the refining of crude oil—stored in their neighborhood. SSCBP has successfully lobbied against open-air petcoke facilities in the Southeast Side of Chicago and aims to permanently rid the 10th Ward of toxic substances.

About Southeast Environmental Task Force (SETF)
The Southeast Environmental Task Force is an environmental nonprofit organization dedicated to serving the Southeast Side and south suburbs of Chicago by promoting environmental education, pollution prevention, and sustainable development. Learn more at setaskforce.org.

About Ironbound Community Corporation (ICC)
Founded in 1969, the Ironbound Community Corporation empowers residents of the Ironbound section of Newark, New Jersey—a diverse neighborhood of 50,000 people—to build better lives for themselves and a better community for all who call the Ironbound home. ICC's mission is to engage and empower individuals, families, and groups in realizing their aspirations and, together, work to create a just, vibrant, and sustainable community. ICC envisions a safe, healthy, just, and nurturing Ironbound, a welcoming and fully inclusive community that supports equal and accessible opportunity and the quest for a better life. ICC's many programs aim to address unmet needs and service gaps, particularly for underserved individuals and families; support child development and strengthen families; develop self-esteem, self-sufficiency, and civic participation; support the development of a just, tolerant, healthy, and sustainable community; and deliver programs in a culturally sensitive and linguistically appropriate manner. Learn more at ironboundcc.org.

LVEJO, SETF and NRDC give their thanks to Keith Harley and the students and other staff of the Greater Chicago Legal Clinic, Inc., whose longstanding work to support environmental justice and represent groups in Chicago has helped paved the way and continues to demonstrate the need for policies that center a cumulative impacts viewpoint.

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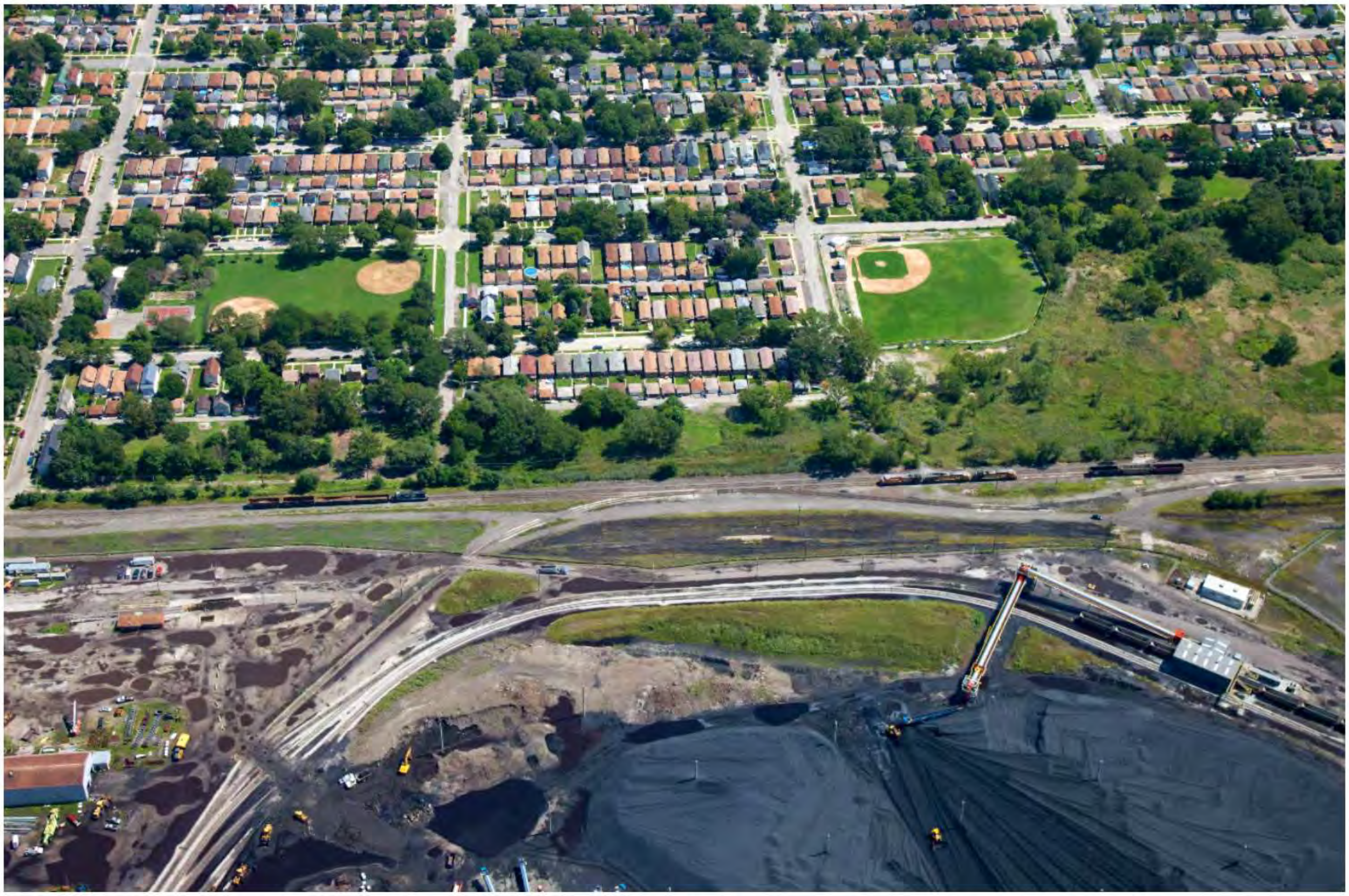
Introduction

The concept of cumulative impacts recognizes that there are multiple, interacting environmental and social stressors that have an impact on environmental justice communities.

Low-income communities and communities of color that bear the brunt of polluted air, water, and soil in the United States know that the harm they face comes from more than a single source. These communities, known as environmental justice (EJ) communities, experience a host of overlapping stressors—that is, physical, chemical, and biological agents as well as nonchemical factors, such as socioeconomic conditions—that have an adverse effect on health.



An aerial view of petcoke piles at KCBX's South terminal located on the banks of the Calumet River, next to a residential neighborhood on the Southeast Side of Chicago, Illinois, on August 27, 2014.

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View in the Ironbound neighborhood of Newark, NJ, November 3, 2018.

EJ communities are often disproportionately burdened by environmental stressors, often brought on by the hazardous use of land and natural resources.[1] For example, residents frequently live near industrial sources of pollution and heavily trafficked throughways, on lands and in buildings plagued by a legacy of contamination. Moreover, due to their low-income status, structural racial/ethnic discrimination, or the historical traumas they have experienced, EJ communities are often marginalized, underserved by public and private entities, and underrepresented in decision-making on issues that affect them. The risks they already face from multiple environmental stressors are heightened because of this vulnerability.[2] For example, they may be breathing high levels of air pollution from local industry while at the same time less likely to visit a doctor to treat their aggravated asthma because of language barriers or lack of health insurance.

Stated another way, the same amount of pollution can result in more harm to people who are experiencing additional stressors. **Cumulative impacts** is a way to describe the combination of multiple environmental and sociodemographic stressors experienced by EJ communities, which contribute to persistent health inequities and disparities in environmental health threats._

An aerial view of a biodiesel refinery and shipping facilities on the Passaic River waterfront with Newark, New Jersey, in the background.

However, for many decades, the science and policy to address EJ communities' lived experience of cumulative impacts have been scant to nonexistent. Regulation often occurs in piecemeal fashion, facility by facility, chemical by chemical, or with a narrow focus on one domain—air, soil, or water—at a time. Health risk assessments typically project the amount of harm to an "average" individual, ignoring the hard reality that environmental hazards disproportionately impact people and communities who are more vulnerable than average due to the social conditions in which they live.[3] And policymaking has compounded the problem by allowing environmental hazards such as facilities that handle especially toxic substances to be located more frequently and densely in certain communities.

Science and policymakers must catch up with what EJ communities already know and account for cumulative impacts when creating environmental policy.

The Emergence of a Cumulative Impacts Framework

Urged by EJ communities, advocates, and scholars, environmental agencies began to develop mapping and screening tools to better address communities' lived experience of cumulative impacts.

The study of cumulative impacts in policy and scientific spaces began as a community-driven effort. EJ communities saw that the existing regulatory landscape and tools like health risk assessments, used by agencies to set limits on pollution, were failing to protect them from environmental hazards. At the same time, decision makers were not taking communities' complaints seriously. As Arsenio Mataka, an EJ advocate from California's Central Valley who later worked for the California Environmental Protection Agency (CalEPA) described it, the information presented in local government meetings by community advocates, including his own parents, was deemed "anecdotal information" and was "never acknowledged."[4] Community leaders and academics lending their expertise to EJ communities began working together to tackle this problem. As Mataka recalled, "We were...driven by the belief that if we could somehow figure out how to quantify the cumulative pollution burden and vulnerabilities in poor communities and communities of color, it would change the course and future of those communities forever."[5]

The community-led effort to create cumulative impacts tools and policies faced what EJ advocate Charles Lee described as "consistent political opposition" but was able to make progress thanks to coordinated efforts and strong leadership from many communities, "sometimes in collaboration with public agencies and sometimes in conflict," Lee said.[6] The movement gained traction in the early 2000s, with several important developments at the national level and in California, as well as in other states such as New Jersey.[7] In 2003 the U.S. Environmental Protection Agency (U.S. EPA) issued its *Framework for Cumulative Risk Assessment*, which called for cumulative approaches in the assessment and management of risk that could quantify combined risks from multiple agents or stressors.[8] This framework, which the agency described as the "first step in a long-term effort," emphasized that agents and stressors include not only chemicals but anything causing harm to humans, organisms, or the ecosystem, such as physical events (e.g., automobile crashes) and socioeconomic stressors (e.g., lack of health care).

In late 2010, the U.S. EPA began to develop a new tool capable of visualizing multiple environmental and socio-demographic characteristics and stressors in communities around the United States.[9] The effort built on earlier work, including a mapping tool developed by the agency's Office of Enforcement and Compliance Assurance, called EJSEAT, and a comprehensive review of that tool conducted by the EPA's National Environmental Justice Advisory Council.[10] The U.S. EPA publicly released its new tool, called EJSCREEN, in 2015. Though EJSCREEN falls short of computing a cumulative (i.e., total) score or ranking out of various environmental and socio-demographic indicators, it nonetheless collects these indicators from different data sources in a centralized mapping tool.[11] Information is provided at the U.S. Census block group level—units of area used for collecting census data where roughly 600 to 3,000 people reside.[12] The agency updates EJSCREEN annually and uses it as a "preliminary step when considering environmental justice" in its work and to inform community outreach; actions on permitting, enforcement, and compliance; and other geographically based initiatives.[13]

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Southeast Side of Chicago, December 2019.

For any cumulative impacts tool, a chief limitation is that the full range of environmental issues experienced by a community will not be completely captured. In the case of EJSCREEN, no information on drinking water quality or indoor air quality is incorporated, and some of the environmental indicators included in EJSCREEN rely on self-reporting by facilities.[14] Thus, while EJSCREEN can be a useful tool providing a screening-level first look at locations, the U.S. EPA stresses that it should not be the sole basis for policy or decision making.[15]

Alongside this development, the CalEPA, propelled by an intersectoral Advisory Committee on Environmental Justice, adopted an EJ Action Plan in 2004 that expressed a commitment to developing guidance on cumulative impacts.[16] Thereafter, CalEPA's Office of Environmental Health and Hazard Assessment began a multiyear participatory process with EJ advocates, community members, and researchers.[17] The process culminated in April 2013 with the release of version 1.0 of CalEnviroScreen, a screening tool that combines data on environmental hazards and exposures, public health factors, and socioeconomic factors.[18] The tool calculates a cumulative impacts score for each of the state's approximately 8,000 census tracts (the next group up in size from a census block group, typically containing 1,200 to 8,000 people). CalEPA has continued to refine CalEnviroScreen, for example adding updated data and new variables like cardiovascular disease and rent-burdened low-income households.[19] In addition to relying on nationally available data sources, the tool draws on data specific to California collected through the state's monitoring systems, such as its regional water and air quality boards, the California Environmental Health Tracking Program, and its Solid Waste Information System.[20] CalEPA uses CalEnviroScreen to administer EJ grants, promote compliance with environmental regulations, and prioritize site cleanup. The scores are also used to identify "disadvantaged communities" for purposes of investing funds from the state's greenhouse gas emissions cap-and-trade program.[21]

CalEnviroScreen and other state tools that have followed in its footsteps show how cumulative impacts experienced in communities can be initially analyzed to better capture their multiple burdens than previous tools allowed.

Increasing Scientific Support for Cumulative Impacts

Scientific evidence showing the importance of a cumulative impacts framework is growing.

