Air Quality and Land Use Planning:

A Review of the Literature on High-Volume Roadways, Health Effects, and Mitigation Strategies

April 2023

SUSTAINABLE BELLEVUE

CITY OF BELLEVUE WASHINGTON

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I. Introduction

Report Summary

Today, Bellevue is at a critical juncture in its evolution where the local need for housing and services across the city is growing, yet the amount of unconstrained developable land in the city is shrinking. The city will plan and adopt policy changes to accommodate an increase of at least 35,000 new housing units for the 2019-2044 planning period. This housing target is significantly higher than the city's previous 25-year housing target of 17,000 new units for the period between 2006-2031.

As Bellevue plans for and encourages the creation of new housing affordable to all income levels, it must balance a variety of factors, including market factors, buildable land capacity, the location of mass transit, and environmental health considerations, when making planning and land use policy decisions about where to locate these residential land uses and their development intensity. None of these factors should be considered in a vacuum.

This report provides environmental health information for the city to consider, along with other factors, when making long-range planning decisions to increase development capacity. Specifically, this report focuses on air pollution that exists around high-volume roadways at concentrations that can be harmful, with analysis informed by studies which have shown that health impacts associated with traffic-related air pollution (TRAP) can be minimized by reducing exposure to high pollutant concentrations. The Annotated Bibliography attached to this report summarizes key findings from the studies referenced and relied upon herein.

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C.1.6. Air quality. Pilot air quality monitoring sensors and incorporate air quality considerations into planning for major rezonings.

As directed by the regional growth management strategy Vision 2050, Bellevue's growth over the next 30 years will be directed to the city's growth center and mixed-use areas. These targeted growth areas, including downtown, BelRed, Eastgate, and Wilburton, are all located in close proximity to major freeways. Bellevue has limited air quality data for the city, and better air quality data will help to support land use planning and development to prevent negative public health impacts from residential development in proximity to major transportation corridors.

Piloting air quality monitoring sensors will help to determine the need for a more robust air quality monitoring program in Bellevue, particularly in high-priority locations undergoing development in proximity to freeways. This action will also involve consideration for policy and land use code updates to account for environmental justice and air quality issues, to ensure that housing and open spaces are sited at a safe distance from major transportation emissions sources, and that mitigation steps are taken for development closer to freeways.

Considerations for air quality will be taken into account for upcoming land use projects, such as Wilburton, BelRed, and the Grand Connection, and for all neighborhoods adjacent to freeways.

States around the nation, as well as local jurisdictions in King County, have been taking a closer look at the health risks associated with exposure to TRAP and have developed mechanisms and guidance to protect vulnerable populations. These planning and land use considerations have focused on Air Pollutant Exposure Zones (APEZs), which are areas within 500 feet of high-volume roadways. Noting these advances plus the historical gap that has existed in the city, Sustainable Bellevue, the City's Environmental Stewardship Plan, adopted action C.1.6 in December 2020 calling for air quality to be considered during land use planning around freeways.

Bellevue will be developing and evaluating different growth alternatives during its periodic update to the City's Comprehensive Plan and the Wilburton Vision Implementation initiative, and the health effects associated with exposure to TRAP should be a consideration. Growth alternatives that increase capacity for sensitive uses outside of APEZs should be explored, and when growth is located within APEZs, specific mitigation measures should be considered. As Bellevue continues to grow, the city should also fill in a historical gap and use available information, including air quality reports and studies, to balance the desire to limit exposure to air pollution with the need to increase growth, particularly housing for all income levels, throughout the city.

A primary purpose of this report is to provide a review of the literature on traffic-related air pollution, its impacts on health, and an overview of planning practices for reducing vulnerable populations' risks of exposure to harmful traffic-related air pollutants. Two documents – the California Air Resources Board's *Air Quality and Land Use Handbook* (2005)[1] and the Environmental Protection Agency's *Best Practices for Reducing Near-Road Pollution Exposure at Schools* (2015)[2] – have informed the guidance, strategies, and mitigation measures identified throughout this report. To support the City's long-range planning efforts, this report aims to increase awareness and understanding of:

- TRAPs and where they tend to concentrate,
- Pollutant impacts on health, especially on the health of vulnerable populations, and
- Potential planning and land use practices the city should consider to minimize and mitigate exposure to TRAP.

Chapter I is an introduction to air quality and traffic-related air pollution with reference to relevant local and regional policy guidance. Chapter II provides an overview of how air quality is measured and the impacts of air quality on public health. Chapter III provides more context on air quality and land use in Bellevue, identifying air pollutants, locations, and populations of concern. Chapter IV provides an overview of strategies to avoid, minimize, and mitigate impacts associated with the siting of land uses next to high-volume roadways along with a summary of strategies from other local governments, primarily for illustrative purposes. Finally, in Chapter V, the report provides additional information for Bellevue to consider when developing different growth alternatives to balance the desire to limit exposure to air pollution with the need to increase growth throughout the city.

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[1] California Environmental Protection Agency, Air Resources Board, 2005, Air Quality and Land Use Handbook, accessed https://www.arb.ca.gov/ch/handbook.pdf

[2] Environmental Protection Agency, 2015, Best Practices for Reducing Near-Road Pollution Exposure at Schools, accessed https://www.epa.gov/sites/default/files/2015-10/documents/ochp_2015_near_road_pollution_booklset_v16_508.pdf

Ultimately, the goal of this report is to provide a framework for the city to consider and evaluate air quality when planning for growth next to freeways. The information provided in this report is intended to inform the process by which planning decisions are made and support informed decision making so that the city may incorporate air quality considerations into its growth management strategies and policies.

NATIONAL IMPACTS OF AIR POLLUTION

According to the American Lung Association, 4 in 10 Americans – more than 135 million people – live where pollution levels frequently make the air too dangerous to breathe. [1] However, exposure to air pollution is not evenly shared. It depends on the concentration of pollutants in the air and how long a person breathes them in over time. Health risks from air pollution vary depending on exposure and a person's health condition, age, and genetic background. Other factors may also increase vulnerability to health effects, such as income, race/ethnicity, and health insurance status. Low-income communities and communities of color bear a disproportionate burden of breathing polluted air. [1]

Overview of Bellevue Context

With three major freeways each carrying upwards of 100,000 average annual daily vehicle trips, Bellevue has a comparatively high proportion of land within APEZs relative to other cities. Nevertheless, the proportion of overall city land falling within these areas is still relatively small at 13 percent. In contrast to older jurisdictions where freeways cut through the middle of dense existing neighborhoods, Bellevue's freeways were placed where development intensity was low. As a result of these growth patterns, APEZs in Bellevue have had low intensity development historically, and the build-out of the city over time has resulted in relatively few people being at risk of exposure to high concentrations of air pollutants. As potential locations for additional housing of a variety of types are considered in the future, this balance could shift if that exposure is not taken into account.

While all areas within 500 feet of a high-volume roadway are in an APEZ, factors such as high traffic volumes, low elevations, prevailing wind patterns, and high levels of congestion can result in certain areas having even higher pollutant concentrations resulting in greater risks of exposure. Higher risk areas exist in portions of all Bellevue's neighborhood areas adjacent to freeways – Newport Hills, Factoria, Eastgate, West Lake Sammamish, Woodridge, West Bellevue, Wilburton, Downtown, Northwest Bellevue, BelRed and Bridle Trails.

Recently, the city began processing the periodic update to its Comprehensive Plan as well as initiatives to update plans for neighborhoods adjacent to freeways, such as the western portion of Wilburton and the BelRed Subarea. Additionally, in the future, the city's housing strategy may include targeted efforts to partner, purchase, or otherwise create housing opportunities aimed at vulnerable populations such as those at risk of being homeless. This report will inform and support the city's consideration of exposure to air pollutants and equity analyses in these long-range planning efforts.

Overview of Environmental Health Impacts

The California Air Resources Board's *Air Quality and Land Use Handbook* (2005)[3] and the Environmental Protection Agency's *Best Practices for Reducing Near-Road Pollution Exposure at Schools* (2015)[4] provide guidance on how to evaluate and mitigate the potential health impacts associated with exposure to air pollution around high-volume roadways, especially for sensitive land uses.

The most effective strategy for reducing exposure to air pollutants is limiting the siting of sensitive uses in APEZs. For example, the California Air Resources Board's *Air Quality and Land Use Handbook* (2005)[5], recommends against siting new sensitive land uses, such as residences, schools, daycare centers, playgrounds, or medical facilities, within 500 feet of a freeway, urban roads with 100,000 vehicles/day, or rural roads with 50,000 vehicles/day.[6] Given the collaboration, trade-offs, and difficult choices that the city will face about the location of growth, the type of growth to be encouraged and supported, environmental health and protection, and the quality of life throughout the city, outright avoidance of APEZs may not always be achievable or desirable.

When avoidance of exposure to air pollutants is not feasible or achievable due to competing policy considerations, other strategies may mitigate exposure risk, and new non-sensitive uses locating within APEZs may reduce exposure to air pollution through mitigation measures, including the following:

- Increasing the distance between sensitive uses and high-volume roadways,
- Installing physical and/or vegetative buffers between buildings and high-volume roadways,
- Siting air intakes so that they are farthest from or shielded from TRAP, and

[3] California Environmental Protection Agency, Air Resources Board, 2005, Air Quality and Land Use Handbook, accessed https://www.arb.ca.gov/ch/handbook.pdf

[4] Environmental Protection Agency, 2015, Best Practices for Reducing Near-Road Pollution Exposure at Schools, accessed https://www.epa.gov/sites/default/files/2015-10/documents/ochp_2015_near_road_pollution_booklset_v16_508.pdf

[5] California Environmental Protection Agency, Air Resources Board, 2005, Air Quality and Land Use Handbook, accessed https://www.arb.ca.gov/ch/handbook.pdf

[6] California Environmental Protection Agency, Air Resources Board, 2005, *Air quality and land use handbook: A community health perspective,* accessed https://www.arb.ca.gov/ch/handbook.pdf

- Installing and regularly maintaining air filters with Minimum Efficiency Reporting Values (MERV) ratings at 13 or above.

Overview of Air Quality Impacts

Despite air quality improving dramatically over the last several decades, air pollution is still one of the greatest environmental risks to health.[7] According to the American Lung Association, 4 in 10 Americans – more than 135 million people – live where pollution levels of particulate matter and ozone are unhealthy.[8]

In addition, research has demonstrated that vehicles burning fossil fuels – particularly diesel-powered vehicles – create pollution hot spots near high-volume roadways. Other sources of TRAP include tire and brake wear, which contribute to ultrafine particles (UFPs). Studies have found that health risks can be attributed to being as far as 1,500 feet from freeways, freight corridors, and other major roadways, with 100,000 average annual daily trips or above, though most pollution levels tend to improve beyond 500 feet.[9,10,11] Areas that fall within 500 feet of a high-volume roadway are considered APEZs.

In Bellevue, about 13 percent of the city's land area is within an APEZ, and about 18 percent of that area is zoned for multifamily or mixed-use residential use. However, this may change as the city plans for minimum growth targets of an additional 70,000 jobs and 35,000 housing units between 2019 and 2044. Over the past 15 years, the city has added additional development capacity to areas adjacent to freeways through updates to several subarea/neighborhood area plans. Residential uses are allowed in some of these subareas—including within the APEZ—as are office/commercial uses.

This increased capacity in areas next to freeways may continue because the city does not have sufficient capacity of land under current zoning to meet its residential growth targets, and the city will need to plan for a significant increase in housing across all income levels over the next 20 years. Similarly, portions of the city's growth centers and areas where transit-oriented development may be desirable and appropriate, are adjacent to freeways.

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[7] World Health Organization, accessed https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

[8] American Lung Association, 2022, *State of the Air Report*, accessed https://www.lung.org/research/sota/

[9] Bae et al., 2007, *The exposure of disadvantaged populations in freeway air-pollution sheds: A case study of the Seattle and Portland regions.*

[10] Gauderman et al., 2005, *Childhood asthma and exposure to traffic and nitrogen dioxide.*

[11] Health Effects Institute, 2010, *Traffic-related air pollution: A critical review of the literature on emissions, exposure, and health effects.*

The city's 2022-2023 planning work includes the city's periodic update to its Comprehensive Plan, which will plan for at least 35,000 new housing units, as well as initiatives to update plans for neighborhoods adjacent to freeways, such as the western portion of Wilburton and the BelRed Subarea. The city will need to intensify residential development, while maintaining livability, and keeping the city economically viable. The city's growth centers, including Downtown, Wilburton, and BelRed, are the few places within the city where increased density is possible without significant changes to the qualities that the city strives to maintain within its existing neighborhoods.

Relevant Local and Regional Policy Direction

The following policies are related to environmental health and provide Bellevue's current policy context.

2021-2025 Sustainable Bellevue Environmental Stewardship Plan[12]

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[12] City of Bellevue, 2021-2025 Environmental Stewardship Plan; Adopted December 14, 2020. Bellevue Environmental Stewardship Plan_Adopted.pdf (bellevuewa.gov)

2021 King County Countywide Planning Policies[13]

The Countywide Planning Policies (CPPs) provide direction for Bellevue's Comprehensive Plan and include both policies and suggested strategies to advance the implementation of those policies. Three relevant policies are outlined below, along with the pertinent suggested strategy from the CPPs.

H-18 Adopt inclusive planning tools and policies whose purpose is to increase the ability of all residents in jurisdictions throughout the county to live in the neighborhood of their choice, reduce disparities in access to opportunity areas, and meet the needs of the region's current and future residents.

> Suggested Strategy: Plan for moderate or high-density housing and complete neighborhoods within a half-mile walkshed of high capacity or frequent transit service in areas already zoned for residential housing and where **exposure to air pollution and particulate matter is low to moderate**.

H-24 Plan for residential neighborhoods that protect and promote the health and well-being of residents by supporting equitable access to parks and open space, safe pedestrian and bicycle routes, clean air, soil and water, fresh and healthy foods, high-quality education from early learning through K-12, affordable and high-quality transit options and living wage jobs and by avoiding or mitigating exposure to environmental hazards and pollutants.

H-10 Adopt intentional, targeted actions that repair harms to Black, Indigenous, and People of Color (BIPOC) households from past and current racially exclusive and discriminatory land use and housing practices.

> Suggested Strategy: Consider environmental health of neighborhoods where affordable housing exists or is planned and plan for environmentally healthy neighborhoods.

Puget Sound Regional Council, Vision 2050 Multi-County Planning Policies (MPP)[14]

MPP-DP-16 Address and integrate health and well-being into appropriate regional, countywide, and local planning practices and decision-making processes.

MPP-DP-18 Address existing health disparities and improve health outcomes in all communities.

MPP-En-22 Meet all federal and state air quality standards and reduce emissions of air toxics and greenhouse gases.

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[13] 2021 King County Countywide Planning Policies, accessed 2021 Proposed CPPs (kingcounty.gov).

[14] Puget Sound Regional Council, Vision 2050, A Plan for the Central Puget Sound Region accessed VISION 2050 | Puget Sound Regional Council (psrc.org).

II. Air Quality and Public Health

This chapter provides an overview of how air quality is measured and the impacts of air quality on public health. The following chapter then provides more context on air quality and land use in Bellevue. Please note that from here on, the term "environmental health" is used in place of "public health" since environmental health is the branch of public health that: focuses on the relationships between people and their environment; promotes human health and well-being; and fosters healthy and safe communities. The field of environmental health works to advance policies and programs to reduce chemical and other environmental exposures in air, water, soil and food to protect people and provide communities with healthier environments. [15]

What is air quality?

Air quality is the degree to which air is free of pollutants. When air quality is good, pollutants represent only a small fraction of the air we breathe and have little to no effect on our health. When air quality is poor, the high concentration of pollutants can interfere with the healthy functioning of our systems. In addition to health effects, poor air quality can also contribute to haziness or poor visibility. However, some pollutants are invisible and can only be measured using air quality sensors.

Air quality is assessed by measuring several indicators of pollution. The Air Quality Index (AQI) was developed to translate data collected from air monitoring stations into a scale that lay audiences could use.[16] The AQI is a number that ranges from 0 to 500 and indicates how clean or polluted air is, and what associated health effects might be of concern to diverse individuals within a population (see Figure 1).

What is air pollution?

Air pollution is a complex and dynamic mixture of gases and small particles suspended in the air. There are natural processes that create air pollution, including volcanic activity, smoke and ash from wildfires, dust storms, and biological decay. However, most air pollution comes from human generated sources, especially from the burning of fossil fuels for transportation, electricity, and

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[15] American Public Health Association, accessed https://www.apha.org/topics-and-issues/environmental-health#:~:text=Environmental%20health%20is%20the%20branch,any%20comprehensive%20public%20health%20system.

[16] AirNow, Air Quality Index (AQI) Basics, accessed https://www.airnow.gov/aqi/aqi-basics/

0-50

- **Good (0-50):** Air quality is considered satisfactory, and air pollution poses little to no risk.

51-99

- **Moderate (51-99):** Air quality is acceptable; however, unusually sensitive people should consider limiting prolonged outdoor exertion.

101 - 150

- **Unhealthy of Sensitive Groups (101-150):**The following sensitive groups should limit prolonged or heavy outdoor exertion: people with heart disease, pregnant women, children and older adults, people with lung disease, such as asthma.

151-200

- **Unhealthy (151-200):** Everyone may begin to experience some adverse health effects (e.g., difficulty breathing and throat irritation), and members of the sensitive groups may experience more serious effects. Sensitive groups should avoid prolonged outdoor exposure.

201-300

- **Very Unhealthy (201-300):** This would generate a health alert suggesting that everyone may experience more serious health effects. Sensitive groups should avoid all outdoor physical activity. Everyone else should avoid prolonged or heavy outdoor activity.

> 300

- **Hazardous (>300):** This would trigger a health warning of emergency conditions. The entire population is more likely to be affected. Everyone should avoid all physical activity outdoors.

Figure 1. Air Quality Index.

industry. Because Bellevue has no heavy industry and its electricity is generated elsewhere, most of Bellevue's human generated air pollution comes from the burning of fossil fuels for transportation.

The Clean Air Act, landmark legislation passed in 1970 and last amended in 1990, requires the Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS) for six common pollutants (also known as "criteria pollutants"), described in Table 1 below.

Pollutant	*What is it?*	*Where does it come from?*	*How does it harm health?*
Ozone	Also known as smog, ozone (O_3) is a gas composed of three atoms of oxygen.	Ground-level ozone forms when a combination of other pollutants from vehicles, power plants, and other sources "cook" together in sunlight.	O_3 irritates the delicate lining of the airways, causing inflammation and other damage. When O_3 levels are high, even healthy people can experience chest tightness, coughing, and shortness of breath. It can also cause or aggravate conditions like asthma, allergic response, and chronic obstructive pulmonary disease (COPD), as well as

Pollutant	*What is it?*	*Where does it come from?*	*How does it harm health?*
			metabolic disorders like diabetes, brain inflammation, preterm birth, and possibly heart disease.
Particulate matter	Also known as soot, particulate matter (PM) includes tiny chemicals, acids, metals, soils, and dust, which are suspended in the air.	Course particles (PM_{10}) can include dust, ash, pollen, and smoke; fine particles ($PM_{2.5}$) and ultrafine particles ($PM_{0.1}$), including brake and tire dust, are often a by-product of cars, trucks, trains, aircraft, factories, power plants, and wood burning.	Due to their small size, course, fine, and ultrafine particles can travel into the deepest parts of our lungs, enter the bloodstream, and then travel to other organs of the body. They can trigger a range of health effects, including heart attacks, stroke, COPD, asthma, diabetes, lung cancer, and dementia, and they are responsible for nearly 48,000 premature deaths in the U.S. every year.
Nitrogen dioxide	Nitrogen dioxide (NO_2) is a reactive gas composed to nitrogen and oxygen and is one of a group of related gases called nitrogen oxides (NO_x).	Cars, trucks, buses, power plants, diesel-powered heavy construction equipment, and off-road equipment are the primary sources of NO_2, as well as sources inside the home.	NO_2 can irritate the lungs and lower resistance to respiratory infections, contribute to acute respiratory symptoms, like coughing and wheezing, and chronic respiratory conditions, including asthma and COPD, and are linked to cardiovascular harm, low birth weight in babies, and premature death. All NO_x can react with other chemicals in the air to form particulate matter and ozone.
Sulfur dioxide	Sulfur dioxide (SO_2) is a colorless gas composed of sulfur and oxygen with a pungent odor.	SO_2 is caused by burning of fossil fuels, particularly coal-fired power plants, ports, and smelters, and from diesel engines in old buses, trucks, and off-road equipment.	SO_2 causes wheezing, shortness of breath, chest tightness, reduced lung function, and asthma. Even in areas without major industrial uses, SO_2 can be a threat when it gets trapped by inversions in the atmosphere and change chemically into sulfates, particulate matter pollution, that can travel great distances.

Pollutant	*What is it?*	*Where does it come from?*	*How does it harm health?*
Carbon monoxide	Carbon monoxide (CO) is a colorless, odorless, tasteless gas composed of carbon and oxygen.	CO comes from vehicle exhaust, machinery that burn fossil fuels, and appliances and other sources inside the home.	CO attaches to hemoglobin in red blood cells and blocs the ability of blood to carry oxygen throughout the body. High levels of CO can cause loss of consciousness and death, while low levels over time may cause permanent mental and physical problems.
Lead	Lead (Pb) is a toxic metal and a naturally occurring element, and it does not dissipate over time.	Until the late 1970s, Pb was used in many industrial processes and was added to gasoline, paint, water pipes, and fertilizers.	Exposure to Pb results in profound effects on nearly every organ system, but the nervous system is its main target. EPA's regulatory efforts to remove lead from gas decreased levels of lead in the air by 98 percent from 1980 to 2014.

Table 1. Six Criteria Pollutants (sources: U.S. Environmental Protection Agency, American Lung Association[17],[18])

Beyond these six common pollutants, air toxics are a group of over 400 other air pollutants.[19] People can inhale air toxics from the air where they live, work, learn, and play. Air toxics can also settle into waterways, streams, rivers, and lakes, so they can pass into the body when people drink them or eat them in fish.

Cars and trucks are the primary sources for ozone, particulate matter, nitrogen dioxide, and carbon monoxide, and they also emit air toxics including diesel, benzene, and formaldehyde.[20] The World Health Organization (WHO) declared diesel exhaust carcinogenic, a cause of lung cancer in the same category as asbestos and mustard gas.[21] The EPA has classified 187 air pollutants as hazardous.[22]

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[17] United States Environmental Protection Agency, Criteria Air Pollutants, accessed https://www.epa.gov/criteria-air-pollutants

[18] American Lung Association, 2022, *State of the Air Report*, accessed https://www.lung.org/research/sota/

[19] U.S. EPA, About Urban Air Toxics, accessed https://www.epa.gov/urban-air-toxics

[20] U.S. EPA, Smog, Soot, and Other Air Pollution from Transportation, accessed https://www.epa.gov/transportation-air-pollution-and-climate-change/smog-soot-and-other-air-pollution-transportation

[21] World Health Organization, International Agency for Research on Cancer, 2012, Diesel engine exhaust carcinogenic, accessed https://www.iarc.who.int/wp-content/uploads/2018/07/pr213_E.pdf

[22] U.S. EPA, About Urban Air Toxics, accessed https://www.epa.gov/urban-air-toxics

Air quality in the United States has improved dramatically over time

Over the last 50 years, air quality in the U.S. has improved dramatically – despite huge population growth (particularly in urban areas), increased economic activity, and more vehicle miles traveled per person.[23] This improved air quality is primarily the result of landmark legislation passed by Congress in 1970 that gave the newly-formed EPA the legal authority to regulate pollution from vehicles and other sources. The EPA and the State of California have led national efforts to reduce air pollution from vehicles, by adopting increasingly stringent standards over the years.[24]

Improved air quality has resulted in significant environmental and public health benefits across the country. Since 1990, concentrations of air pollutants have dropped significantly (see Appendix B, Air Quality Trends):[25]

- Carbon monoxide (8-hour average) has declined by 74 percent
- Lead (3-month average) has declined by 82 percent
- Nitrogen dioxide (annual) has declined by 57 percent
- Nitrogen dioxide (1-hour average) has declined by 50 percent
- Ozone (8-hour average) has declined by 21 percent
- Particulate matter 10 (24-hour average) has declined by 26 percent
- Particulate matter 2.5 (annual) has declined by 39 percent
- Particulate matter 2.5 (24-hour average) has declined by 34 percent
- Sulfur dioxide (1-hour average) has declined by 89 percent

Additionally, numerous air toxics have declined with percentages varying by pollutant.

