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Technical Review of the Washington State Environmental Health Disparities Map

The 2021 Washington State Legislature directed the Washington State Institute for Public Policy (WSIPP) to conduct a technical review of the measures and methods used in the Washington State Department of Health's Environmental Health Disparities (EHD) Map.

WSIPP was directed to identify how the measures used in the EHD Map compare to measures used in other similar tools that aim to identify communities that are disproportionately impacted as a result of environmental justice issues; compare characteristics such as the reliability, validity, and clinical importance of individual and composite measures included in the map and other similar tools; and compare methodologies used in the map to statistical methodologies used in other similar tools.[1]

The reported is presented in four sections. Section I provides background on environmental justice and the Washington EHD Map. Section II details the methodology used to find and compare similar tools. Section III presents our findings, and Section IV summarizes our findings and key takeaways.

Summary

We found that Washington's Environmental Health Disparities (EHD) Map is one of many in the United States. It uses a similar range of indicators, methodology, and source data compared with the most sophisticated environmental justice (EJ) mapping tools. These EJ tools use some of the best data available at small geographical levels to measure environmental exposures and health disparities. They provide insight into a variety of the environmental harms present in communities and how well-equipped these communities are to overcome those challenges.

Over time, developers will need to regularly review their EJ map tools. The HEAL Act requires the Washington EHD Map to be regularly revised and updated, with comprehensive evaluations occurring every three years. Currently, Washington's tool is comparable in sophistication and detail to other existing tools. However, there are a few additional or enhanced features found in other state tools that Washington does not have, including the following:

- Additional indicators reflecting sensitive populations;
- Additional water quality measures;
- Specific statistical adjustments for missing data; and
- Easily accessible user guides and how-to videos on the hosting website.

Suggested citation: Ingraham, B., & Krnacik, K. (2022). *Technical review of the Washington State Environmental Health Disparities Map* (Document Number 22-11-3201). Olympia: Washington State Institute for Public Policy.

[1] Engrossed Second Substitute Senate Bill 5141, Chapter 314, Laws of 2021.

I. Background

Since the US Environmental Protection Agency (EPA) was formed in 1970, federal and state governments have worked together to address general environmental issues such as water and air quality but with little focus on who benefits from these actions.

In the past three decades, there has been a greater acknowledgment of the *cumulative impacts* of a person's social and physical environment on their health. It has also become evident that *health disparities* related to environmental effects are present across different populations.

The 2021 Washington Health Environment for All (HEAL) Act is one of the latest laws enacting a legislative framework for embedding *environmental justice (EJ)* considerations into government operations and state-agency decision-making in Washington. Exhibit 1 contains detailed definitions of the italicized terms.

WSIPP Legislative Assignment

The Washington state institute for public policy must conduct a technical review of the measures and methods used in the environmental health disparities map. The review must, to the extent possible, address the following:

(i) Identify how the measures used in the map compare to measures used in other similar tools that aim to identify communities that are disproportionately impacted as a result of environmental justice issues;

(ii) Compare characteristics such as the reliability, validity, and clinical importance of individual and composite measures included in the map and other similar tools; and

(iii) Compare methodologies used in the map to statistical methodologies used in other similar tools.

E2SSB 5141, Chapter 314, Laws of 2021, Section 19

Exhibit 1

Common Terms and Definitions

Terms	Definitions
Environmental justice	*Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. EPA has this goal for all communities and persons across this Nation. It will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work.**
Cumulative impacts	*The total burden—positive, neutral, or negative—from chemical and non-chemical stressors and their interactions that affect the health, well-being, and quality of life of an individual, community, or population at a given point in time or period of time.*[#]
Health disparities	*A particular type of health difference that is closely linked with social, economic, and/or environmental disadvantage. Health disparities adversely affect groups of people who have systematically experienced greater obstacles to health based on their racial or ethnic group; religion; socioeconomic status; gender; age; mental health; cognitive, sensory, or physical disability; sexual orientation or gender identity; geographic location; or other characteristics historically linked to discrimination or exclusion.*[^]

Notes:

Sources:

* U.S. Environmental Protection Agency.

[#] U.S. Environmental Protection Agency Office of Research and Development. (2022). *Cumulative impacts recommendations for ORD research.*

[^] U.S. Department of Health and Human Services. *Health equity in healthy people 2030.*

Healthy Environment for All (HEAL) Act

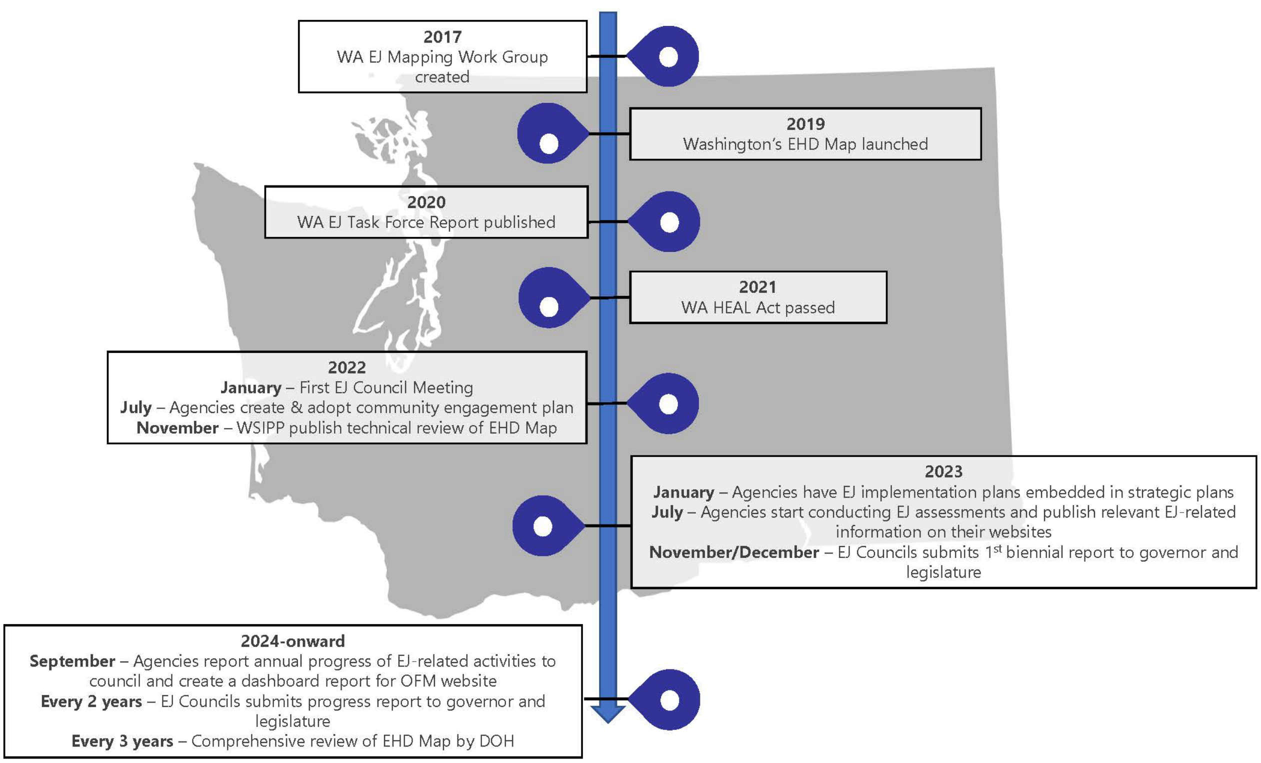
In 2020, the Washington EJ Task Force published a report outlining recommendations for prioritizing EJ in Washington State government.[2] The 2021 HEAL Act implemented the following recommendations:

- Have state agencies include EJ impact assessments in their major decisions,
- Create an EJ council to provide guidelines and review EJ-related government actions, and
- Mandate the Washington State Department of Health (DOH) to maintain and regularly update the EHD Map.[3]

Exhibit 2 outlines the development of the EHD Map and key dates of implementation of the HEAL Act.

Exhibit 2

Timeline of Environmental Justice Work in Washington



[2] Established by 2019-2021 proviso in Engrossed Substitute House Bill 1109, Chapter 415, Laws of 2019, Section 221 Subsection 48.

[3] Only certain agencies are required. This list includes the Department of Ecology, Department of Health, Department of Natural Resources, Department of Commerce, Department of Agriculture, Department of Transportation, and Puget Sound Partnership. Other agencies may opt in.