In 2011, researchers in California published a paper summarizing evidence that was "beginning to show how the cumulative effects of social and environmental stressors can work in combination to produce health disparities."[22] The researchers summarized the findings under four key concepts, paraphrased below.[23]

1. **There are significant disparities in the health outcomes of different racial/ethnic and socioeconomic groups, and these disparities exist for diseases linked to social and environmental factors.**[24] For example, Black people and people of lower socioeconomic status (SES) experience higher rates of adverse birth outcomes, including low birth weight and preterm birth, which in turn can contribute to health complications later in the child's life. People of color also experience higher rates of cardiovascular disease and asthma and worse self-described health.
2. **There are significant disparities in levels of exposure to environmental hazards that are related to poor health outcomes.**[25] For example, low-income individuals and people of color are much more likely to live near pollution sources such as industrial facilities and heavily trafficked throughways, and proximity to these pollution sources is connected to harmful health outcomes, including adverse birth outcomes, cardiovascular disease, and respiratory illness. People of color and low-income households are also more likely to be exposed to many harmful chemicals and indoor air pollutants.
3. **Certain intrinsic factors—such as age, genetics and gene expression, and preexisting health conditions—can heighten or lessen a person's sensitivity to pollution.**[26] For example, the same amount of pollution can have a worse health impact on people who are more biologically susceptible due to a preexisting condition like cardiovascular disease, obesity, diabetes, or asthma. Genes—and environmental factors that "turn on" or "turn off" the expression of genes—also affect biological susceptibility.
4. **Certain extrinsic factors, like socioeconomic status and the social constructs of race, ethnicity, and gender, can also amplify a person's vulnerability to environmental hazards.**[27] For instance, the same levels of air pollution appear to lead to worse health outcomes among people who belong to certain racial or ethnic groups, have lower socioeconomic status, or live in poorer neighborhoods.

The evidence supporting each of these four concepts has been accumulating over recent years, strengthening the case for decision makers to use cumulative impacts as a conceptual and analytic framework. Breakout boxes I through IV below present more detailed scientific findings with citations to supplement the examples given above for each of the four concepts. We provide these details for readers who may be less familiar with the literature, and to better equip those who are making the case for cumulative impacts analysis and policies in their own communities. While our search was not exhaustive, we sought to include findings from new or recent research and systematic reviews (those that draw conclusions from looking methodically across multiple studies). Among other topics, there has been important recent evidence on the impact of neighborhood conditions, the effects of noise exposure, and disparities in safe drinking water.

A Note on Terminology

In describing existing scientific studies, data sets, and methodologies, we have, to the extent possible, used the same terminology as the terminology used in the original cited sources. This choice does not reflect our endorsement of that terminology; rather, we have done this to make it clear what data are being referenced. Unfortunately, this means that certain terms may be imprecise and/or different from the terms the referenced groups prefer for self-identification. For example, studies have used terms such as *African-American* or *Hispanic* instead of *Black*, *black*, or *Latinx*, likely reflecting the terminology used in census and other socio-demographic data. Similarly, as of the writing of this brief, the term *minority* is still incorrectly being used as shorthand for *nonwhite* in the U.S. EPA EJSCREEN data set.

I. CUMULATIVE IMPACTS: DISPARITIES IN HEALTH OUTCOMES

There are significant disparities in health outcomes for different racial/ethnic and socioeconomic groups, and these disparities exist for diseases linked to social and environmental factors. Takeaways from the scientific literature include:

ADVERSE BIRTH OUTCOMES

Black people experience higher rates of adverse birth outcomes, such as low birth weight and preterm births.[28] Such outcomes can adversely affect child development and health in adulthood.[29] Moreover, research has linked these disparities to social circumstances and environmental exposures, more so than to genetic factors or shortfalls in medical care alone.[30] For example, premature births have been associated with poor socioeconomic conditions at the individual and neighborhood levels, living in highly segregated areas, life experiences with racism, maternal stress, and environmental exposures (e.g., to air pollutants and other chemicals).[31] Restricted fetal growth and lower birth weight have also been associated with environmental exposures (e.g., to lead, air pollutants, and pesticides), living in highly segregated areas, experiences with racial discrimination, maternal stress, individual socioeconomic status, and neighborhood hardship.[32]

CARDIOVASCULAR DISEASE

Significant disparities along racial/ethnic lines and by socioeconomic status exist in cardiovascular disease (CVD) outcomes (e.g., stroke and heart disease, mortality from CVD events) and CVD risk factors (e.g., hypertension, diabetes, obesity, high cholesterol, low physical activity).[33] Vulnerable subgroups include those with lower income or education, uninsured individuals, Blacks, Hispanics/Mexican Americans, and residents of the southern and southeastern United States and Appalachia.[34] Beyond individual-level factors, place-based factors—such as state-level economic conditions, policy measures, and food environments[35] and neighborhood-level socioeconomic characteristics[36]—are related to disparities in CVD risk factors and certain outcomes. Environmental exposures, such as to air pollution, metal pollutants, and noise, can also impact the development and severity of CVD.[37]

ASTHMA

Socioeconomic and racial/ethnic disparities in asthma prevalence, morbidity, hospitalization, and mortality are well documented in the United States.[38] Disparities have been observed for both adult and childhood asthma.[39] African-Americans, Puerto Ricans, and Native Americans appear to be the most vulnerable racial/ethnic subpopulations.[40] Asthma disparities have been linked to individual-level factors (e.g., maternal smoking, preterm birth, and low birth weight), community-level factors (e.g., neighborhood inequality and disadvantage, and stress), and environmental conditions (e.g., housing quality, indoor environmental exposures, and traffic-related air pollution) as well as disparities in treatment and access to care.[41]

SELF-RATED HEALTH

Disparities in self-rated health have persisted over the years, with Blacks/African-Americans, Hispanics/Latinos, American Indians or Alaska Natives, and lower-income individuals more likely to report poor or fair health status than whites and those living at a level at least two times greater than the poverty level.[42] Moreover, research has revealed self-rated health to be an increasingly valid predictor of mortality and therefore a good indicator of overall health.[43] In addition to individual-level factors, differences in neighborhood socioeconomic context help explain some of the racial disparity in self-rated health.[44]

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Altgeld Gardens' breezy tunnel—an underpass in the middle of the neighborhood—in Chicago, Illinois, on October 26, 2020. Thousands of names are listed on a memorial wall inside the tunnel commemorating loved ones who have passed due to cancer, asthma and other respiratory issues.

II. CUMULATIVE IMPACTS: UNEQUAL EXPOSURE TO ENVIRONMENTAL HAZARDS

There are significant disparities in levels of exposure to environmental hazards that are related to poor health outcomes. Ample research has documented this finding. Some examples, grouped by categories that are not mutually exclusive, include:

INDUSTRIAL FACILITIES AND OTHER POLLUTING LAND USES

Low-income individuals, people of color, and those without a high school diploma are more likely to live near industrial facilities, hazardous waste sites, major U.S. freight gateways (e.g., ports and rail yards), and other polluting land uses.[45] Living near these locally unwanted land uses exposes people to a higher risk of adverse health outcomes, such as cancer (including childhood cancer), respiratory illness, cardiovascular disease, birth defects, and low birth weight.[46]

ROADWAYS AND TRAFFIC

There are racial/ethnic and socioeconomic disparities in residential proximity to major throughways[47] and exposures from traffic.[48] For example, a six-city study involving approximately 6,000 participants found that those living in neighborhoods whose population was more than 60 percent Hispanic were exposed to 31 percent higher concentrations of nitrogen oxides, a good marker of traffic-related air pollution, than those residing in neighborhoods with less than 25 percent Hispanic population.[49] Traffic contributes not only to air pollution, but also to noise pollution.[50] Living close to heavily trafficked areas has been associated with adverse health outcomes, such as preterm birth, low birth weight, respiratory illness, and cardiovascular disease.[51] Research suggests that noise from traffic is associated with sleep disturbance as well as various cardiovascular disease risk factors and outcomes, independent of the effect that traffic-related air pollution may have.[52]

CHEMICALS

A 2018 review found that low-income, African-American, and Latino individuals are disproportionately exposed to five classes of environmental endocrine-disrupting chemicals that are associated with diabetes.[53] Sources of exposure to these chemicals—polychlorinated biphenyls, organochlorine pesticides, multiple chemical constituents of air pollution, bisphenol A, and phthalates—include contaminated food products, drinking water, building materials and fixtures, dust, soil, industrial air emissions, combustion, household chemicals, appliances, plastics, and personal care and other consumer products.[54] While in theory anyone can be exposed to such sources, people of color and low-income individuals experience higher exposures due to patterns of employment, housing conditions, and neighborhood infrastructure.[55] Further, discount retail stores ("dollar stores") that serve predominantly low-income communities and communities of color have been slow to eliminate products containing toxic chemicals from their shelves.[56]

DRINKING WATER CONTAMINANTS

There are racial and socioeconomic disparities in the extent to which communities are exposed to drinking water contaminants that can have harmful health impacts, such as elevated risk of cancers, reproductive toxicity, adverse birth outcomes, and developmental effects.[57] A recent national-level analysis found that rates of drinking water violations from June 2016 through May 2019 were higher in U.S. counties with more racial, ethnic, and language vulnerability; crowded housing; limited transportation access; and socioeconomic vulnerability.[58]

INDOOR POLLUTANTS

People of color and low-income households also face higher indoor concentrations of some pollutants, which may be caused by disparities in the quality of indoor residential environments, as well as outdoor pollution that filters inside.[59] For example, research has shown higher lead concentrations in household dust in non-Hispanic Black households than in non-Hispanic white households, even after accounting for characteristics of the home (year of construction, presence of smoker, etc.).[60] Childhood lead poisoning attributed to lead paint and lead-contaminated soil is one of the most notable examples of disparate indoor pollutant exposure,[61] and research reveals persistent disparities by race/ethnicity and socioeconomic status in blood lead levels among children.[62] Higher levels of cockroach allergens (parts of cockroaches that can trigger asthma or allergies) have been associated with lower household income, living in high-poverty areas, less maternal education, and Black or Hispanic race/ethnicity.[63] Low-income households in multifamily buildings may face higher concentrations of nitrogen dioxide and other combustion pollutants that aggravate respiratory conditions due to poorer ventilation and smaller apartment size.[64]

OCCUPATIONAL/WORKPLACE HAZARDS

Certain racial/ethnic and socioeconomic groups could face high exposure to hazards from employment in specific occupational/workplace conditions. A national study found elevated risks of workplace injury for non-Hispanic Black workers and foreign-born Hispanic workers, even after accounting for gender and education differences.[65] A recent analysis conducted by NRDC similarly found that Blacks, Latinos, and low-wage workers are overrepresented in the occupations most highly exposed to the types of extreme weather associated with climate change.[66] These include buildings and grounds maintenance, transportation and materials transport, and agriculture. In the agricultural sector in particular, there are an estimated 2.5 to 3 million agricultural workers in the United States, of which 73 percent are foreign-born, 69 percent do not speak English well, and 89 percent have no education beyond high school.[67] Farmworkers and their children experience greater exposure to pesticides.[68] There is suggestive evidence linking pesticides to certain cancers,[69] neurological conditions,[70] respiratory conditions,[71] and reproductive health problems.[72] Additionally, farmworkers face a high risk of heat-related illness.[73]

NEIGHBORHOOD ENVIRONMENTS

Beyond these hazards, there are also disparities in neighborhood environments. Neighborhoods with lower socioeconomic status and higher proportions of Black and Hispanic residents have less access to healthy food options and greater exposure to fast-food outlets and convenience stores that sell prepared, high-calorie foods and limited fresh produce.[74] A review of research on park access found that while there is not a straightforward relationship between race and SES and proximity to parks, there appear to be disparities in terms of park quality and park acreage, with whiter and wealthier neighborhoods having an advantage over poorer communities, Blacks, and Latinos.[75] Looking more broadly at green spaces, a national-level study found that urban census tracts with higher poverty or greater percentages of Blacks or Hispanics had less green space coverage than other census tracts.[76] There is growing evidence that contact with nature is associated with positive health benefits, including the findings of one recent study that used a randomized trial to show that a greening intervention could *cause* improved mental health.[77]

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The Schroud Property Superfund site in the Hegewisch neighborhood on the Southeast Side of Chicago, formerly used to store and dump slag material from steel manufacturing, December 2019.

III. CUMULATIVE IMPACTS: INTRINSIC FACTORS

Certain intrinsic factors—such as age, genetics and gene expression, and preexisting health conditions—can heighten or lessen a person's sensitivity to pollution. Scientific evidence supports the following:

AGE

Age has an impact on an individual's susceptibility to pollution. For example, young children are more susceptible because their bodies absorb and metabolize chemicals differently; they may also have increased contact with pollution due to recreational behaviors (e.g., hand-to-mouth activity or playing outdoors).[78] Exposure to pollution early in life and at key moments in their growth can affect their development and health as adults.[79] Elderly individuals also appear to be more susceptible to some pollution effects, due to normal and pathological aging and related processes that are associated with declines in immune responses and weakening cardiovascular and respiratory systems.[80] For example, a 2015 review found that the elderly generally faced higher risks from outdoor air pollution than did the rest of the population, especially from short-term exposure.[81] A 2014 meta-analysis of ozone-related mortality found strong evidence that older persons have higher susceptibility to short-term exposure.[82]

HEALTH CONDITIONS

There is evidence—epidemiological and toxicological—suggesting that certain preexisting health conditions can increase susceptibility to pollution.[83] These include diabetes, obesity, hypertension,[84] and cardiovascular disease (e.g., a history of myocardial infarction, congestive heart failure, or coronary artery disease).[85] Asthma can also increase a person's susceptibility, with air pollution triggering symptoms among asthmatics,[86] and one early study showed that asthmatics experience a higher risk of contracting pneumonia when ambient particulate pollution levels are high.[87] Further, as described in breakout box I, above, there are disparities in who is more likely to suffer from these health conditions.