In addition to historic improvements, replacing vehicles that burn fossil fuels with vehicles powered by electricity, hydrogen, or other cleaner fuels is predicted to significantly reduce air pollution, particularly in urban centers.[26] Though electric cars are charged using a power grid that in parts of the country is fueled by coal or natural gas, they still provide health benefits by reducing emissions at the street level, where people tend to be most impacted.[27] In Washington State, due to the Clean

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[23] U.S. EPA, History of Reducing Air Pollution from Transportation in the United States, https://www.epa.gov/transportation-air-pollution-and-climate-change/history-reducing-air-pollution-transportation

[24] Daley, B. Why California gets to write its own auto emissions standards: 5 questions answered, *The Conversation*. Accessed https://theconversation.com/why-california-gets-to-write-its-own-auto-emissions-standards-5-questions-answered-94379

[25] U.S. EPA, 2019, *Our Nation's Air*, accessed https://gispub.epa.gov/air/trendsreport/2019/

[26] Choma et al., 2020, *Assessing the health impacts of electric vehicles through air pollution in the United States.*

[27] Harvard TH Chan School of Public Health News, 2021, *Increasing the use of electric cars could improve health outcomes.*

Energy Transformation Act[28] (SB 5116, 2019), utilities are required to transition to 100 percent renewable energy by 2045. In addition, Washington has followed California's vehicle emissions standards to accelerate the transition to electric vehicles, passing a law to require all new cars sold in Washington state to be electric by 2035[29]. Researchers and policymakers have found that vehicle electrification in urban areas is an opportunity to both reduce greenhouse gas emissions and achieve large public health benefits in a relatively short timeframe.[30]

Fleet turnover and electrification efforts are expected to continue improving air quality, but many threats are on-going. For example, diesel is a known carcinogen, and heavy-duty diesel-powered vehicles, like buses, trucks, and construction vehicles, are expected to be the last to be electrified, due the costs of batteries for the largest vehicles.[31] Emissions from tire and break dust will also continue, despite vehicle electrification progress. Climate change may also increase risks of air pollution, particularly because of the synergistic health effects of air pollution, temperature, and pollen exposure.[32] In the Pacific Northwest, risks may be compounded by longer and more intense wildfire seasons. More ongoing research will be needed to track the impact of vehicle electrification on near-road air pollution, and how that might impact pollutant concentrations near freeways. Air quality in King County[33] and Bellevue has improved over the last 20 years as well, however the number of days with particle pollution has increased in the last several years, due to increased forest fires.

Despite the overall trends of improved air quality over time in major U.S. cities and throughout King County, the Puget Sound Clean Air Agency's (PSCAA's) *Near-Road Air Toxics Study in the Chinatown-International District*[34] from 2018, demonstrates that air pollution is a more localized concern and the Chinatown-International District's (CID's) greatest air toxic risk is from diesel particles from I-5 and I-90. PSCAA's modeling of cancer risk due to direct diesel exhaust, based on data collected in the CID study, illustrates a significantly increased risk of cancer in areas near high-volume roadways.

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[28] Washington State Legislature, Clean Energy Transformation Act, 2019. 5116-S2.SL.pdf (wa.gov).

[29] Washington State Legislature, Motor Vehicle Emissions Standards – Zero Emission Vehicles, 2020; 5811.SL.pdf (wa.gov)

[30] Choma et al., 2020, *Assessing the health impacts of electric vehicles through air pollution in the United States.*

[31] NRDC, 2021, *Medium- and Heavy-Duty Vehicle Electrification 101*, accessed https://www.nrdc.org/experts/shelby-parks/medium-and-heavy-duty-vehicle-electrification-101

[32] Annenberg et al., 2020, *Synergistic health effects of air pollution, temperature, and pollen exposure: A systematic review of epidemiological evidence*

[33] American Lung Association, State of the Air Report Card, King | American Lung Association.

[34] Puget Sound Clean Air Agency, *Near-Road Air Toxics Study in the Chinatown-International District*, 2018; Air-Toxics-Study-in-the-Chinatown-International-District-Reduced (pscleanair.gov).

What are the health impacts of air pollution?

While exposure to air pollution contributes to impaired lung development, reduced lung function, and chronic lung diseases (like asthma, chronic obstructive pulmonary disease, and cystic fibrosis), respiratory impacts are just one of many health effects linked to air pollution.[35]

Over the last couple decades, more health studies have highlighted the association between various air pollutants and non-respiratory health effects. For instance, fine particle pollution has particularly harmful cardiovascular effects, including myocardial infarctions, arrhythmias, congestive heart failure, hypertension, stroke, and death.[36]

Additionally, many air toxics are classified as carcinogens, and diesel engine exhaust is linked to increased risk of lung and bladder cancer.[37] Emerging evidence has also linked air pollution with pulmonary malignancies, adverse birth outcomes (including low birthweight and preterm birth), diabetes, deep venous thrombosis, neuropsychiatric disease, neurological and brain development impacts, ear infections, and other adverse health

Key Health Findings

Reduced lung function in children was associated with traffic density, especially trucks, within 1,000 feet and the association was strongest within 300 feet (Brunekreef, 1997).

Increased asthma hospitalizations were associated with living within 650 feet of heavy traffic and heavy truck volume (Lin, 2000).

Asthma symptoms increased with proximity to roadways and the risk was greatest within 300 feet (Venn, 2001).

Asthma and bronchitis symptoms in children were associated with proximity to high traffic in a San Francisco Bay Area community with good overall regional air quality (Kim, 2004).

A San Diego study found increased medical visits in children living within 550 feet of heavy traffic (English, 1999).

[35] American Lung Association, 2022, Health Impacts, *State of the Air Report*, accessed https://www.lung.org/research/sota

[36] Du et al., 2016, *Air particulate matter and cardiovascular disease: The epidemiological, biomedical, and clinical evidence.*

[37] American Cancer Society, *Diesel exhaust and cancer risk*, accessed https://www.cancer.org/healthy/cancer-causes/chemicals/diesel-exhaust-and-cancer

effects.[38],[39],[40],[41],[42],[43],[44] The growing body of evidence has been building slowly over time, and researchers have replicated studies across diverse populations and contexts (see Figure 2).

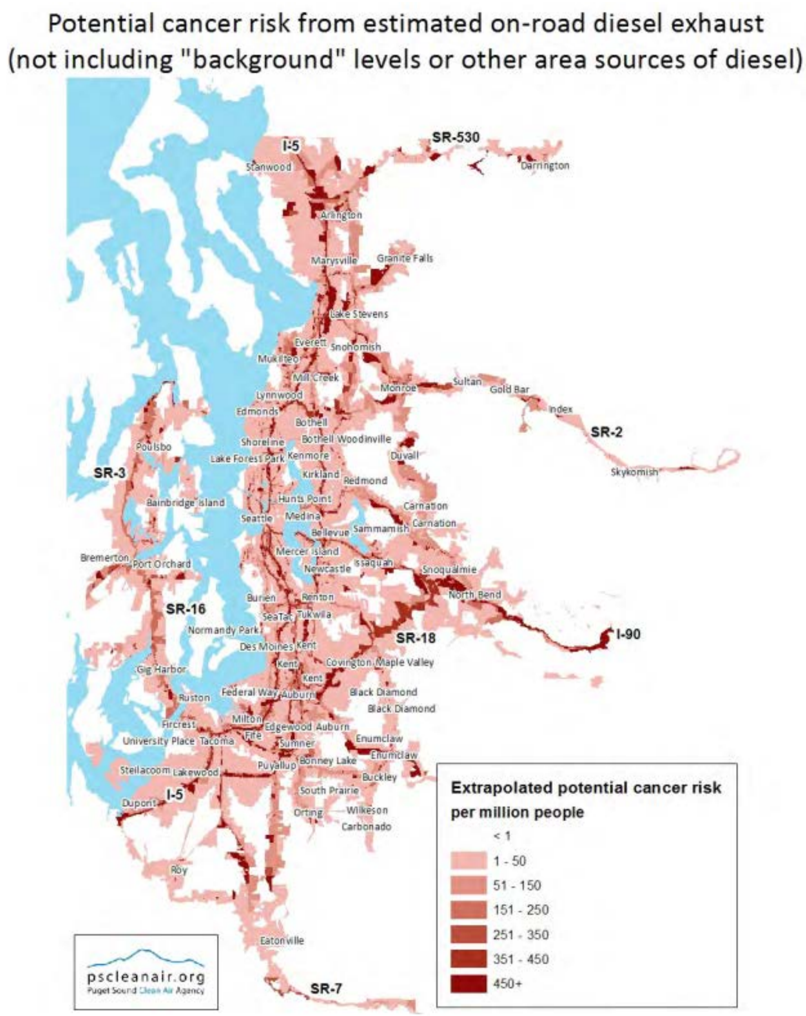

Figure 2. Extrapolated Potential Cancer Risk due to Direct Diesel Exhaust from On-Road Vehicles at Census Block Level, PSCAA Chinatown-International District Study, 2018.

[38] American Lung Association, 2016, *The connection between lung cancer and outdoor air pollution*, accessed https://www.lung.org/blog/lung-cancer-and-pollution

[39] Shah et al., 2010, *Air pollution and birth outcomes: A systematic review*

[40] Li et al., 2019, *Association between air pollution and type 2 diabetes: An updated review of the literature*

[41] Baccarelli et al., 2011, *Exposure to particulate air pollution and risk of deep vein thrombosis*

[42] Hahad et al., 2020, *Ambient air pollution increases the risk of cerebrovascular and neuropsychiatric disorders through induction of inflammation and oxidative stress*

[43] Kim et al., 2020, *Air pollution and central nervous system disease: A review of the impact of fine particulate matter on neurological disorders*

[44] Bhattacharyya et al., 2010, *Air quality improvement and the prevalence of frequent ear infections in children*

Who is affected by air pollution?

Clean air is essential for health, so *everyone* can be affected by air pollution. However, exposure to air pollution varies depending on the concentration of pollutants in the air and how long a person breathes in toxins over time. Health risks from air pollution also depend on a person's sensitivity due to their health condition, age, and/or genetic background. Infants and small children are more vulnerable because of their small body size and increased inhalation rate as compared to adults. Expectant mothers, developing fetuses, children, older adults, and people with certain health conditions, including diabetes, heart disease, and lung disease, are also more sensitive to the health effects of air pollution.

Other factors may also increase a person's vulnerability by lowering their adaptive capacity. Factors such as income, race and ethnicity, and health insurance status may hinder people's ability to respond effectively to exposure risks thereby making them more vulnerable to the effects of air pollution.[45] Poor communities and communities of color, for example, are more likely to be exposed to and more likely to suffer harm from air pollution.[46] People in poverty are also more likely to have one or more chronic conditions making them more vulnerable to the effects of air pollution.[47] [48]

In 2019, about 7.9 percent of children, 7.5 percent of adults 65 years and over, and 14.6 percent of female single-parent families in Bellevue were in poverty, and about a fifth of Bellevue's households had incomes less than $50,000 per year[49]. In the 2021 Community Healthy Assessment by Overlake Hospital[50], one of the primary medical facilities serving Bellevue and the Eastside of Lake Washington, the study notes a 5 percent asthma rate for children in East King County, compared to a 6 percent rate in all of King County. Asthma hospitalization rates for children in East King County

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[45] Healthy People 2030, U.S. Department of Health and Human Services, Office of Disease Prevention and Health Promotion. Retrieved 11/30/2022, from https://health.gov/healthypeople/objectives-and-data/social-determinants-health

[46] American Lung Association, Disparities in the Impact of Air Pollution. Retrieved 11/30/2022, from https://www.lung.org/clean-air/outdoors/who-is-at-risk/disparities

[47] Apelberg BJ, Buckley TJ, White RH. Socioeconomic and racial disparities in cancer risk from air toxics in Maryland. Environ Health Perspect. 2005 Jun;113(6):693-9. doi: 10.1289/ehp.7609. PMID: 15929891; PMCID: PMC1257593.

[48] United States Environmental Protection Agency. Research on Health Effects from Air Pollution, accessed 11/22/2022 from https://www.epa.gov/air-research/research-health-effects-air-pollution

[49] City of Bellevue, Human Services Community Profile, 2021, accessed hs-needs-2021-2022-community_profile.pdf (bellevuewa.gov)

[50] Overlake Hospital Community Health Needs Assessment, 2021: Overlake Community Health Needs Assessment 2021.pdf (overlakehospital.org)

were lower than for the entire county, with a rate of 90.8 per 100,000 persons for East King County, compared to 131 per 100,000 for King County.[51]

As Bellevue grows over time and seeks to be a welcoming place for diverse communities, it is incumbent upon the city to consider environmental health in connection with its planning and land use decisions.

How does proximity to high-volume roadways affect pollutant levels?

Air pollutant concentrations are highest closest to their source and begin dissipating as pollutants fall out of the atmosphere and settle on the ground, vegetation, or structures, and/or as they disperse and mix with less concentrated volumes of air until they match background level concentrations. Pollutants emitted by vehicles come from exhaust, wear from brake pads and tires, and dust from disturbing the road surface.

Research has demonstrated that traffic – particularly diesel-powered vehicles – create pollution hot spots near high-volume roadways. Studies have found that health risks can be attributed to being as far as 1,500 feet from freeways, freight corridors, and other major roadways, though most pollution levels tend to improve beyond 500 feet, though their rates of decline vary by pollutant (see Figure 3). [52],[53],[54]

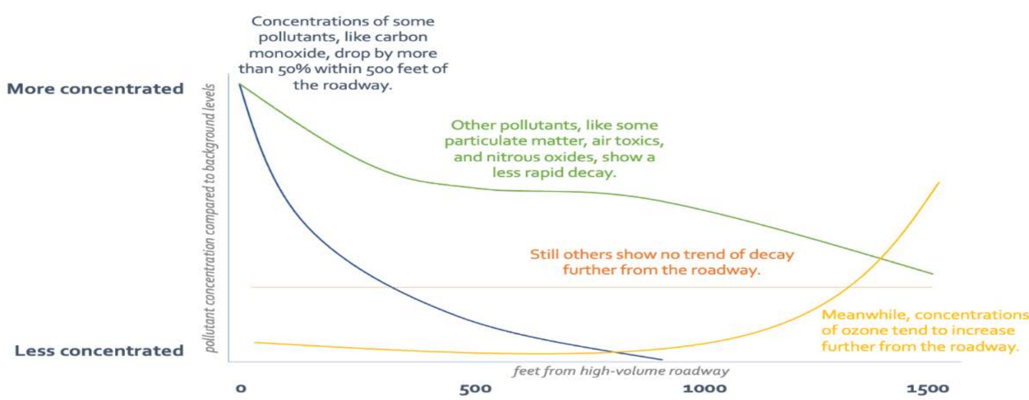

Figure 2. Rates of decline of different pollutants, adapted from Karner et al., 2010.

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[51] Overlake Hospital Community Health Needs Assessment, 2021, page 50: [Overlake Community Health Needs Assessment 2021.pdf (overlakehospital.org)]

[52] Bae et al., 2007, *The exposure of disadvantaged populations in freeway air-pollution sheds: A case study of the Seattle and Portland regions.*

[53] Gauderman et al., 2005, *Childhood asthma and exposure to traffic and nitrogen dioxide.*

[54] Health Effects Institute, 2010, *Traffic-related air pollution: A critical review of the literature on emissions, exposure, and health effects.*

California's Air Resources Board recommends against siting new sensitive land uses, such as residences, schools, daycare centers, playgrounds, or medical facilities, within 500 feet of a freeway, urban roads with 100,000 vehicles/day, or rural roads with 50,000 vehicles/day.[55] This recommendation is to avoid the worst of the pollution hot spots generated by traffic. Currently, Bellevue's busiest arterial is NE 8th Street in the vicinity of 116th Avenue NE with approximately 40,000 vehicles/day, and the freeways in Bellevue, I-405, I-90, and SR-520 all carry over 100,000 vehicles per day (see Appendix C, Traffic Volumes).

What factors influence the creation of air pollution hot spots?

A variety of factors influence air pollution hot spots, and air pollution hot spots created by vehicles vary by traffic volume, speed, and mix of fleet. Roadways with 100,000 annual average trips per day generate air pollution at concentrations harmful to people's health, and areas where vehicles travel at slower speeds, such as on and off ramps and other places of congestion, increase the density of vehicles leading to higher concentrations of pollutants. Brake and tire wear dust are also more likely during acceleration and deceleration, which is more common at on and off ramps[56] and in stop and go traffic.

The mix of fleet in terms of the type of fuel burned and the age of vehicles also influences the amount of pollution along high-volume roadways. According to the EPA, buses, trucks, and construction vehicles produce at least half of the hydrocarbons and nitrogen oxides generated by high-volume roadways.[57] These types of vehicles tend to be diesel-powered. In an effort to lessen impacts within the region, King County Metro has committed to electrifying the King County bus fleet by 2035[58].

In terms of vehicle age, new cars, SUVs and pickup trucks are roughly 99 percent cleaner compared to 1970 vehicle models for common pollutants (hydrocarbons, carbon monoxide, nitrogen oxides and particle emissions).[59] Yet, while newer vehicles – especially hybrid and electric vehicles – emit

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[55] California Environmental Protection Agency, Air Resources Board, 2005, *Air quality and land use handbook: A community health perspective*, accessed https://www.arb.ca.gov/ch/handbook.pdf

[56] Kumar, World Economic Forum, 2015, *Why traffic lights are pollution hotspots*, accessed https://www.weforum.org/agenda/2015/02/why-traffic-lights-are-pollution-hotspots/

[57] U.S. EPA, *History of Reducing Air Pollution from Transportation in the United States*, https://www.epa.gov/transportation-air-pollution-and-climate-change/history-reducing-air-pollution-transportation

[58] King County Metro Transit's Zero Emission Fleet Transition Plan, 2022; Microsoft Word - FTA_draft_052022 (kingcounty.gov).

[59] U.S. EPA, *History of Reducing Air Pollution from Transportation in the United States*, https://www.epa.gov/transportation-air-pollution-and-climate-change/history-reducing-air-pollution-transportation

fewer pollutants, they can still contribute to air pollution through tailpipe emissions, brake and tire dust. One study found that emissions from particulate matter from tire wear can be 1,000 times worse than emissions from tailpipes, which underscores the need to continue to support multi-modal transportation options to address transportation related greenhouse gas emissions and air pollution.[60]

Other factors contributing to hot spots include wind direction and topography. Intuitively, wind direction and wind speed influence where air pollutants travel and how quickly they disperse. At higher elevations and in more exposed areas, moderate wind will cause pollutants to disperse more quickly. Conversely, in low-lying areas where it is harder for wind to penetrate, air pollutants can become trapped causing levels of air pollution to rise.

Meteorology and micrometeorology, which are influenced by time of year, topography, and nearby land use, can also contribute to the formation of air pollution hot spots.

Many of these factors also vary by time of day. For example, traffic congestion is a daily feature of many people's morning and evening commutes. These traffic patterns are predictable, and so are pollution hot spots – they are more likely during morning and evening hours, as well as on weekends.[61]

8 Lessons of Traffic-Related Air Pollutants
(Adapted from Brugge et al., 2014)

1. Vehicles on highways emit high levels of gases and particles.
2. Pollutants behave in different ways, so interventions must be targeted to specific pollutants of concern.
3. Highway traffic patterns are predictable.
4. Wind direction and wind speed affect exposure.
5. Distance from highways affects exposure.
6. Time of day and time of year affect exposure.
7. Pollutants can penetrate building envelopes.
8. Exposure to pollutants can be estimated.

What can local governments do?

Beyond the ability of individuals to limit their exposure to air pollution, municipalities and local agencies have opportunities – in connection with long-range land use planning, zoning, site design, building design review, code regulations, health risk assessments, and community risk reduction plans – to consider environmental health factors, including but not limited to air quality impacts

[60] Emissions Analytics, 2020, *Pollution from tire wear 1,000 times worse than exhaust emissions*, accessed https://www.emissionsanalytics.com/news/pollution-tyre-wear-worse-exhaust-emissions
[61] Brugge et al., 2014, Improving Health in Communities Near Highways, accessed https://sites.tufts.edu/cafeh/files/2011/10/CAFEH-Report-Final-2-26-15-hi-res1.pdf

associated with freeways. By way of example, Appendix E includes a selection of related policies that have been implemented in other municipalities.

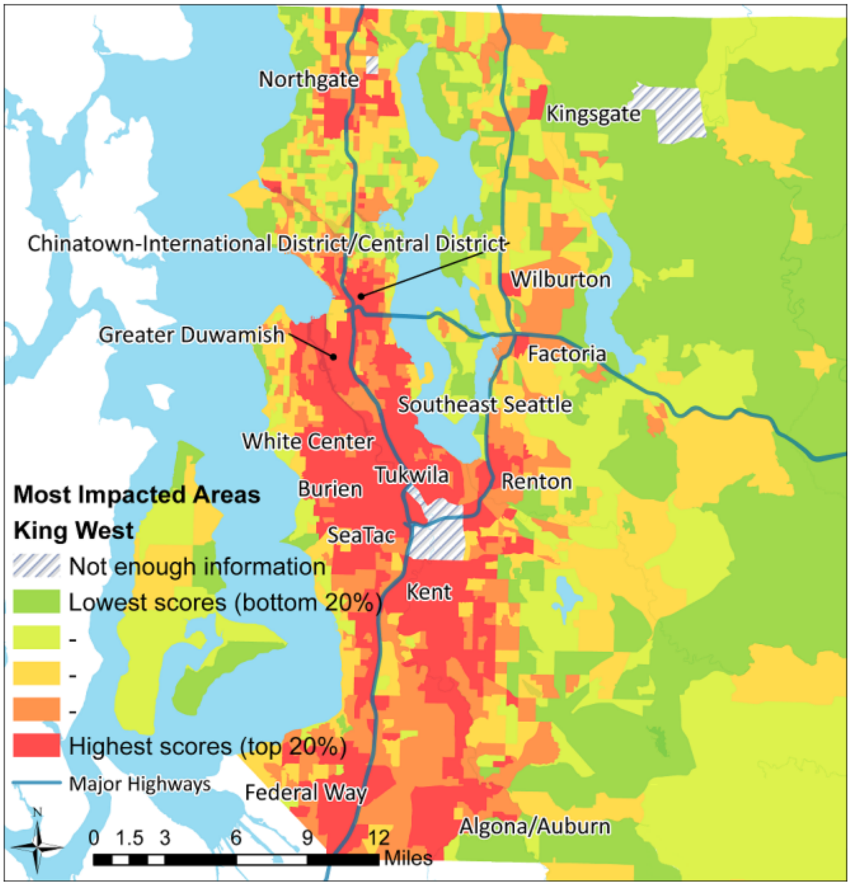


Figure 3. Most Impacted Areas in King County, Puget Sound Clean Air Agency, Highly Impacted Communities, 2014. Accessed at: [Highly-Impacted-Communities-HI-C-ReportPDF (pscleanair.gov)](https://www.pscleanair.gov).

Technical reports can provide guidance and support for local planning decisions, including decisions that seek to balance environmental health with competing factors. Key reports from the Puget Sound Clean Air Agency, for example, have identified air pollution hot spots in highly impacted communities around King County[62] (see Figure 4). Additionally, guidance from state and federal authorities, like the California Air Resources Board's *Air Quality and Land Use Handbook* (2005)[63] and the Environmental Protection Agency's *Best Practices for Reducing Near-Road Pollution Exposure at*

[62] Park et al., 2014, Puget Sound Clean Air Agency, Highly Impacted Communities, PS Clean Air Committee Recommendations, accessed https://www.pscleanair.gov/DocumentCenter/View/2323/Highly-Impacted-Communities-HI-C-ReportPDF?bidId=

[63] California Environmental Protection Agency, Air Resources Board, 2015, Air Quality and Land Use Handbook, accessed https://www.arb.ca.gov/ch/handbook.pdf

Schools (2015),[64] can help foster informed decision-making when policymakers are evaluating the appropriate level of growth, the location of growth, the regional transportation system, the type of growth to be encouraged, public spending, environmental protection, and the quality of life throughout the municipality.