The Washington EHD Map

The Washington State Environmental Health Disparities (EHD) Map is an online, publicly available tool that displays information on environmental exposures and community vulnerability factors related to poor health outcomes at the 2010 census tract level.[4] It combines these measures to calculate a final composite score. This score ranks each census tract based on its cumulative environmental health risk.[5]

This tool is used to inform policymakers, state agencies, and the public about the potential environmental health impacts faced by the different communities in Washington. The 2021 HEAL Act specifically cites the EHD Map as a tool to be maintained and regularly updated to provide timely information that can be used to conduct environmental impact assessments. [6]

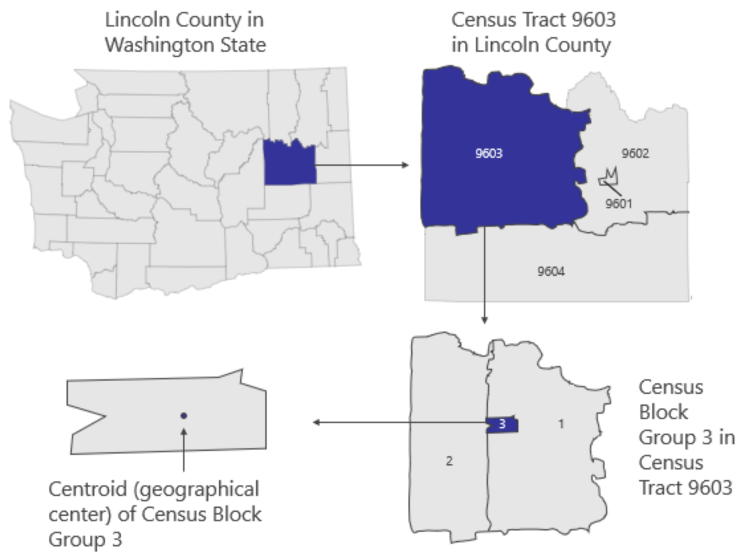
Development

Development of the EHD Map started in 2017 with the creation of the Washington Environmental Justice (EJ) Mapping Work Group.[7] They used a community-driven framework to form the map and to select indicators based on data availability and indicator appropriateness for Washingtonians.[8] This process included community listening sessions, reviews of similar EJ mapping tools and literature, and sensitivity analyses.

The methodology of the EHD Map is based on two main predecessors—the CalEnviroScreen (California) published in 2013 and the EJScreen (federal) published in 2015.

Exhibit 3

Geographical Areas



[4] DOH. *Washington Environmental Health Disparities Map.*

[5] University of Washington Department of Environmental & Occupational Health Sciences and Washington Department of Health. (2022). *Washington environmental health disparities map: Cumulative impacts of environmental health risk factors across communities of Washington State: Technical report version 2.0.*

[6] E2SSB 5141, Chapter 314, Laws of 2021. The HEAL Act suggests the use of the EHD Map and other sources to conduct cumulative impact analyses.

[7] Including organizations: Front and Centered, Puget Sound Sage, University of Washington's Department of Environmental & Occupational Health Sciences, WA Department of Health, Washington Tracking Network program, WA Department of Ecology, and the Puget Sound Clean Air Agency.

[8] Min, E., Gruen, D., Banerjee, D., Echeverria, T., Freelander, L., Schmeltz, M., . . . Seto, E.Y. (2019). The Washington State Environmental Health Disparities Map: Development of a community-responsive cumulative impacts assessment tool. *International Journal of Environmental Research and Public Health*, *16*(22), 4470.

Both mapping tools include two types of indicators: measures of environmental threats and measures of vulnerable populations. These indicators are combined to form a composite score (in the case of California) or EJ indexes (federal) that can be compared at different levels of geography such as counties, census tracts, or census block groups (which can be seen in Exhibit 3).

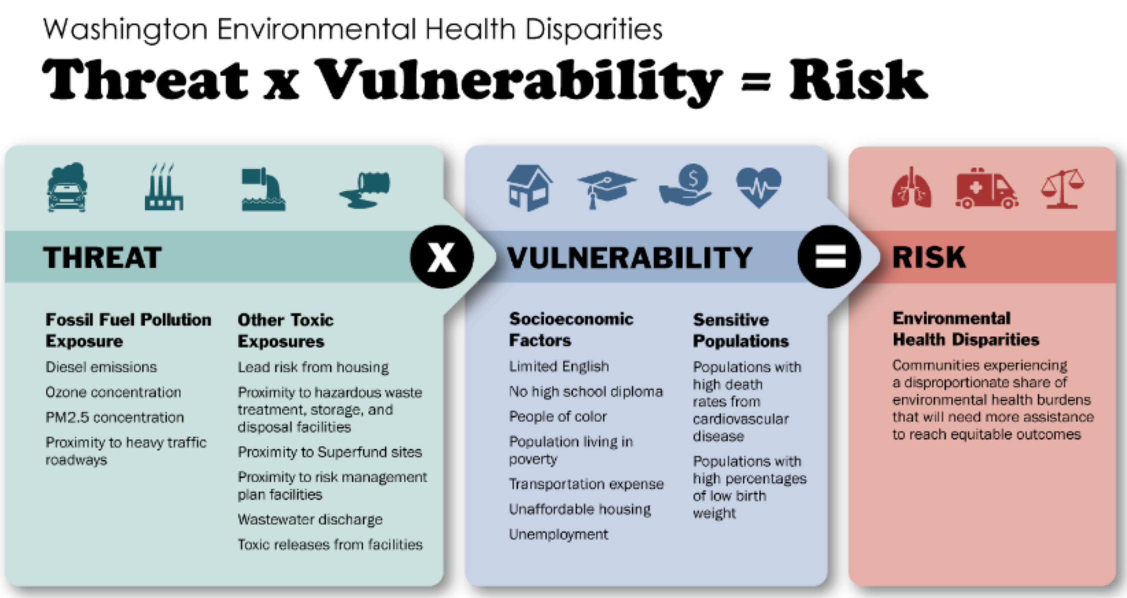
Washington follows the methodology of California. It combines all the indicators to form a composite score and composite score rank as seen in Exhibit 4.

Washington also relies on data from the federal tool for measures of environmental exposures and effects.

The first version of the EHD Map was launched in 2019 and published on Washington's Tracking Network (WTN) website.[9] Since publication, the tool has been updated with more years of information as source data has become available. The most recent version, 2.0, was published on July 28, 2022, and was the focus of this technical review.

Exhibit 4

Washington Environmental Health Disparities Map



Note:
Source: The above graphic is from Washington Environmental Health Disparities Map. Washington State Department of Health.

[9] The WTN is a DOH program that tracks health and environmental data to inform the public and policymakers to improve health and health equity in Washington; the initial tracking website was launched in 2008. Washington is one of 25 states funded by the Centers for Disease Control and Prevention (CDC) to build, implement, and maintain a local environmental public health tracking network as part of their National Environmental Public Health Tracking Network. Information by location: *Washington Tracking Network (WTN). Information by Location | Washington Tracking Network (WTN).*

II. Methodology and Scope of Current Technical Review

To conduct this technical review, we first identified similar tools to compare to Washington's EHD Map. Once comparable tools were identified, we reviewed indicators, composite measures, and statistical methods across the different tools.

Identifying Comparable Tools

WSIPP was tasked to find similar tools that "aim to identify communities that are disproportionately impacted as a result of environmental justice issues."[10]

We searched the web using the search terms "Environmental Health Disparities Map," "Environmental Justice Map," and "EJ Screen." For a tool to be included as a comparison in our analysis, we required that it applied to at least an entire state, was publicly available, and measured environmental risks and population characteristics.

In addition, to be included in our analysis, we only compared tools that allowed comparisons of counties, census tracts, or census block groups and combined individual measures to form some overall composite measures. We considered tools published through July 31, 2022. For all comparisons, we used the most recent online versions available as of the study cut-off date.

Scope of Technical Review

The methodological scope of this review included examining the tools as published online, reviewing technical documentation, reviewing supporting documentation from data sources used, conducting a literature review, and consulting with the creators of the tool when information was needed for clarification.

The topical scope of this review focused on the components of the tools and their supplemental information. These fit into three broad categories of characteristics—

1) Individual indicators formally included in the tool and how they are measured;
2) Statistical methods, including the formation of the composite score, and how the score is operationalized into cumulative environmental impact; and
3) Other functions and features of the tools.

For each of these categories, we present detailed information and synthesis in the Appendix. Section III of this report summarizes the findings.

[10] E2SSB 5141, Chapter 314, Laws of 2021.

The first category includes all the measures that are formally incorporated into the tool's composite measure to determine cumulative environmental health score.[11] We reviewed each measure included in Washington's tool and made direct comparisons with measures from other tools that embodied the same concept. Exhibits A4-A22 in the Appendix detail each tool's data source, list the years of data used, reference modeling and calculation methods, and are followed by a summary of our findings on the validity, reliability, and clinical importance of the measures.[12]

Our validity, reliability, and clinical importance sections summarize the literature referenced across the different tools' technical documents and are supplemented by additional literature reviews and interpretations (Exhibit 5).[13]

In addition, we compiled information on indicators that Washington does not include but other similar tools do include. For each of these non-Washington measures, we evaluated the measure with similar review criteria as the Washington measures and assessed how reasonable and feasible it would be for Washington to include the measure in future versions of the EHD Map.