EPIGENETIC FACTORS

Genetics can heighten or lessen a person's susceptibility to the effects of pollution.[88] This is due not only to differences in individuals' genetic code but also to *epigenetic factors*—aspects of the environment that influence biological mechanisms that "switch" certain genes on or off, thereby altering susceptibility to disease. For example, developmental and epigenetic mechanisms link early-life environmental factors, such as stress and discrimination experienced by the mother during pregnancy, to racial disparities observed in adult health outcomes, such as hypertension, diabetes, stroke, and coronary heart disease.[89] One U.S.-based study that followed a group of 105 infants through mid-adolescence found that the amount of DNA methylation (a well-known epigenetic mechanism that has the capacity to modify gene expression and appears linked to health outcomes later in life) observed in the adolescents was associated with the amount of stress reported by the mother during the child's infancy and by the father during the child's preschool years.[90] Another study following 494 participants in the Philippines found that household socioeconomic status and extended absence of a parent during childhood were factors significantly associated with the amount of DNA methylation measured in young adulthood.[91]

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Homes next to the S.H. Bell facility on Chicago's Southeast Side, December 2019. The facility, which handles manganese, has been cited by the EPA for emitting the pollutant at excessive levels that can cause neurotoxic and other health effects.

IV. CUMULATIVE IMPACTS: EXTRINSIC FACTORS

Certain extrinsic factors, like socioeconomic status and the social constructs of race, ethnicity, and gender, can also amplify a person's vulnerability to environmental hazards. In other words, it is not just that certain groups are disproportionately exposed to pollution (as described in breakout box II), but that, even faced with the same amount of pollution, certain populations may be more vulnerable and experience worse outcomes.

INDIVIDUAL-LEVEL FACTORS

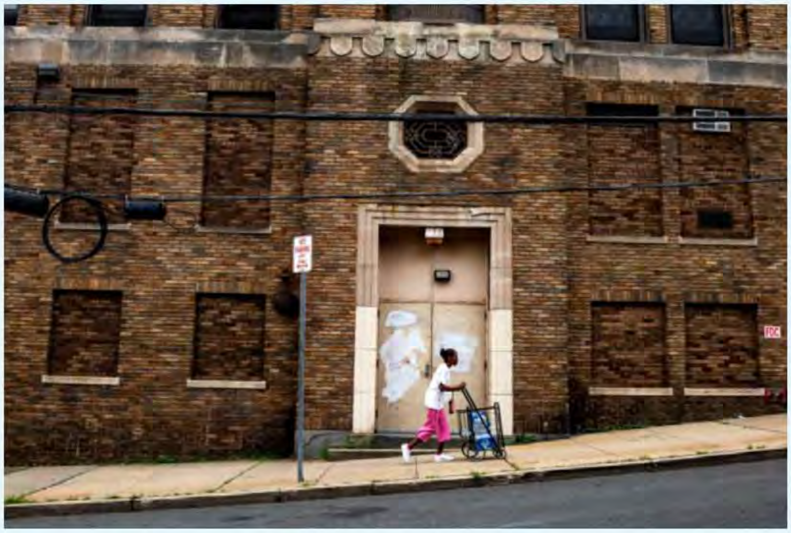
Several systematic reviews have found that certain socio-demographic characteristics, such as lower educational attainment, income, and employment status, appear to increase vulnerability to the physical health impacts of air pollution.[92] In 2017, researchers published one of the first studies reporting a statistically significant association between ambient fine particulate matter ($PM_{2.5}$) exposure and adverse mental health symptoms.[93] The study, based on a nationally representative group of 4,008 elderly individuals, found that the association between exposure and moderate to severe anxiety symptoms was significantly enhanced among those with less than a high school education.[94]

Beyond air pollution, research has also suggested that children from families of lower SES are more vulnerable to the impacts of lead exposure.[95] For example, a study on early-childhood lead exposure in North Carolina found not only that higher blood lead levels between the ages of 9 and 36 months were associated with lower test scores in the fourth grade, but that this effect was more pronounced at the lower end of the distribution of test scores.[96] Lower test scores tended to come from children enrolled in the free/reduced lunch program, children whose parents were less educated, and children who were exposed to more lead, with Black children overrepresented in all three of these "riskier" groups.[97] The findings thus revealed that children experiencing "these cumulating deficits" would have an especial disadvantage that could explain the school achievement gap between wealthier white children and Black and lower SES children.[98]

NEIGHBORHOOD-LEVEL FACTORS

Research has highlighted the potential for neighborhood-level conditions to increase vulnerability as well. For example, a 2017 study in three U.S. cities found that the association between ozone pollution and pediatric respiratory disease was higher among children in low-SES environments than among children in high-SES environments.[99] Meanwhile, a 2017 systematic review synthesized studies published between 2005 and 2016, aiming to investigate how socioeconomic position affected the relationship between multiple air pollutants (ozone, particulate matter, sulfur dioxide, nitrogen dioxide) and cardiovascular health.[100] In broad terms, the review found that vulnerability varied by a person's education, income, and occupation as well as by an area's level of poverty, unemployment, and deprivation.[101] The effect was generally in the expected direction, meaning that fewer material resources were related to greater vulnerability.[102] In this vein, a study using Medicare patient data from 207 U.S. cities revealed that the association between long-term $PM_{2.5}$ exposure and mortality differed on the basis of community-level characteristics, with the effect being worse in cities with higher obesity rates, percentage of residents living in poverty, percentage of Black residents, and percentage of population without high school degrees.[103]

The previously cited national study on $PM_{2.5}$ and adverse mental health also investigated the role of neighborhood context. It found that the association between $PM_{2.5}$ exposure and moderate to severe depressive symptoms was significantly greater for those living in more impoverished census tracts—even after accounting for individual-level socioeconomic status.[104]



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A local resident wheeling home a cart carrying cases of bottled water from the Newark Department of Health and Welfare in Newark, New Jersey, on August 15, 2019.

Despite the substantial body of research documenting environmental injustice and demonstrating a need for a cumulative impacts framework, EJ communities still often hear counterarguments from polluting industries and government agencies, who may acknowledge that they suffer from health disparities (concept I) but maintain that these health problems are a result of the communities' own life choices and behaviors rather than environmental policies and conditions. EJ communities are thus offered, at most, interventions like behavior-change programs, education, and individual services.[105] Such blame-shifting discourse is refuted by the overwhelming evidence of disparate exposures (concept II), as well as the evidence showing that social circumstances can and do in fact heighten vulnerability (concept IV). On this latter point, there is consensus that health-supporting behaviors cannot fully eliminate the increased risk of adverse health outcomes that will come with ongoing exposure to stressors.[106] The pathways through which extrinsic factors can amplify vulnerability are detailed in the breakout box below.

UNDERSTANDING VULNERABILITY AND IMPACTS ON HEALTH

Emerging scientific research is shedding light on how the extrinsic factors described earlier exacerbate vulnerability to environmental hazards and thus poor health.

STRESS RESPONSE AND ALLOSTATIC LOAD

One prominent explanation is that individuals in disadvantaged situations can face chronic stress, leading to accumulated wear and tear on the body known as allostatic load.[107] When stress chemicals are continually secreted, they can falter in their ability to protect the distressed person and instead begin to damage the brain and body.[108] Over time, this affects not only the neuroendocrine system (the system responsible for stress response in the first instance) but also the cardiovascular, metabolic, and immune systems as they try to compensate.[109] Initial evidence of this stress pathway was mixed, possibly due to the relatively few studies on the topic and the challenge of measuring something as complex as stress.[110] Nonetheless, a systematic review of the evidence concluded that there is a relationship between allostatic load and factors such as socioeconomic status (SES), social relationships, workplace, lifestyle, race/ethnicity, gender, and stress exposure.[111]

Research focusing specifically on children and adolescents provides further evidence.[112] For example, a study of African-American adolescents living in Michigan found that both individual and neighborhood-level factors reflecting socioeconomic disadvantage were associated with higher levels of cortisol, a key stress response hormone that regulates central nervous, metabolic, and immune systems; when levels are abnormal, adverse health outcomes can result.[113] A recent study of a racially diverse sample of kindergarten children in California over the course of a school year similarly found that the highest cortisol levels and greatest physical health problems among children were observed in families of lower SES and neighborhoods with less opportunity.[114] Moreover, the negative effects of family SES on children's cortisol levels and physical health were influenced by neighborhood attributes, such that higher-opportunity neighborhoods appeared to be a buffer against some of these effects.[115] Overall the researchers concluded that their study supported the existence of the stress–physiology pathway, whereby adverse conditions impair cortisol response, elevating the risk of physical health problems.[116]

The stress experienced by individuals in situations of social disadvantage may also have intergenerational impacts. Maternal cortisol is one of the pathways through which maternal emotional state and stress affect a fetus's developing brain; maternal cortisol concentrations influence fetal cortisol concentrations.[117] For example, a study in New Zealand found that women with lower SES had higher biological indicators of stress during pregnancy, and their babies were more biologically reactive to stress.[118] Further, women's experiences of racial/ethnic discrimination appeared related to their own stress levels, their self-rated health, and how their babies responded to stress.[119] This research provides evidence of the intergenerational impacts that SES and racial/ethnic discrimination may have on stress responses. When individuals (and their offspring) are then confronted with hazardous pollution, they are more vulnerable to the health impacts due to their altered stress responses. This is a key pathway by which social vulnerability contributes to cumulative impacts.

HEALTH CARE DISPARITIES

Additionally, factors like race/ethnicity and socioeconomic status may increase vulnerability to environmental hazards because, as evidence has long shown, individuals who are nonwhite or low-income or reside in certain geographic areas have less access to health care and lower-quality care.[120] Individual, provider, and community-level factors all contribute to disparities in access and quality of care.[121] These include not only a person's insurance status, access to material resources, and level of education—which tend to be correlated with race/ethnicity—but also implicit racial and other biases that affect how care providers interact with patients and how patients in turn respond.[122] Efforts to expand health insurance coverage, such as the Affordable Care Act and state Medicaid expansion, have reduced some disparities in insurance status and utilization of health care services, but they are insufficient by themselves to affect disparities in health outcomes.[123] In fact, a systematic review of 77 studies concluded that the effects of ACA-related Medicaid expansion on gaining health insurance have been comparable across racial/ethnic groups, suggesting that the disparities that previously existed still largely remain.[124]

One example of how disparities in health care magnify the impact of environmental exposures can be found in the exacerbation of asthma due to air pollution. Lack of adequate health care to manage asthma means that asthma exacerbations are more likely to result in emergency department visits, hospitalizations, and deaths.[125] One nationwide study of 5,535 children found that in 2008, children with uncontrolled asthma were seven times more likely to visit the emergency department than were children with well-controlled asthma, a finding researchers deemed disturbing given its suggestion that most emergency department visits could have been prevented by proper asthma management.[126]

Using Cumulative Impacts Analysis to Create Change—Case Studies in Chicago and Newark

We can use a cumulative impacts framework and cumulative impacts mapping tools to work with environmental justice communities to bring change.

Around 2017, NRDC and environmental justice groups in Chicago (the Southeast Side Coalition to Ban Petcoke, the Southeast Environmental Task Force, and the Little Village Environmental Justice Organization) and Newark, New Jersey (the Ironbound Community Corporation) decided to bring together their expertise to explore how a cumulative impacts framework could advance environmental justice. We aimed to work in close partnership to develop a method that could assess cumulative environmental burdens in those two cities and potentially be used in other places. Community–academic partnerships elsewhere had been working toward a similar goal, and proposals for draft tools and cumulative impacts policy had already been surfacing to varying extents in Illinois and New Jersey due to advocacy by EJ groups.[127] We sought to build on those efforts, adapt them as needed, and document the lessons learned for cumulative impacts–based advocacy.

METHOD AND APPROACH

We aimed to create a method that would be easily understood by nontechnical audiences, as well as be credible and persuasive for specific advocacy objectives when presented to policymakers. Moreover, we wanted the process to yield useful, actionable information while navigating around limitations and uncertainties of available data.

With these considerations in mind, we decided to use the indicators collected by the U.S. EPA's EJSCREEN as our principal source of environmental and population data. While we recognized the limitations in EJSCREEN described earlier, these were outweighed by the advantages of adhering to a set of indicators already vetted and endorsed by the U.S. EPA. The 2018 version of EJSCREEN (the most up-to-date version at the time) contains 6 socio-demographic indicators and 11 environmental indicators for each U.S. Census block group in the country (see Table 1).