Ultimately, the balancing of a variety of local considerations will determine the appropriate suite of air quality policies that may be implemented in a particular municipality. Local circumstances, market factors, the location of transit, or the local need for specific land uses may result in unique choices and solutions by individual cities. For instance, whether a city wants to emphasize the creation of housing stock over environmental health considerations is a policy choice that may or may not be mutually exclusive. In Bellevue, the city's growth centers, including Downtown, Wilburton, and BelRed, are the few places within the city that have access to excellent transportation infrastructure to support increased growth, and they are places where increased density is possible without significant changes to the qualities that the city strives to maintain within its existing neighborhoods. Yet, parts of those areas are proximate to freeways resulting in a need to consider the risk of exposure to air pollutants as well. These types of policy choices will almost always require the balancing of competing interests that will affect the specific location of particular land uses and development intensities, community character and design, and site development standards. Recognizing the impacts of policy decisions on all residents is key to ensuring equitable planning and development.

[64] Environmental Protection Agency, 2015, Best Practices for Reducing Near-Road Pollution Exposure at Schools, accessed https://www.epa.gov/sites/default/files/2015-10/documents/ochp_2015_near_road_pollution_booklet_v16_508.pdf

III. Bellevue Context

This chapter provides detail on air quality and land uses near high-volume roadways in Bellevue.

Do air pollution hot spots exist in Bellevue and if so, how many people live and work within these areas?

With three major freeways carrying upwards of 100,000 vehicle trips per day, Bellevue has about an eighth of its land area within an Air Pollution Exposure Zone (APEZ) where people could be exposed to unhealthy levels of air pollution. The Puget Sound Clean Air Agency has conducted extensive air monitoring and has identified pollution hot spots in proximity to high-volume roadways generally.[65] The agency has also identified air pollution hot spots in highly impacted communities around King County, including the Wilburton and Factoria neighborhoods in Bellevue.[66]

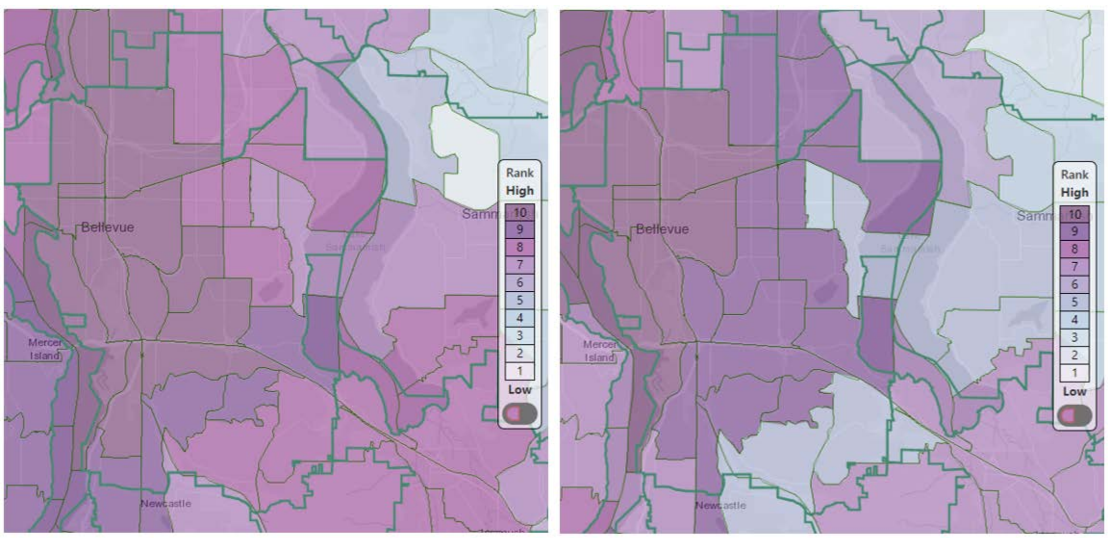


Figure 4. Populations Near Heavy Traffic Roadways (left); NOx-Diesel Pollution (right), from [Washington Environmental Health Disparities Map](#).

Today, approximately 8,531 people live within the APEZ in Bellevue, and approximately 40,000 people work within the APEZ, equaling about six percent of Bellevue's population and over a quarter of Bellevue's workforce. Workers in these areas who work outdoors or who are frequently exposed to outdoor air are more at risk of being exposed to air pollution than those who work indoors. In

[65] Puget Sound Clean Air Agency, 2017, Chinatown International District Toxics Study: Community Report, accessed https://pscleanair.gov/DocumentCenter/View/3399/Air-Toxics-Study-in-the-Chinatown-International-District-Community-Report

[66] Park et al., 2014, Puget Sound Clean Air Agency, Highly Impacted Communities, PS Clean Air Committee Recommendations, accessed https://www.pscleanair.gov/DocumentCenter/View/2323/Highly-Impacted-Communities-HI-C-ReportPDF?bidId=

addition, other sensitive uses in Bellevue, such as early childhood education centers, senior living facilities, and parks and open spaces, exist near high-volume roadways.

How do factors besides distance affect risk of exposure across the city?

As described in the previous section, risk of exposure varies depending on certain factors including slope of adjacent land, meteorology and micrometeorology, the amounts of vegetative and structural barriers, and the types of buildings and activities occurring adjacent to roadways. In low elevation areas adjacent to freeways, air tends to stagnate resulting in greater pollutant concentrations, compared to areas of higher elevation with good air circulation where pollutants tend to disperse more quickly. Low elevation areas, therefore, are places that present the greatest risk of exposure to unhealthy levels of air pollution and are of particular concern, especially low areas downwind of freeways.

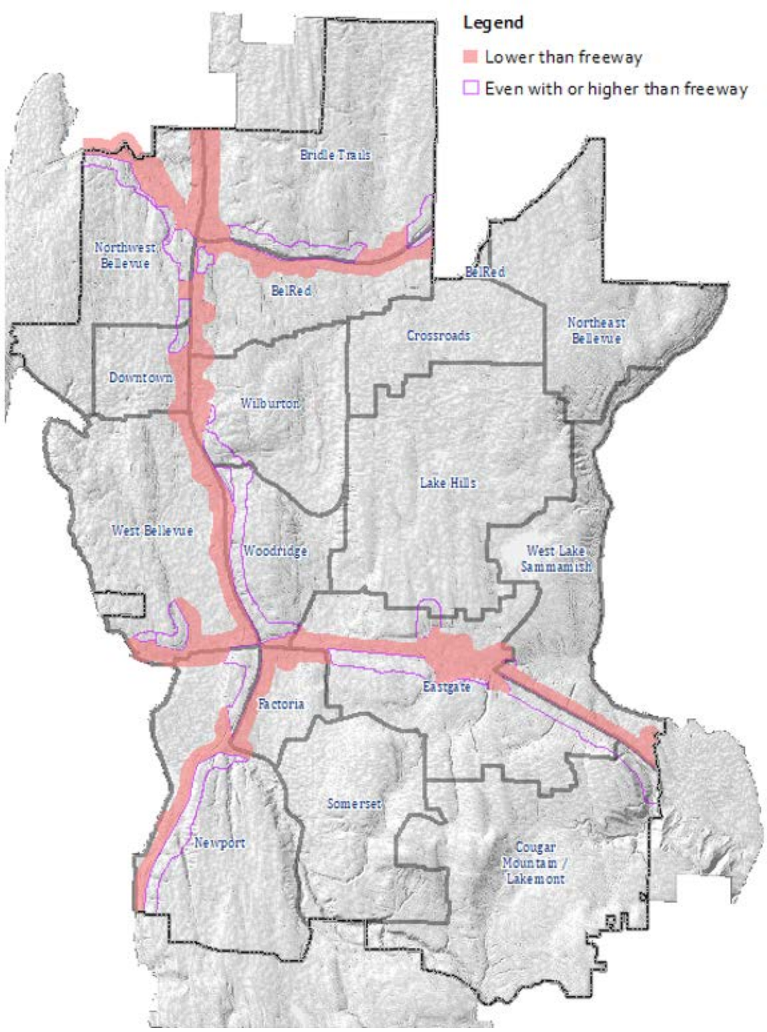


Figure 5. Hillshade Map showing low elevation areas within 500 feet of freeways.

Low elevation areas exist around all of Bellevue's freeways, yet they vary by topography (see Figure 6 above). Along SR 520 east of I-405, low elevation areas exist primarily to the south in BelRed; west of I-405, low elevations exist both north and south of SR 520. Along I-90, east of I-405, low elevation areas exist primarily to the north in West Lake Sammamish and Eastgate; west of I-405, low elevation areas exist both north and south of I-90. Along I-405, north of SR 520, low elevation areas exist both to the east and west of the freeway; between SR 520 and Downtown, low elevation areas exist primarily east of I-405 in BelRed; low elevation areas exist in both Downtown and Wilburton; between Wilburton and I-90, low elevation areas exist primarily to the west of I-405; south of I-90, low elevations exist to the east in Factoria then flip to the west in Newport. Additional images of low elevation areas can be found in Appendix D.

Prevailing wind patterns also influence exposure to air pollution. Winds during winter months, tend to be from the south, resulting in roadway air pollutants drifting northward of each roadway. Conversely, winds during summer months often originate from the north, causing pollutants to drift southward. Different areas at different times of year tend to be more or less exposed to higher pollutant concentrations.

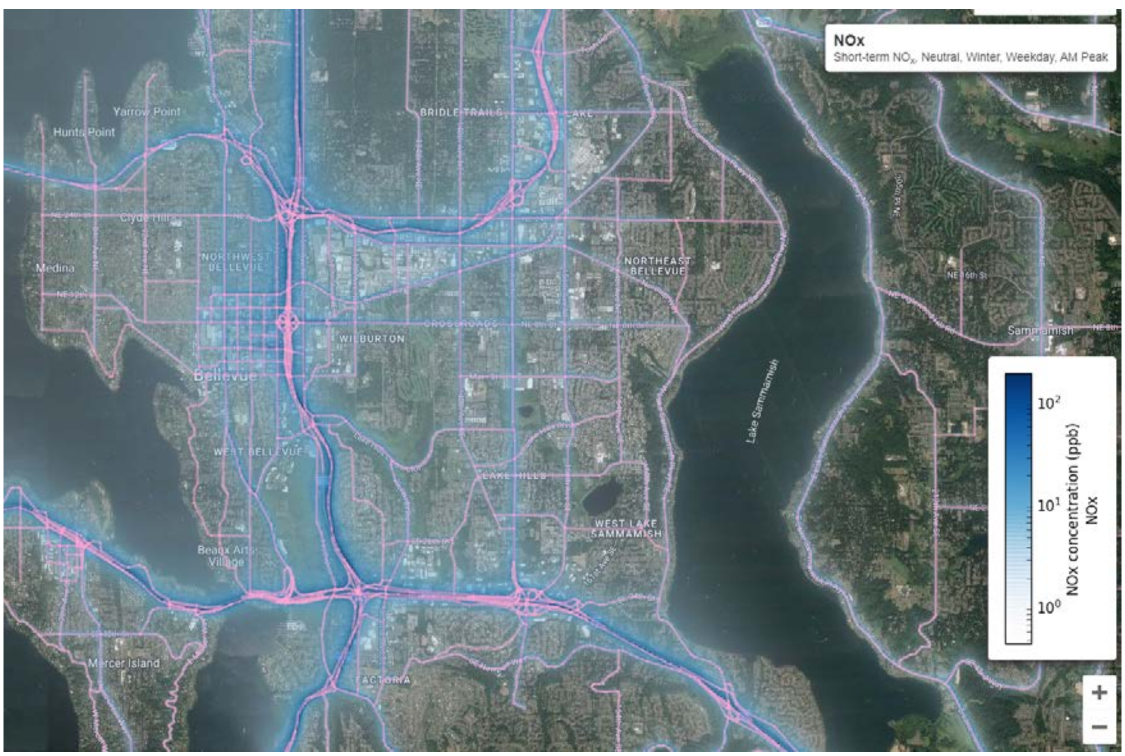


Figure 6. NOx pollutant model for short-term neutral, winter weekday AM peak. Captured from the Community LINE Source Model (C-LINE) program on 7/10/2022. *(C-Line is a web-based model designed to inform the community user of local air quality impacts due to mobile-sources in their area of interest using a simplified modeling approach. Additional information on the overall tool is available in Barzyk et. al., Environ. Model. Softw., 2015. C-LINE (unc.edu))*

Structural elements, such as noise walls, and/or vegetative buffers along high-volume roadways can protect adjacent areas from pollution exposure. See Chapter IV, Review of Mitigation Strategies, for more information. Wide berms planted with evergreen trees and shrubs provide the greatest level of protection and can be found along the east side of I-405 in parts of Newport and Factoria.

Additionally, increasing tree canopy throughout neighborhoods can also mitigate air pollution so long as trees are planted in a way that doesn't reduce airflow around roadways, inadvertently trapping pollutants. Dense, lush, varied vegetation planted in neighborhoods can filter harmful particles as they pass through and accumulate on leaf surfaces.

The type of land use and activity taking place adjacent to high-volume roadways can also increase or decrease risk of exposure. New commercial office buildings with the latest heating, ventilation and cooling system technologies are more likely to have tighter buildings with better filtration systems and workers who spend most of their day working inside. In contrast, older light industrial buildings such as service and repair shops, fabrication facilities, warehouses, and construction yards are more likely to be open to the air with less effective filtration and have workers working in more exposed conditions. Within Bellevue, employees working in older buildings adjacent to freeways without mitigation in Richards Valley, BelRed, and Wilburton may be exposed to higher levels of air pollution than employees working in enclosed office buildings downtown.

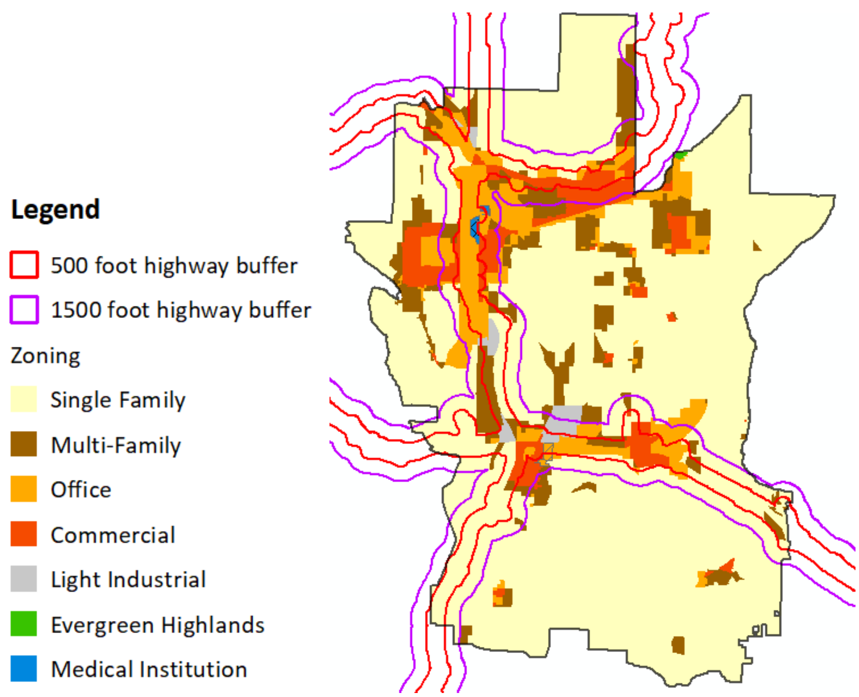


Figure 7. Zoning Districts with 500' and 1500' highway buffers.

Vegetative Buffers in Newport. From top: looking north along I-405 at 164th St SE a wide vegetative buffer to the west of I-405 provides a filter to pollutants that might otherwise flow downhill to the west; steep earthen berms and wide swaths of evergreen trees protect people living adjacent to I-405 from exposure to air pollution in the Newport Neighborhood Area; a wide vegetative buffer between I-405 and homes to the east helps disburse and filter pollutants; homes to the east of I-405 sit slightly uphill of the freeway, but the width of vegetative barrier varies; similarly, to the west of I-405 the width of vegetative barrier varies in Newport.

Development near freeways.

Top: Looking west of I-405 opposite Factoria Mall. Tall, thick vegetation is lacking;

Middle: Between NE Main and NE 12th streets. Some vegetation exists east of I-405 in Wilburton, but is lacking west of I-405 in Downtown;

Bottom: Noise wall being installed along north side of I-90.

Commercial development near freeways.

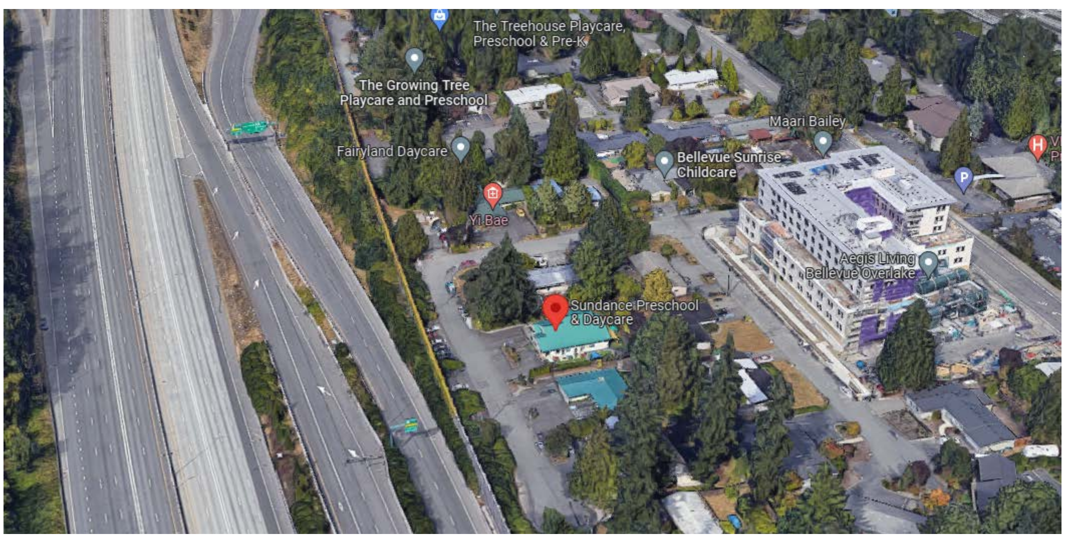
Top: Looking north along I-405, warehouse sits west and lower than I-405m but has large buffer;

Middle: Warehouses and other light industrial uses in Richards Valley sitting to the north and lower than I-90;

Bottom: Warehouses to the south of I-405 looking southwest sit low in elevation and have little vegetative buffer.

Land uses such as daycares, schools, medical clinics, senior housing and low-income housing that serve sensitive populations may also be located adjacent to high-volume roadways. In cities where development capacity is inelastic to the pressures of growth and land prices escalate, areas directly adjacent to freeways are often more affordable places for low-revenue businesses and low-income households. Tensions may exist between the need to utilize available land to provide housing and services to children, older adults and low-income residents and the need to protect these vulnerable populations from impacts that may result from exposure to air pollution. Tensions may also exist between a desire for convenient access to childcare, older adult, and low-income population services.

Within Bellevue, the Dogwood Park neighborhood north of NE 12th Street between 116th Avenue NE on the east, I-405 on the west and SR-520 on the north has become a location with a cluster of childcare facilities, medical clinics, and new senior housing developments. More than 10 childcare and/or early learning facilities, several medical clinics, and two new senior housing projects can be found within the area. Various mitigation strategies exist in this area, including dense tree canopy, and a noise wall.

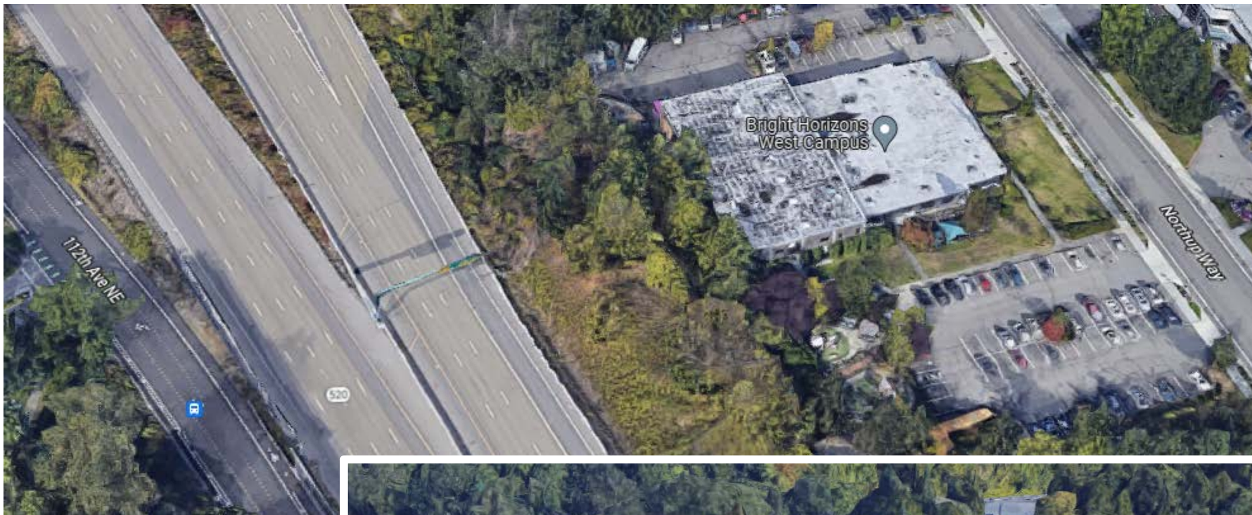


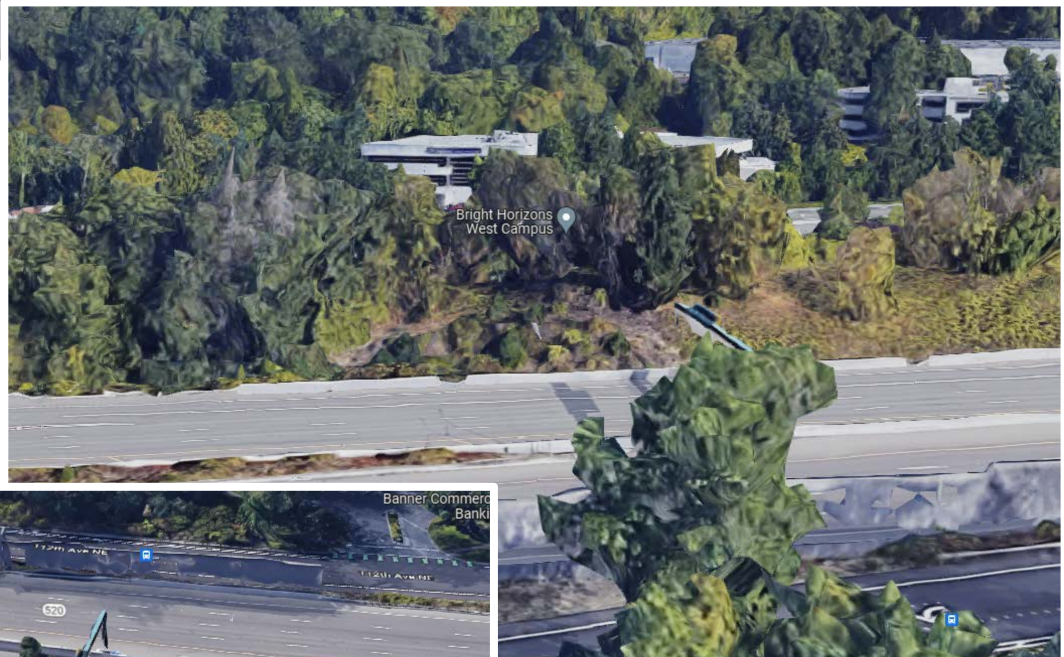
Sensitive uses.