The second category includes the statistical methods used to model complex measures and create the composite measure of cumulative environmental health rank. We directly compared Washington's methodology to each of the other tools and any best practices outlined in the research literature.

Exhibit 5

Validity, Reliability, & Clinical Importance

Indicator	Questions
Validity	• Does this indicator measure the concept of interest? • What is the quality of the data source (self-report, survey, administrative data)? • If it uses a proxy, is it a good proxy?
Reliability	• Is the measure reliability consistent over time? • Is the measure consistent over sub-populations? • Any variance with seasonality or other consistency Issues?
Clinical importance	• Is this specific measure tied to worse health outcomes? • Does the indicator measured capture the exposure and risk to health?

[11] Formal inclusion means that the indicator is included in the composite score calculation, rather than extra maps of data included on the larger tool's platform. For example, Washington maps tribal lands on the WTN platform, but this is not a formal measure in the EHD Map.

[12] Indicators were considered to be reasonably valid if they came from a data source that was systematically collected, processed, and used by other researchers or government agencies, using statistical methods that were recommended by that data source or had been subject to peer review. Indicators were considered reasonably reliable if there was no known or logically obvious patterns of measurement error or bias that would systematically impact the correct ranking of lower to higher environmental threats or vulnerabilities.
Clinical importance was defined broadly to include importance or connection with health, or something of public health importance. We did not require that the measure had to be correlated with a specific biometric or patient-reported outcome.

[13] Tool creators had an opportunity to review the Appendix for accuracy; the reviews were incorporated into the findings.

The third category is broader and compares different functions and features of the tools including how they were developed, the usability and accessibility of the tools and their hosting website, the range of supporting materials to explain the tool, the presentation and explanation of the composite scores, the availability of supplemental or contextual data embedded in the maps, access to raw data, how limitations of the instrument were framed, and other mapping functions in the tool application.

In the following sections of the report, we will present the following:

- Describe the differences between tools;
- Outline the pros and cons between methodologies; and
- Highlight platform features, new or alternative data sources, and best practices that have evolved in the literature.

III. Findings

In this section, we summarize key findings from our review. We first outline the other tools we found comparable to Washington's EHD Map and their relationship to one another. Then, we compare indicators within each theme, the composite scores, and other functionalities and features of the mapping tools.

Similar Environmental Justice Tools

Our search resulted in 19 tools that either mapped environmental exposures or health measures, or some combination, with a range of sophistication. Some tools simply mapped separate indicators and some created a composite score. Exhibit 6 displays if an EJ mapping tool has been created for a state. Darker shades of blue indicate greater sophistication and documentation.

Exhibit 6

EJ Map Availability Across the US

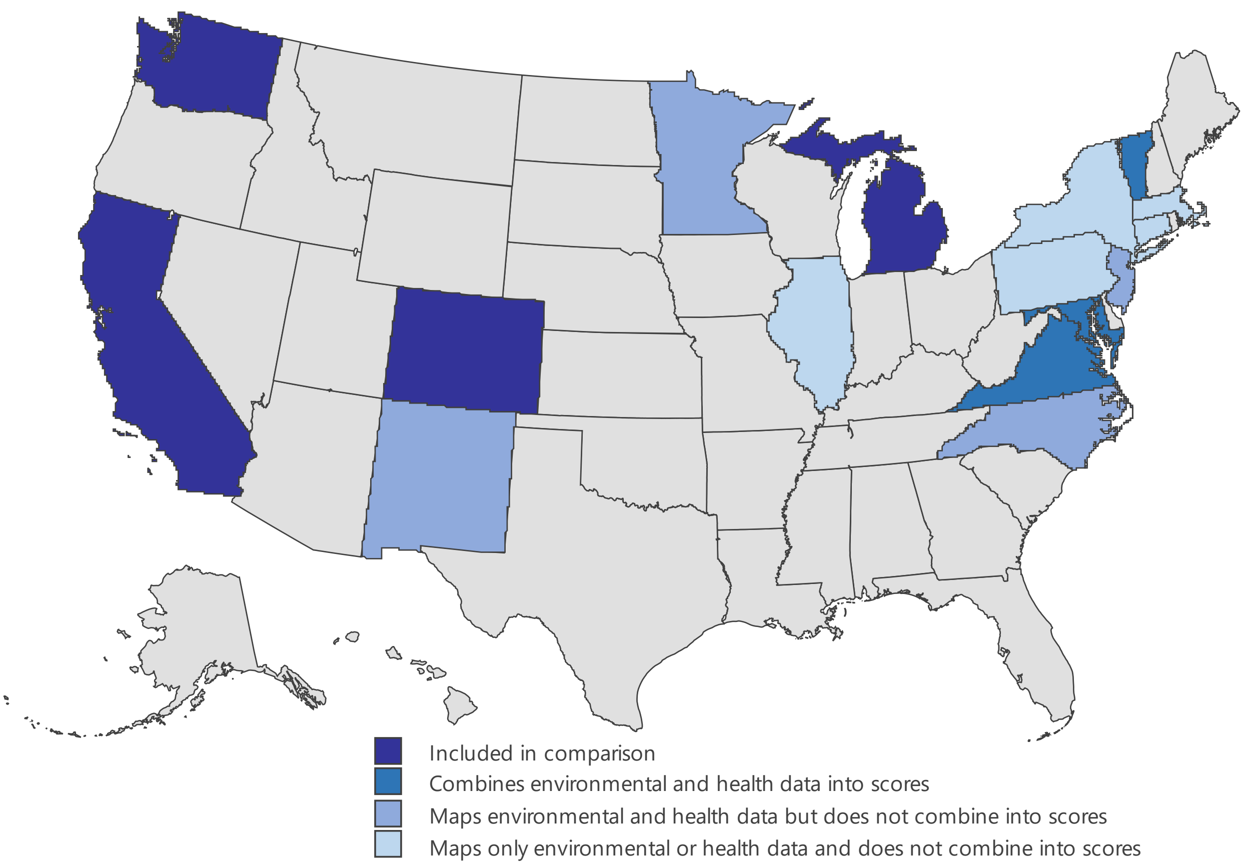
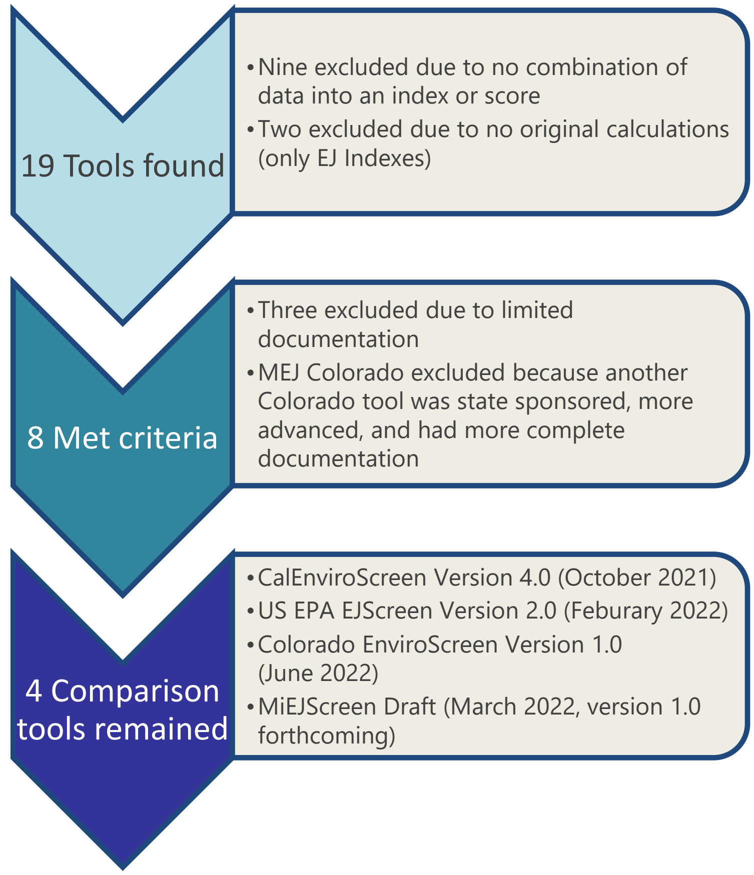


Exhibit 7 details our process for selecting the final comparison tools. Based on our criteria, we selected three other state tools to compare to Washington's EHD Map version 2.0, in addition to the federal tool.[14] These were CalEnviroScreen (California), MiEJScreen (Michigan), and EnviroScreen (Colorado).[15] A full list of tools considered can be found in Exhibit 1A in the Appendix.[16]

Exhibit 7

Comparison EJ Tools Selection Process



Note:
All tools were compared to version 2.0 of Washington's EHD Map published on July 28, 2022.

[14] EJScreen was created and is maintained by the US Environmental Protection Agency.

[15] CalEnviroScreen was created and is maintained by the California Office of Environmental Health Hazard Assessment. MiEJScreen was created and is maintained by the Michigan Department of Environment, Great Lakes, and Energy. Colorado EnviroScreen was created and is maintained by the Colorado Department of Public Health and Environment.