To combine these indicators, we decided to adapt a method developed by researchers in California known as the Environmental Justice Screening Method.[128] Our approach is summarized here; for more detail, see the Technical Appendix. First, we ranked block groups within a chosen geographic area (e.g., a city or county) according to each of the 17 indicators. Next, for each block group, we combined its 11 rankings corresponding to the environmental indicators into a sub-score ranging from 1 to 5, and its 6 rankings corresponding to the socio-demographic indicators into another sub-score also ranging from 1 to 5. From there, we added the two sub-scores to get a final total score for each block group. This total score, ranging from 2 to 10, reflects how heavily burdened a given block group is, relative to other block groups within the area of interest; the higher the score, the greater the disproportionate cumulative burden. The result of this cumulative impacts analysis calls attention to areas that face a high combined burden from multiple environmental stressors and socio-demographic vulnerabilities, which, as we have seen, can have negative cumulative impacts on health and well-being.[129]

Though a cumulative impacts analysis such as the one we developed may yield results that are unsurprising to those affected by the problem, EJ communities and groups have found it valuable to their policy advocacy to have a data-driven visual that describes their lived experience of cumulative, disproportionate burdens.

Our initial discussions revealed that communities are eager to use cumulative impacts maps and analyses to inform land use and economic development policies, which historically have contributed to the burden and health inequities of EJ communities in important ways.[130] Having the tools to provide a visual and quantifiable understanding of the combined impacts of land use and economic development policies on environmental and public health can help advocates push policymakers to pay attention to these accumulated burdens.

DAYLIGHTING THE PROBLEM

As applied to the city of Chicago, the analysis we conducted in 2018 and updated in 2019 highlighted communities in the west, southwest, and southeast as areas experiencing high cumulative burdens and potential vulnerability to environmental health impacts (see Map 1). The mayor at the time, Rahm Emanuel, was in the process of championing the Industrial Corridor Modernization Process (ICMP), which was presented as a beneficial public process "to refine land use policies for continued growth and private investment" in Chicago's industrial corridors.[131] However, EJ advocates noted from early on that the process effectively gentrified some corridors while distributing burdens to others. For example, as part of the ICMP, the City Council in 2017 not only rezoned the North Branch Corridor to prohibit many heavy industrial uses and enable high-end commercial and residential development, but also designated certain industrial corridors to be "receiving corridors" for the industry displaced by this gentrification.[132] These so-called receiving corridors, including Little Village and the Southeast Side, are predominantly located in or adjacent to low-income communities of color. EJ groups in Chicago were able to leverage our analysis and the corresponding cumulative impacts map of the city to argue for more careful and health-protective development of areas like the Little Village, Pilsen, and Southeast Side industrial corridors.

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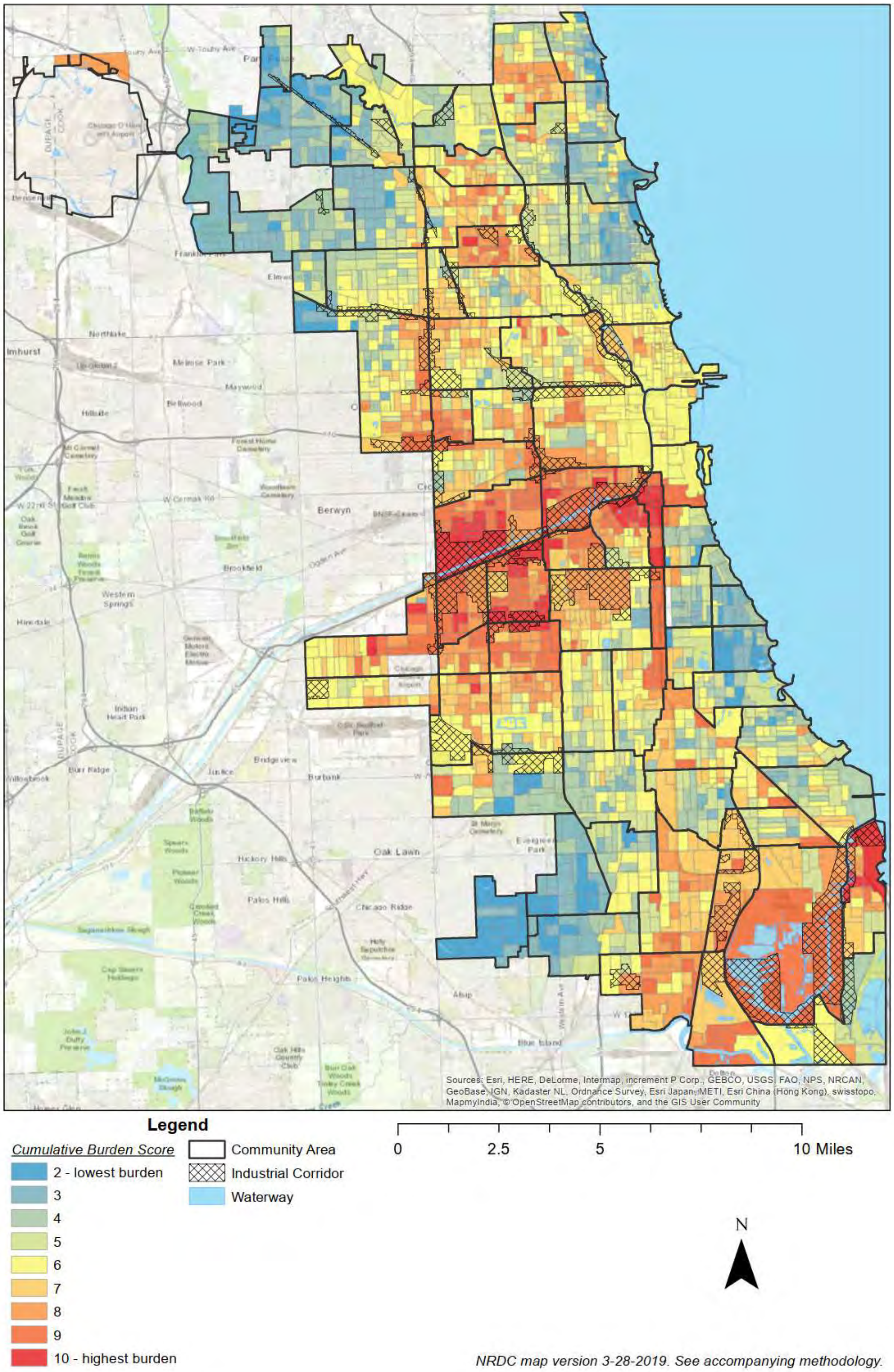
Little Village, Chicago, December 2019.

TABLE 1: INDICATORS FROM EJSCREEN 2018 INCORPORATED INTO CUMULATIVE IMPACTS ANALYSIS

INDICATORS	EJSCREEN'S SOURCE	SOURCE YEAR
ENVIRONMENTAL INDICATORS		
Particulate Matter 2.5 ($PM_{2.5}$)	U.S. EPA Office of Air and Radiation (OAR) modeled and monitoring data	2014
Ozone	U.S. EPA OAR modeled and monitoring data	2014
Diesel Particulate Matter	U.S. EPA National Air Toxics Assessment (NATA)	2011
Air Toxics Respiratory Hazard Index	U.S. EPA NATA	2011
Air Toxics Cancer Risk	U.S. EPA NATA	2011
Lead Paint	American Community Survey	2012–2016
Traffic Proximity	U.S. Department of Transportation	2014
Proximity to Superfund (National Priorities List) Sites	U.S. EPA Superfund Program	2018
Proximity to Risk Management Plan (RMP) Facilities	U.S. EPA RMP Database	2018
Proximity to Treatment Storage Disposal Facilities	U.S. EPA RCRAInfo Database and Biennial RCRA Report	2018
Wastewater Discharge	U.S. EPA Risk-Screening Environmental Indicators Model 2.3.5, Using Toxics Release Inventory 2015	2017
SOCIO-DEMOGRAPHIC INDICATORS		
Low-Income	American Community Survey	2012–2016
Minority[133]	American Community Survey	2012–2016
Less Than High School Education	American Community Survey	2012–2016
Linguistic Isolation	American Community Survey	2012–2016
Under Age 5	American Community Survey	2012–2016
Over Age 64	American Community Survey	2012–2016

MAP I: CHICAGO CUMULATIVE IMPACTS MAP



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

NRDC map version 3-28-2019. See accompanying methodology.

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The coal-fired Crawford Generating Station in South Lawndale, Chicago. Demolition of the plant began in 2019. On April 11, 2020, the concrete smokestack was imploded, blanketing the nearby Little Village neighborhood with toxic dust.

We also presented the cumulative impacts framework and map to the Chicago Department of Public Health (CDPH) to urge for more tailored research on the health status of disproportionately burdened neighborhoods. In 2016, the city had launched its Healthy Chicago initiative to promote community health and well-being, but there was limited application of health data to environmental issues. By emphasizing disproportionately burdened neighborhoods, our analysis sought to focus attention on current inequities and counter the notion that communities must first prove that a specific hazard is causing a specific health outcome in order for action to be taken.[134] On the basis of our analysis and discussions with them, the CDPH agreed to include, for the first time, environmental stressors in its Chicago Health Atlas (chicagohealthatlas.org) and related data compilations, including the Healthy Chicago 2025 Data Compendium.[135] The exchange also helped inspire CDPH's creation of a new Air Quality and Health Index, released in July 2020, which combines indicators on air pollution, polluted sites, health factors, and social factors.[136] And it encouraged the adoption of environmental justice as a priority area in the upcoming Healthy Chicago 2025 community health improvement plan.

Meanwhile, in Newark, our city-level cumulative impacts analysis, conducted in 2018 and updated in 2019, highlighted the Ironbound neighborhood in eastern Newark as especially burdened when compared with the rest of the city (see Map 2). We used this analysis to call attention to disparities within Newark and emphasize the need to implement cumulative impacts policies.

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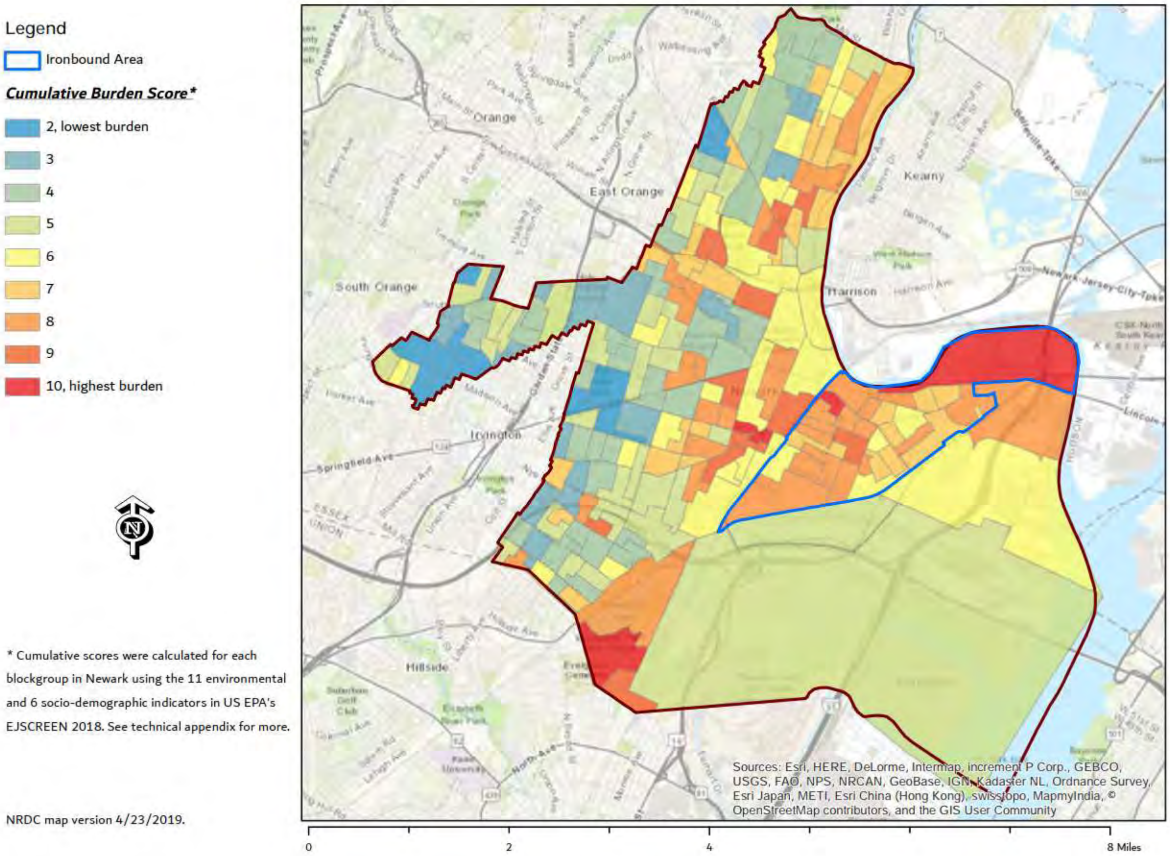
A pile of exhaust pipes and discarded steel parts in one of many dumping grounds on the South Side of Chicago, Illinois, shot on October 25, 2020.