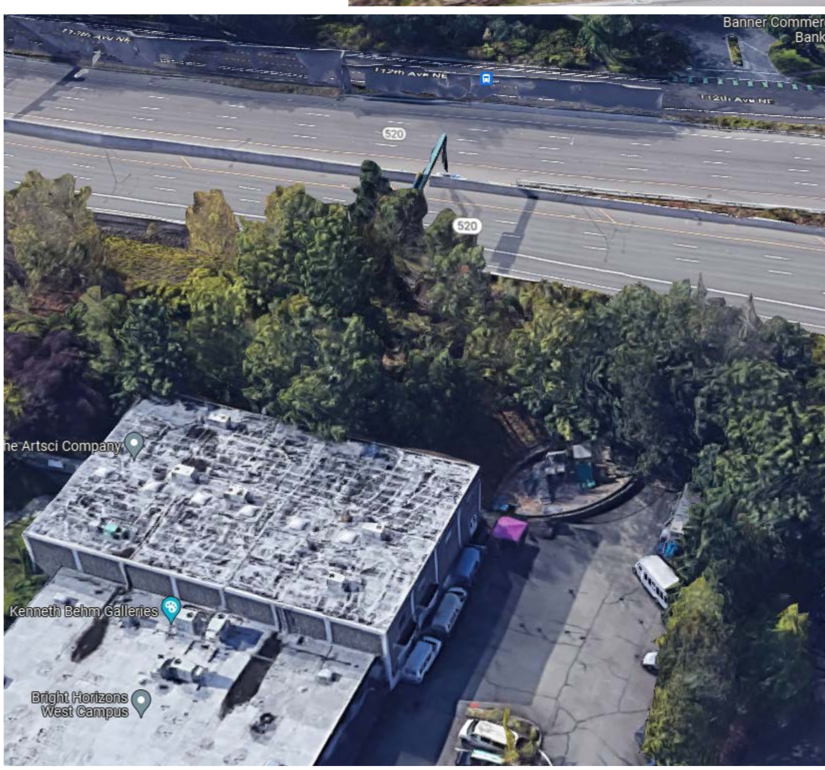
From top: Childcare facilities in Dogwood Park; preschool located adjacent to I-405 with noise wall serving as buffer.

Sensitive uses.

From top: Preschool and elementary school south of SR 520; Childcare facility north of SR 520, west of 108th Ave NE.







Sensitive uses

Three different views of a childcare facility and its play area nestled in the trees buffering it from SR 520.

How should we plan for future growth?

Upcoming long-range planning processes should consider effective strategies for avoiding and mitigating exposures to air pollution around high-volume roadways. With the periodic update to Bellevue's Comprehensive Plan and the implementation of the Wilburton Vision, Bellevue will facilitate growth and development and the creation of new mixed-use residential neighborhoods. At a minimum, Bellevue will be planning to add 35,000 housing units and 70,000 jobs by 2044. The Wilburton study area, located on the west edge of the Wilburton Neighborhood Area, is itself being studied to add between 5,000-15,000 housing units and over 20,000 jobs by 2044.

Ensuring enough capacity exists to house households of all income levels, household types and age groups is a critical issue facing the city during the next planning cycle. This is particularly true given that the city does not, under current zoning, have sufficient capacity of land to meet its housing needs. Further, available land adjacent to transit may also be located adjacent to freeways, which gives rise to competing environmental health interests that may not always be compatible.

Relatedly, when planning for jobs, the city must ensure enough development capacity exists for a wide range of business sizes, revenues, and types, especially capacity for key neighborhood services such as childcare and elder care. Locating many of these services throughout the city in low exposure risk areas could have the added benefit of enhancing convenient access to services, thereby reducing emissions.

IV. Review of Mitigation Strategies

Environmental health has traditionally focused on reducing exposure to environmental hazards, but emphasis has increasingly shifted to upstream interventions.[67] While this chapter focuses on various approaches that may be considered to avoid and minimize exposure to air pollution generated by high-volume roadways, it begins by describing "primary mitigation strategies" that eliminate and reduce health-harming air pollutants.

Primary mitigation strategies

Primary mitigation strategies include interventions before pollution happens, such as reducing vehicle trips and improving the fuel efficiency of on-road vehicles. Bellevue is already working to reduce vehicle miles traveled (VMT) through investments in pedestrian and bicycle facility improvements, rideshare programs, and implementation of other transportation demand management strategies. Additional efforts to reduce emissions include diesel retrofit programs and electrifying the city's fleet, as well as efforts at the state-level to accelerate the adoption of electric vehicles.

Key terms

Primary mitigation strategies – interventions before pollution happens.

Secondary mitigation strategies – interventions that reduce the effects of pollution.

Tertiary mitigation strategies – interventions aimed at helping people affected by pollution.

Land-use buffer – land use policies that restrict sensitive uses within a specified distance of an emission source.

Another primary mitigation strategy that focuses on land use includes transit-oriented development (TOD). The City of Bellevue is already promoting TOD around its future light rail stations and major transit centers, to create more walkable complete communities. However, as mentioned above, available land adjacent to transit within the city may also be located adjacent to freeways, potentially within the APEZ. Thus, when evaluating appropriate uses within TOD, or within specific areas next to transit that are also within the APEZ, the city will need to balance and reconcile various environmental health considerations to reach informed planning and land use decisions.

[67] Prevention Institute, 2019, Spectrum of Intervention, accessed https://www.preventioninstitute.org/tools/spectrum-prevention-0

Land use buffers

Secondary mitigation strategies include interventions that reduce the effects of pollution. For example, land-use buffers are land use policies and regulations that seek to limit sensitive uses from locating within a specified distance of a high-volume roadway. Sensitive land uses include schools, daycare facilities, residences, active park land, active travel corridors, and medical facilities.

Land use buffers may be the most effective regulatory model to address impacts of air pollution, but a prohibition has the effect of eliminating land that would otherwise be available for development of sensitive uses.[68] "Overall, the evidence suggests that exposure to traffic-related air pollution can be decreased by 40 to 90 percent, depending on the pollutant, by siting sensitive land uses 200 meters or more from highways and other busy roads."[69] By limiting new sensitive land uses from locating within a buffer zone, the risk of exposing new residents and the most vulnerable populations to high concentrations of these harmful pollutants is avoided.

> Land-use buffers can result in exposure reductions of up to 90 percent.
>
> *-Brugge and Ron, 2011.*

However, it may be difficult to site these uses, particularly when the amount of land available for development is shrinking, when market forces may constrain the production of these uses within the city, or when resident opposition to increased density limits potential policy changes that could otherwise be enacted within existing neighborhoods. Striking the appropriate balance between facilitating and encouraging sensitive land uses, optimizing buildable land capacity, and prioritizing environmental health considerations may be challenging. Thus, planning for future residential and sensitive uses, should take into account air quality, along with other considerations such as the need for additional housing, availability of land for development, transportation impacts, proximity of housing to jobs, and neighborhood character.

Improved urban design

Improved urban design is another secondary mitigation strategy to consider, which could be implemented through land use code regulations or design guidelines. Urban air pollution can be reduced by 50 percent or more through urban design practices such as the careful placement of buildings and open space. [70] This tactic would be achieved most readily in neighborhoods where the

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[68] Brugge & Ron, 2021, An argument for a regulatory approach to transportation-related ultrafine particle exposure, accessed https://www.mapc.org/wp-content/uploads/2021/06/Particulate-Policy-062121.pdf

[69] Brugge & Ron, 2021, An argument for a regulatory approach to transportation-related ultrafine particle exposure, accessed https://www.mapc.org/wp-content/uploads/2021/06/Particulate-Policy-062121.pdf

[70] Brugge et al., 2014, Improving Health in Communities Near Highways

urban design was addressed holistically, such as for a neighborhood rezoned for redevelopment. To achieve improved urban design, "buildings should be oriented to readily allow dilution of polluted air, and a variety of techniques should be applied to reduce emissions in less well-ventilated areas." [71]

Other urban design strategies to consider include:

- Limiting proximity to on/off ramps and/or pursuing alternate on/off ramp designs;
- Moving freight corridors away from residential areas; and
- "...avoiding wind flow through open areas below raised highways or orienting street canyons so that wind flows through them instead of stagnating could reduce pollutant concentrations by one third to one half." [72]

Roadside barriers

Roadside barriers are a strategy that may feature noise walls or solid barriers, earthen berms, vegetative walls, vegetative buffers, or functional buffers[73]. Pollutant concentrations behind a barrier located downwind of a roadway are typically lower than concentrations in the absence of a barrier.[74] The effectiveness of this approach depends on roadway configuration, local meteorology, barrier height, design elements, and endpoint location. For example, pollutant concentrations may be higher downwind of a wall if there are gaps in the wall that allow pollutants to pass through.

A wall or solid barrier (i.e., a noise barrier) has been shown to reduce air pollution levels by 10 to 50 percent when the wind direction is across the road.[75] Barriers are less effective for other wind directions, and they should be avoided in neighborhoods with high levels of local traffic where pollution may aggregate on the non-highway side of the barrier.[76] This approach is also

> A wall or solid barrier (i.e., a noise barrier) has been shown to reduce air pollution levels by up to 50 percent when the wind direction is across the road.

[71] Brugge et al., 2014, Improving Health in Communities Near Highways

[72] Brugge & Ron, 2021, An argument for a regulatory approach to transportation-related ultrafine particle exposure, accessed https://www.mapc.org/wp-content/uploads/2021/06/Particulate-Policy-062121.pdf

[73] Baldauf, R. Recommendations for Constructing Roadside Vegetation Barriers to Improve Near-Road Air Quality. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-16/072, 2016.

[74] Bauldauf et al., 2008, Impacts of noise barriers on near-road air quality

[75] Bowker et al., 2007, The effects of roadside structures on the transport and dispersion of ultrafine particles from highways

[76] Brugge et al., 2014, Improving Health in Communities Near Highways, accessed https://sites.tufts.edu/cafeh/files/2011/10/CAFEH-Report-Final-2-26-15-hi-res1.pdf

advantageous because it also decreases noise pollution.

Municipalities can also consider creating a vegetative buffer along highways. Trees and plants along roadways can act as a physical barrier and can filter particles as they pass through and accumulate on leaf surfaces. While evidence of the efficacy of vegetative buffers is less consistent than that for solid barriers, dense, lush, varied vegetation may achieve reductions like those for solid barriers.[77] Mature vegetation tends to be more effective than young vegetation, evergreen species are typically more effective than deciduous species, and vegetation with needle-like greenery tends to be less effective than broadleaved trees.[78] Particle removal rates tend to be higher when vegetation is located close to the pollutant source and when wind speeds are low.[79] In general, the vegetation barrier should be thick (approximately 20 feet or more) and have full leaf and branch coverage from the ground to the top of the canopy along the entire length (i.e., no gaps in-between or underneath the vegetation).[80] The vegetation chosen should also maintain its structure during all seasons; thus, coniferous trees would be preferable to hardwood species.[81]

A barrier (solid or vegetative) should be at least six meters in height to be effective for air pollution reduction.[82] To maximize their effectiveness, vegetation and other barriers should be arranged so that they do not impede ventilation, particularly in street canyons.[83] Several researchers have found that the presence of a solid noise barrier and a vegetative buffer resulted in the lowest downwind pollutant concentrations, compared to either strategy alone.[84], [85]

The presence of a solid noise barrier and a vegetative buffer resulted in the lowest downwind pollutant concentrations, compared to either strategy alone.

[77] Brugge et al., 2015, Developing Community-Level Policy and Practice to Reduce Traffic-Related Air Pollution Exposure

[78] Bauldauf et al., 2013, Integrating vegetation and green infrastructure into sustainable transportation planning

[79] Tong et al., 2016, Roadside vegetation barrier designs to mitigate near-road air pollution impacts

[80] Bauldauf et al., 2008, Impacts of noise barriers on near-road air quality

[81] Nguyen et al., 2015, Relationship between types of urban forest and PM 2.5 capture at three growth stages of leaves

[82] Washington State Department of Transportation. (2016). Effects of Roadside Barriers on Near-Road Pollutant Concentrations.

[83] Brugge et al., 2015, Developing Community-Level Policy and Practice to Reduce Traffic-Related Air Pollution Exposure

[84] Bowker et al., 2007, The effects of roadside structures on the transport and dispersion of ultrafine particles from highways

[85] Tong et al., 2016, Roadside vegetation barrier designs to mitigate near-road air pollution impacts

Finally, functional barriers may achieve multiple aims. For a project in Boston, recent engagement with community members suggests that functional barriers may be preferable to traditional walls or vegetative buffers. In a charrette in the Boston area, for example, "Charrette participants opted for more functional barriers such as minimally occupied structures including parking garages and commercial buildings (with high efficiency filtration) situated between the highway and proposed new housing."[86] Collocating commercial and residential parking garages or large storage facilities immediately adjacent to highways can provide a functional buffer to more sensitive land uses. Adding green roofs and covering such structures in vegetation may reduce air pollution locally but with limited effective distance, so it is unlikely to dramatically affect human exposure. However, these interventions can make such buildings more attractive.

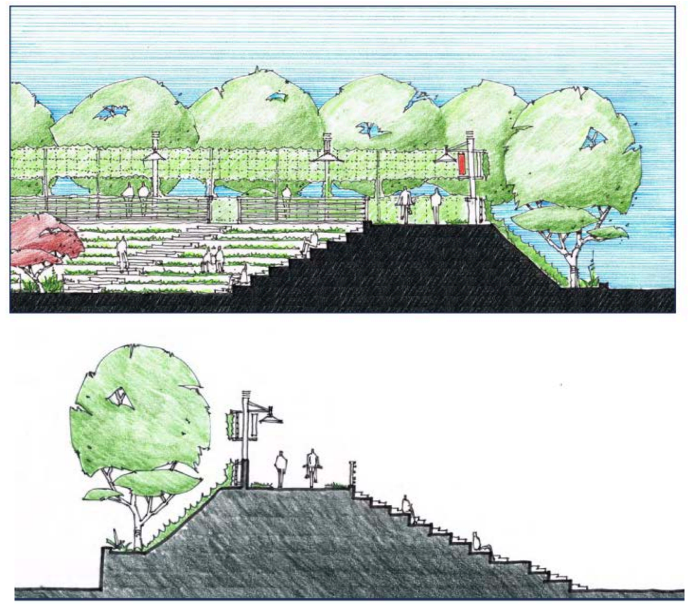

Figure 8. Schematics of functional barriers preferred by charrette participants, used with permission from Brugge et al., 2014.

Air pollution may be reduced by ~60 to 90 percent within parks relative to nearby streets, indicating that the presence of a park with lush vegetation can have a positive effect on pollution exposure.

[86] Brugge et al., 2014, Improving Health in Communities Near Highways, accessed https://sites.tufts.edu/cafeh/files/2011/10/CAFEH-Report-Final-2-26-15-hi-res1.pdf

Decking or lids over highways

Decking or lids over highways appear to be an effective mitigation strategy with some important caveats. Evidence suggests that moderate reductions in air pollution (less than 40 percent) are possible with decking or lids over high-volume roadways.[87] However, at the ends of a highway deck/lid, air pollution will aggregate. Therefore, designs should consider including large-scale air filtering of tunnel exhaust. Additionally, decking may increase commuter exposure to air pollutants, so air filtering of tunnel exhaust should be considered to ensure pollutant levels are not harmful for those driving through the tunnel. An important co-benefit of this approach is the linking of urban areas and creation of productive land, which might make it worthwhile to pursue this tactic (even though the air pollution effects are less well documented). Further study of mitigation strategies related to freeway decks or lids would need to be performed as part of the Grand Connection freeway lid effort.

Building design strategies

Building design strategies include a full suite of secondary mitigation strategies that include improved ventilation, improved filtration, green spaces inside buildings, tightening of buildings as part of energy efficiency measures and weatherization, adding triple-paned glass for noise and pollution reduction, and creating non-idling zones near buildings and their ventilation systems. Among the many opportunities to improve ventilation and filtration, several specific strategies are described below:

- Siting ventilation systems far from high-volume roadways can help mitigate exposure to air pollution and achieve improved indoor air quality. Locating building air intake vents both vertically and horizontally as far from traffic sources of pollution such as on rooftops or on sides buildings that do not face roads can decrease pollutant concentrations indoors.[88] Design guidelines for neighborhoods adjacent to freeways could include this strategy.
- Another approach is recommending or requiring higher Minimum Efficiency Reporting Value (MERV) ratings for HVAC systems near roadways. Filtration is an effective method for improving indoor air quality with reductions up to 50-90 percent.[89] Filters for residences and schools near busy roadways should be MERV 14 or above, mainly because the ultrafine

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[87] Brugge et al., 2015, Developing Community-Level Policy and Practice to Reduce Traffic-Related Air Pollution Exposure
[88] Brugge et al., 2015, Developing Community-Level Policy and Practice to Reduce Traffic-Related Air Pollution Exposure
[89] Environmental Protection Agency, Improving Indoor Air Quality, accessed https://www.epa.gov/indoor-air-quality-iaq/improving-indoor-air-quality

particle removal efficiencies of filters with lower MERV ratings are not reported.[90] Although existing standards are variable, a higher MERV rating is preferable, as long as the unit meets noise requirements. Filters with electrostatic precipitation should be carefully evaluated prior to use to avoid removing particulate pollution at the expense of increased ozone levels. If filters are to be used for air pollution reduction, steps should be taken to ensure maintenance and use. Long-term benefits of improved filtration require proper filter replacement and long-term maintenance.

- Triple-paned windows and other envelope tightening strategies may decrease exposure to air pollutants. Additionally, they have energy efficiency, weatherization, and noise benefits. This could potentially be addressed in design guidelines or through updates to the building code.

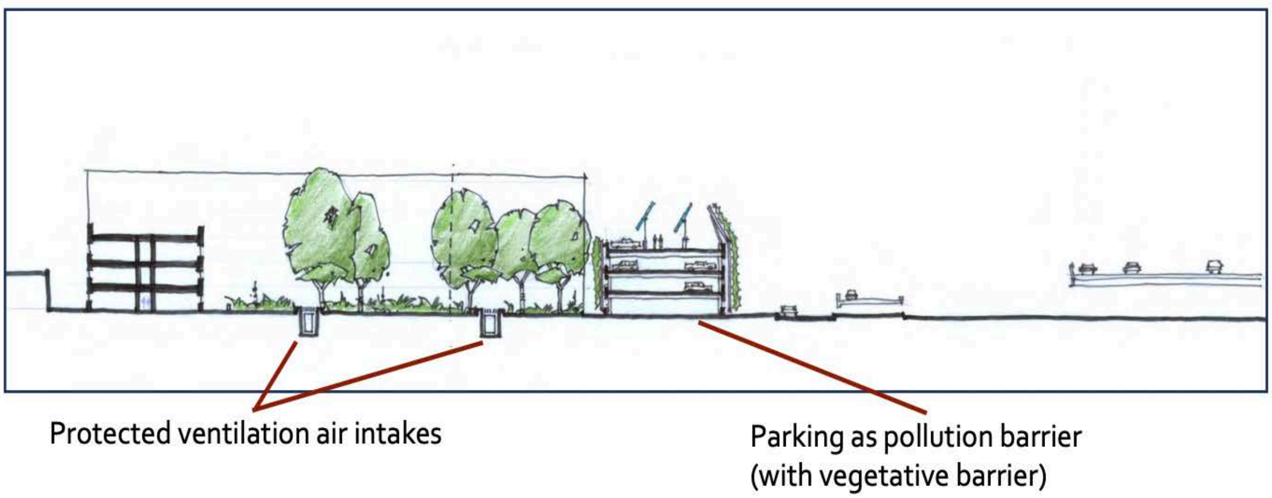


Figure 9. Schematic of protected ventilation air intakes and parking as pollution barrier, used with permission from Brugge et al., 2014.

Example air quality policies from other local governments

Appendix E includes examples of policies, codes, and plans targeted at limiting the risk of exposure to air pollution generated by high-volume roadways. Most examples are from jurisdictions located in California as California has historically been out in front of the rest of the country on air quality protections, but a couple of examples are from local jurisdictions. While not exhaustive, examples

[90] Environmental Protection Agency, 2015, Best Practices for Reducing Near-Road Pollution Exposure at Schools, accessed https://www.epa.gov/sites/default/files/2015-10/documents/ochp_2015_near_road_pollution_booklet_v16_508.pdf

range from preventative to mitigation and in general include policies and codes related to limiting sensitive uses within exposure zones, site and building design mitigation measures, and the development of community risk reduction plans with requirements for health impact assessments that may include requirements for air quality monitoring.

The following policies are illustrative. It is important to remember that local needs and circumstances should inform city consideration of the location and type of land uses and growth to be encouraged and supported, environmental health and protection, and the quality of life throughout the city.

Example site design policies and regulations include:

- Limiting sensitive land uses within an APEZ.
- Requiring residential buildings to be sited farthest from pollution sources and buildings or open spaces not housing people being located closest to the source of emissions, and/or
- Requiring installation of a combined solid barrier and dense, evergreen, vegetative buffer.

Example of building design policies and regulations include:

- Prohibiting sensitive uses on the ground floor, or any floor at the same or lower elevation of an adjacent roadway, where applicable building code provisions do not require exit directly to the exterior,
- Requiring and/or encouraging the installation of air intakes in locations as far away as is feasible from emission sources to provide the cleanest air to the building occupants, and/or
- Requiring the installation and implementation of an air filtration system (minimum of MERV 13) along with a maintenance plan detailing how the filtration system will be maintained.

Example community risk reduction plans (CRRP) and health risk assessments include:

- A CRRP with a baseline inventory of toxic air pollutants, objectives and performance targets for air quality improvement along with a set of local actions to reduce health impacts for disproportionately exposed communities,
- Requirements for health risk assessments for proposed developments along with reduction measures to reduce health risks to acceptable levels.

V. Forward-Looking Strategies for Bellevue

The following strategies in this chapter are based on a comprehensive review of the literature on reducing exposure to transportation related air pollution (TRAP). Recognizing that local land use planning and major rezones are complex, multiple factors must be considered and balanced. Prioritizing or implementing any of these strategies would depend on several factors, including the need and demand for housing, commercial space, daycares, and healthcare; the proximity to transit; and the supply, or lack thereof, of affordable land. As Bellevue plans equitably for growth, the city can consider the benefits of increasing development capacity near high frequency transit and job centers along with the benefits of limiting exposure to air pollution. Opportunities for informed review of existing policies will take place during city planning processes for the periodic update to the Comprehensive Plan, the Wilburton Vision Implementation, and the BelRed Look Forward.

Land use strategies

The following strategies are recommended for consideration when updating future plans and policies:

- Consider applying a land use buffer for new sensitive land use capacity (schools, childcare centers, and residential uses) within Air Pollution Exposure Zones (APEZ), a minimum of 500 feet from high-volume roadways, when alternative locations with lower health risks exist.
- Explore growth alternatives that increase capacity for sensitive uses outside of APEZs, and when growth is located within APEZs, specific mitigation measures should be considered.
- Explore ways to discourage new sensitive land uses (e.g. daycares) from locating on the ground floor of existing buildings within APEZs, where applicable building code provisions do not require exit directly to the exterior.
- Explore ways to encourage land uses that act as physical buffers (e.g. parking garages, storage buildings, and other low-population density structures) to locate between freeways and other more sensitive land uses.
- Expand capacity for sensitive land uses (schools, childcare centers, and residential uses) by planning for a greater mix and intensity of uses in areas outside of APEZs throughout the city.

Urban design strategies

When updating future plans, consider adding urban design policies calling for elements that mitigate impacts from high-volume roadways on new or expanded uses sited near high-volume roadways, and in particular existing sensitive uses:

- Consider adding policies calling for design standards and guidelines that could improve air flow near freeways and prevent stagnation of air pollution. This may include standards such as maximum floor plate sizes, building siting requirements, and open space requirements between buildings.

- Consider adding policies to require or incentivize installation of solid barriers, earthen berms, sound walls, and/or the planting of dense rows of trees and/or other vegetation between buildings and high-volume roadways (>= 100,000 AADT), for new or expanded uses sited within APEZs. Large, evergreen trees with long life spans work best for trapping air pollution (e.g. Western red cedar and Douglas fir).
- Consider the location of high-volume roadways (>= 100,000 AADT) when amending policies or regulations that would affect the siting of new or expanded buildings.
- Consider adding policy that would encourage the siting of building air intakes farthest from or shielded from transportation related air pollutants, where feasible.

Overall strategies

The following recommendations apply broadly to Bellevue's policy and planning processes, and build on existing city planning processes:

- Apply an equity lens during all planning processes for land use adjacent to high-volume roadways. This centers environmental justice and redresses the cumulative health impacts to people of color, low-income communities, and other historically underrepresented groups (e.g., who would benefit most from increasing residential capcacity across the city, and who could potentially be harmed).

- Continue to prioritize pedestrian and bicycle facility improvements, transit-oriented development, rideshare programs, and efforts to electrify the city's fleet. Identify opportunities to support and accelerate medium and heavy-duty vehicle electrification.

- Prioritize increasing density through infill development to turn low-density neighborhoods into ones that support accessing goods and services by walking, bicycling, and use of transit.