[16] Two other reviews have examined these tools and their capabilities. This study is the first of our knowledge to compare indicators and composite score methodologies directly across tools of similar sophistication. Konisky, D., Gonzalez, D., & Leatherman, K. (2021). Mapping for Environmental Justice: An Analysis of State Level Tools. *Environmental Resilience Institute, O'Neill School of Public And Environmental Affairs, Indiana University*; and Arriens, J., Schlesinger, S., & Wilson, S. (n.d.) Use and potential in policy making to address climate change. National WildlifeFederation.

Comparison Tools

Similar to Washington's EHD Map, Michigan and Colorado use a substantial amount of the federal tool's data and California's methodology (Exhibit 8). The methods for calculating the composite score are largely the same; there is significant overlap of indicator measures and how they are organized across tools. [17]

All but Colorado's tool has four themes of indicators.

1) Environmental exposures
2) Environmental effects
3) Sensitive populations
4) Socioeconomic factors

Using a weighted average, these four themes are combined into two *component scores*—

1) Pollution burden and
2) Population characteristics.

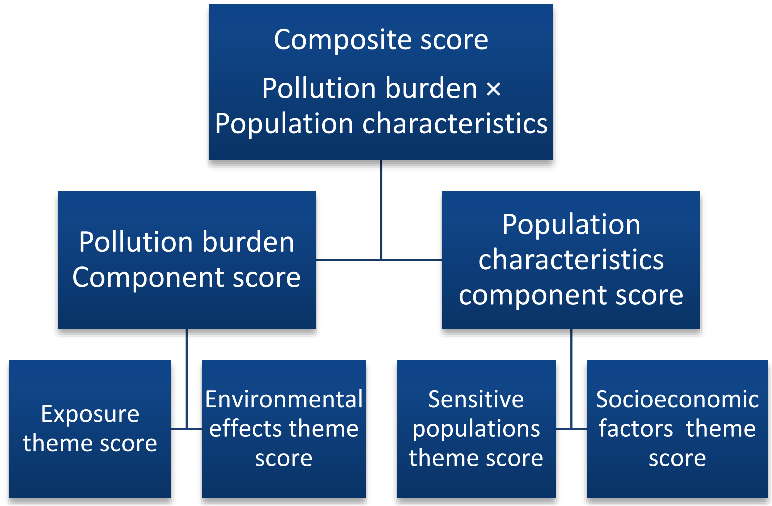
These component scores are then multiplied together to create the composite score. This is based on the following conceptual formula:

$$Risk = Threat \times Vulnerability$$

This reflects the relationship documented in the public health literature that the effects of environmental exposures can be amplified by characteristics in a community that can represent extra susceptibility to the harms of pollution.[18]

Exhibit 8

California's Screen Composite Score



The exception to this single composite score framework is the federal tool. Instead of one overall score, there are 12 EJ Indexes, one for each environmental exposure or environmental effect. Their indexes follow the same $Risk = Threat \times Vulnerability$ formula by multiplying their environmental exposure indicator with their demographic index.

The biggest differences across the tools are the number of indicators and which indicators are included in their composite score (Exhibit 9). The next four sections summarize the differences in indicators across the common themes. Each section includes a table that lists all indicators found for that theme.

[17] Exact names of the themes vary across tools. Colorado has a 5th category, climate burden. Environmental exposures are direct measures of pollution levels, like ozone concentration, while environmental effects are known hazards where direct contact is less certain, like proximity to landfills. Sensitive populations are populations who are at greater risk environmental threats due to biological factors, while socioeconomic factors measure characteristics the modify pollution burden.

[18] University of Washington Department of Environmental & Occupational Health Sciences and Washington Department of Health (2022).

Exhibit 9

Indicator Counts Across Comparison Tools

Indicator	Number of indicators
Federal EJScreen	**14**
Washington EHD Map	**19**
California CalEnviroScreen	**21**
Michigan MiEJScreen	**26**
Colorado EnviroScreen	**35**

Environmental Exposures

Environmental exposure indicators capture direct measures of well-known and documented harms that can be present in a community's environment. Exposure (either short/concentrated or longer/low to moderate) has been linked to a higher risk of developing health conditions and exacerbating existing health conditions.

Studies have also shown ecological effects, i.e., that community-level measures of higher environmental exposures are tied to worse community-level outcomes of health.[19] This is important to note for the application of these mapping tools. Pollution exposures can rarely be measured at the individual level using national or state-wide data.

Studies that show reliable ecological effects demonstrate that these measures (despite the potential to misspecify exposure at the individual level) are still strong predictors of community health outcomes *on average*.[20]

Exhibit 10 shows the environmental exposure indicators included in each tool, with the most widely used indicators listed first. For this theme, the majority of the indicators are air pollution measures.

Every state tool measures diesel particulate matter 2.5 emissions, ozone, particulate matter 2.5 (PM2.5), traffic density, and toxic air emissions.[21] For air measures (diesel, ozone, PM2.5), Michigan and Colorado use the federal tool data, while Washington and California use their state-specific data and similar methodology.

The methods for traffic density measures vary across tools. Washington's EHD Map is the only tool that does not use a cumulative measure of traffic for a geographical unit and instead applies the maximum measure. This may not account for a consistent level of moderate traffic. For more details, see Section II. A) of the Appendix.

[19] Ecological effect means that there is relationship at more than the individual level, for example the city, census block

[20] Krishnan, R. M., Sullivan, J. H., Carlsten, C., Wilkerson, H. W., Beyer, R. P., Bammler, T., ... & Kaufman, J. D. (2013). A randomized cross-over study of inhalation of diesel exhaust, hematological indices, and endothelial markers in humans. *Particle and Fibre Toxicology*, *10*(1), 1-10.; Patel, M. M., Chillrud, S. N., Deepti, K. C., Ross, J. M., & Kinney, P. L. (2013). Traffic-related air pollutants and exhaled markers of airway inflammation and oxidative stress in New York City adolescents. *Environmental Research, 121*, 71-78.; Fann, N., Lamson, A.D., Anenberg, S.C., Wesson, K., Risley, D., & Hubbell, B.J. (2012). Estimating the national public health burden associated with exposure to ambient PM2. 5 and ozone. *Risk Analysis: An International Journal*, *32*(1), 81-95.; Adar, S.D., Sheppard, L., Vedal, S., Polak, J.F., Sampson, P.D., Diez Roux, A. V., . . . Kaufman, J.D. (2013). Fine particulate air pollution and the progression of carotid intima-medial thickness: a prospective cohort study from the multi-ethnic study of atherosclerosis and air pollution. *PLoS Medicine*, *10*(4).; Agarwal, N., Banternghansa, C., & Bui, L.T. (2010). Toxic exposure in America: Estimating fetal and infant health outcomes from 14 years of TRI reporting. *Journal of Health Economics*, *29*(4), 557-574; and Berglind, N., Bellander, T., Forastiere, F., von Klot, S., Aalto, P., Elosua, R., . . . Nyberg, F. (2009). Ambient air pollution and daily mortality among survivors of myocardial infarction. *Epidemiology*, 110-118.

[21] More information on these indicators can be found in the Appendix.

Lead exposure is measured by all tools; some tools include it in the environmental effects theme.

All tools also have measures of toxic air emissions, but they are too different to compare directly. See Section II. E) in the Appendix for more details.

California and Colorado both include indicators for drinking water contaminates. California includes a measure for pesticide use and Colorado includes a measure for noise.

All the environmental exposure measures presented are reasonably valid and reliable and are sourced from reputable data sources. They have documented ties to health, which we define as having clinical importance. For more details on each indicator, see Section II in the Appendix.

Exhibit 10

Environmental Exposure Indicators Included Across Tools

Indicator	Washington EHD Map	California CalEnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Lead risk and exposure	X (Environmental effects)	X	X (Environmental effects)	X	X (Environmental effects)
Traffic density	X	X	X	X	X
Diesel exhaust particulate matter (PM) 2.5 emissions	X	X	X	X	X
Ozone	X	X	X	X	X
Particulate matter 2.5 (PM2.5)	X	X	X	X	X
Toxic releases from facilities*	X	X			
NATA air toxics cancer risk*			X		X
NATA air toxics respiratory hazard index*			X		X
Air toxic emissions*				X	
Other air pollutants*				X	
Drinking water contaminates		X		X	
Pesticide use		X			
Noise				X	

Notes:
* Indicators are measures of air emissions that combine different mixes of toxins.
Lead risk and exposure for the EHD Map, EJScreen, and MiEJScreen are included in the environmental effects section.
See Section II of the Appendix for more detail on the environmental exposure indicators.

Environmental Effects

Environmental effects indicators capture well-known and documented sources of poor environmental quality that can be present in a community's environment, such as living in older housing or areas with industrial land uses. These environmental measures may have less precision. For example, most reporting for sites with hazardous substances is mandatory but the detail required is minimal and the type, mixture, and volume of hazardous substances can vary substantially.