MAP 2: NEWARK CUMULATIVE IMPACTS MAP



* Cumulative scores were calculated for each blockgroup in Newark using the 11 environmental and 6 socio-demographic indicators in US EPA's EJSCREEN 2018. See technical appendix for more.

NRDC map version 4/23/2019.

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Community advocates in Newark, including the Ironbound Community Corporation, have long fought against the disproportionate siting of polluting facilities in low-income communities and communities of color, deriving from a legacy of permissive zoning, weak code enforcement, and race-based residential segregation.[137] In 2016, after efforts by EJ advocates, the city passed an Environmental Justice and Cumulative Impacts Ordinance, which amended its zoning regulations and required all industrial and commercial development applicants to submit an EJ checklist for consideration by the zoning board.[138] The ordinance also charged an Environmental Commission with the task of developing a Natural Resource Inventory for the city, which applicants were to use as a baseline guide for assessing cumulative impacts and preparing the EJ checklist.[139] At the time we conducted our cumulative impacts analysis for Newark, the Natural Resource Inventory was still in development and had not been officially adopted by the Environmental Commission. To help inform that process, we presented our analysis to the Environmental Commission as an example of a relatively simple method and data set that could be used.

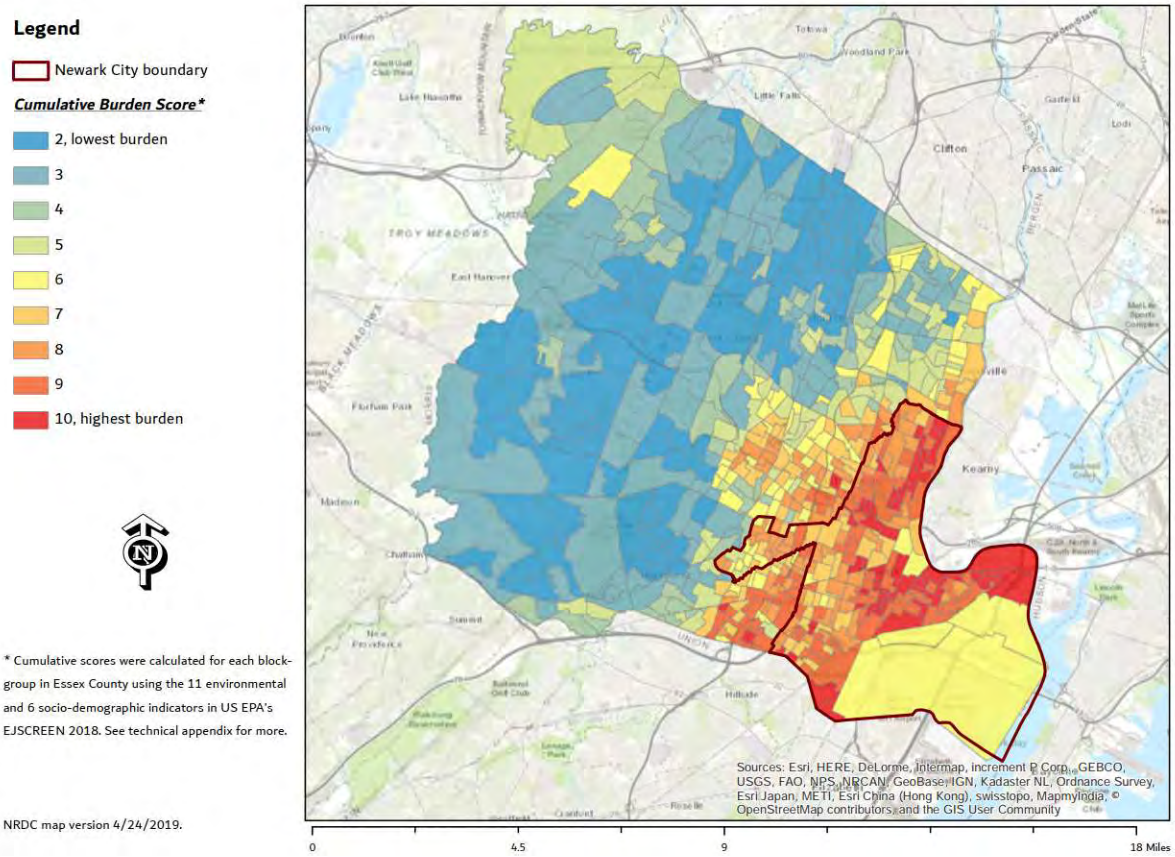
The Newark analysis has been used by the Ironbound Community Corporation (ICC) in educating community youth about environmental justice. The map can also be used to debunk a common misperception observed by ICC that supposedly "the entire northern part [of the state] is a wasteland." It does so by demonstrating that there are still hot spots and disparities—areas of relative privilege and disadvantage—within minutes' driving distance of each other.

Environmental justice advocates have stressed that comparing marginalized neighborhoods only to each other falls into the trap of "playing oppression Olympics," and that the city of Newark as a whole could be considered marginalized; three out of every four Newark residents are people of color, and the median household income is approximately $35,000, much lower than the national average of $60,000.[140] For this reason, our assessment also incorporated a complementary, county-level cumulative impacts analysis for Essex County, New Jersey, where Newark is located. The resulting comparison shows that the city of Newark is disproportionately burdened, compared with the rest of Essex County (see Map 3). An added benefit of this analysis is that adjusting the area of comparison can be helpful depending on the level of policymaker and type of policy targeted. For example, many zoning and permitting decisions are made at the city level, but decisions about waste disposal and green space can be made at the county level.

The New York City skyline as seen from the Ironbound neighborhood of Newark on November 3, 2018.

© Photomuse/Kristin Reimer, for ICC and The New School

MAP 3: ESSEX COUNTY CUMULATIVE IMPACTS MAP



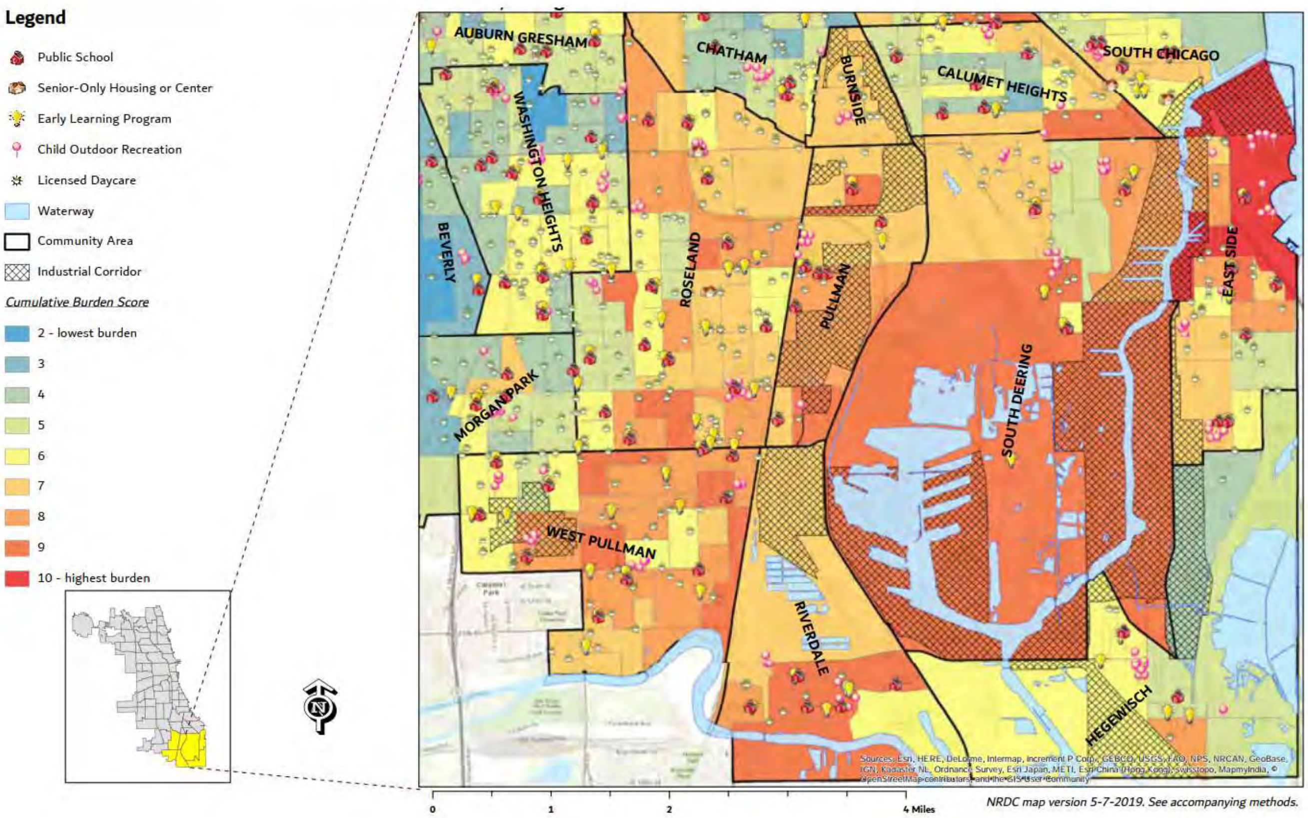
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

* Cumulative scores were calculated for each block-group in Essex County using the 11 environmental and 6 socio-demographic indicators in US EPA's EJSCREEN 2018. See technical appendix for more.

NRDC map version 4/24/2019.

Community advocates in Chicago and Newark have heard the argument that areas plagued by cumulative polluting sources are not areas where people live. Thus, a subsequent step in our analysis involved the use of overlays to refute this argument. We took a more detailed look at both cities and overlaid the locations of sensitive sites like day care facilities, schools, and public housing on top of our cumulative burden map. The results helped demonstrate the real juxtaposition of pollution and population (see Maps 4, 5, and 6).