- Consult with builders and developers (e.g., Master Builders, BOMA, etc.) and impacted communities when looking to implement regulatory policies or guidance aimed at air pollution mitigation.

Recommendations for further study

Although this report is focused on strategies for future land use planning, the following strategies are also related to reducing exposure to air pollution around high-volume roadways, yet they apply more broadly. They are included here for consideration when developing future work programs.

Building Strategies

- Incentivize installation and require regular maintenance of air filters with MERV ratings at 13 or above e.g. through retrocommissioning support.

- Explore linkages between green building strategies, emerging building technologies, and air quality near high-volume roadways.

Air Quality Monitoring and Existing Uses

- Partner with agencies such as the Puget Sound Clean Air Agency, WA Department of Ecology Air Quality program, King County Public Health, and/or WA Department of Transportation to pilot air quality monitoring sensors at existing sensitive use locations within APEZs to gather information on existing localized conditions (see Appendix F for EPA's School Ventilation & Filtration System Assessment to guide decision-making about existing buildings).
- Partner with Seattle King County Public Health and the Puget Sound Clean Air Agency to:
    1. Inform owners of existing sensitive land uses located near high-volume roadways of:
        - The risk of exposure to high concentrations of air pollutants, especially from outdoor activities;
        - Steps they can take to assess indoor air quality as well as measure/monitor levels of air pollution outside their buildings;
        - Steps they can take to improve indoor air filtration including relocation of air intake valves oriented as far away from emission sources as possible (e.g. on roofs or high on building walls to avoid ground-level pollutants) and use of filters with MERV ratings of 13 or above; and
        - Steps they can take to improve outdoor air quality through installation of physical and/or vegetative buffers.
    2. Evaluate the need for relocation of sensitive uses outside of APEZs.
    3. Incentivize heat pumps for residential uses near high-volume roadways and/or for people with respiratory conditions/vulnerabilities, to limit respiratory impacts due to lack of air conditioning during heat events.

Advocacy

Opportunities to collaborate regionally and advocate for regional and state policies and resources to support improving air-quality and planning near high-volume roadways include:

- Advocate for updates to the International Building Code that require enhanced ventilation systems in new construction in proximity to high-volume roadways (MERV ratings 13 or higher).

- Advocate for regional or state standards for ultrafine particulates and other pollutants that lack federal standards.

- Advocate and collaborate with the State Mechanical Code Technical Advisory Committee and the Regional Code Collaborative to update code to consider best practices and standards for buildings located near high-volume roadways.
- Collaborate with local jurisdictions to share best practices for land use planning near high-volume roadways.
- Advocate for incorporating the location of sensitive land uses into the criteria for siting and installation of noise walls.
- Advocate for increased air quality monitoring in Bellevue from relevant state or regional air quality monitoring organizations, especially for sensitive uses near high-volume roadways, through programs such as the new air quality monitoring program part of the WA Climate Commitment Act.

Other Strategies:

- Pilot air quality monitoring sensors in air pollutant exposure zones near existing sensitive uses.
- Explore linkages between green building strategies, emerging building technologies, and air quality near high-volume roadways.
- Explore alternative on-/off-ramp designs that reduce idling, acceleration, and deceleration.
- Evaluate lidding, decking, or tunneling of I-405 as a strategy for the Grand Connection, which could have additional environmental health and air pollution benefits.
- Develop interactive maps showing weather, air quality monitoring data, and impacted communities to identify Air Pollutant Exposure Zones where poor air quality, exposure risk, and community vulnerability to exposure align (see examples from the San Francisco Department of Public Health, Bay Area Air Quality Management District, and Washington Department of Health's Environmental Health Disparities Map).
- Monitor development and air pollution trends over time to ensure equitable outcomes.
- Identify opportunities for increasing tree canopy within close proximity of high-volume roadways, in particular near existing sensitive uses.
- Develop approaches to educate the community, school and childcare administrators, healthcare providers, building developers, elected officials, and other stakeholders about the risks of air pollution with targeted, proactive, and appropriate messaging.
- Identify potential sites to install noise walls or other physical barriers coupled with vegetative barriers between highways and adjacent lower elevation areas, especially where sensitive land uses exist, utilizing the WSDOT noise wall framework for projects that can trigger the development of a noise wall: Type 1; significant roadway construction projects and Type 2;

retrofit barriers in neighborhoods that existed before noise abatement regulations were established[91].

[91] Washington State Department of Transportation Noise Walls & Barriers webpage, accessed September 14, 2022; Noise walls & barriers | WSDOT.

Appendix A. Annotated bibliography

This annotated bibliography aims to organize and collate references and resources about air quality and relevant related topics. This is valuable to readers so they can understand the array of sources that were used to construct this report. Because it is not a systematic review, it does not include every resource and reference on these topics. Because it is not a literature review, it does not editorialize or synthesize information. Each of these references is included – implicitly or explicitly – somewhere in the body of the report, and each reference includes a brief overview of findings, as well as tags for topics of interest. They are presented in the order in which they are referenced in the report.

American Lung Association. (2022). State of the Air 2021 Report. Accessed on March 25, 2022, from https://www.lung.org/research/sota

The ALA produces an annual national air quality report using air quality data from the Environmental Protection Agency. It grades counties and cities based on their scores for ozone, year-round particle pollution and short-term particle pollution levels. The most recent State of the Air Report found that despite progress on cleaning up air pollution, more than 40 percent of Americans are living in places with unhealthy levels of ozone or particle pollution.

Tags: health effects

Anenberg, S.C., Haines, S., Wang, E., Nassikas, N., & Kinney, P.L. (2020). Synergistic health effects of air pollution, temperature, and pollen exposure: A systematic review of epidemiological evidence. *Environmental Health*. 19, 130.

Anenberg et al. systematically review epidemiological evidence from 56 studies for interactive effects of multiple exposures to heat, air pollution, and pollen on human health. They conclude that there is sufficient evidence that simultaneous exposure to heat and air pollution have synergistic effects on human health, meaning that the effects from both combined are larger than the effects from each alone. However, they also conclude that there is less evidence that simultaneous exposure to air pollution, heat and pollen or simply air pollution and pollen have synergistic effects on human health. Nearly all studies were at risk of bias from exposure assessment error. These findings raise concern for cumulative health impacts from air pollution and heat exposure may worsen as climate change increases exposure to heat.

Tags: climate change, health effects

Bae, C. C., Sandlin, G., Bassok, A., & Kim, S. (2007). The exposure of disadvantaged populations in freeway air-pollution sheds: A case study of the Seattle and Portland regions. Environment and Planning B: Planning and Design Environ. Plann. B, 34(1), 154-170.

Bae et al. investigate the effects of air pollution from high-volume roadways on vulnerable populations in Seattle and Portland. They find that many mobile-source emissions decay rapidly and approach background concentrations at 330 feet from the freeway. They also explore the relationship between house price values in Seattle and freeway proximity, policy options, planning implications, land-use prescriptions, and other mitigation measures. They found clustering of low-income and minority population near freeways, that the residential choices of the minority and/or low-income population are limited, and that housing prices are lower when other negative environmental factors such as traffic noise are accounted for. They conclude that people living in such locations make trade-offs for cheaper housing versus higher health risks.

Tags: residential, vulnerable populations, environmental justice, distance from road

Baldauf, R. W., Khlystov, A., Isakov, V., Thoma, E., Bowker, G. E., Long, T., & Snow, R. (2008). Impacts of noise barriers on near-road air quality. Atmospheric Environment, 42, 7502–7507.

Baldauf et al. assess traffic emissions impacts on air quality near a high-volume roadway, including a parcel of land that includes an open field, a section with a noise barrier alone, and a section with a noise barrier with vegetation combined. They found that the presence of a noise barrier can lead to higher pollutant concentrations during certain wind conditions but that the presence of mature trees in addition to the barrier reduced pollutant concentrations.

Tags: mitigation strategies, noise

Baldauf, R., McPherson, G., Wheaton, L., Zhang, M., Cahill, T. Hemphill Fuller, C., Withycombe, E., & Titus, K. (2013). Integrating vegetation and green infrastructure into sustainable transportation planning. Transportation Research News, September-October, 14-18.

Baldauf et al. assess the effects of vegetation and other green infrastructure for transportation planning. The review article includes discussions of vegetation barriers, computational models, cobenefits and disbenefits, barrier design considerations, addressing negative effects, and planting trees. Ultimately, they note that there are many considerations and questions that remain in the implementation of any mitigation strategies, and they advocate for pilot studies to help resolve these.

Tags: mitigation strategies

Barboza, T. (2017, July 9). L.A. requires air filters to protect residents near freeways. Are they doing the job? Los Angeles Times. Accessed on April 7, 2022, from https://www.latimes.com/local/lanow/la-me-ln-freeway-pollution-filters-20170709-story.html

Despite growing warnings about the health problems tied to traffic pollution, Los Angeles officials continue to approve a surge in residential development along freeways. The crux of their effort to protect people's lungs is a requirement that developers install air filters. To be effective, however, filters must be replaced frequently, and ventilation systems must run virtually non-stop.

Tags: Mitigation, residential zoning, building measures, filtration

Bateson, T.F. & Schwartz, J. (2007). Children's Response to Air Pollutants, Journal of Toxicology and Environmental Health, Part A, 71:3, 238-243.

Bateson & Schwartz highlight effects of air pollution on the lungs of young people. They note that it is important to focus on children with respect to air pollution because (1) their lungs are not completely developed, (2) they can have greater exposures than adults, and (3) those exposures can deliver higher doses of different composition that may remain in the lung for greater duration. The observed consequences of early life exposure to adverse levels of air pollutants, particularly diesel exhaust, include diminished lung function and increased susceptibility to acute respiratory illness and asthma.

Tags: vulnerable populations, health effects

Berglund, B., Lindvall, T., & Schwela, D. A. (1999). Guidelines for community noise. WHO.

This WHO document recognizes noise as an environmental problem. It compares and contrasts environmental noise to other pollutants and describes the evidence of human health impacts and dose-response relationships. Further, it attempts to derive guidelines for community noise and guidance for environmental health authorities and professions trying to protect people from the harmful effects of noise in non-industrial environments.

Tags: noise pollution

Boehmer, T.K., Foster, S.L., Henry, J.R., Woghiren-Akinnifesi, E.L., & Yip, F.Y. (2013). Residential proximity to major highways – United States, 2010. MMWR, 62(3):36-50). Accessed on February 22, 2022, from https://www.cdc.gov/mmwr/pdf/other/su6203.pdf

Boehmer et al. aim to discuss and raise awareness of the characteristics of persons exposed to traffic-related air pollution and to prompt actions to reduce disparities. They found that approximately 11.3 million people (4 percent of the total U.S. population) live within 150 meters of a major highway. Among these, the authors identified that the greatest disparities were observed for race/ethnicity, nativity, and language spoken at home; the populations with the highest estimated percentage living within 150 meters of a major highway included members of racial and ethnic minority communities, foreign-born persons, and persons who speak a language other than English at home. They describe primary prevention strategies (e.g., transit, rideshare programs, diesel retrofitting, etc.), as well as secondary prevention strategies (e.g., roadside barriers, improved ventilation systems, land-use policies that limit new development).

Tags: vulnerable populations, environmental justice

Bowker, G. E., Baldauf, R., Isakov, V., Khylstov, A., & Petersen, W. (2007). The effects of roadside structures on the transport and dispersion of ultrafine particles from highways. Atmospheric Environment, 41, 8128-8139.

Bowker et al. examine the effects of roadside barriers on the flow patterns and dispersion of pollutants from a high-traffic highway in Raleigh, North Carolina. The authors found that air pollutant concentrations near the road were generally higher in open terrain situations with no barriers present; however, concentrations decreased faster with distance than when roadside barriers were present. The presence of a noise barrier and vegetation resulted in the lowest downwind pollutant concentrations.

Tags: mitigation strategies

Brugge, D., Durant, J., Patton, A., Newman, J., & Zamore, W. (2014). Improving Health in Communities Near Highways: Design Ideas from a Charrette. Community Assessment of Freeway Exposure and Health. Accessed on February 10, 2022, from https://sites.tufts.edu/cafeh/files/2011/10/CAFEH-Report-Final-2-26-15-hi-res1.pdf

This design charette is part of a larger Community Assessment of Freeway Exposure and Health (CAFEHG) project and focused on enacting positive changes for projects to reduce exposure to ultrafine particles near-highway locations in the Boston Area, including Boston's Chinatown and communities in the City of Somerville. Among these projects and policies, Brugge et al. describe:

1. filtration
2. air inlet locations
3. sound proofing
4. land use buffers
5. vegetative or built wall barriers
6. trees and plantings

7. decking over highways
8. urban design
9. garden locations & healthy vegetables
10. park locations
11. active travel locations

The authors note that municipalities will likely use zoning and public health regulations as effective tools for mitigating health effects from traffic pollution, but also that community activism and litigation have also produced effective actions in very specific situations in some states and municipalities.

Tags: mitigation strategies, participatory research

Brugge, D., Patton, A. P., Bob, A., Reisner, E., Lowe, L., Bright, O. M., Zamore, W. (2015). Developing Community-Level Policy and Practice to Reduce Traffic-Related Air Pollution Exposure. Environmental Justice, 8(3), 95-104.

Brugge et al. hosted a multidisciplinary design charrette that resulted in designs that successfully utilized many protective tactics and also led to engagement with the designers and developers of sites adjacent to high-volume roadways. The authors note that growth of interest in ''green buildings'' and ''healthy homes'' has mostly focused on addressing indoor sources of air pollution; however, they suggest an equally important need to consider and prevent exposure to ambient pollutants that infiltrate into homes and schools. Brugge et al. describe nine community-level tactics for reducing exposure to traffic-related air pollutants, including:

1. high-efficiency particulate arrestance (HEPA) filtration
2. appropriate air-intake locations
3. sound proofing, insulation
4. land-use buffers
5. vegetation or wall barriers
6. street-side trees, hedges and vegetation
7. decking over highways
8. urban design including placement of buildings
9. garden and park locations
10. active-travel locations, including bicycling and walking paths.

Tags: mitigation strategies, participatory research

Brugge, D. & Ron, S. (2021). An argument for a regulatory approach to transportation-related ultrafine particle exposure. Retrieved on February 10, 2022, from https://www.mapc.org/wp-content/uploads/2021/06/Particulate-Policy-062121.pdf

Brugge & Ron offer an overview of the risks of traffic-related ultrafine particle exposure, as well as practical steps toward regulating them. It is geared toward lay audiences. The authors note that, unlike PM2.5, UFP are not federally regulated, yet due to their small size they are a serious health concern since they can get into people's lungs, blood and brain where they have been linked to increased risks for respiratory disease, heart disease, and neurological health conditions as well as early death. Also, they note that while PM2.5 spreads out over multiple neighborhoods or towns, UFP often have large concentration gradients in the immediate vicinity (300-500 feet, or one-tenth of a mile) of sources, including, most notably, roadway corridors (Patton et al. 2014).

The authors also note that findings of adverse health effects and the intervention techniques tested are directly relevant to the struggle to create a healthy environment for all of the Commonwealth's residents, especially those who have been denied the opportunity to live, work, and play in an environment free from pollution due to their race, income, or citizenship.

The authors suggest that action must be taken at the local, regional, and state levels. Among the solutions they describe, the authors include:

1. establishing high-efficiency air filtration and ventilation standards for new buildings
2. using portable air filters in existing buildings
3. locating housing, schools, and parks away from highways or busy streets
4. building noise barriers

Tags: mitigation strategies, regulatory, environmental justice

Brunekreef, B., Nicole A. H. Janssen, De Hartog, J., Harssema, H., Knape, M., & Van Vliet, P. (1997). Air Pollution from Truck Traffic and Lung Function in Children Living near Motorways. Epidemiology, 8(3), 298-303.

Brunekreef et al. measured air pollution at schools near major roads in the Netherlands, as well as lung function in children attending those schools. They identified an association between lung function and truck traffic density. This association was stronger in children living closest to roads (within 300 meters). The strongest association was with diesel exhaust particles.

Tags: vulnerable populations, health effects, schools

California Environmental Protection Agency. Air Resources Board. (2005). Air quality and land use handbook: A community health perspective. Sacramento, CA: California Environmental Protection Agency, Air Resources Board.

This handbook recommends that communities avoid siting new sensitive land uses such as residences, schools, daycare centers, playgrounds, or medical facilities within 500 feet of a freeway, urban roads with 100,000 vehicles per day, or rural roads with 50,000 vehicles/day. They note that localized air pollution exposures can be reduced as much as 80 percent with this buffer.

Tags: distance from road

Cohn, L., Harris, R., Shu, N., & Li, W. (2005). Highway Noise and Land Use Compatibility. Journal of Urban Planning and Development, 131(3), 125-129.

Noise is a great impediment to land use compatibility with adjacent highways and freeways. This article reports on the results from two research projects that utilized a common data-gathering effort, and examines the relationship between highway noise and land use compatibility, based on two recent studies performed by the writers. The principal goal of one of those studies was to "push the envelope" on this interrelatedness, in an attempt to examine the bigger issue of how noise should be considered in the future in relation to definitions of appropriate land use. In doing so, a series of questions was put forth and then answered, based on an extensive literature review and a survey of state highway agencies. Several recommendations were made, the most important of which was the creation of a state-funded retrofit program to be used to solve problems for residences that otherwise would not qualify for noise abatement consideration. That recommendation is under implementation by the Arizona Department of Transportation.

Tags: Noise, land use, zoning

Dadvand, P., Rivas, I., Basagaña, X., Alvarez-Pedrerol, M., Su, J., Pascual, M. D., & Nieuwenhuijsen, M. J. (2015). The association between greenness and traffic-related air pollution at schools. Science of The Total Environment, 523, 59-63.

Dadvand et al. examined the association between greenness within and surrounding school boundaries and monitored indoor and outdoor levels of traffic-related air pollutants (including NO_2, ultrafine particles, black carbon, and traffic-related $PM_{2.5}$) at 39 schools across Barcelona, Spain. They found an inverse association between greenness within and surrounding school boundaries and indoor and outdoor pollution. They conclude that including school and neighborhood greenness could be a way to address high burden of health effects of air pollution for schoolchildren, as well as to achieve other health co-benefits of greenness such as better behavioral development and school performance.

Tags: mitigation strategies, schools

Daigle, C. C., Chalupa, D. C., Gibb, F. R., Morrow, P. E., Oberdorster, G., Utell, M. J., and Frampton, M. W. 2003. Ultrafine particle deposition in humans during rest and exercise. Inhal. Toxicol.15(6):539– 552.

Daigle et al. measured the deposition of various size particles during breathing at rest and exercise. They concluded that particle deposition increased as particle size decreased, and that the ultrafine particle burden to the alveolar epithelium is significantly greater during exercise. They recommend caution for children and people exercising outdoors near high-volume roadways or other sources of UFP.

Tags: vulnerable populations, health effects, land use

DeWinter, J.L., Brown, S.G., Seagram, A.F., Landsberg, K., & Eisinger, D.S. (2018). A national-scale review of air pollutant concentrations measured in the U.S. near-road monitoring network during 2014 and 2015. Atmospheric Environment. 183:94-105

DeWinter et al. performed a national-scale assessment of air pollutants measured at 81 sites in the near-road environment during 2014 and 2015. They evaluated how concentrations at these locations compared to the National Ambient Air Quality Standards and estimated the contribution of emissions for adjacent roadways at each near-road site to the PM2.5 concentrations above the local urban background concentrations. The first two years of air quality monitoring data collected in the near-road environment across the U.S. indicate that near-road concentrations of CO and NO2 are typically below NAAQS thresholds, while PM2.5 concentrations were above NAAQS thresholds for a subset of near-road sites. The authors identified only a weak relationship between near-road mean CO, NO2 or PM2.5 concentrations and distance from roadway, likely due to confounding influences such as meteorology and urban-scale pollutant concentrations.

Tags: national data

Eisinger, D., Craig, K., Lansberg, K., Mukherjee, A., DeWinter, J., McCarthy, M., & Brown, S. (2021). Near-road air quality: Insights for a U.S. DOT five-year transportation pooled fund study. TR News.

In this review of a five-year transportation study funded by the United States Department of Transportation, the authors note that pollutants directly emitted by vehicles (from exhaust, wear from brake pads and tires, and dust from the road surface) are of special concern in areas adjacent to heavily travelled roads. Traffic, especially diesel-powered trucks and buses, create pollution hot spots within a few hundred meters of major roads. These are of particular concern given the growing awareness of environmental justice and community-based air quality. Given these concerns, eight state and federal agencies pooled their research efforts on this topic. They found that CO is no longer a near-road problem. Furthermore, virtually all near-road NO2 concentrations fell below existing health-based air quality standards. Most areas in the study have PM2.5 concentrations below NAAQS, and emissions trends suggest that future conditions will continue to improve. PM2.5 emissions based on EPA's emissions model, MOVES, were reduced by 92 percent between 2006 and 2035.

Tags: national data

English, P., Neutra, R., Scalf, R., Sullivan, M., Waller, L., & Zhu, L. (1999). Examining associations between childhood asthma and traffic flow using a geographic information system. Environmental Health Perspectives, 107(9), 761–767.

Using GIS data, English et al. explored the association of childhood residence proximal to high-volume roadways and asthma in a low-income population in San Diego County, California. Analysis of cases and controls within a 550-ft buffer region did not show any significantly elevated odds ratios. However, among cases, those residing near high traffic flows were more likely than those residing near lower traffic flows to have two or more medical care visits for asthma than to have only one visit for asthma during the year. This study suggests that higher traffic flows may be related to an increase in repeated medical visits for asthmatic children. Repeated exposure to particulate matter and other air pollutants from traffic exhaust may aggravate asthmatic symptoms in individuals already diagnosed with asthma.

Tags: vulnerable populations, health effects, residential

Forns J, Dadvand P, Foraster M, Alvarez-Pedrerol M, Rivas I, López-Vicente M, Suades-Gonzalez E, Garcia-Esteban R, Esnaola M, Cirach M, Grellier J, Basagaña X, Querol X, Guxens M, Nieuwenhuijsen MJ, Sunyer J. 2016. Traffic-related air pollution, noise at school, and behavioral problems in Barcelona schoolchildren: a cross-sectional study. Environ Health Perspect 124:529–535.

Forns et al. evaluated students in Barcelona to determine the associations between noise and indoor and outdoor concentrations of elemental carbon (EC), black carbon (BC), and nitrogen dioxides (NO2) and child behavioral development scores. The authors found that increases in indoor and outdoor concentrations of EC, BC, and NO2 were associated with more frequent behavioral problems, and that noise exposure at school was associated with more ADHD symptoms.

Tags: vulnerable populations, health effects, schools

Gauderman, W., Avol, E., Lurmann, F., Kuenzli, N., Gilliland, F., Peters, J., & McConnell, R. (2005). Childhood Asthma and Exposure to Traffic and Nitrogen Dioxide. Epidemiology, 16(6), 737-743.

Gauderman et al. examined the association between traffic-related pollution and childhood asthma in 208 Children's Health Study subjects from ten Southern California communities using multiple indicators of exposure. Lifetime history of doctor-diagnosed asthma was associated with outdoor NO2. The authors also observed increased asthma associated with closer residential distance to a freeway. Freeway exposure and measured NO2 concentrations were also associated with wheezing and use of asthma medication. Asthma was not associated with traffic volumes on roadways within 150 meters of homes or with model-based estimates of pollution from non-freeway roads.

Tags: vulnerable populations, health effects, residential

Goodkind, A.L., Tessum, C.W., Coggins, J.S., Marshall, J.D. (2019). Fine-scale damage estimates of particulate matter air pollution reveal opportunities for location-specific mitigation of emissions. PNAS, 116(18):8775-8780. Accessed on June 15, 2022, from https://doi.org/10.1073/pnas.1816102116

Goodkind et al. estimate that anthropogenic PM2.5 was responsible for 107,000 premature deaths in 2011, at a cost to society of $886 billion. The authors also applied a tool to assess the impacts of pollution emissions on a hyperlocal scale, underscoring the importance of capturing the variability in health impacts at a sub-county level.

Hankey, S., Lindsey, G., & Marshall, J. (2017). Population-Level Exposure to Particulate Air Pollution during Active Travel: Planning for Low-Exposure, Health-Promoting Cities. Environmental Health Perspectives, 125(4), 527-534.