Despite the imprecision, the harms caused by these environmental sources are very serious when populations are exposed. Studies have shown reliable ecological effects and that these measures can be strong predictors of community health outcomes *on average*.[22]

Exhibit 11 shows the environmental effects indicators included in each tool, with the most widely used indicators listed first. All tools measure lead exposure risk, proximity to hazardous waste generator sites, and proximity to Superfund sites.[23] All but California also includes indicators for wastewater discharge and proximity to facilities with highly toxic substances.[24]

As mentioned in the previous section, lead exposure is measured by all tools, but some tools include it in the environmental exposures theme rather than the environmental effects theme.

Methods vary for some of the measures. For lead exposure, Washington and California take a different approach compared to the federal tool and others. They account for different levels of lead risk across different decades, while the federal tool uses a threshold for housing units built before 1960.

For proximity to hazardous waste generator sites and proximity to Superfund sites, there is a split between the methods used by California and Michigan and the federal method that everyone else uses. The California and Michigan method accounts for more specific risks associated with a facility, while the federal method accounts more for site proximity to more densely populated areas.

[22] American Academy of Pediatrics Committee on Environmental Health. (2005). Lead exposure in children: prevention, detection, and management. *Pediatrics*, *116*(4), 1036-1046.; Kouznetsova, M., Huang, X., Ma, J., Lessner, L., & Carpenter, D.O. (2007). Increased rate of hospitalization for diabetes and residential proximity of hazardous waste sites. *Environmental Health Perspectives*, *115*(1), 75-79.; Sergeev, A.V., & Carpenter, D.O. (2005). Hospitalization rates for coronary heart disease in relation to residence near areas contaminated with persistent organic pollutants and other pollutants. *Environmental Health Perspectives*, *113*(6), 756-761.; Ala, A., Stanca, C.M., Bu-Ghanim, M., Ahmado, I., Branch, A.D., Schiano, T.D., . . . Bach, N. (2006). Increased prevalence of primary biliary cirrhosis near Superfund toxic waste sites. *Hepatology*, *43*(3), 525-531.; Baibergenova, A., Kudyakov, R., Zdeb, M., & Carpenter, D.O. (2003). Low birth weight and residential proximity to PCB-contaminated waste sites. *Environmental Health Perspectives*, *111(*10), 1352-1357.; Elliott, M.R., Wang, Y., Lowe, R.A., & Kleindorfer, P.R. (2004). Environmental justice: frequency and severity of US chemical industry accidents and the socioeconomic status of surrounding communities. *Journal of Epidemiology & Community Health, 58*(1), 24-30.; Brender, J.D., Maantay, J.A., & Chakraborty, J. (2011). Residential proximity to environmental hazards and adverse health outcomes. *American Journal of Public Health*, *101*(S1), S37-S52.; and VanDerslice, J. (2011). Drinking water infrastructure and environmental disparities: evidence and methodological considerations. *American Journal of Public Health*, *101*(S1), S109-S114.

[23] Hazardous waste generator sites are also referred to as hazardous waste treatment, storage, and disposal facilities (TSDFs). Superfund sites are also referred to as national priorities list sites (NPLs) or cleanup sites.

[24] These facilities are also referred to as risk management plan (RMP) sites.

All but California includes indicators for proximity to facilities with highly toxic substances and wastewater discharges. All the state tools use the federal measure.

Tools other than Washington's EHD Map include additional water measures that may be relevant for Washington and measures for mining, oil, and gas that may be less relevant.

For additional information on the other measures that states include see Section III. F) of the Appendix.

All of the environmental effects measures presented are reasonably valid and reliable and are sourced from reputable data sources. They all have documented ties to health or clinical importance. For more details on each indicator, see Section III of the Appendix.

Exhibit 11

Environmental Effects Indicators Included Across Tools

Indicator	Washington EHD Map	California CalEnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Lead risk and exposure	X	X (Environmental exposures)	X	X (Environmental exposures)	X
Proximity to hazardous waste generators and facilities (aka TSDFs)	X	X	X	X	X
Proximity to Superfund sites (aka cleanup sites or NPLs)	X	X	X	X	X
Proximity to facilities with highly toxic substances (aka RMPs)	X		X	X	X
Wastewater discharge	X		X	X	X
Impaired water bodies		X		X	X
Solid waste sites and facilities		X			X
Groundwater threats		X			
Mines				X	
Oil and gas				X	

Notes:
TSDF = Treatment, storage, and disposal facilities.
NPL = National priorities list sites.
RMP = Risk management plan.
Lead risk and exposure for the CalEnviroScreen and the EnviroScreen are included in the environmental exposure section.
See Section III of the Appendix for more detail on the environmental effects indicators.

Climate Vulnerability

Colorado has a third theme that contributes to its pollution burden component score and is treated similarly to the environmental effects theme.

Although the federal tool and the EHD Map do not include a climate vulnerability theme in their scoring formulas, both include the ability to view climate data on their map overlays. The federal tool has these data overlays in its climate change section. The Washington Tracking Network platform has them under its "Map Features" tab.

Most of these measures are not currently set up to be available at the census tract or census block group level. More work would be needed to design an appropriate indicator for these levels of geography.

Exhibit 12 shows the climate vulnerability indicators included in the Colorado, federal, and Washington versions. Colorado's rationale for including them is to represent "climate change risks that have been associated with health impacts."[25]

Colorado is the most recent state EJ tool published and the first to include climate vulnerability indicators. In the future, more tools may opt to formally include these measures in the calculations of their composite or may continue to supply them as overlays to provide extra contextual information for the future forecasted conditions in a geographical location.

Exhibit 12

List of Climate Vulnerability Indicators

Indicator	Washington EHD map (overlay only)	Federal EJScreen (overlay only)	Colorado EnviroScreen
Wildfires	X	X	X
Drought	X	X	X
Extreme heat days	X		X
Coastal flood plain	X	X	
100-year floodplains	X	X	X
Sea level rise	X	X	

Sensitive Populations

Sensitive population indicators capture information about the prevalence of health conditions in a census tract or the average health status of persons in a census tract. Persons living with lower health status or certain conditions are already experiencing poor health outcomes and can be even more vulnerable to environmental exposures than their healthier counterparts.

Census tracts with higher rates of a condition, like asthma or cardiovascular disease, can be more heavily impacted by environmental exposures. The presence of environmental exposures may exacerbate health conditions to a greater degree than they would in a healthier population with the same level of environmental exposure. These indicators are commonly of interest to public health and epidemiology fields and are frequently used in other policy planning tools like Healthy People 2030.[26]

[25] Colorado EnviroScreen tool team. (2022). Colorado EnviroScreen tool technical document. Denver, Colorado, USA.

[26] *Healthy People 2030. Office of Disease Prevention and Health Promotion (ODPHP).*

The federal tool does not include sensitive population indicators in their demographic index or their environmental justice indexes calculations, but they do map these measures at the census tract level to provide supportive information.

Exhibit 13 shows the sensitive population indicators included in each tool, with the most widely used indicators listed first. Every state tool measures low birth weight (LBW) and included a proxy for cardiovascular disease prevalence. Washington EHD Map is the only state tool that does not include a measure of asthma.[27]

The EHD Map is also the only tool that excludes pre-term births in their calculations for the LBW indicator. Pre-term births can be tied to low maternal socioeconomic status and other social and health stressors—this exclusion could lead to overestimates of LBW in more affluent census tracts and underestimates in less affluent census tracts.

The federal tool and the two most recent state tools include life expectancy. Michigan also includes a measure of blood lead level and Colorado includes measures for cancer, diabetes, and mental health. Colorado also includes high-risk age group indicators (65+ years old, less than 5 years old), while other tools included those age measures in the socioeconomic factors theme.

Exhibit 13

Sensitive Population Indicators Included Across Tools

Indicator	Washington EHD Map	California CalEnviroScreen	EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Low birth weight (LBW)	X	X		X	X
Cardiovascular disease	X	X	X (Overlay only)	X	X
Asthma		X	X (Overlay only)	X	X
Life expectancy			X (Overlay only)	X	X
Cancer				X	
Diabetes				X	
Mental health				X	
Blood lead level					X
Population under age 5			X (Overlay only)	X	X (Socioeconomic factors)
Population over age 65			X (Overlay only)	X	X (Socioeconomic factors)

Notes:
Population under age 5 and over age 65 for MiEJScreen are included in the socioeconomic factors section.
See Section IV of the Appendix for more detail on the environmental exposure indicators.

[27] This was a goal of the WA EHD Map to develop in later years once reliable data became available.

We found that the most common indicators (low birth weight, cardiovascular disease, and asthma) depended on the availability of state-level data resources. As these data sources differ across states, there is greater variation in how indicators are measured. Some states have more robust health data and can create direct estimates of disease prevalence or valid proxies at the census tract level.