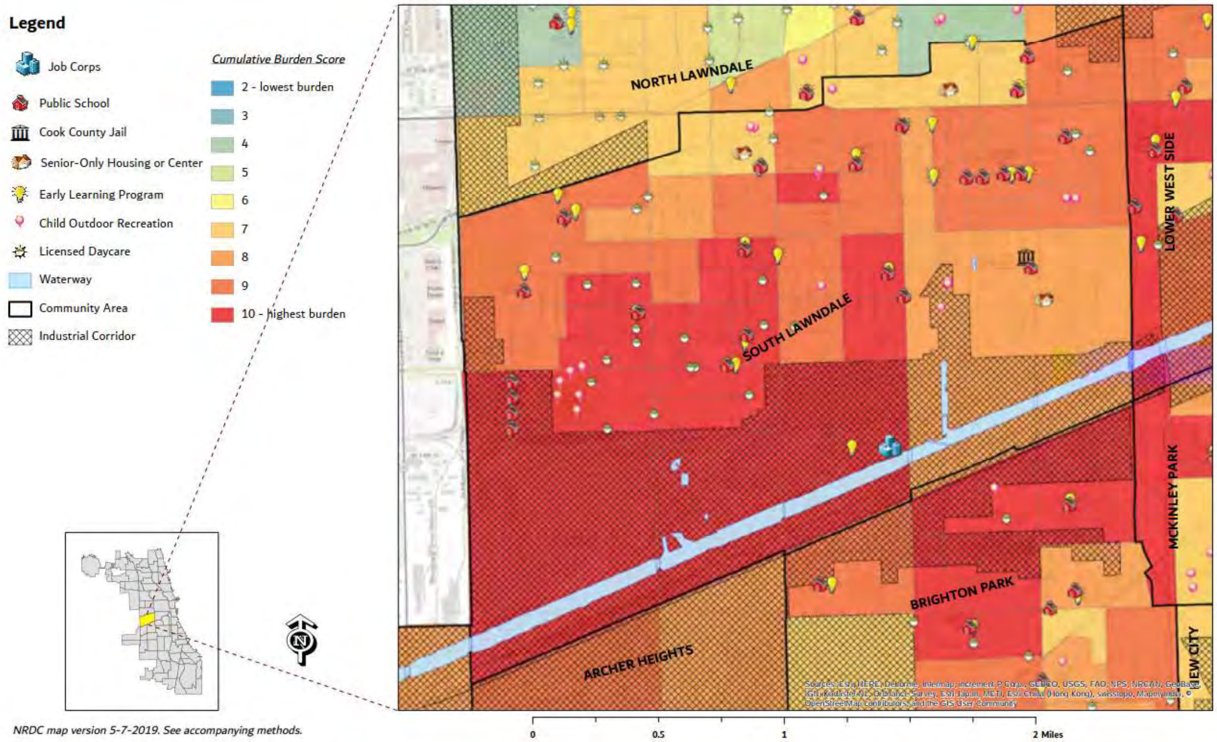
MAP 4: SOUTHEAST SIDE, CHICAGO, CUMULATIVE IMPACTS MAP WITH SENSITIVE SITES



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

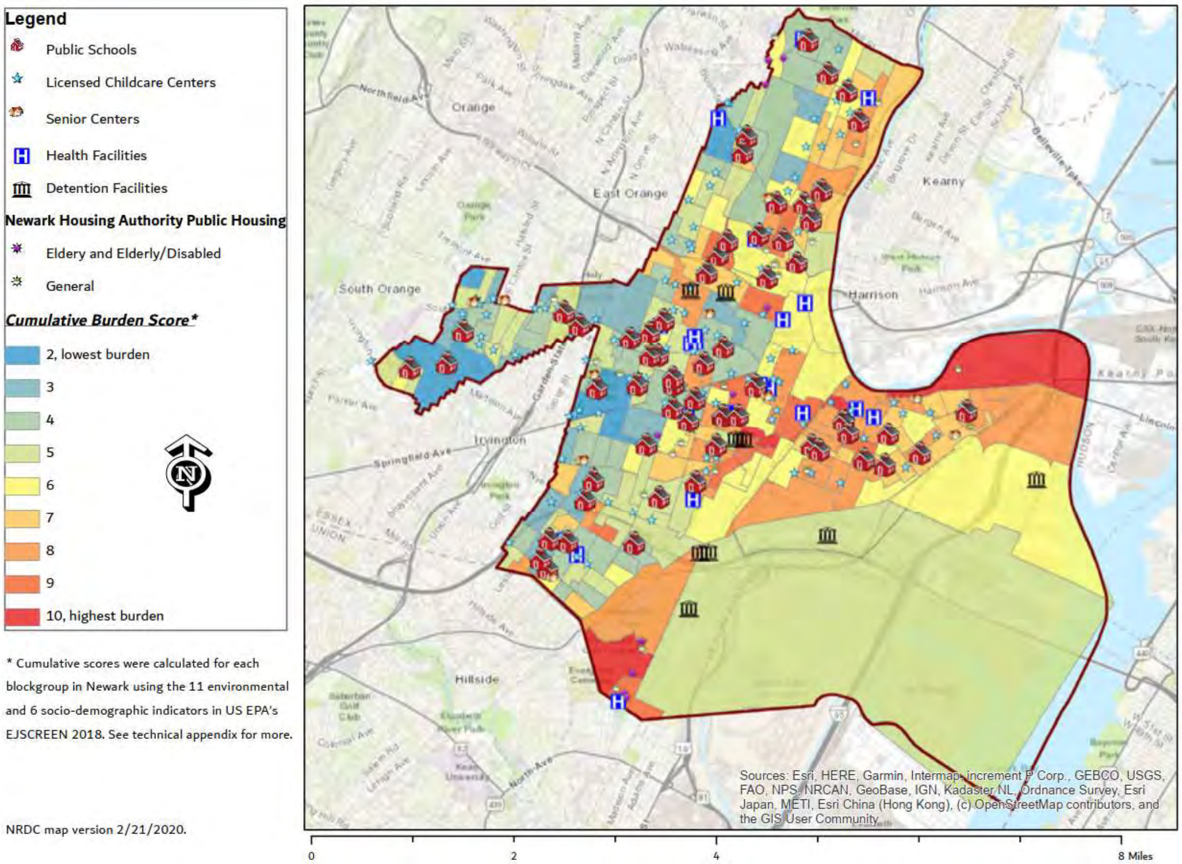
NRDC map version 5-7-2019. See accompanying methods.

MAP 5: SOUTH LAWNDALE, CHICAGO, CUMULATIVE IMPACTS MAP WITH SENSITIVE SITES



NRDC map version 5-7-2019. See accompanying methods.

MAP 6: NEWARK CUMULATIVE IMPACTS MAP WITH SENSITIVE SITES



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

* Cumulative scores were calculated for each blockgroup in Newark using the 11 environmental and 6 socio-demographic indicators in US EPA's EJSCREEN 2018. See technical appendix for more.

NRDC map version 2/21/2020.

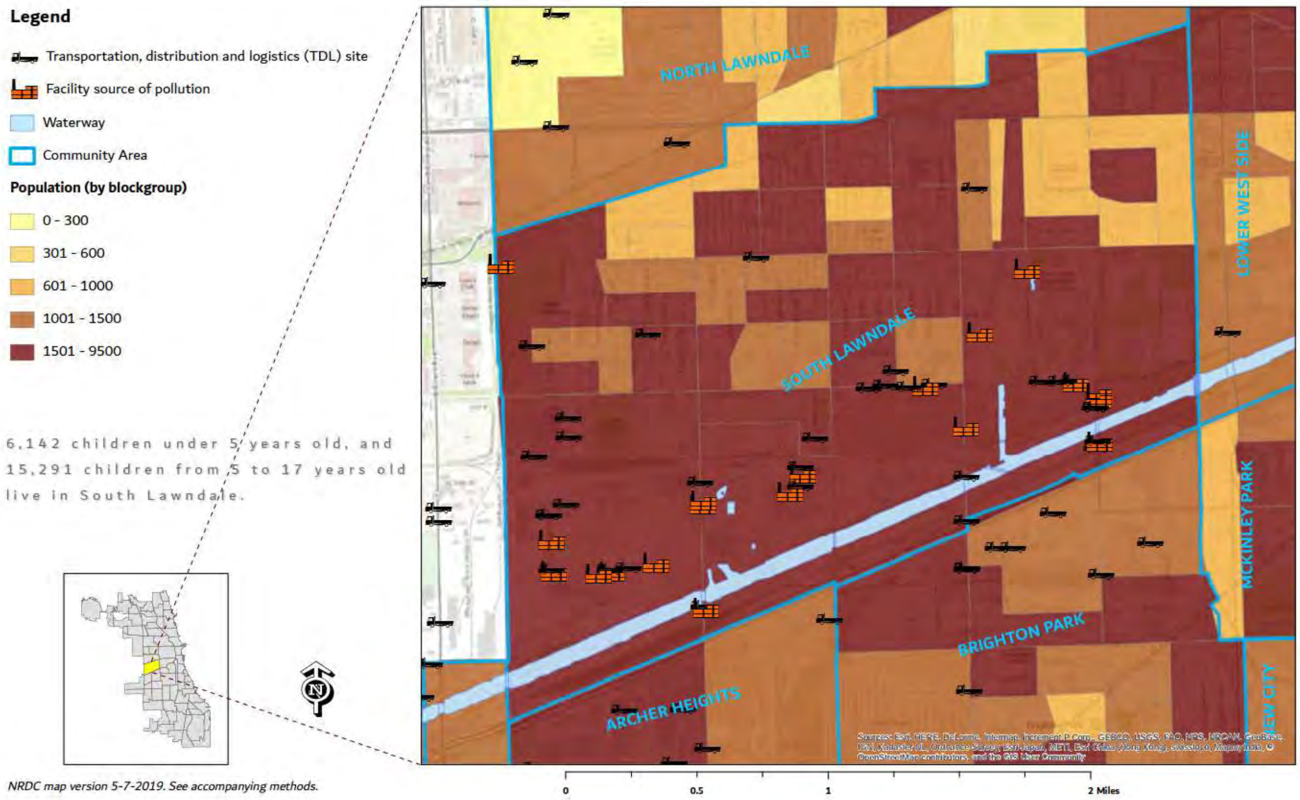
Overlays can be helpful in other instances for including additional population or environmental information absent from official data sources, as well as ground-truthed or community-documented data that fill gaps in agency monitoring. For example, EJSCREEN's traffic indicator does not distinguish among types of vehicles, even though certain types, such as heavy-duty diesel trucks, contribute more pollution than others.[141] However, in Chicago, the Little Village Environmental Justice Organization has conducted truck counts and an inventory of transportation, distribution, and logistics sites, allowing us to create a more accurate picture of pollution burdens (see Map 7). In Newark, the Ironbound Community Corporation has similarly tracked numerous facilities and other pollution sources that do not appear in any U.S. EPA database. Through overlays, this community-based information helps supplement the cumulative impacts analysis, providing a more precise picture of the environmental burden for issues overlooked in official data.

As demonstrated by these case studies, the fact that some communities clearly show up as disproportionately burdened can stimulate discussions about which policies are responsible for that disparity and, conversely, the kinds of development that can most promote health and well-being. The maps help to describe the problem at hand so that effective policy solutions can be crafted.

© Photomuse/Kristin Reimer, for ICC and The New School

Down Bottom Farms, part of the Ironbound Community Corporation's Urban Agriculture program, November 3, 2018.

MAP 7: SOUTH LAWNDALE, CHICAGO, POPULATION AND POLLUTION



NRDC map version 5-7-2019. See accompanying methods.

Developing and Implementing Solutions at the State and Federal Levels

As EJ leaders have long warned, the creation of tools to depict cumulative impacts should not overshadow the implementation of policies to create real change.

Cumulative impacts analysis is useful for understanding and demonstrating the burden facing many EJ communities, but that is only a first step. We need policies that act on this information. In municipalities and states across the country, EJ communities and advocates have been fighting for, and making some progress on, policies that advance environmental justice and address cumulative impacts.[142] One of the most significant policies proposed by EJ advocates to address cumulative impacts is a restriction on permitting new pollution sources or renewing permits for existing facilities in areas that are already overburdened. With this type of policy, advocates and policymakers can use a cumulative impacts analysis similar to the one described here, alongside methods that help address the limitations of such an analysis to identify areas as overburdened; such methods could include incorporating qualitative data, ground-truthing, and allowing a mechanism for communities to self-designate as overburdened. In the overburdened communities identified, rather than allowing more pollution, there should be efforts to reduce pollution and increase environmental goods, such as green space and green infrastructure.

© Sebastián Hidalgo for NRDC

Activists holding protest signs at the Youth Rally Against General Iron in the South Side of Chicago, Illinois, on October 25, 2020.

For more than a decade, the New Jersey Environmental Justice Alliance (NJEJA), Ironbound Community Corporation (ICC), and Clean Water Action, alongside other groups interested in EJ and environmental issues, have pushed for the adoption of such a statewide cumulative impacts policy in New Jersey. A 2013 NJEJA memorandum and subsequent NJEJA policy documents outlined a model statewide policy, including: (1) the identification of communities that are overburdened by pollution, have a significant percentage of low-income population, and/or have a significant percentage of persons of color; (2) the requirement that facilities applying for new permits or permit renewals in such communities demonstrate that they have considered all alternatives for minimizing/eliminating the pollution emitted by their operations; (3) the denial of new permits in these communities unless the facility results in no overall increase in pollution; and (4) the denial of permit renewals unless the applicant can show an overall decrease in emissions.[143]

Advocates for the adoption of a statewide cumulative impacts policy in New Jersey, including NJEJA, ICC, and Clean Water Action, achieved a landmark victory in the summer of 2020. Following 12 years of advocacy and negotiations, New Jersey lawmakers passed state bill S232/A2212, establishing a precedent-setting cumulative impacts law that requires the state Department of Environmental Protection (NJDEP) to deny or condition permits for certain types of facilities, if approval would contribute to disproportionately high "adverse cumulative environmental or public health stressors" in communities meeting certain socio-demographic criteria.[144] Excerpts from the law are contained in the breakout box below. There are some important differences between NJEJA's statewide model policy and the law as passed.[145] Still, pioneers of the policy, including Drs. Ana Baptista and Nicky Sheats, have described the law, respectively, as "a model for other states" and "a foundation from which New Jersey can address environmental justice."[146] Baptista, who is on the Board of Trustees of ICC and NJEJA, and Sheats, who serves on the Board of NJEJA, were part of a small group of veteran EJ advocates who were at the forefront of the fight for the state's cumulative impacts law. This group also included Melissa Miles of NJEJA, Maria Lopez-Nuñez of ICC, and Kim Gaddy of Clean Water Action.

At the federal level, there have been a few recent, significant steps forward in this direction, such as two proposed EJ bills in the House and Senate that would incorporate consideration of cumulative impacts into air and water permitting decisions.[147] As of the writing of this brief, however, neither of these bills had been signed into law.

EJ advocates have also been clear in noting that a problem as broad and deeply rooted as cumulative impacts cannot be solved by just a single policy. Alongside a more careful and just permitting framework, additional measures for tackling cumulative impacts should include:

- Land use and public health reforms to address the industrial facilities, diesel truck traffic, hazardous materials, noxious odors, and other environmental hazards that are located immediately adjacent to parks, schools, and residential neighborhoods;
- Targeted environmental monitoring, enforcement activities, and other types of regulatory attention in vulnerable areas;

© Edwin J. Torres/New Jersey Governor's Office

Melissa Miles (center), Executive Director of NJ Environmental Justice Alliance, speaks alongside Maria Lopez-Nuñez (left), Deputy Director of Organizing and Advocacy at the Ironbound Community Corporation, during the signing ceremony for Senate Bill 232 in Newark, New Jersey, on September 18, 2020.