Active travel (e.g., walking, biking) often occurs on high-traffic streets or near activity centers where particulate concentrations are highest (i.e., 20–42 percent of active travel occurs on blocks with high population-level exposure). Only 2–3 percent of blocks (3–8 percent of total active travel) are "sweet spots" (i.e., high active travel, low particulate concentrations); sweet spots are located a) near but slightly removed from the city-center or b) on off-street trails. They identified 1,721 blocks (~ 20 percent of local roads) where shifting active travel from high-traffic roads to adjacent low-traffic roads would reduce exposure by ~ 15 percent. Active travel is correlated with population density, land use mix, open space, and retail area; particulate concentrations were mostly unchanged with land use. Public health officials and urban planners may use our findings to promote healthy transportation choices.

Tags: Land use, open space, density, public health

Health Effects Institute. (2010). Traffic-related air pollution: A critical review of the literature on emissions, exposure, and health effects. Special Report 17.

This critical review of the best available evidence concludes that traffic-related emissions affect ambient air quality on a wide range of spatial scales, from local roadsides and urban scales to broadly regional background scales. The authors identify an exposure zone within a range of up to 300 to 500 m from a major road as the area most highly affected by traffic emissions. They note that the range reflects the variable influence of background pollution concentrations, meteorological conditions, and season. Finally, they conclude that the sufficient and suggestive evidence for these health outcomes indicates that exposures to traffic-related pollution are likely to be of public health concern and deserve public attention.

Tags: distance from road, health effects

Hjortebjerg, D., Andersen, A. N., Christensen, J. S., Ketzel, M., Raaschou-Nielsen, O., Sunyer, J., & Sorensen, M. (2016). Exposure to Road Traffic Noise and Behavioral Problems in 7-Year-Old Children: A Cohort Study. Environmental Health Perspectives, 124(2), 228-234.

Hjortebjerg et al. investigate the association of road traffic noise exposure and behavioral problems in 7-year-old Danish children. They determined that a 10-dB increase in average time-weighted road traffic noise exposure from birth to 7 years of age was associated with a 7 percent increase in abnormal versus normal total difficulties; 5 percent increase in borderline hyperactivity/inattention; 9 percent increase in abnormal hyperactivity/inattention; 5 percent increase in abnormal conduct problem; and 6 percent increase in peer relationship problems.

Tags: noise pollution

Hygge, S., Evans, G., & Bullinger, M. (2002). A Prospective Study of Some Effects of Aircraft Noise on Cognitive Performance in Schoolchildren. Psychological Science, 13(5), 469-474.

Hygge et al. found that children exposed to aircraft noise have impaired long-term memory, reading, short-term memory, and speech perception.

Tags: noise pollution

IMIM (Hospital del Mar Medical Research Institute). (2022, March 15). Living near green areas reduces the risk of suffering a stroke by 16 percent, study finds. ScienceDaily. Retrieved March 18, 2022 from www.sciencedaily.com/releases/2022/03/220315113023.htm

The risk of suffering an ischaemic stroke, the most common type of cerebrovascular event, is 16 percent less in people who have green spaces less than 300 meters from their homes. The study took into account information on exposure to three atmospheric pollutants linked to vehicle traffic in more than three and a half million people selected from among the 7.5 million residents of Catalonia, over the age of eighteen who had not suffered a stroke prior to the start of the study.

Tags: mitigation strategies

Karner, A. A., Eisinger, D. S., & Niemeier, D. A. (2010). Near-roadway air quality: Synthesizing the findings from real-world data. Environmental Science & Technology, 44(14), 5334-5344.

The authors synthesize data from 41 roadside monitoring studies to determine concentration-distance relationship among air pollutants. With one analysis, they found almost all pollutants decay to background by 115-570 meters; with another analysis, they found almost all pollutants decay to background by 160-570 meters. Changes in pollutant concentrations with increasing distance from the road fell into one of three groups: at least a 50 percent decrease in peak/edge-of-road concentration by 150 m, followed by consistent but gradual decay toward background (e.g., carbon monoxide, some ultrafine particulate matter number concentrations); consistent decay or change over the entire distance range (e.g., benzene, nitrogen dioxide); or no trend with distance (e.g., particulate matter mass concentrations).

Tags: distance from road

Kim, H. H., Lee, C. S., Yu, S. D., Lee, J. S., Chang, J. Y., Jeon, J. M., … Lim, Y. W. (2016). Near-Road Exposure and Impact of Air Pollution on Allergic Diseases in Elementary School Children: A Cross-Sectional Study. Yonsei Medical Journal, 57(3), 698–713.

Kim et al. classified seven schools according to their neighborhood characteristics: three were in traffic-related zones, two were in urban zones, and two were in industrial zones. The frequency of asthma treatment during the previous 12 months showed a significant increase with exposure to NO2, as did the frequency of allergic rhinitis treatment with exposure to black carbon. Finally, the risk of asthma, allergic rhinitis, and atopic dermatitis was higher among children in schools in traffic related and complex source zones compared to children in schools in the control group.

Tags: vulnerable populations, health effects, schools

Kim, J.J., Smorodinsky, S., Lipsett, M., Singer, B.C., Hodgson, A.T., Ostro, B. (2004). Traffic-related Air Pollution near Busy Roads. American Journal of Respiratory and Critical Care Medicine. 170: 5(520-526).

Kim et al. conducted a school-based cross-sectional analysis in the San Francisco Bay area and found that although pollutant concentrations at 10 school sites were relatively low, they were higher at schools near and/or downwind of major roads. They found associations between respiratory symptoms and traffic-related pollutants, as well as spatial variability in pollutants and associated differences in respiratory symptoms in a region with relatively good air quality.

Tags: vulnerable populations, health effects, schools.

Kingsley, S.L., Eliot, M.N., Carlson, L., Finn, J., MacIntosh, D.L., & Suh, H.H. (2014). Proximity of U.S. schools to major roadways: A nationwide assessment. Journal of Exposure Science and Environmental Epidemiology, 24, 253–259.

The authors examined data at 114,644 U.S. public and private schools and calculated their distance to the nearest major roadway. They found 3.2 million students (6.2 percent) attended schools located within 100 meters of a major roadway, and an additional 3.2 million (6.3 percent) students attended schools located 100-250 meters from a major roadway. Schools serving predominantly Black students were 18 percent more likely to be located within 250 m of a major roadway, as were schools where most students were eligible for free/reduced price meals.

Tags: vulnerable populations, distance from roads, schools, environmental justice

Lin, S., Munsie, J.P., Hwang, S.A., Fitzgerald, E., Cayo, M.R. (2002). Childhood asthma hospitalization and residential exposure to state route traffic. Environmental Research, Section A. 8873^81

Lin et al. studied children age 0-14 to determine whether pediatric hospitalization for asthma was associated with residing near high-volume roadways. They found that children hospitalized for asthma were more likely to live on roads with the most vehicle miles traveled. They suggest that residential exposure within 200 meters contributes to childhood asthma hospitalizations.

Tags: residential, vulnerable populations, health effects

Marshall, J., Brauer, M., & Frank, L. (2009). Healthy Neighborhoods: Walkability and Air Pollution. Environmental Health Perspectives, 117(11), 1752-1759.

The authors found that increased concentration of activities in urban settings yields both health costs and benefits. They identified neighborhoods that do especially well and especially poorly for walkability and air pollution exposure. They note that more work is needed to ensure that the poor do not bear an undue burden of urban air pollution and that neighborhoods designed for walking, bicycling, or mass transit do not adversely affect residents' exposure to air pollution. The authors' analyses could be replicated in other cities and tracked over time to better understand interactions among neighborhood walkability, air pollution exposure, and income level.

Tags: urban design, air pollution, residential use

McCarthy, M.C., Ludwig, J.F., Brown, S.G., Vaughn, D.L., & Roberts, P.T. (2013). Filtration effectiveness of HVAC systems at near-roadway schools. Indoor Air, 23(3), 196-207.

McCarthy et al. measured levels of black carbon and gaseous pollutants at three indoor classroom sites and at seven outdoor monitoring sites in Las Vegas. Initial HVAC filtration systems effected a 31-66 percent reduction in black carbon particle concentrations. After improved filtration systems were installed, black carbon particle concentrations were reduced by 74-97 percent. These findings suggest improving the filtration systems of an HVAC system may decrease exposure to near-roadway diesel particulate matter. However, reducing exposure to the gas-phase air toxics, which primarily originate from indoor sources, may require multiple filter passes on recirculated air.

Tags: mitigation strategies

Mendell, M. J., & Heath, G. A. (2005). Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. Indoor Air, 15(1), 27-52.

Mendell et al. reviewed the scientific evidence relating to indoor pollutants and thermal conditions to human performance and attendance. They find persuasive evidence that links higher indoor concentrations of NO2 and reduced school performance, and suggestive evidence that links low ventilation rates to reduced performance. They also include indirect associations among many studies that link indoor dampness and microbiologic pollutants (primarily in homes) to asthma exacerbations and respiratory infections, which in turn have been related to reduced performance and attendance. Finally, they describe evidence that links poor IEQ (e.g., low ventilation rate, excess moisture, and formaldehyde) with adverse health effects in children and adults. They conclude that immediate actions are warranted in schools to prevent dampness problems, inadequate ventilation, and excess indoor exposures to substances such as NO2 and formaldehyde. Also, siting of new schools in areas with lower outdoor pollutant levels is preferable.

Tags: vulnerable populations, health effects, schools

Minguillón, M., Rivas, I., Moreno, T., Alastuey, A., Font, O., Córdoba, P., & Querol, X. (2015). Road traffic and sandy playground influence on ambient pollutants in schools. Atmospheric Environment, 111, 94-102.

Minguillón et al. examined four schools in Barcelona, Spain and found NOx, BC and PMx concentrations were higher in the school located nearest to traffic in the city center with the daily pattern reflecting the traffic rush hours. The NOx concentrations were found to decrease with distance to the main road. The road traffic influence on ambient pollutants was higher on weekdays than weekends.

Tags: schools, distance from road

Morgenstern, V., Zutavern, A., Cyrys, J., Brockow, I., Koletzko, S., Krämer, U., Behrendt, H.,Herbarth, O., von Berg, A., Bauer, C.P., Wichmann, H.E., & Heinrich, J. (2008). Atopic Diseases, Allergic Sensitization, and Exposure to Traffic-related Air Pollution in Children. American Journal of Respiratory and Critical Care Medicine.177,12:1331-1337.

Morgenstern et al. followed a prospective birth cohort during the first 6 years of life to determine the relationship between long-term exposure to particulate matter and NO2 at residential addresses. They found strong positive associations between distance of residence to nearest main road and asthmatic bronchitis, hay fever, eczema, and sensitization. They found a distance-dependent relationship, and odds ratios were highest among children who lived less than 50 meters from main roads.

Tags: vulnerable populations, residential, distance from road

Mori, J., Hanslin, H. M., Burchi, G., & Sæbø, A. (2015). Particulate matter and element accumulation on coniferous trees at different distances from a highway. Urban Forestry & Urban Greening, 14(1), 170-177.

Mori et al. tested coniferous trees in southwestern Norway to determine their capacity to accumulate particulate matter on the leaf surface or in the waxes on the leaf surface. They found that older trees had accumulated more particulate matter compared to younger trees. They also found a higher accumulation of course particulate matter in samples taken closest to the road.

Tags: mitigation measures

Mullen, N.A., Bhangar, S., Hering, S.V., Kreisberg, N.M., & Nazaroff, W.W. (2011). Ultrafine particle concentrations and exposures in six elementary school classrooms in northern California. Indoor Air, 21(1), 77-87.

Mullen et al. measured ultrafine particles inside and outside of six classrooms in northern California during normal occupancy and use. The authors found that particle number concentrations were higher when classrooms were occupied because of higher outdoor concentrations and higher ventilation rates during occupancy. Indoor air quality appeared mostly influenced by outdoor sources of ultrafine particles.

Tags: vulnerable populations, schools

Mueller, N., Rojas-Rueda, D., Basagaña, X., Cirach, M., Cole-Hunter, T., Dadvand, P., Nieuwenhuijsen, M. (2017). Urban and Transport Planning Related Exposures and Mortality: A Health Impact Assessment for Cities. Environmental Health Perspectives, 125(1), 89-96.

Authors estimated that annually, nearly 20 percent of mortality could be prevented if international recommendations for performance of physical activity; exposure to air pollution, noise, and heat; and access to green space were followed. Estimations showed that the greatest portion of preventable deaths was attributable to increases in physical activity, followed by reductions of exposure to air pollution, traffic noise, and heat. Access to green spaces had smaller effects on mortality. Physical activity factors and environmental exposures can be modified by changes in urban and transport planning. Authors emphasize the need for a) the reduction of motorized traffic through the promotion of active and public transport and b) the provision of green infrastructure, both of which are suggested to provide opportunities for physical activity and for mitigation of air pollution, noise, and heat.

Tags: Roadway exposure, heat, noise, air pollution, mitigation, air pollution

Ng, S. L., Chan, L. S., Lam, K. C., & Chan, W. K. (2003). Heavy metal contents and magnetic properties of playground dust in Hong Kong. Environmental Monitoring And Assessment, 89(3), 221-232.

Ng et al. examined seven heavy metals in playground dust in Hong Kong. The authors found high concentrations of zinc, cadmium, and chromium, and qualitative examination of dust samples under microscope indicated local traffic as one of the important pollutant sources.

Tags: vulnerable populations, schools

Nguyen, T., Yu, X., Zhang, Z., Liu, M., Liu, X. (2015.) Relationship between types of urban forest and PM 2.5 capture at three growth stages of leaves. Journal of Environmental Sciences.

Nguyen et al. examined five commonly cultivated kinds of urban forest types in Beijing at three stages of leaf growth. They found that the urban forest system is capable of storing and capturing dust from the air. Shrubs and broadleaf trees have the ability to capture particulate matter < 2.5 nanometers, and they were most effective when leaves have fully developed. During leafless season, conifer and mixed tree types are most effective in removing dust from the air. Grassland cannot control particles suspended in the air but can reduce dust pollution caused by dust from the ground blown by the wind back into the air.

Tags: mitigation strategies

Nowak, D.J., Crane, D.E., Stevens, J.C. (2006.) Air pollution removal by urban trees and shrubs in the United States. Urban Forestry & Urban Greening 4: 115-123.

Nowak et al. modeled hourly meteorological and pollution concentration data from across the U.S. and found that urban trees remove large amounts of air pollution. Pollution removal of O3, PM10, NO2, SO2, and CO by U.S. urban trees was estimated at 711,000 metric tons ($3.8 billion value). They conclude that increasing tree canopy cover can be a viable strategy to improve urban air quality and help meet clean air standards.

Tags: mitigation strategies

Patton, A., Perkins, J., Zamore, W., Levy, J., Brugge, D., & Durant, J. (2014). Spatial and temporal differences in traffic-related air pollution in three urban neighborhoods near an interstate highway. *Atmos Environ.* 99: 309–321.

Over the course of a year, Patton et al. measured distance-decay gradients of seven TRAPs (PNC, pPAH, NO, NO_X, BC, CO, $PM_{2.5}$) in near-highway (<400 m) and background areas (>1 km) in several neighborhoods in the Greater Boston Area (Somerville, Dorchester/South Boston, Chinatown, and Malden) to determine whether (1) spatial patterns in concentrations and inter-pollutant correlations differ between neighborhoods, and (2) variation within and between neighborhoods can be explained by traffic and meteorology. They found that pollutant levels generally increased with highway proximity, consistent with I-93 being a major source of TRAP; however, the slope and extent of the distance-decay gradients varied by neighborhood as well as by pollutant, season, and time of day.

Tags: distance from road

Pieters, N., Koppen, G., Van Poppel, M., De Prins, S., Cox, B., Dons, E., & ... Nawrot, T. S. (2015). Blood Pressure and Same-Day Exposure to Air Pollution at School: Associations with Nano-Sized to Coarse PM in Children. Environmental Health Perspectives, 123(7), 737-742.

Pieters et al. used mixed models to study the association between blood pressure and ambient concentrations of particulate matter and ultrafine particles (UFP) measured in school playgrounds. The authors found that children attending school on days with higher UFP concentrations (diameter < 100 nm) had higher systolic blood pressure, that the association was dependent on UFP size, and that there was no association with the PM2.5 mass concentration.

Tags: vulnerable populations, health effects, schools

Polidori, A., Fine, P. M., White, V., & Kwon, P. S. (2013). Pilot study of high-performance air filtration for classroom applications. Indoor Air, 23(3), 185-195.

Polidori et al. examined the effectiveness of three air purification systems inside nine Southern California classrooms. An HVAC-based high-performance panel filter (HP-PF), a register-based air purifier (RS), and a stand-alone air cleaning system (SA) were tested alone and in different combinations for their ability to remove the monitored pollutants. The combination of a RS and a HP-PF was the most effective solution for lowering the indoor concentrations of BC, UFPs, and PM2.5, with study average reductions between 87 percent and 96 percent. When using the HP-PF alone, reductions close to 90 percent were also achieved. The authors conclude that the installation of effective air filtration devices in classrooms may be an important mitigation measure to help reduce indoor pollutants of outdoor origin including ultrafine particles and diesel particulate matter, especially at schools located near highly trafficked freeways, refineries, and other important sources of air toxics.

Tags: mitigation strategies

Puget Sound Clean Air Agency. (2014). 2014 Chinatown International District Near-Road Study. Accessed on February 22, 2022, from https://www.pscleanair.gov/DocumentCenter/View/2284/2014-Chinatown-ID-ReportPDF?bidId=

The Puget Sound Clean Air Agency conducted a special study in August and September 2014 to improve understanding of the impact of I-5 on the Seattle Chinatown-International District community. The agency detected a strong diurnal and spatial pattern consistent with a significant source of pollution. Pollution decreased with distance from I-5 and was close to background by 300 meters. The agency concluded that local traffic and other sources of pollutants could have measurable short-term impacts on air quality over relatively localized areas, although the longer-term impact was not evident.

Tags: distance from roads

Puget Sound Clean Air Agency. (2021). 2020 Air Quality Data Summary. Accessed on February 22, 2022, from https://www.pscleanair.gov/DocumentCenter/View/4548/Air-Quality-Data-Summary-2020

This summary document provides air quality data from the Puget Sound Clean Air Agency's core monitoring network, including the EPA's six criteria air pollutants and air toxics. The report notes that over the last two decades, many pollutant levels have declined, and air quality has improved overall. In 2020, overall air quality remained good, though the agency notes challenges due to wildfire smoke. Elevate fine particle levels (PM2.5) pose the greatest air quality challenge for this region. For example, on 25 days in 2020, fine particle levels exceeded the agency's local PM2.5 health goal. These days occurred during wildfire smoke and in winter months. Ozone levels also remain a concern for the region. Air toxics were measured at levels known to cause adverse health risks, including cancer, respiratory, and developmental effects.

Tags: local data

Puget Sound Regional Council. (no date). Information Item: Regional Air Quality Status. Accessed on February 22, 2022, from https://www.psrc.org/sites/default/files/air-quality-summary.pdf

The Puget Sound Regional Council evaluates four of the EPA's criteria air pollutants. Exceeding the standard can cause the EPA to designate an area as nonattainment. This document includes charts of carbon monoxide, course particulate matter, fine particulate matter, and ozone from 1985 through 2016.

Tags: local data

Reid, S., Bai, S., Du, Y., Craig, K., Erdaskos, G., Baringer, L., Eisinger, D., McCarthy, M., & Landsberg, K. (2016). Emissions modeling with MOVES and EMFAC to assess the potential for a transportation project to create particulate matter hot spots. Transportation Research Record: Journal of the Transportation Research Board, no. 2570.

Reid et al. sought to identify project characteristics that could reasonably exclude the project from consideration as a project of local air quality concern (pOAQC). In particulate matter (pm) nonattainment and maintenance areas, quantitative hot-spot analyses are required to assess air quality impacts of transportation projects that are identified as pOAQC. The authors performed scenario analysis for a hypothetical project that featured a new freeway. The mO Vehicle Emission Simulator and the Emission FACtors models were used to quantify PM10 and PM2.5 emissions for a 2006 analysis and to evaluate the impact of fleet turn-over and truck percentages on project-level emissions from 2006 to 2035. Fleet turnover effects sharply reduce project-level PM2.5 emissions over time but do not substantially reduce PM10 emissions, since re-entrained road dust emissions and tire wear and brake wear emissions increasingly dominate project-level inventories over time.

Tags: fleet turnover

Rundell, K. W., Caviston, R., Hollenbach, A. M., & Murphy, K. (2006). Vehicular Air Pollution, Playgrounds, and Youth Athletic Fields. Inhalation Toxicology,18(8), 541-547.

Rundell et al. examined particulate matter (PM1,0.02–1.0 µm diameter) levels at four elementary school athletic and playground fields and at one university soccer field. Lowest mean values were recorded at measurement sites furthest from the highway and followed a second-order logarithmic decay with distance away from the highway. Ozone increased with rising temperature and was highest in the warmer afternoon hours. The authors suggest that these findings reveal potential functional effects of chronic combustion-derived PM exposure on exercising school children and young adults.

Tags: vulnerable populations, schools

Sandlin, G. M., (2005). At the Microscale: Compact Growth and Adverse Health Impacts. Informational Paper Prepared for Puget Sound Regional Council.

This review of the California Air Resources Board document notes that it characterizes sensitive populations as "segments of the population most susceptible to poor air quality (i.e. children, the elderly and those with pre-existing serious health problems affected by air quality)" and sensitive land uses as residences, schools, daycare centers, playgrounds, and medical facilities.

Tags: definitions

Schilling, J., & Linton, L. (2005). The public health roots of zoning: In search of active living's legal genealogy. American Journal of Preventive Medicine, 28(2 Suppl 2), 96-104.

Legal, historical, and policy rationales support the modernization of zoning and land use policies that allow sensible mixes of land uses. Zoning and public health laws evolved from the same legal ancestors—the common law of public nuisance and the expansion of state police powers, both premised on protection of the public's health. When the U.S. Supreme Court approved zoning in the 1926 case of Ambler Realty v. Village of Euclid, it nominally recognized the health basis of zoning. But it went on to craft a new legal rationale focused more on protection of property rights and residential neighborhoods. Since Euclid, court decisions have given little consideration to the public health roots of zoning. Given an emerging body of research demonstrating the importance of walking-friendly environments and the deference shown by the courts to the passage of zoning laws, the courts are likely to support policymakers as they move to change zoning systems conceived long ago.

Tags: zoning, public health, residential

Silli, V., Salvatori, E., Manes, F. (2015.) Removal of Airborne Particulate Matter by Vegitation in an Urban Park in the City of Rome (Italy): An Ecosystem Services. Annali di Botanica.

Silli et al. explored the effect of urban vegetation of PM concentrations in a historical park located north of Rome. The park, Villa Ada, is surrounded by densely built areas and by high-traffic density roads. The authors found that trees may effectively abate suspended particles, with evergreen broadleaf trees being most effective in the summer, reducing the average air concentration of PM10.

Tags: mitigation measures

Staiano, M. A. (n.d.). Highway-Compatible Residential Development. Accessed: https://www.staianoengineering.com/images/TR_News--Hwy_Compat_Devel.pdf

Many communities have achieved highway-compatible residential development. Consistently successful outcomes, however, demand well-written and intelligently implemented regulations. This requires sophistication on the part of local planning and zoning authorities, not only to set reasonable and appropriate goals but also to determine if a developer's plan for noise mitigation is feasible and if the analysis is competent.

Tags: Residential zoning, compatibility, roadway, mitigation

Stranger, M., Potgieter-Vermaak, S. S., & Van Grieken, R. (2008). Characterization of indoor air quality in primary schools in Antwerp, Belgium. Indoor Air, 18(6), 454-463.

Stranger et al. assessed indoor air quality at 27 primary schools in Antwerp, Belgium. They found elevated indoor PM2.5 and BTEX concentrations in primary school classrooms, exceeding the ambient concentrations, raising concerns about possible adverse health effects on susceptible children. The results suggest that local outdoor air concentrations measurements do not provide an accurate estimation of children's personal exposures to the identified air pollutants inside classrooms.

Tags: vulnerable populations, schools

Suades-González, E., Gascon, M., Guxens, M., & Sunyer, J. (2015). Air Pollution and Neuropsychological Development: A Review of the Latest Evidence. Endocrinology, 156(10), 3473-3482.