Other states rely on model estimates from the Behavioral Risk Factors Surveillance System (BRFSS) data and predict the prevalence of disease based on census tract demographic data. While this approach relies on more assumptions, and those assumptions may not hold up, it requires less granular data and can be used to calculate the prevalence of more health conditions.[28] Colorado was able to include more health measures for this reason. They rely on Centers for Disease Control and Prevention (CDC) Places data that are available for most census tracts in the United States.[29]

All the sensitive population measures presented are reasonably valid and reliable and are sourced from reputable data sources. They all have documented ties to health or clinical importance. For more details on each indicator, see Appendix IV.

Socioeconomic Factors

Socioeconomic factor indicators capture socioeconomic information about communities at the census tract level and are generally correlated with greater environmental exposures and worse health outcomes. This implies that having a lower socio-economic status raises the likelihood of living in a community that has more environmental harms, *in addition* to being more vulnerable to environmental harms when they are present.[30]

This means that in a community with many members who have low socio-economic status, the relationship between health and environmental exposures would be further compounded by less access to resources that can shield against environmental harm and health outcomes. These measures are commonly captured as measures of vulnerability and are frequently used in other policy planning tools like Healthy People 2030.[31]

[28] Zhang, X., Holt, J.B., Lu, H., Wheaton, A.G., Ford, E.S., Greenlund, K.J., & Croft, J.B. (2014). Multilevel regression and poststratification for small-area estimation of population health outcomes: a case study of chronic obstructive pulmonary disease prevalence using the behavioral risk factor surveillance system. *American Journal of Epidemiology*, *179*(8), 1025-1033.; Zhang, X., Holt, J.B., Yun, S., Lu, H., Greenlund, K.J., & Croft, J.B. (2015). Validation of multilevel regression and poststratification methodology for small area estimation of health indicators from the behavioral risk factor surveillance system. *American Journal of Epidemiology*, *182*(2), 127-137.; and Wang, Y., Holt, J.B., Zhang, X., Lu, H., Shah, S.N., Dooley, D.P., . . . Croft, J.B. (2017). Comparison of methods for estimating prevalence of chronic diseases and health behaviors for small geographic areas: Boston validation study, 2013. *Preventing Chronic Disease, 14,* E99.

[29] Centers for Disease Control and Prevention. (2022). *Places: Local data for Better Health. Centers for Disease Control and Prevention.*

[30] For example, lower socio-economic status could be correlated with less time and resources to buy water and air filters, receive prompt and preventative healthcare, invest in the quality of their daily living space, and engage in community activities and resources that decrease the harm of environmental exposures.

[31] Centers for Disease Control and Prevention. (2022). *CDC/ATSDR social vulnerability index (SVI). Centers for Disease Control and Prevention* and Healthy People 2030.

The federal tool includes poverty and race to create a demographic index that is then combined with environmental indicators. They also have measures of education, linguistic isolation, unemployment, and populations 65+ years old and under 5 years old, but only as supplemental information.

Exhibit 14 shows the socioeconomic factor indicators included in each tool, with the most widely used indicators listed first. Every state tool includes some measure of education, linguistic isolation, and poverty. All but California included some measure of race, though California does conduct a separate analysis examining how the composite score is impacted by and Washington, California Colorado, and Michigan's tools included housing burden, but Washington was the only tool to also include transportation expenses to capture the trade-off between high housing expenses and high-cost, time-consuming commutes.

Washington, California, Michigan, and the federal tools included an unemployment measure while Colorado did not. Michigan and Colorado both include age groups in their tools.[32] Colorado was the only state to include disability status. For more details see Section V. G) of the Appendix.

Exhibit 14

Socioeconomic Factor Indicators Included Across Tools

Indicator	Washington EHD Map	California CalEnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Low educational attainment	X	X	X (Overlay only)	X	X
Housing burden	X	X		X	X
Transportation expense	X				
Linguistic isolation	X	X	X (Overlay only)	X	X
Poverty	X	X	X	X	X
Race (people of color)	X		X	X	X
Unemployment	X	X	X (Overlay only)		X
Disability				X	
Population under age 5			X (Overlay only)	X (Sensitive populations)	X
Population over age 65			X (Overlay only)	X (Sensitive populations)	X

Notes:
Population under age 5 and over age 65 for EnviroScreen are included in the sensitive populations section.
See Section V of the Appendix for more detail on the environmental exposure indicators.

[32] Colorado included age groups in their sensitive populations theme rather than socioeconomic factors.

The socioeconomic factor indicators are fairly uniform across the tools, and they all rely on data from the American Community Survey. However, there is some variance in how they are used. Washington uses a slightly different poverty cut-off and uses a state-specific data source for race.

All the socioeconomic factors measures presented are reasonably valid and reliable and are sourced from reputable data sources. They all have documented ties to health or clinical importance. For more details on each indicator, see Section V of the Appendix.

Composite Score Methods

All the previous measures of indicators are combined to form a composite score and composite score rank. The methodology of combining indicators and calculating the composite scores is very similar across tools. Most state tools follow the original California method very closely, but some variations stand out.

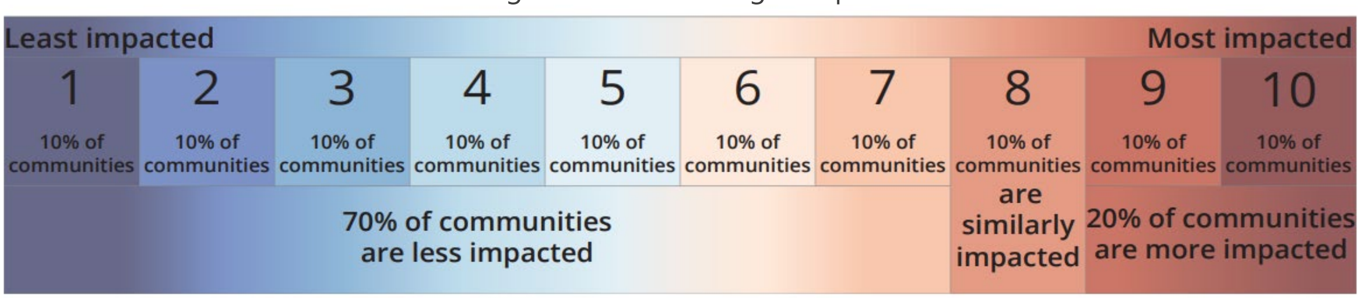
This section explains the California method, the federal method, and variations in methods across state tools. All tools use some kind of ranking method (i.e., percentiles or deciles) to rank census tracts by the values of each indicator and the composite score.[33] A ranking method lines up scores for census tracts from small values to large values and then assigns each census tract a rank from 1-100 (or 1-10 for deciles) based on that census tract's position in the lineup.

For a census tract assigned a percentile rank of 81, we can interpret that the tract is more impacted by cumulative environmental threats than 80% of other census tracts and is less impacted by cumulative environmental threats than 19% of other census tracts.

Washington's EHD Map uses a form of decile ranking. Exhibit 15 displays the EHD Map ranking categories and provides an example of how to interpret a community with a rank of 8.[34] The main difference is instead of a range of 1 to 100, the range is from 1 to 10.

Exhibit 15

Washington Decile Ranking Interpretation



Note:
Source: The graphic is from the Department of Health Washington EHD Map Version 1.0 technical report.

[33] EJScreen also ranks by census block groups, and Colorado EnviroScreen also ranks by census block groups and counties.
[34] University of Washington Department of Environmental & Occupational Health Sciences and Washington Department of Health. (2019). *Washington environmental health disparities map: Comparing environmental health risk factors across communities: Technical report version 1.0.*

California (CalEnviroScreen)

California compares indicators across all census tracts in California, ranking census tracts into percentiles.[35] It then combines all the indicators to form a single cumulative environmental score (Exhibit 16) and places census tracts in ranked bins that represent a census tract's environmental health risk compared to other California census tracts.

Federal (EJScreen)

The federal tool maps and compares indicators across the entire country and presents data at the census block and census tract level.[36] They then create individual EJ indexes for each of their environmental indicators by combining the indicator and their demographic index.