- Additional localized environmental and public health research, focusing on areas flagged as disproportionately burdened;
- Increased public health resources like access to screening and health services for impacted communities;
- Deployment of additional methods to characterize and understand cumulative impacts, such as biomonitoring, cumulative risk assessment, and health impacts assessments.[148]

One possibility for implementing all or a subset of these policies is through the creation of special zoning districts known as overlay zones, where reducing cumulative impacts and addressing environmental justice would be specific goals, and where a city could add regulations or incentives to guide development toward these goals.[149] Green zones are a particular form of overlay zone aimed not only at controlling pollution but also at encouraging economic development, aligning with the EJ movement's efforts to address economic justice.[150] Cities such as East Austin, Los Angeles, and Minneapolis have used overlay zones and green zones to reduce the concentration of industrial activity near residential areas, mitigate existing pollution burdens, enhance community participation, direct resources, and promote green business development in priority communities, among other goals.[151]

PROGRESS ON ENVIRONMENTAL JUSTICE: NEW JERSEY PASSES A LAW ON CUMULATIVE IMPACTS

NJ state bill S232/A2212 was signed into law on September 18, 2020, making New Jersey the first state in the nation to require denial of permits based on an analysis of cumulative impacts in environmental justice communities. The law applies to:

- **"Overburdened communities,"** defined as census block groups in which the latest U.S. Census data show "(1) at least 35% of the households qualify as low-income households [defined as earning less than twice the federal poverty level]; (2) at least 40% of the residents identify as minority or as members of a State recognized tribal community; or (3) at least 40% of the households have limited English proficiency."[152]
- **Permit applications for new facilities, expansion of facilities, or renewal of facilities for the following types of facilities:** (1) major sources of air pollution (as per the Clean Air Act); (2) resource recovery facilities or incinerators; (3) sludge processing facilities, combustors, or incinerators; (4) sewage treatment plants above a given capacity; (5) solid waste facilities or recycling facilities above a given throughput; (6) landfills; and (7) certain medical waste incinerators.

For a permit application for a covered facility located wholly or partially within an "overburdened community," the law establishes the following:

1. The permit applicant must prepare a detailed Environmental Justice Impact Statement (EJIS) that assesses both the "potential environmental and public health stressors" associated with the proposal and the "environmental or public health stressors already borne by the overburdened community as a result of existing conditions."
2. The permit applicant must submit the EJIS at least 60 days in advance of a public hearing. Specific notice requirements for the hearing are followed regarding mode of communication, timing, language, and content. Interested parties have an opportunity to submit written comments to the applicant.
3. The public hearing will be held in the overburdened community. The municipality will also be invited to participate. At the hearing, there will be an opportunity for meaningful public participation. Interested parties can submit written or oral comments. The applicant will transcribe the hearing, and DEP will consider the testimony presented and any comments received.
4. DEP will not issue a decision until at least 45 days after the public hearing. The DEP "shall deny a permit for a new facility" if it finds that it "would, together with other environmental or public health stressors affecting the overburdened community, cause or contribute to adverse cumulative environmental or public health stressors in the overburdened community that are higher than those borne by other communities within the State, county, or other geographic unit of analysis." (The specific rules are determined in rulemaking that will follow the law's adoption.)
5. For renewals and expansions, DEP "may...apply conditions" to mitigate impacts if it finds that the renewal or expansion "would, together with other environmental and public health stressors affecting the overburdened community, cause or contribute to the adverse cumulative environmental or public health stressors in the overburdened community that are higher than those borne by other communities within the State, county, or other geographic unit of analysis."
6. As part of the process, DEP can charge the applicant fees associated with the costs of providing technical assistance to overburdened communities.

Conclusion

Across the country, the proximity of pollution to neighborhoods where people live, work, and play is a public health threat. As these case studies demonstrate, a partnership combining community experience, knowledge, and advocacy with scientific support can be used to develop cumulative impacts analyses that highlight the environmental justice communities being hit the hardest because of especially high pollution burdens and social vulnerability. Moving from knowledge to action is the next crucial step, and action must come not only from environment and health agencies, but also from those responsible for zoning and planning. A multiagency response to address cumulative impacts, informed by community experience and knowledge, is both necessary and overdue.

Additional resources:

- American Public Health Association, *Policy Statement on "Advancing Environmental Justice to Achieve Health Equity,"* approved in November 2019. The statement describes the connection between environmental justice and public health and suggests actions that public health departments and professionals can take to confront cumulative impacts and promote environmental justice. https://www.apha.org/policies-and-advocacy/public-health-policy-statements/policy-database/2020/01/14/addressing-environmental-justice-to-achieve-health-equity
- Ana Baptista, *Local Policies for Environmental Justice: A National Scan*, Tishman Environment and Design Center, February 2019. The report details efforts by communities in more than 20 cities to transform zoning and local land use policies as a means to address cumulative impacts. https://www.nrdc.org/sites/default/files/local-policies-environmental-justice-national-scan-tishman-201902.pdf

Technical Appendix

This document describes the cumulative impacts analysis methodology and data sources used to produce the maps contained in the policy brief "Seeing the Whole: Using Cumulative Impacts Analysis to Advance Environmental Justice." We first describe the data sources and methodology used to conduct the cumulative impacts analysis, and then describe additional data sources used to produce the overlays that appear in the maps.

In 2017 NRDC began working with the Little Village Environmental Justice Organization, the Southeast Side Coalition to Ban Petcoke, and the Southeast Environmental Task Force to develop a cumulative impacts analysis methodology. The purpose was to analyze the cumulative burden of environmental hazards and socio-demographic characteristics that increase vulnerability and susceptibility to the impacts of those hazards. After conducting a scan of available spatial data and exploring various candidate methodologies, the group decided to adapt the Environmental Justice Screening Method (EJSM) developed by environmental scientist James Saad and colleagues and apply it to the data collected by the 2018 version of the U.S. Environmental Protection Agency's (EPA) environmental justice screening tool, EJSCREEN.[153] EJSM was chosen because it has been shown to be flexible, transparent, and relatively easy for lay audiences to understand. EJSCREEN 2018 was selected as the main source of socio-demographic and environmental information for the analysis because it is fairly comprehensive, current, and credible. Moreover, the data are available nationally (allowing the method to be applied elsewhere in the country) and at a relatively high spatial resolution (at the census block group level). The methodology was initially applied to Chicago, and then to Newark and Essex County, New Jersey.

DATA SOURCES

EJSCREEN 2018, the latest available version at the time of our analysis, compiles data from various government entities on 11 environmental indicators and 6 population indicators.[154] (More information about the data behind these indicators can be found on the EPA's website.[155]) Values for each of those 17 indicators are provided for each census block group in the country. The data file containing EJSCREEN 2018 results for all U.S. census block groups was downloaded from the EJSCREEN website in March 2019 for the Illinois analysis and in April 2019 for the New Jersey analysis.[156] At both times, the "last modified" date of the spreadsheet used, "EJSCREEN_2018_StatePctile.csv," was July 18, 2018.

We downloaded shapefiles for Illinois and New Jersey block groups based on 2014 census geographies from the U.S. Census Bureau website in March and April 2019, respectively.[157] Census geographies for 2014 were used because according to the EJSCREEN website (as accessed in spring of 2019), EJSCREEN 2018 incorporated indicators from the American Community Survey's five-year data for 2012–2016, "which is based on 2014 Census boundaries." A shapefile for Chicago's city boundary was downloaded from the City of Chicago data portal in March 2019.[158] A shapefile representing Newark's wards, dated 2012, was downloaded from the City of Newark data portal in April 2019.[159]

STEPS TO PREPARE THE DATA

FOR CHICAGO:

The Illinois census block group shapefile and Chicago city boundary shapefile were imported into ArcMap 10.6 and projected into the Illinois State Plane East projected coordinate system. A spatial join was performed to join the city boundary to Illinois block groups to derive the block groups located in Chicago. This generated 2,328 block groups, which were manually refined to 2,180 block groups based on zooming in and hand-excluding block groups that were mostly located outside the city boundary. In R, data from the full EJSCREEN 2018 data set were matched to the 2,180 Chicago block groups based on the census block group ID. Four block groups were further excluded because they were missing values for three environmental indicators in EJSCREEN (the three corresponding to the National Air Toxics Assessment). Thus, the final data set used for the Chicago cumulative impacts analysis consisted of 2,176 block groups and the 17 EJSCREEN indicators for them.

FOR NEWARK:

The New Jersey census block group shapefile and Newark ward shapefile were imported into ArcMap 10.6 and projected into the New Jersey State Plane projected coordinate system. Block groups that appeared to fall within Newark's wards were manually selected, yielding 204 Newark block groups. In R, data from the full EJSCREEN 2018 data set were matched to the Newark block groups. The final data set used for the Newark cumulative impacts analysis consisted of 204 block groups and the 17 EJSCREEN indicators for them.

FOR ESSEX COUNTY:

We were able to obtain block group IDs for block groups in Essex County directly from the American Community Survey (ACS). (We downloaded a data table for Essex County from the ACS for 2012–2016 five-year estimates of total population to get the block group IDs.) There were 671 block groups identified as belonging to Essex County. In R, data from the full EJSCREEN 2018 data set were matched to the Essex County block groups. The final data set used for the Essex County cumulative impacts analysis consisted of 671 block groups and the 17 EJSCREEN indicators for them.

ANALYSIS

Analysis was performed in R for each area of focus (Chicago, Newark, and Essex County). As an illustration, analysis for Chicago was conducted as follows: For each of the 17 indicators, each Chicago block group was assigned a quintile score from 1 to 5, corresponding to its value for that indicator. A score of 1 meant that the block group's value for that indicator fell into the bottom 20 percent of all Chicago block groups; a score of 5 meant that the value for that indicator was in the top 20 percent. For all EJSCREEN indicators, higher scores correspond to higher levels of pollution or socio-demographic vulnerability.

For each block group, we summed the quintile scores for the 11 environmental variables, which gave us a total that theoretically could range from 11 to 55.[160] Next we determined where each block group score stood in relation to all of the other Chicago block group scores and assigned a new quintile number to each block group. For instance, if a block group's total was in the bottom fifth of all Chicago block groups, it received a score of 1. This was its "environment quintile score."

We repeated the same process for the population variables. For each block group, we summed the quintile scores for the 6 socio-demographic variables, which yielded a total that could theoretically be anywhere from 6 to 30. We then assigned a new quintile score, from 1 to 5, to each block group based on how this total ranked within the totals for all of the other Chicago block groups. This was its "population quintile score."

The last step consisted of adding each block group's environment quintile score and population quintile score to get a final number, ranging from 2 to 10. For example, a block group that was in the highest quintile for both environmental and socio-demographic factors would have a final score of 10 (5+5). For both environmental and socio-demographic indicators, higher values denote greater pollution or vulnerability. Thus, the higher the block group's final score, the greater the cumulative burden. The final scores were joined back to the block groups and mapped in ArcMap.

The same methodology was followed using Newark and Essex County as areas of analysis.

ADDITIONAL DATA SOURCES FOR OVERLAYS SHOWN

- Chicago industrial corridors: shapefile obtained from City of Chicago data portal in May 2018.[161]
- Chicago community areas: shapefile obtained from City of Chicago data portal in March 2019.[162]
- Chicago waterways—shapefile obtained from City of Chicago data portal in March 2019.[163]
- Ironbound community boundary: created from manual selection of block groups, based on Google map of Ironbound community.
- Chicago public schools: addresses downloaded from Chicago Public Schools website in March 2019 (file appeared to have been last updated in October 2018).[164]
- Chicago senior-only housing and senior centers:
    - For senior centers, a list, dated March 7, 2019, was obtained from the City of Chicago data portal in March 2019.[165]
    - For senior-specific public housing, in March 2019 we accessed the Chicago Public Housing Authority's list of public housing and used its search engine to search for senior-specific housing.[166] (For the purpose of creating this layer for the maps shown, we included only the two senior public housing facilities located in the Southeast Side and South Lawndale.)
    - For other senior housing, in March 2019 we accessed the City of Chicago's Family & Support Services web page.[167] A list of assisted living, supportive living, and nursing homes was assembled. By definition, supportive living facilities house only older individuals, so these were all included. For assisted living and nursing homes, we called facilities to determine which ones were limited to seniors and included only the ones that were.
- Chicago early-learning programs (ELPs): addresses downloaded from the City of Chicago data portal in March 2018 (we checked in March 2019 to noted that there was no more recent version of the spreadsheet, which was dated December 2017).[168] These appear to be city-funded ELPs.
- Chicago child outdoor recreation sites: shapefile obtained from City of Chicago data portal in March 2019.[169] (This file was dated November 2016, last updated in May 2017.) We considered features described as playground parks, playgrounds, spray features, junior baseball/softball, and outdoor pools as child outdoor recreation sites.