This review of the association between air pollution and neuropsychological development found sufficient evidence of detrimental effects of pre- or postnatal exposure to polycyclic aromatic hydrocarbons on global IQ, an association between pre- or post-natal exposure to fine particulate matter (PM2.5) and autism spectrum disorder, and limited evidence between nitrogen oxides and autism spectrum disorder. For other exposure-outcome associations reviewed, the evidence was inadequate or insufficient. They concluded that the public health impacts of pollutants warrants caution and the precautionary principle should be applied to protect children.

Tags: vulnerable populations, health effects

Sunyer, J., Esnaola, M., Alvarez-Pedrerol, M., Forns, J., Rivas, I., López-Vicente, M., ... Querol, X. (2015). Association between Traffic-Related Air Pollution in Schools and Cognitive Development in Primary School Children: A Prospective Cohort Study. PLoS Medicine, 12(3), e1001792

Sunyer et al. conducted a prospective study of 2,715 children from 39 schools in Barcelona. They found that students from schools with higher levels of EC, NO_2, and UFP indoors and outdoors had a smaller growth in cognitive development than children from the paired lowly polluted schools, including working memory and inattentiveness.

Tags: vulnerable populations, health effects, schools

Tang, J., McNabola, A., & Misstear, B. (2020). The potential impacts of different traffic management strategies on air pollution and public health for a more sustainable city: A modelling case study from Dublin, Ireland. Sustainable Cities and Society, 60, 102229.

In this study, based on the traffic conditions of 2013 in Dublin, Ireland, the impact of a change in transport infrastructure, a traffic regulation change, speed limit changes and fleet composition changes on air quality and air pollution related public health were assessed. Two pollutants were considered in this study: NO_2 and $PM_{2.5}$. A traffic model, emissions model, dispersion model and a health impact model were adopted. The study highlighted the importance of the consideration of all possible affected areas within a city. It also highlighted the balance of the safety issues and the environmental health impact, when assessing the impact of traffic management strategies.

Tags: Fleet composition, regulation, public health impact model, mitigation

Tobías, A., Recio, A., Díaz, J., & Linares, C. (2015). Health impact assessment of traffic noise in Madrid (Spain). Environmental Research, 137, 136-140.

Tobías et al. aimed to quantify avoidable deaths resulting from reducing the impact of equivalent diurnal noise levels (LeqD) on daily cardiovascular and respiratory mortality among people aged ≥65 years in Madrid. They determined an association between LeqD exposure and mortality for both causes that suggests an important health effect. The magnitude of the health impact is similar to reducing average $PM_{2.5}$ levels by 10µg/m(3). They conclude that regardless of air pollution, exposure to traffic noise should be considered an important environmental factor having a significant impact on health.

Tags: noise pollution

Tong, Z., Baidauf, R.W., Isakov, V., Deshmukh, P. (2016.) Roadside vegetation barrier designs to mitigate near-road air pollution impacts. Science of the Total.

Tong et al. aimed to evaluate the effects of a wide vegetative barrier with high leaf area density and vegetation-solid barrier combinations on near-road air quality. They found that the impacts of these two strategies on near-road air quality are particle-size dependent. They found that a solid barrier creates an upward deflection in incoming airflow and deceleration of the approaching flow, which increases the on-road particle number concentration but results in a large concentration drop across it. In this case, deposition due to vegetation is absent and reductions are driven by dispersion only. Meanwhile, solid barrier with a vegetative cover combination was similar to a solid-barrier only. The additional particle reduction by having vegetation cover on the solid barrier is insignificant. A vegetation-solid barrier combination results in the highest reduction in downwind particle concentrations.

Tags: mitigation measures

U.S. Environmental Protection Agency. (2009). About Air Toxics, Health, and Ecological Effects. Accessed on February 22, 2022, from http://www.epa.gov/air/toxicair/newtoxics.html

This EPA resource includes extensive information about pollution and air quality, indoor air, research, air quality management, air quality by location, air pollutants, data, laws, and regulations.

Tags: health effects

U.S. Environmental Protection Agency. (2015). Best Practices for Reducing Near-Road Pollution Exposure at Schools. Retrieved on February 10, 2022, from https://www.epa.gov/sites/default/files/2015-10/documents/ochp_2015_near_road_pollution_booklet_v16_508.pdf

This EPA publication aims to help school communities identify strategies for reducing traffic-related pollution exposure at schools located downwind from heavily traveled roadways, along corridors with significant trucking traffic, and near other sources of vehicular pollution. The strategies highlighted include:

1. Educate staff on ventilation and indoor air quality best practices
2. Air-seal around windows, doors, HVAC ducts, etc.

3. Relocate air intake or source if roadway/pollution source is near intake vent
4. Use filtration
5. Improve HVAC system design to be compatible with high-efficiency filtration
6. Implement anti-idling/idle reduction policies
7. Upgrade school bus fleet
8. Encourage active transportation (e.g., walking and biking) to school
9. Locate school site away from pollution sources
10. Design school site to minimize pollutant sources
11. Use solid and vegetative barriers

Many of the best practices highlighted in this report may be effective at reducing exposure to other sources of particulate air pollution for existing buildings and other land uses.

Tags: vulnerable populations, mitigation strategies, schools

van Kempen, E.M., Kamp, I. V., Stellato, R. K., Lopez-Barrio, I., Haines, M. M., Nilsson, M. E., & Stansfeld, S. A. (2009). Children's annoyance reactions to aircraft and road traffic noise. Journal of the Acoustical Society of America. 125(2), 895.

Van Kempen et al. aim to investigate children's reactions to aircraft and road traffic noise in home and school settings. The authors found an exposure-response relationship between exposure to aircraft noise at school and severe annoyance in children. Specifically, the percentage severely annoyed children was predicted to increase from about 5.1 percent at 50 dB to about 12.1 percent at 60 dB. Aircraft noise at home) demonstrated a similar relation with severe annoyance. Children attending schools with higher road traffic noise were also more annoyed.

Tags: noise pollution

Vohra, K., Vodonos, A., Schwartz, J., Marais, E.A., Sulprizio, M.P., Mickley, L.J. (2021). Global mortality from outdoor fine particle pollution generated by fossil fuel combustion: Results from GEOS Chem. *Environmental Research.* 195. Retrieved from https://doi.org/10.1016/j.envres.2021.110754

Vohra et al. found that more than 8 million people died in 2018 as a result of air pollution from burning fossil fuels. This equates to 1 in 5 deaths worldwide. This groundbreaking analysis allowed researchers to directly attribute premature deaths from fine particulate pollution to fossil fuel combustion, underscoring the detrimental effects of fossil fuels on global health. In the U.S., 350,000 premature deaths were attributed to fossil fuel pollution in 2018, much more than previous analyses found.

Wang, S., Zhang, J., Zeng, Y., Wang, S., & Chen, S. (2009). Association of Traffic-Related Air Pollution with Children's Neurobehavioral Functions in Quanzhou, China. Environmental Health Perspectives, 117(10), 1612-1618.

Wang et al. collected data at two primary schools in Quanzhou, China. The authors found a significant association between chronic low-level traffic-related air pollution exposure and neurobehavioral function. Students from the school with higher concentrations of indoor and outdoor ambient air pollutants (including NO2 and particulate matter) were significantly more likely to perform poorly on a battery of neurobehavioral tests (including visual simple reaction time, continuous performance, digit symbol, pursuit aiming, and sign register).

Tags: vulnerable populations, health effects, schools

Washington State Department of Transportation. (2016). Effects of Roadside Barriers on Near-Road Pollutant Concentrations.

This review of the effects of roadside barriers on near-air quality concluded that barriers can effectively mitigate and dilute concentrations of mobile-source-emitted pollutants. The magnitude of those reductions depends on several factors (e.g., strength source, distance, meteorological conditions, roadway configuration, barrier height, length, configuration, and type). Assuming perpendicular wind conditions and a barrier of typical height (~ 6 meters), reductions are 20-60 percent within the first 100 meters. Barrier effectiveness increases with barrier height.

Tags: mitigation strategies

Zhu, Y., Hinds, W. C., Kim, S., & Sioutas, C. (2002). Concentration and size distribution of ultrafine particles near a major highway. Journal of the Air & Waste Management Association, 52(9), 1032-42.

Zhu et al. measured particle number concentration and size distribution in the size range from 6 to 220 nm at 30, 60, 90, 150, and 300 meters downwind and 300 meters upwind from I-405 at the Los Angeles National Cemetery. At this location, average traffic flow during the sampling periods was 13,900 vehicles/hr, and 93 percent of vehicles were gasoline-powered cars or light trucks. They found that particle number concentration decreased exponentially with downwind distance from the freeway. Ultrafine particle number concentration measured 300 m downwind from the freeway was indistinguishable from upwind background concentration. These data may be used to estimate exposure to ultrafine particles in the vicinity of major highways.

Tags: distance from road

Appendix B. Air Quality Trends

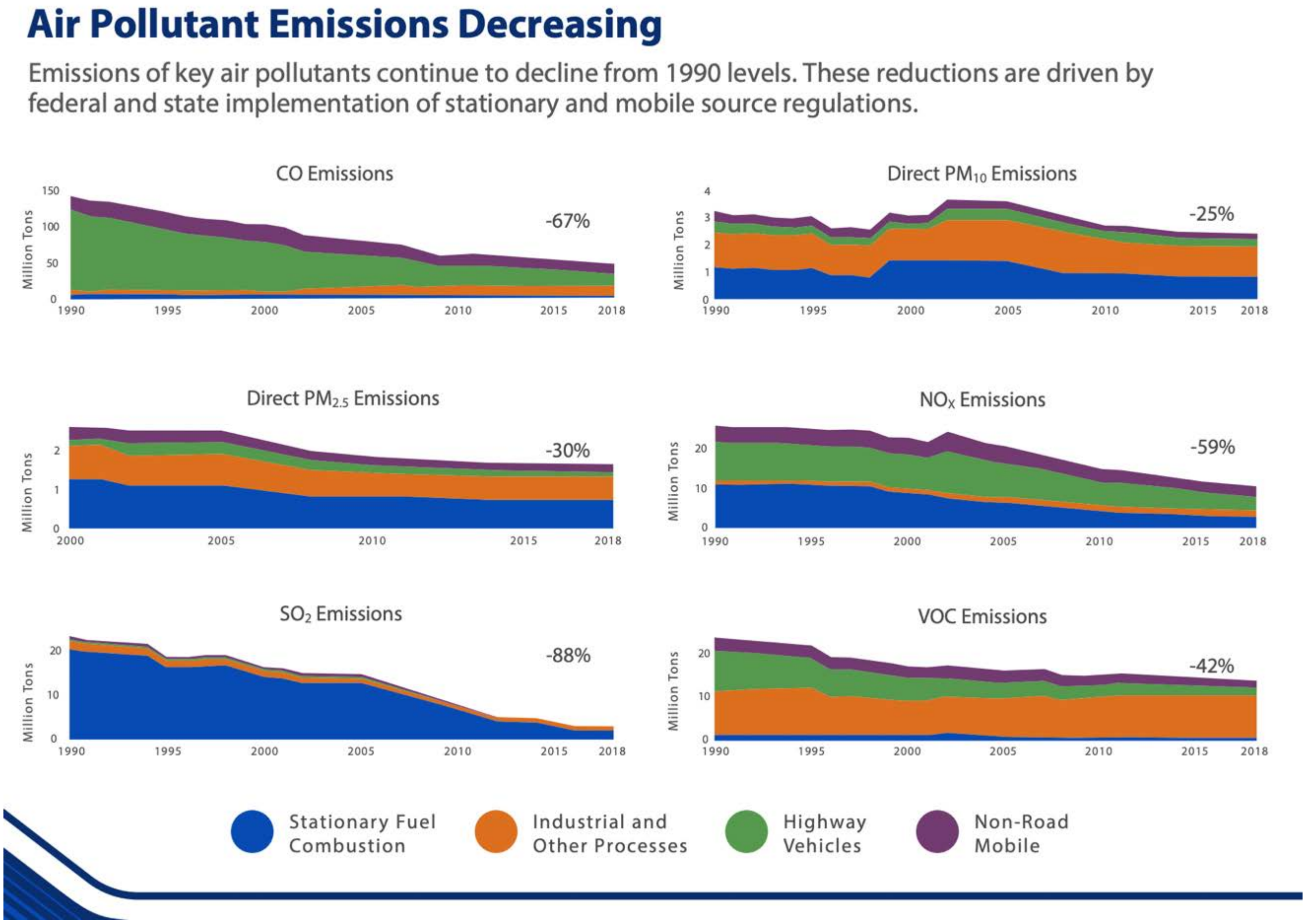


Figure 10. Emissions of key air pollutants continue downward trend, source: EPA, used with permission.

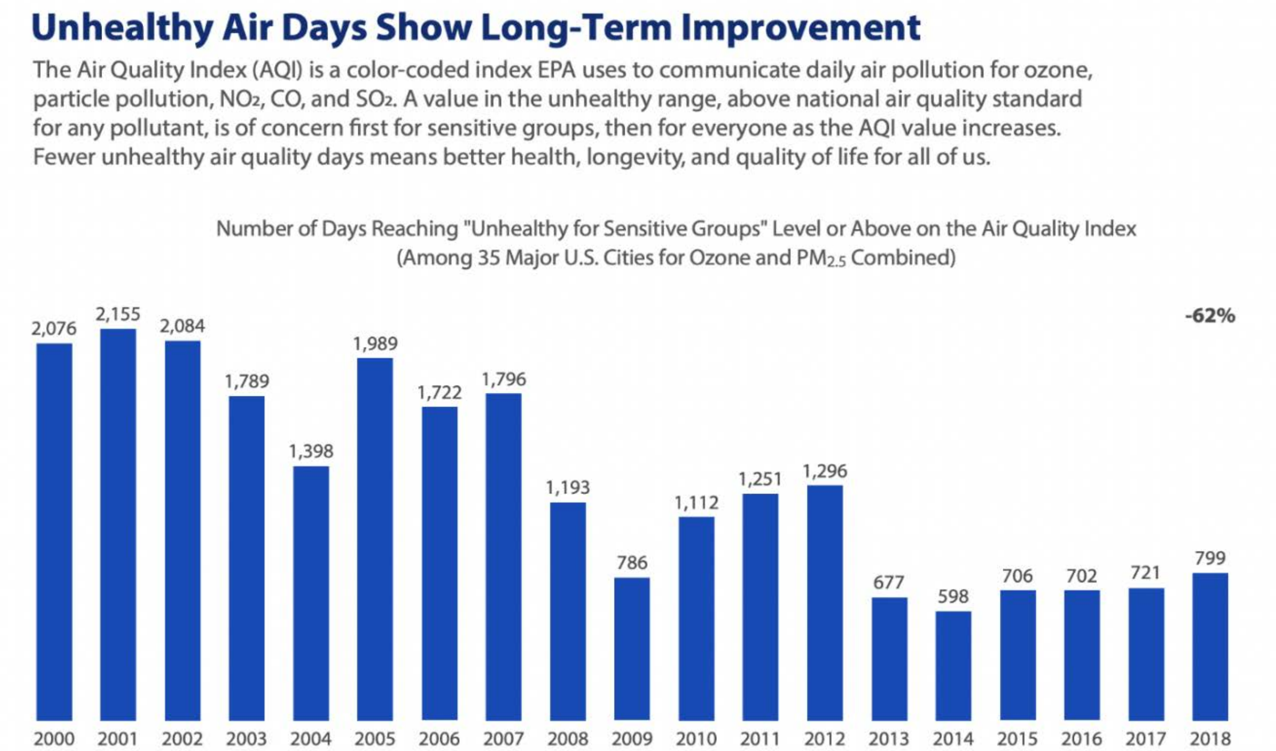


Figure 11. Unhealthy Air Days, source: EPA, used with permission.

Today, more than 135 million people in the U.S. live in counties where pollution levels frequently make the air too dangerous to breathe. That includes 799 unhealthy air days across 35 major U.S. cities in 2018 (see Figure 12).[92]

[92] U.S. EPA, 2019, *Our Nation's Air*, accessed https://gispub.epa.gov/air/trendsreport/2019/

Appendix C. Average Annual Daily Traffic Volumes

Bellevue's three high-volume roadways – I-405, I-90 and SR 520 – all have traffic volumes exceeding 100,000 vehicle trips per day. Approximately 8,500 people or six percent of Bellevue's population live within 500 feet and 29,200 people live within 1,500 feet of these roadways in 2021. Roadways with average annual daily trips of 100,000 or more are considered high-volume roadways around which measures should be taken to reduce exposure.

High-volume roadway segments

The greater the number of vehicle trips, the greater the amount of air pollutants generated. In Bellevue, I-405 has had the highest trip volumes followed by I-90 and then by SR 520. Segments of I-405 just south of Downtown and north of I-90 had the highest traffic volumes reaching over 200,000 average annual daily trips (AADT) per day in 2019. Freeway traffic volumes decrease slightly as vehicles exit the freeway and disperse into Downtown. Traffic volumes between 175,000 and 200,000 AADT in 2019 were located on I-405 near Bridle Trails, BelRed and Factoria where traffic from SR 520 or I-90 merged onto the roadway. On I-405 south of I-90 near Newport, and on I-90 near Eastgate, traffic volumes were between 150,000 and 175,000. Segments of SR 520 west of I-405 were the only highway segments in Bellevue where average annual daily trips were less than 100,000 at 69,000 and 84,000 AADT.

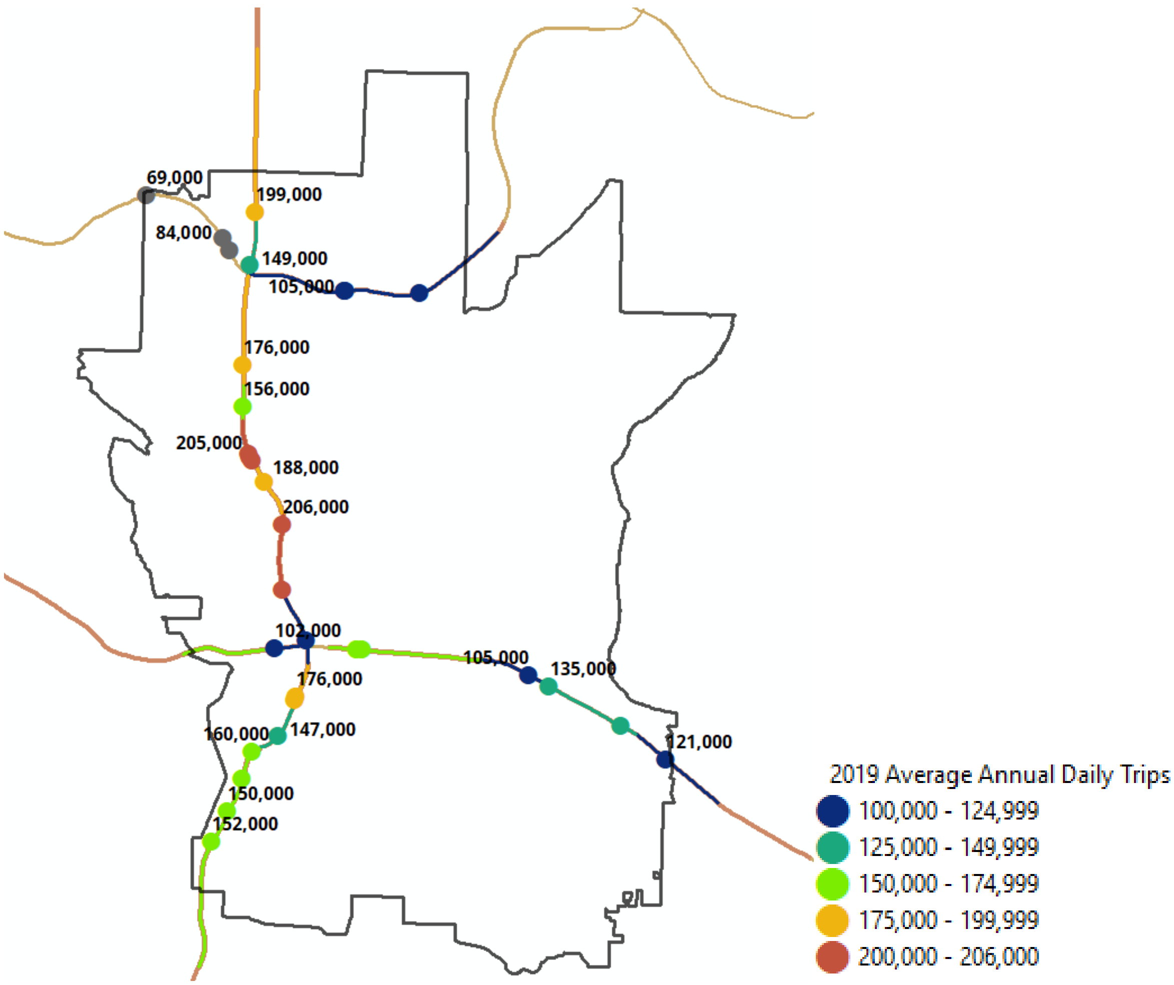


Figure 13. 2019 Average Annual Daily Vehicle Trips.

Truck volume and tonnage

In addition to overall traffic volume, the mix of vehicles affects pollution levels. While automobiles are expected to become cleaner as the fleet switches to electric powered motors, trucks are not anticipated to convert to electric motors soon. Both the type of fuel burned, and the tonnage of cargo transported affects the amount of air pollution generated. Trucks burning diesel fuel generate higher levels of particulate matter, and heavy cargo results in higher levels of tire and brake dust further increasing particulate matter levels.

In Bellevue, I-405 had the highest truck traffic volumes in 2019 with 9,700 AADT, 83 percent more than the truck volumes on I-90 at 5,300 AADT, and four times the truck volumes on SR 520 with 2,400 AADT. Trucks on I-405 also carried the highest tonnage with 39.8M tons in 2019, 63 percent more tonnage than that carried on I-90 with 24.4M tons, and nearly five times the tonnage carried on SR 520 with 8.2M tons.

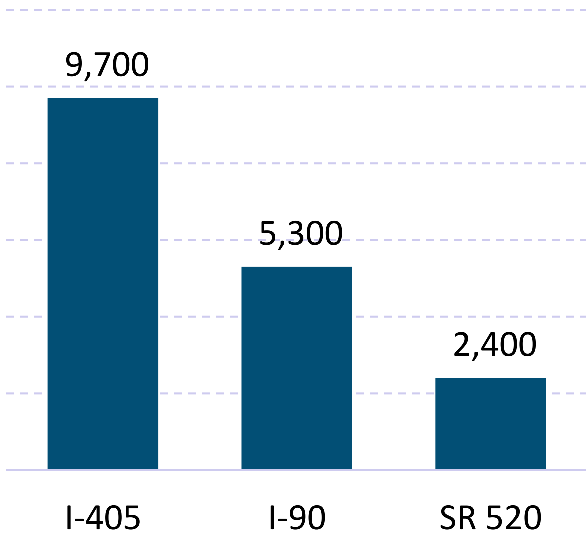


Figure 14. 2019 Average Annual Daily Truck Trips.

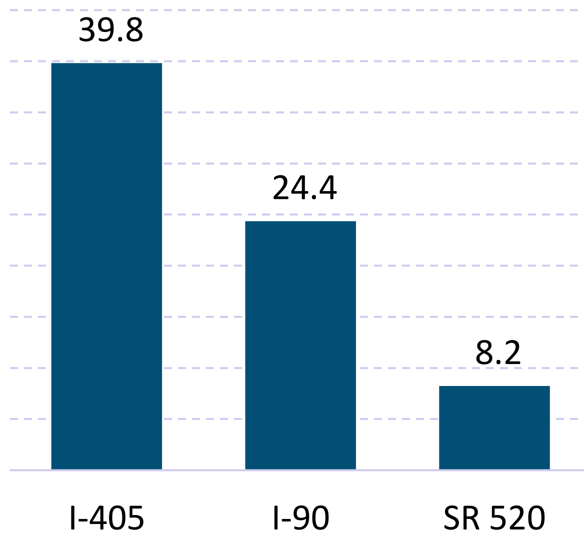


Figure 15. 2019 Truck Tonnage (millions of tons).

High-volume on-off ramps

High-volume on-off ramps where vehicles either idle during periods of peak congestion or accelerate and decelerate when there is no congestion, are also places of high emissions. Highest on/off ramp volumes in Bellevue exist in the I-405 / I-90 interchange around Factoria, Richards Valley / Lower Woodridge as well as just north of Downtown. The second highest volume cluster is located around the I-405 and SR 520 interchange. Comparatively lower ramp volumes existed around Downtown Bellevue, Eastgate, Newport, and West Lake Sammamish / Lakemont / Cougar Mountain.