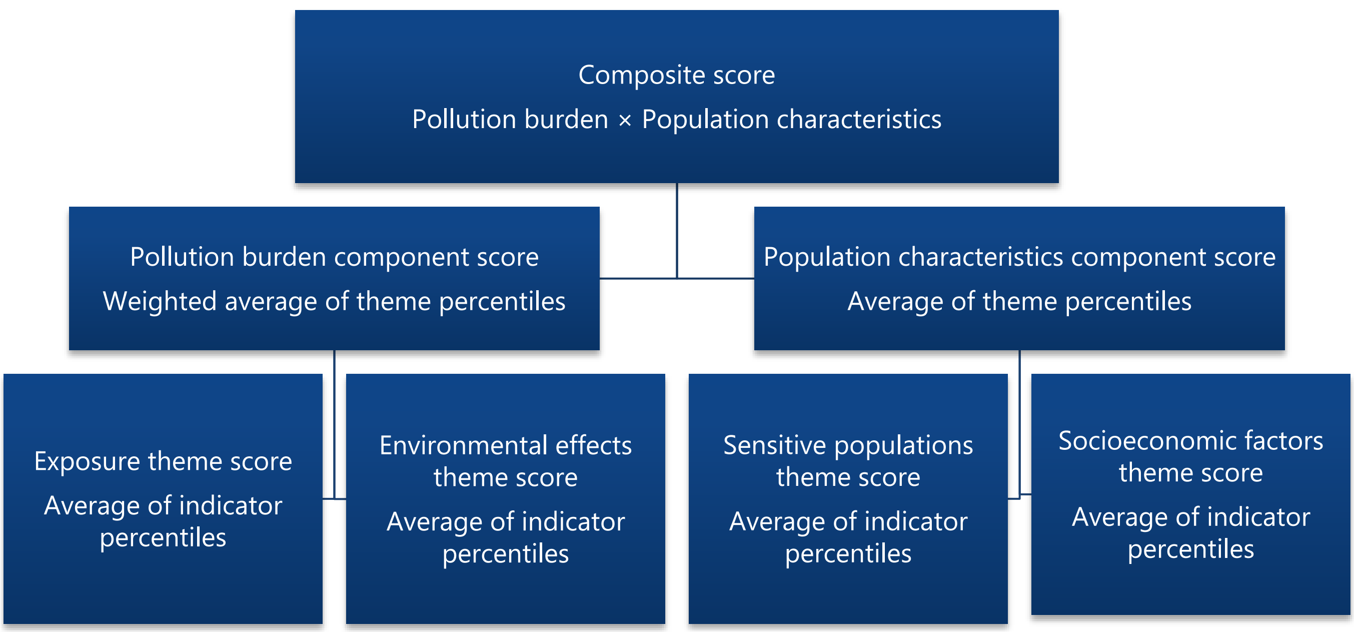
The federal tool does not calculate a cumulative score. Instead, they have 12 separate EJ indexes that incorporate demographic information.

Differences in Composite Score Calculation

As mentioned above, the EHD Map uses deciles instead of percentiles when calculating its composite score. This results in a loss of precision in rankings of census tracts that are close in scores compared to the percentile method that the other tools use. Despite this loss of precision, it theoretically should not impact the overall ranking of a census tract by much.

Exhibit 16

California Composite Score



[35] August, L., Bangia, K., Plummer, L., Prasad, S., Ranjbar, K., Slocombe, A., Wieland, W. (2021). *Update to the California Communities Environmental Health Screening Tool CalEnviroScreen 4.0.* California Office of Environmental Health Hazard Assessment.

[36] U.S. Environmental Protection Agency. (2019). *EJSCREEN Technical Documentation.*

Exhibit 16 outlines the structure of the composite score for California's tool. All indicators within a theme are combined to form a theme score. Most tools use an arithmetic mean or simple average except for Colorado which uses a geometric mean to calculate its theme score. This difference could change the ranking of census tracts substantially; it is unclear which is better. Colorado cites that geometric means are better for combining correlated values, which is a concern for indicators within a theme as they are highly correlated.

Once component scores are calculated, most other tools scale the score to a 1-10 range by dividing the component score by the maximum census tract in that state and multiplying by ten. This forces the final composite score to be in a range between 1-10. The Washington EHD Map is the only tool that does not do this. However, completing this extra step does not change the final scores' rank percentile or decile, which is ultimately what is presented in the mapping tools.

Data Variability Checks

California also employs reliability checks on indicators from sample populations, which are mostly measures from the American Community Survey (ACS) and/or from health data sources. When data were categorized as unreliable or missing for a geographic area, such as census data with large uncertainties, the data were excluded from the percentile calculation and not assigned a score for that indicator. This ensures that the census tract's estimate and its rank are based on a certain standard of reliability. No other tools use this method for the ACS data, and they effectively allow for indicators to have a missing value. Colorado and Michigan allow for missing or "not applicable" values and those census tracts are not assigned a percentile rank for that indicator.[37]

Currently, the EHD Map is limited to the functionality of the WTN's "information by location" decile ranking that forces missing or unreliable values to have a rank of zero. A rank of zero implies "low risk" which may not be an accurate representation of that census tract's risk. This treatment of missing data is not ideal.

Indicator Placement and Weights

Other differences to consider are indicator placement in the themes. Where indicators are located impacts the weight that they contribute to the overall composite score. For example, Colorado includes age group indicators (percent under 5 years & percent 65 years and older) in their sensitive populations rather than their demographics or socioeconomic factors theme like Michigan's tool.

[37] Michigan Department of Environment, Great Lakes, and Energy. (2022). *Michigan environmental justice mapping and screening tool: Draft technical report.* Office of the environmental justice public advocate.

If Washington considered adding both measures, which theme they were added to could have a large impact on the weight of other scores. The impact of including age groups in the socioeconomic factors theme (7 indicators) would be relatively small but adding them to the sensitive population's theme (2 indicators) would drop the current contribution of the cardiovascular and low birth weight indicators by half.

Another instance of indicators switching themes is in California’s and Colorado’s tools, lead-based paint is in the environmental exposures theme rather than the environmental effects theme like the Washington and Michigan tools. This gives the lead-based paint indicator roughly double the weight that it would have in the environmental effects theme due to the differential weighting of those themes in the component score.

Validity, Reliability, and Clinical Importance

The goal of something like a composite score or EJ index is to assess what environmental threats a community is facing and its ability to withstand the negative effects of these threats. The true values of these concepts for any given community are unknown and impossible to calculate. However, it is possible to systematically gather known threats and vulnerabilities and reasonably summarize these data.

All these tools complete that task in a valid, reliable method and use measures that have established relationships with health and clinical meaning. However, the methodological literature has not been developed enough to conclusively determine which methods are best. Further sensitivity and methodology development and testing are needed. See Section VI of the Appendix for a detailed discussion of methods and existing sensitivity analysis.

Other Functions and Features

Aside from indicators and methods used by each tool, there is also variation in the development, interface, and documentation of the online tools. This section summarizes some of these differences.

Development

Overall, all tools use very similar methods to determine what indicators to include with a heavy emphasis on community input and reviewing prior work on how to measure environmental threats and vulnerabilities. Earlier tools relied more on expert recommendations and peer review, while later tools relied more on existing established methodologies of other tools.

Host Websites

All comparison tools have a home webpage with an introduction to the tool, easy-to-identify links to the map application, user guides, videos, updates, reports or technical documentation, and other helpful information including how the tools were used by the government agency hosting it. The Washington EHD Map’s webpage has most of these features, but it was difficult to find the how-to videos and the user guide was not available until the user opened the tool.

User Guides and How-Tos

All tools include helpful tips on how to use the maps once the tool is opened in the web browser.[38] Colorado and California initially present their maps as windows within a webpage with plenty of information to guide the user while actively using the map, along with links to the underlaying data.[39] The other tools open to a map with a menu of measures to plot and icons that provide extra information on how to use the tool, guides for interpretation, underlaying technical information on the source data, and additional extra functions. The Washington EHD Map has limited icons and functions compared to the other tools.

Presentation of Ranks

California and Michigan present their ranks in 10-percentile increments (roughly deciles), like the EHD Map. Colorado does 20 percentile increments (quintiles), and the federal tool has unique ranked categories (95-100, 90-95, 80-90, 70-80, 60-70, 50-60, and below 50) that highlight the top 20 percentiles. Most tools use bold colors to emphasize that the census tracts in the highest 20% to 30% are of the most concern.

Supplemental or Contextual Data

The platforms hosting each of the tools include additional overlays or data that are mapped but not formally included in the composite score or an index. Washington, Colorado, Michigan, and the federal tool include additional overlays. California is the one exception to this, with its tool only including the data for the indicators included in the calculation of the composite score.

The types of additional data vary by tool. Colorado includes county and site-specific information on oil and gas, rural communities, state-defined disproportionally impacted communities, and information from other tools like the federal Justice40 census tracts.[40]

Michigan, Washington, and the federal tools include many overlays like historic redlining, food deserts, tribal areas, and infrastructure information like schools, hospitals, and legislative districts that provide context for the cumulative impact ranks.

Access to Raw Data

All tools allow users to download the underlying data, both raw values and percentiles, though ease and accessibility vary. For example, California has all its model data in a single excel file on the mapping webpage, while the federal tool requires you to follow multiple links and files without clear instructions or explanations for how the data is organized. States also censor sensitive data as needed and these values are not released.[41] One example of this is the EHD Map's censoring of raw values for low birth weight for small census tracts.

[38] Tools are on a variety of platforms. Washington is on the WTN's information by location platform. Colorado EnviroScreen is R shiny, CalEnviroScreen and MiEJScreen use ArcGis ESCRI, and EJScreen is on EnviroMapper.