- Chicago licensed day care facilities: addresses obtained through a search performed in March 2019 on the Illinois Department of Children & Family Services website.[170] A search for "Chicago" as city and "City of Chicago" as county generated 2,549 day care facilities.
- South Lawndale, Chicago, and surrounding community areas' transportation, distribution, and logistics (TDL) sites: sites obtained from the Little Village Environmental Justice Organization's data sets.
- Newark public schools: list obtained from Newark Public Schools website in February 2020.[171]
- Newark licensed child care centers: list obtained from the New Jersey Office of Information Technology's Open Data Center in April 2019.[172]
- Newark senior centers: addresses obtained from a senior resources web page and from the City of Newark's Division of Senior Services' list of senior centers in February 2019.[173]
- Newark health facilities: list of health facilities compiled from conducting Google searches, consulting community partners, and looking at city resources, including the City of Newark Department of Health and Community Wellness and Newark Community Health Centers, throughout 2018.[174]
- Newark detention facilities: list of detention facilities compiled from Google searches and from state and county websites, including the New Jersey Department of Corrections, throughout 2018.[175]
- Newark Housing Authority public housing: spreadsheet of all affordable housing for Essex County, dated 2015, downloaded from the New Jersey Department of Community Affairs website in June 2018.[176] We selected records corresponding to public housing under the Newark Housing Authority. Distinction between senior-specific and general public housing was made on the basis of a variable in the spreadsheet called "type" with values "family" and "age."

All spatial data files were imported into ArcMap and projected into the corresponding projected coordinate system. All locations/addresses were geocoded in ArcMap using the ArcGIS World Geocoding Service.

ENDNOTES

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9 U.S. EPA, "EJSCREEN: Environmental Justice Screening and Mapping Tool: How Was EJSCREEN Developed?," https://www.epa.gov/ejscreen/how-was-ejscreen-developed (accessed February 24, 2020).

10 National Environmental Justice Advisory Council (NEJAC) to the U.S. EPA, *Nationally Consistent Environmental Justice Screening Approaches*, May 2010, https://www.epa.gov/sites/production/files/2015-02/documents/ej-screening-approaches-rpt-2010.pdf. Although there were various early screening tools at the U.S. EPA, many of them were intended to be used only internally and were generally unavailable to the public. U.S. EPA, *EJSCREEN Environmental Justice Mapping and Screening Tool: EJSCREEN Technical Documentation*, September 2019, https://www.epa.gov/sites/production/files/2017-09/documents/2017_ejscreen_technical_document.pdf.

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127 James Sadd et al., "Playing It Safe: Assessing Cumulative Impact and Social Vulnerability Through an Environmental Justice Screening Method in the South Coast Air Basin, California," *International Journal of Environmental Research and Public Health* 8, no. 5 (May 2011): 1441–59, https://doi.org/10.3390/ijerph8051441. George Alexeeff et al., "A Screening Method for Assessing Cumulative Impacts," *International Journal of Environmental Research and Public Health* 9, no. 2 (February 2012): 648–59, https://doi.org/10.3390/ijerph9020648. Amy Schulz et al., "Race and the Distribution of Social and Physical Environmental Risk: A Case Example From the Detroit Metropolitan Area," *Du Bois Review: Social Science Research on Race* 13, no. 2 (October 2016): 285–304, https://doi.org/10.1017/S1742058X16000163.

128 The Environmental Justice Screening Method (EJSM) was developed by a group of California-based researchers who have been at the forefront of advancing cumulative impacts analysis. In the process, the researchers received extensive input not only from the state's agency scientists and other scientific colleagues, but also from community stakeholders working on environmental health and environmental justice. As a result, EJSM is a scientifically sound tool capable of providing regulatory guidance while also being transparent and easily understandable to diverse audiences. These qualities motivated us to choose the EJSM as a basis for our method over alternative, more complex methodologies. Sadd et al., "Playing It Safe: Assessing Cumulative Impact."

129 It is important to note that cumulative impacts analysis is different from typical scientific measurements, which yield specific estimates and measures of uncertainty, because here the "measurements" are relative and the uncertainty is not explicit. There is, of course, uncertainty in the underlying environmental and demographic indicators that we use. Our analysis is only as reliable as the data provided through EJSCREEN, and there are limitations to EJSCREEN, as described earlier. Despite these limitations, our cumulative impacts analysis provides a general sense of the relative burden experienced across city areas. Results should always be supplemented with additional research and local knowledge.

130 American Public Health Association, *Policy Statement on "Advancing Environmental Justice."*

131 City of Chicago, Department of Planning and Development, "Industrial Corridor Modernization Initiative," updated May 14, 2020, https://www.chicago.gov/city/en/depts/dcd/supp_info/repositioning-chicago-s-industrial-corridors-for-today-s-economy.html.

132 City of Chicago, Department of Planning and Development and Department of Transportation, *Mayor Emanuel's Industrial Corridor Modernization: North Branch Framework*, May 2017, https://www.chicago.gov/content/dam/city/depts/dcd/supp_info/industrial/NBIC_Adopted_Final_For-Web.pdf. Municipal Code of Chicago, § 16-8-020.

133 *Minority* is the term used by EJSCREEN to indicate the portion of the population that is nonwhite. We are not endorsing this terminology, but we do utilize it here to make it clear which EJSCREEN indicator we are referencing.

134 For a description and case study of how the dominant paradigm of "expert" data production and evidentiary requirements reinforces environmental racism and denies recourse to EJ communities, see Lauren Richter, "Constructing Insignificance: Critical Race Perspectives on Institutional Failure in Environmental Justice Communities," *Environmental Sociology* 4, no. 1 (January 2018): 107–21, https://doi.org/10.1080/23251042.2017.1410988. As described by Richter, this problem is particularly serious in the context of cumulative exposures and renders the harm caused by these exposures "scientifically and legally invisible."

135 Nikhil Prachand et al., *Healthy Chicago 2025 Data Compendium*, City of Chicago, Department of Public Health, October 2019, https://www.chicago.gov/content/dam/city/depts/cdph/CDPH/Healthy_Chicago_2025_Data-Compendium_10222019.pdf.

136 City of Chicago, *Air Quality and Health Report*, 2020, https://www.chicago.gov/content/dam/city/depts/cdph/statistics_and_reports/Air_Quality_Health_doc_FINALv4.pdf.

137 Ana Baptista, *Local Policies for Environmental Justice: A National Scan*, Tishman Environment and Design Center, February 2019, https://www.nrdc.org/sites/default/files/local-policies-environmental-justice-national-scan-tishman-201902.pdf.

138 City of Newark, New Jersey, "Environmental Justice and Cumulative Impact Ordinance," no. 16-0803, July 2016, https://www.njeja.org/wp-content/uploads/2019/10/Newark_EJ_CumulativeImpacts_ordinance.pdf.

139 Ibid.

140 U.S. Census Bureau, "QuickFacts: Newark City, New Jersey; United States," https://www.census.gov/quickfacts/fact/table/newarkcitynewjersey,US/PST045219 (accessed September 30, 2020).

141 Union of Concerned Scientists, "Cars, Trucks, Buses and Air Pollution," July 2008, updated July 2018, https://www.ucsusa.org/resources/cars-trucks-buses-and-air-pollution. U.S. Department of Transportation, Bureau of Transportation Statistics, "Estimated US Average Vehicle Emissions Rates per Vehicle by Vehicle Type Using Gasoline and Diesel," https://www.bts.gov/content/estimated-national-average-vehicle-emissions-rates-vehicle-vehicle-type-using-gasoline-and (accessed July 1, 2020).

142 A 2019 national landscape assessment commissioned by NRDC, LVEJO, SETF, and SSCBP and conducted by EJ expert and New School professor Ana Baptista describes several of these reforms. The policies, used to address cumulative impacts and environmental justice more broadly, are classified under six categories: (1) bans on specific types of polluting facilities, (2) general EJ policies, (3) targeting existing land uses, (4) proactive planning, (5) public health codes/policies, and (6) review processes. Baptista, *Local Policies for Environmental Justice.*

143 Nicky Sheats et al., "Cumulative Impacts and the Permitting Process," memorandum of the New Jersey Environmental Justice Alliance Cumulative Impacts Committee, June 2013, https://njeja.org/wp-content/uploads/2021/08/NJEJA-Statewide-Cumulative-Impacts-Policy_2019.pdf. New Jersey Environmental Justice Alliance, "Statewide Policy Platform: 2017–2018," 2018, http://www.njeja.org/wp-content/uploads/2018/02/NJEJA-Policy-Platform-Final.pdf.

144 The final text of the signed law is available at https://www.njleg.state.nj.us/2020/Bills/S0500/232_R2.htm (accessed October 9, 2020). See also New Jersey State Senate, "Committee Statement on the 'Environmental Justice and Cumulative Impacts Bill' (S232) Submitted to the 219th Legislature," June 25, 2020, https://www.njleg.state.nj.us/2020/Bills/S0500/232_S2.PDF. Clean Water Action, "NJ Assembly and Senate Just Passed National Precedent Setting Environmental Justice Bill This Afternoon," August 27, 2020, https://cleanwateraction.org/releases/nj-assembly-and-senate-just-passed-national-precedent-setting-environmental-justice-bill.

145 A detailed analysis of these policies, including their differences, is beyond the scope of this brief but will be covered in a forthcoming publication by Nicky Sheats et al.

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147 Environmental Justice Initiative of Chair Raúl M. Grijalva and Representative A. Donald McEachin, "Discussion Draft of 'Environmental Justice for All Act,'" February 26, 2020, https://www.popvox.com/madison/documents/environmental-justice-for-all-act. Office of U.S. Senator Cory Booker, "Booker Reintroduces Sweeping Environmental Justice Bill," July 24, 2019, https://www.booker.senate.gov/news/press/booker-reintroduces-sweeping-environmental-justice-bill.

148 On these additional methods for studying cumulative impacts, see Solomon et al., "Cumulative Environmental Impacts."

149 Baptista, *Local Policies for Environmental Justice.*

150 Ibid.

151 Ibid.

152 Note that these socio-demographic thresholds were negotiated between policymakers and advocates and chosen specifically for the New Jersey context; these thresholds may not be the most appropriate for other states seeking to implement a similar policy. Note also that as of the writing of this document, there is variation in the usage of the terms *overburdened community* and *environmental justice community* for purposes of policy. The New Jersey law refers to low-income communities and communities of color as "overburdened communities," whereas elsewhere (such as in the memorandum by the NJEJA Cumulative Impacts Committee cited above), these communities are called "environmental justice communities."

153 James Sadd et al., "Playing It Safe: Assessing Cumulative Impact and Social Vulnerability Through an Environmental Justice Screening Method in the South Coast Air Basin, California," *International Journal of Environmental Research and Public Health* 8, no. 5 (May 2011): 1441–59, https://doi.org/10.3390/ijerph8051441.

154 The environmental variables are: air toxics cancer risk, air toxics respiratory hazard, ozone, diesel particulate matter (PM), fine particulate matter ($PM_{2.5}$), traffic, potential lead paint exposure, proximity to Superfund sites, proximity to hazardous waste management facilities, proximity to facilities with potential chemical accidents, and toxic releases into waterways. The population indicators are the percentages of the population with the following characteristics: household income less than twice the poverty level, minority status, less than a high school education, linguistic isolation, under age 5, and over age 64.

155 U.S. Environmental Protection Agency (hereinafter EPA), "EJSCREEN: Environmental Justice Screening and Mapping Tool: Understanding EJSCREEN Results," https://www.epa.gov/ejscreen/understanding-ejscreen-results (accessed August 11, 2020).

156 EPA, "EJSCREEN: Environmental Justice Screening and Mapping Tool," https://www.epa.gov/ejscreen (accessed August 11, 2020).

157 U.S. Census Bureau, "TIGER/Line Shapefiles," https://www.census.gov/cgi-bin/geo/shapefiles/index.php (accessed August 11, 2020).

158 City of Chicago, "Data Portal," https://data.cityofchicago.org/ (accessed August 11, 2020).

159 City of Newark, "Open Data Portal," http://data.ci.newark.nj.us/ (accessed August 11, 2020).

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161 City of Chicago, "Data Portal."

162 Ibid.

163 Ibid.

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165 City of Chicago, "Data Portal."

166 Chicago Housing Authority, "Find Public Housing," https://www.thecha.org/residents/public-housing/find-public-housing (accessed August 11, 2020).

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168 City of Chicago, "Data Portal."

169 Ibid.

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173 Senior Center Resources for Seniors, "Senior Centers in Newark NJ," https://seniorcenter.us/senior-centers-city/newark_nj (accessed August 11, 2020). City of Newark, "Senior Services," https://www.newarknj.gov/card/newark-senior-services (accessed August 11, 2020).

174 City of Newark, "Department of Health and Community Wellness," https://www.newarknj.gov/departments/healthcommunitywellness (accessed August 11, 2020).

175 State of New Jersey, "Department of Corrections," https://www.state.nj.us/corrections/pages/index.shtml (accessed August 11, 2020).

176 State of New Jersey, Department of Community Affairs, "List of Affordable Developments by County," https://www.nj.gov/dca/divisions/codes/publications/developments.html (accessed August 11, 2020).