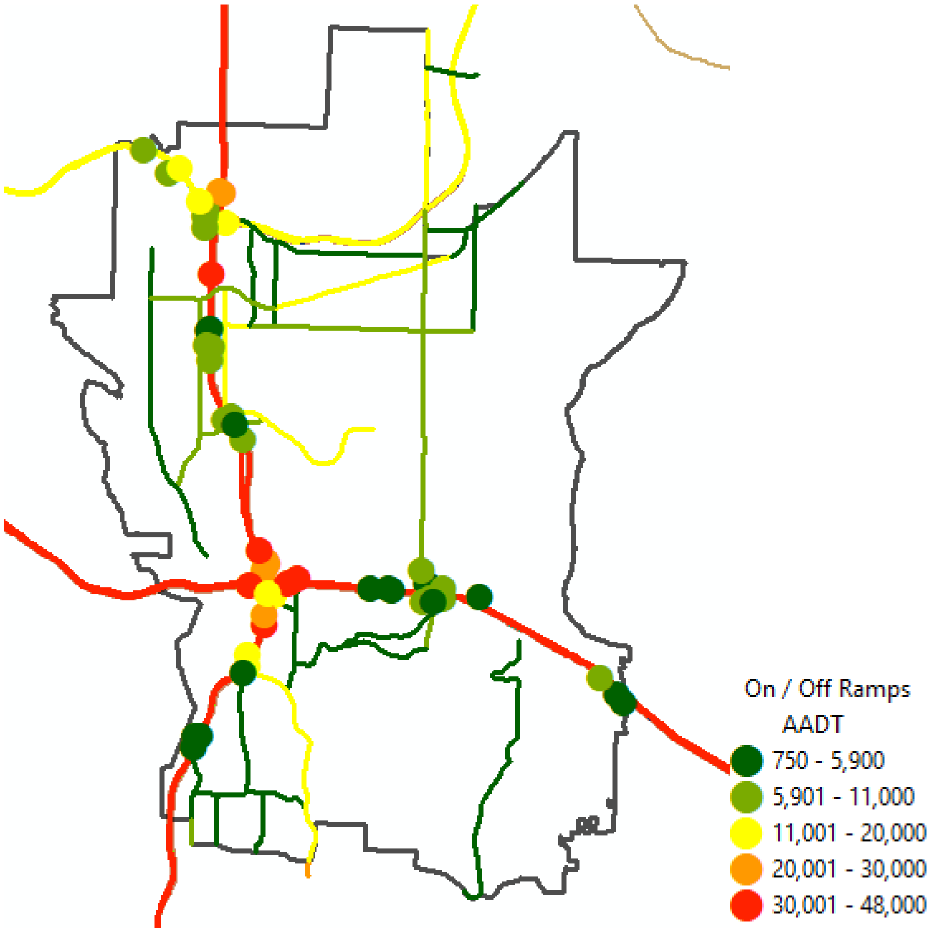


Figure 16. 2019 Average Annual Daily Vehicle Trips on On/Off Ramps.

Appendix D. Low Elevation Areas Adjacent to Freeways

This appendix includes additional images of areas located at lower elevations than the adjacent freeway based on the Aspect Ratio map shown below.

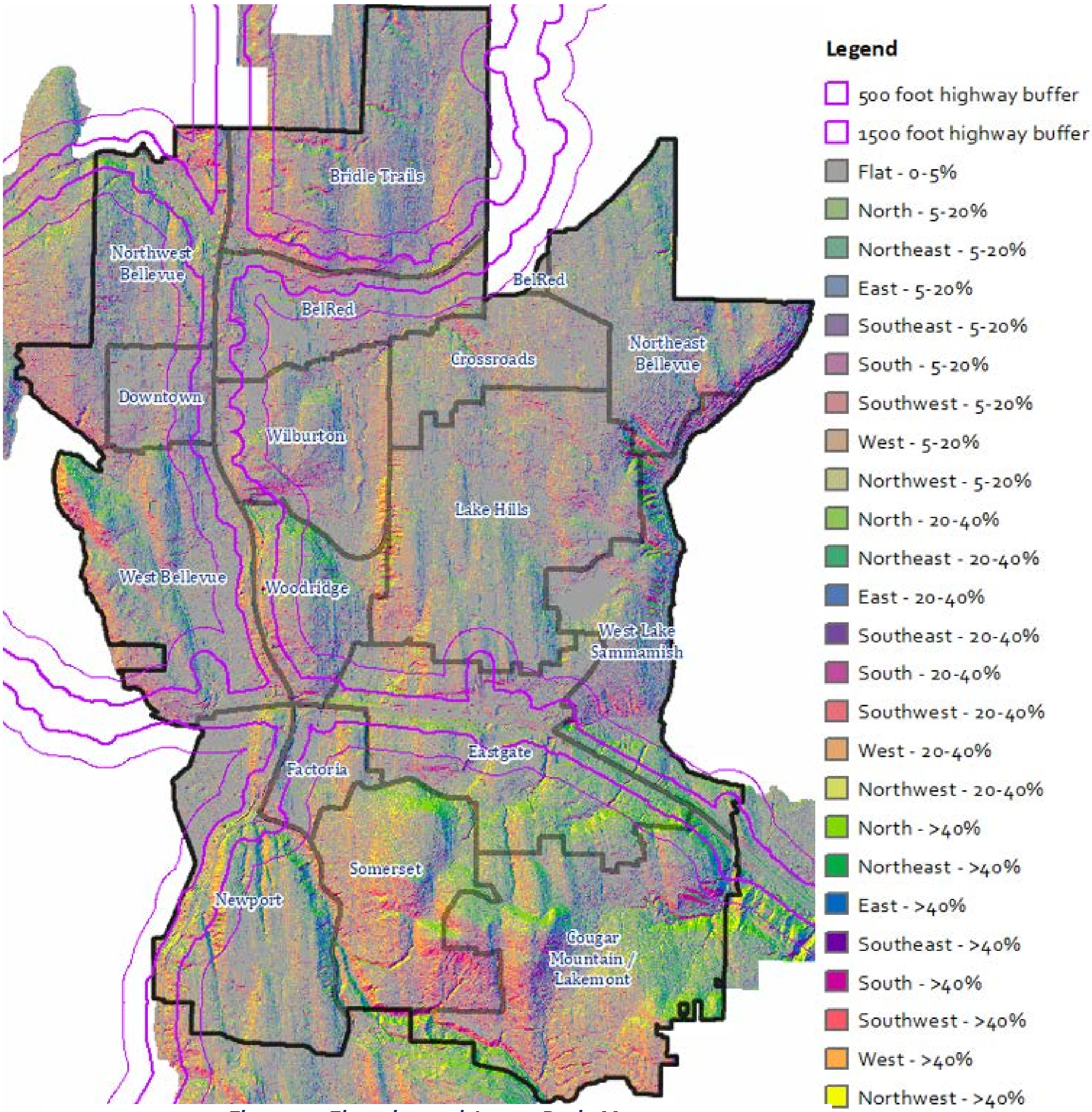
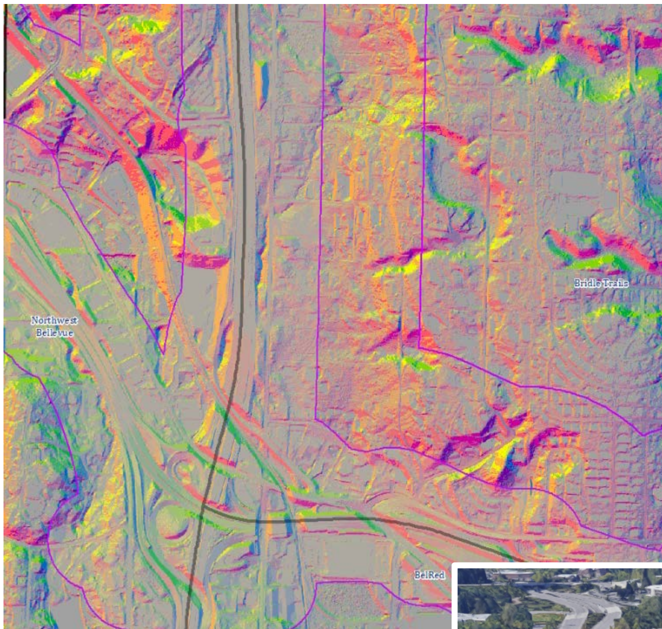


Figure 17. Elevation and Aspect Ratio Map.



Differing elevations near freeways.

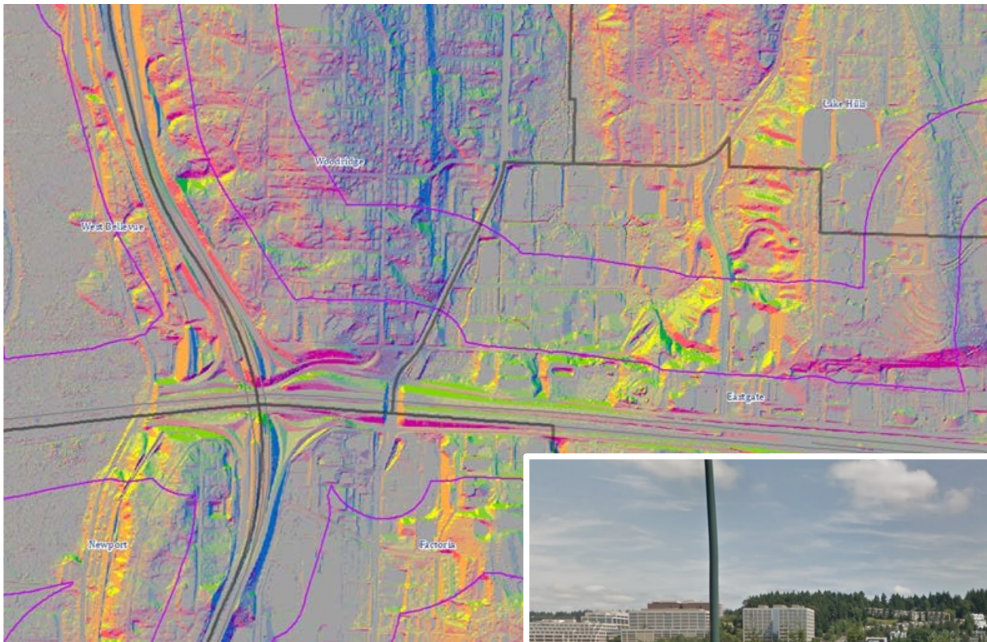
Top: Aspect Ratio map showing areas around the interchange of I-405 and SR 520.

Middle: Low elevation areas north of SR 520 looking north along 112th Ave NE.

Low elevations near freeways.

Top: Low elevation areas south SR 520 in BelRed.

Bottom: Low elevation area west of I-405 north of

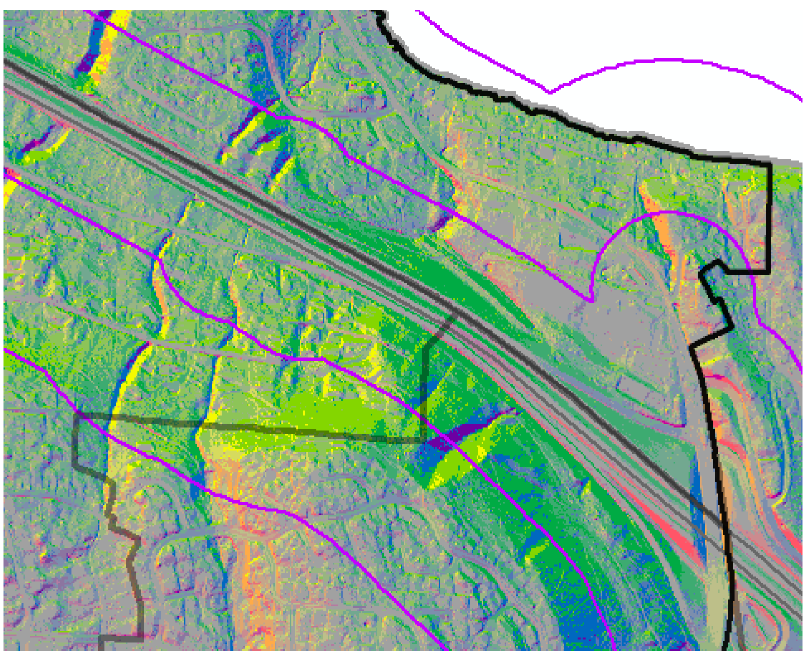


Varying elevations near freeways

Top: Aspect Ratio Map Zoomed in to Woodridge and Factoria. Zooming in, one can see that the west side of the Woodridge Neighborhood Area lies at a higher elevation than I-405, whereas Factoria lies at a lower elevation.

Middle: Looking eastward from I-405 toward Factoria. Only the tops of trees can be seen as the shopping area sits at an elevation lower than the freeway.

Bottom: Mockingbird Hill neighborhood. Located south of Factoria Mall, this neighborhood sits just below I-405 to the east.



Elevation example and map

Top: Looking northwest along I-90 at Lakemont Boulevard SE at elementary school and childcare facility.

Bottom: Aspect Ratio Map Zoomed into West Lake Sammamish and Cougar Mountain/Lakemont. The grey area north of I-90 just west of the city's boundary indicates that the area sits lower than the freeway in contrast to the green area south side of I-90 which slopes upward.

Appendix E. Policy, Code and Plan Examples

This appendix includes examples of policy, code, and plans related to limiting the risk of exposure to air pollution generated by high-volume roadways that other jurisdictions, primarily located in California, have adopted. California has historically been out in front of the rest of the country on air quality protections. These policies, while not exhaustive, range from preventative to mitigation.

General plan policy and code examples

1. City of Bothell, 12.48.170 Air quality buffer. Ordinance 2341
   - The Canyon Park Subarea Plan calls for a 500-foot buffer from the centerline of each directional roadway of Interstate 405 to prevent residential and other sensitive uses (e.g., schools, daycares) within close proximity to very heavy traffic volumes (where air pollution and health impacts are typically highest). (Ord. 2341 § 5 (Exh. A), 2020).
2. City of San Jose, 2040 General Plan
   - Require new residential development projects and projects categorized as sensitive receptors to incorporate effective mitigation into project designs or be located an adequate distance from sources of toxic air contaminants (TACs) to avoid significant risks to health and safety.
3. City of Hayward General Plan
   - NR-2.16 Sensitive Uses: The City shall minimize exposure of sensitive receptors to toxic air contaminants (TAC), fine particulate matter (PM2.5), and odors to the extent possible, and consider distance, orientation, and wind direction when siting sensitive land uses in proximity to TAC- and PM2.5-emitting sources and odor sources in order to minimize health risk.
   - NR-2.18 Exposure Reduction Measures for New Receptors: The City shall require development projects to implement all applicable best management practices that will reduce exposure of new sensitive receptors (e.g., hospitals, schools, daycare facilities, elderly housing and convalescent facilities) to odors, toxic air contaminants (TAC) and fine particulate matter (PM2.5).
   - NR-2.19 Exposure Reduction Measures for both Existing and New Receptors: The City shall work with area businesses, residents and partnering organizations to provide information about best management practices that can be implemented on a voluntary basis to reduce exposure of sensitive receptors to toxic air contaminants (TAC) and fine particulate matter (PM2.5).
4. Santa Clara County General Plan
   - HE-G.7 Sensitive receptor uses: Promote measures to protect sensitive receptor uses, such as residential areas, schools, daycare centers, recreational playfields and trails, and medical facilities *by locating uses away from major roadways and stationary area*

sources of pollution, where possible, or incorporating feasible, effective mitigation measures.

Site design policy and code examples

1. City of San Jose, 2040 General Plan
    - Encourage the use of pollution absorbing trees and vegetation in buffer areas between substantial sources of TACs and sensitive land uses.
2. City of Oakland, Standard Conditions of Approval
    - 2. The project applicant shall incorporate the following health risk reduction measures into the project. These features shall be submitted to the City for review and approval and be included on the project drawings submitted for the construction-related permit or on other documentation submitted to the City:
        - Installation of air filtration to reduce cancer risks and Particulate Matter (PM) exposure for residents and other sensitive populations in the project that are in close proximity to sources of air pollution. Air filter devices shall be rated MERV-13 [MERV-16 for projects located in the West Oakland Specific Plan area] or higher. As part of implementing this measure, an ongoing maintenance plan for the building's HVAC air filtration system shall be required.
        - Where appropriate, install passive electrostatic filtering systems, especially those with low air velocities (i.e., 1 mph).
        - Phasing of residential developments when proposed within 500 feet of freeways such that homes nearest the freeway are built last, if feasible.
        - The project shall be designed to locate sensitive receptors as far away as feasible from the source(s) of air pollution. Operable windows, balconies, and building air intakes shall be located as far away from these sources as feasible. If near a distribution center, residents shall be located as far away as feasible from a loading dock or where trucks concentrate to deliver goods.
        - Sensitive receptors shall be located on the upper floors of buildings, if feasible.
        - Planting trees and/or vegetation between sensitive receptors and pollution source, if feasible. Trees that are best suited to trapping PM shall be planted, including one or more of the following: Pine (Pinus nigra var. maritima), Cypress (X Cupressocyparis leylandii), Hybrid popular (Populus deltoids X trichocarpa), and Redwood (Sequoia sempervirens).
        - Sensitive receptors shall be located as far away from truck activity areas, such as loading docks and delivery areas, as feasible.

Building design policies and code examples

1. City of San Jose, 2040 General Plan
    - Encourage the installation of appropriate air filtration at existing schools, residences, and other sensitive land uses adversely affected by pollution sources.
2. Santa Clara County, General Plan
    - HE-G.9 Healthy infill development: Promote measures and mitigations for infill development to protect residents from air and noise pollution, such as more stringent building performance standards, proper siting criteria, development and environmental review processes, and enhanced air filtration.
3. City of San Francisco, Article 38
    - Article 38 requires enhanced ventilation systems "capable of achieving the protection from particulate matter (PM2.5) equivalent to that associated with MERV 13 filtration (as defined by ASHRAE standard 52.2)" to be installed in sensitive use buildings that are identified within the Air Pollutant Exposure Zones that are either
        - a) newly constructed;
        - b) undergoing a "major alteration to existing building"; or
        - c) subject of an application for a Planning Department-permitted Change of Use. Additional information, including a map of the Air Pollutant Exposure Zones, is located on the City of San Francisco's Article 38 webpage
4. The City of Oakland also requires certain conditions to apply to projects that meet the following criteria:
    - a. The project involves any of the following sensitive land uses: residential uses; new or expanded daycares, schools, parks, nursing homes, or medical facilities; AND
    - b. The project is located within 1,000 (or other distance as specified below) of one or more of the following sources of air pollution:
        - Freeway;
        - Roadway with significant traffic (at least 10,000 vehicles/day);
        - Rail line (except BART) with over 30 trains per day;
        - Distribution center that accommodates more than 100 trucks per day, more than 40 trucks with operating TRU units per day, or where the TRU unit operations exceed 300 hours per work week.
        - Major rail or truck yard (such as the Union Pacific rail yard adjacent to the Port of Oakland);
        - Ferry Terminal;
        - Stationary pollutant source requiring permit from BAAQMD (such as a diesel generator);
        - Within 0.5 miles of the Port of Oakland or Oakland Airport;
        - Within 300 feet of a gas station;

    - Within 300 feet of a dry cleaner with a machine using PERC (or within 500 feet of a dry cleaner with two or more machines using PERC); AND
  - c. The project exceeds the health risk screening criteria after a screening analysis is conducted in accordance with the BAAQMD CEQA Guidelines.
5. City of Oakland, Standard Conditions of Approval
  - 2. The project applicant shall incorporate the following health risk reduction measures into the project. These features shall be submitted to the City for review and approval and be included on the project drawings submitted for the construction-related permit or on other documentation submitted to the City:
    - Installation of air filtration to reduce cancer risks and Particulate Matter (PM) exposure for residents and other sensitive populations in the project that are in close proximity to sources of air pollution. Air filter devices shall be rated MERV-13 [MERV-16 for projects located in the West Oakland Specific Plan area] or higher. As part of implementing this measure, an ongoing maintenance plan for the building's HVAC air filtration system shall be required.
    - Where appropriate, install passive electrostatic filtering systems, especially those with low air velocities (i.e., 1 mph).

Health risk assessments and community risk reduction plan examples

1. City of San Francisco, Community Risk Reduction Plan (CRRP)
  - The purpose of the CRRP is to protect human health through the reduction of emissions and exposure to ambient air pollution in the City and County of San Francisco. The CRRP is expected to establish citywide objectives and targets for air quality improvement and a set of local actions to reduce health impacts for disproportionately exposed communities in San Francisco.
2. City of San Jose, 2040 General Plan
  - Require completion of air quality modeling for sensitive land uses such as new residential developments that are located near sources of pollution, such as freeways and industrial uses.
  - Consult with the Air District to identify stationary and mobile TAC sources and determine the need for and requirements of a health risk assessment for proposed developments.
3. City of San Jose, 2040 General Plan
  - Develop and adopt a comprehensive Community Risk Reduction Plan that includes: baseline inventory of toxic air contaminants and particulate matter smaller than 2.5 microns ($PM_{2.5}$) emissions from all sources, emissions reduction targets, and enforceable emission reduction strategies and performance measures. The

Community Risk Reduction Plan will include enforcement and monitoring tools to ensure regular review of progress toward the emission reduction targets, progress reporting to the public and responsible agencies, and periodic updates of the plan, as appropriate.

4. City of Hayward, General Plan
    - NR-2.15 Community Risk Reduction Strategy: The City shall maintain and implement the General Plan as Hayward's community risk reduction strategy to reduce health risks associated with toxic air contaminants (TACs) and fine particulate matter (PM2.5) in both existing and new development.
5. City of Oakland, Standard Conditions of Approval
    - 1. The project applicant shall retain a qualified air quality consultant to prepare a Health Risk Assessment (HRA) in accordance with California Air Resources Board (CARB) and Office of Environmental Health and Hazard Assessment requirements to determine the health risk of exposure of project residents/occupants/users to air pollutants.
        - The HRA shall be submitted to the City for review and approval.
        - If the HRA concludes that the health risk is at or below acceptable levels, then health risk reduction measures are not required.
        - If the HRA concludes that the health risk exceeds acceptable levels, health risk reduction measures shall be identified to reduce the health risk to acceptable levels.
        - Identified risk reduction measures shall be submitted to the City for review and approval and be included on the project drawings submitted for the construction-related permit or on other documentation submitted to the City.

Appendix F. EPA's School Ventilation & Filtration System Assessment

The EPA's 2015 *Best Practices for Reducing Near-Road Pollution Exposure at Schools* includes a school ventilation and filtration system assessment, which may be helpful for building owners, operators, and others to evaluate whether there are strategies that can be implemented to improve building operation and reduce exposure to near-road pollution. While the assessment is specific to schools, it can be adapted for other building types and land uses. The assessment is included below:

1. Assess whether near-road pollution may be a problem.
    a. Is there a major roadway near the school? If so:
        i. How far away is it?
        ii. Is the school downwind of the road?
    b. Where does school bus pick-up and drop-off occur?
        i. Are there opportunities to reduce bus idling or relocate loading zones away from classrooms and outdoor recreation areas?
2. Assess the current ventilation and filtration system.
    a. Is ventilation achieved passively or mechanically?
    b. If mechanical:
        i. Is a central HVAC system used or a single-classroom unit?
        ii. Are filters being used?
        iii. What is the blower capacity?
        iv. Is filtration being used? If so, what is the MERV rating of the filter(s)?
3. Assess ventilation operation.
    a. Are teachers leaving windows and/or doors open during the day?
    b. Are there opportunities to bring in air during off-peak emission times?
    c. Are teachers turning systems off due to noise issues?
    d. Are filters being inspected, cleaned, and replaced according to the schedule recommended by the manufacturer?
4. Assess air-sealing needs to limit infiltration of unconditioned air.
    a. Can infiltration of polluted air be reduced by sealing around any of the following:
        i. Windows?
        ii. Doors?
        iii. HVAC ducting?
5. Evaluate air intake location(s) relative to roadways or other pollutant sources such as school bus drop-off and pick-up locations.

a. Is air intake located near a roadway, loading zone, or other pollutant source, such as designated smoking areas? Are supply and exhaust vents unobstructed?
b. Can the air intake be relocated to an area that is less influenced by pollutant sources?