[39] There is an option to open the map in its own window.

[40] Justice40 census tracts refers that tracts that have been identified as disadvantages communities according to the Justice 40 initiative from Presidential Executive Order 14008 Tackling the Climate crisis at Home and Abroad. The Justice40 initiative directs 40% of the overall benefits of certain Federal investments to flow to disadvantaged communities.

[41] In this case, censor means states do not release specific data values to the public that have too few people in the sample because of data privacy concerns.

Map Functions

Most tools also allow for location searches, zooming in and out of the state, printing or screenshot options, and allowing the user to click on a census tract for more information. Some like Colorado and Washington create extra graphics like bar charts and box and whisker plots. The federal tool and Michigan allow for a side-by-side tool to create comparison reports and allow for the user to add their data to the existing map. The federal tool and Colorado also allow the user to access different levels of geography like counties and census block groups in addition to census tracts.

No tool currently uses 2020 census boundaries or includes 2020 data from the American Community Survey. There are ways to access previous versions of online tools, but no tool currently allows the user to look at differences over time. If implemented, cumulative rank over time may be a difficult measure to interpret. If a census tract's rank changes over time, that does not necessarily mean conditions in that census tract improved or worsened. For example, if a tract has a higher ranking, it could simply be that other tracts have gotten worse, which has improved the relative standing of this tract.

Framing Limitations and Use

All tools emphasize on their website and in their supporting documentation that their tool has significant limitations and should be used as a *starting point* for interested parties to understand the environmental challenges that a community faces. It is not recommended that these mapping applications, used alone, be utilized to conduct a risk assessment or to diagnose or label a community. The tools also emphasize that scores do not represent all environmental justice concerns for a community and a low score does not indicate that there are little or no environmental justice concerns present.

Ongoing Development in this Area

Mapping health disparities is a growing area of research with tools getting updated and new tools going online. Washington, California, and the federal tools were all updated in the past 12 months. Colorado's and a draft of Michigan's tool were released for the first time this summer (2022); by the end of the calendar year, Michigan and Maryland plan to have new versions online.

Federal agencies have also launched new tools related to environmental justice. The Council on Environmental Quality released the beta version of its Climate and Economic Justice Screening Tool in February, and the CDC just released its own EJ Index in August of 2022.

CDC EJ Index Methods

The CDC's EJ Index has the most recent methods approach for a cumulative environmental impact score. They include 36 measures and group their indicators into 3 themes: social vulnerability, environmental burden, and health vulnerability. This index differs from the state tools we reviewed in a couple of ways. Key differences and cited reasons for their decisions are summarized in Exhibit 17. The composite score is based on an EJ screening method that was developed prior to California's tool.[42]

The EJ Index also does not factor in reliability issues like the WA EHD Map, cautioning that small differences in tract-level ranking should not necessarily be interpreted as meaningful. They also reformat their health measures to try to avoid the methodological issues that are of concern when using CDC places data like Colorado's EnviroScreen.

Exhibit 17

CDC Environmental Justice Index Differences

Difference	Cited reason
All environmental measures are equally weighted when combined	Lack of evidence of a specific weighting scheme
Vulnerabilities and burdens are summed rather than multiplied	Preference of earlier alternative EJ screening method model, and easier interpretation
Social and health vulnerabilities are kept separate Two different versions of the score can be calculated, with one version excluding health vulnerabilities	Separated out health vulnerabilities that could both 1) be caused by environmental exposures and 2) exacerbated by environmental exposures Separation also allows for studying associations between environmental burden (excluding health vulnerabilities) and health outcomes

[42] Sadd, J.L., Pastor, M., Morello-Frosch, R., Scoggins, J., & Jesdale, B. (2011). Playing it safe: assessing cumulative impact and social vulnerability through an environmental justice screening method in the South Coast Air Basin, California. *International Journal of Environmental Research and Public Health*, *8*(5), 1441-1459.

IV. Discussion & Conclusions

We found that Washington's Environmental Health Disparities Map is one of many EJ mapping tools in the United States. It uses a similar range of indicators, methodology, and source data compared to other environmental justice mapping tools. Due to regionality differences in the intended purpose, data availability, and community stakeholder preferences, we found that Washington's EHD Map differed from other tools in the following ways:

- Fewer sensitive populations indicators;
- Fewer water quality measures;
- Greater use of state-specific data; and
- Slightly different composite score calculations and treatment of missing data.

Pollution Burden Indicators

In general, the Washington EHD Map uses similar measures, methods, and data sources compared to other tools. When available, state-level data and air quality models are used, and methods align closely with California's methods using their state data. The EHD Map includes fewer water measures compared to other states that intersect with or manage large bodies of water, like California or Michigan. For more specific details, see Sections II and III in the Appendix.

Population Characteristic Indicators

The Washington EHD Map uses very similar measures to capture vulnerable populations compared to other tools. Adaptations are made to incorporate state data when available, like health measures, which is preferable.[43] Some differences in measurement thresholds, such as ≤185% federal poverty line, are used to align data with other state agency thresholds. Fewer health measures are included compared to other tools due to data availability. For more specific details, see Sections V. D) of the Appendix.

Composite Score

While there are some small technical differences in how the EHD Map calculates the composite score, this has a minimal impact on the final score calculation and final ranking presented to users (deciles or quintiles for all tools). For a more detailed discussion see Section VI. B) of the Appendix.

Other Features

We found that other tools had some features that may be of interest to WA in future years. These include the following:

- Easier access to user guides and how-to videos on the hosting website;
- More guidance on use and interpretation in the mapping application; and
- Extra functions like side-by-side comparisons or the ability to overlay user data.

[43] U.S. Environmental Protection Agency. (2019). *EJSCREEN technical documentation* and (2022). *Centers for Disease Control and Prevention and Agency for Toxic Substances Disease Registry*.

We also found that the EHD Map had one of the greatest amounts of supplemental or contextual data that may benefit users seeking to understand more about a geographical location. This is because the EHD Map is hosted on the larger Washington Tracking Network. It is very convenient to have so much information in one place.

Strengths & Limitations of EJ Mapping Tools

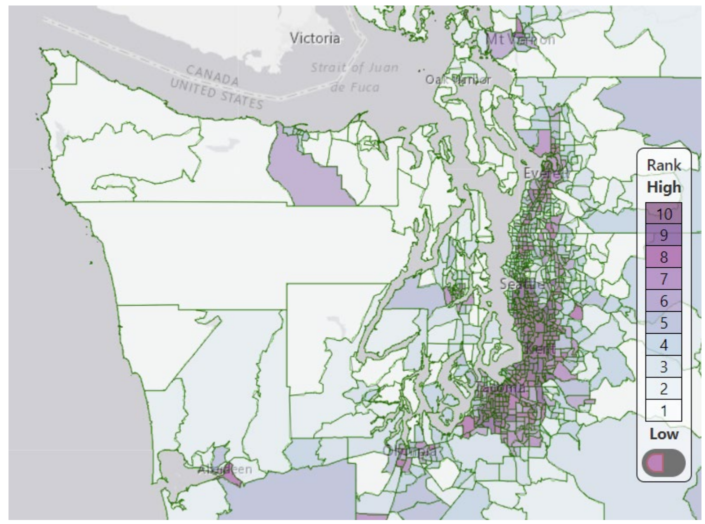
While these tools provide useful information, they have limitations. As the documentation for most of these tools stated, these tools are best used as a *starting point* for identifying and assessing cumulative impact. It provides an overview of differences in environmental justice concerns across communities at the census tract level. Being publicly available it provides a vetted, common pool of information for policymakers, government agencies, healthcare providers, business-owners, and individual citizens. It starts the process of understanding the environmental needs of a community and the potential impact of changes to that community's environment.

However, it does not represent census tracts equally well. By tying all measures exclusively to the census tract level, it potentially misaligns what small rural communities in large census tracts are experiencing. This is because a census tract is built to collect information on *people* in the same geographic area. Exposures, like air quality, can vary substantially in a census tract, especially in large rural tracts, and they do not fit well in broad swipes of geography.

For example, there is a census tract that spans the width of the Olympic peninsula. Everyone in the entire tract is assigned the same indicator values, however, the real environmental conditions of the communities on the west side are likely different than those on the east side (see Exhibit 18).

Exhibit 18

Washington EHD Map Screenshot



Note:
Source: The graphic is from the Department of Health Washington EHD Map Version 2.0. The measure depicted is the overall cumulative rank.

These composite scores representing cumulative impacts are backed thoroughly by the public health literature to have a relationship with health outcomes, and some studies have shown correlations to life expectancy.[44] But they have not been extensively empirically tested, and they have not been built to have a specific predictive power for any specific health outcome. It would be difficult to use the EHD Map, or the other mapping tools, to directly calculate attributable risks and impacts for an upcoming government action without knowing this empirical relationship.

These tools are also limited to information available for nearly all parts of a state. They do not provide all the information possible on all environmental harms *or* assets. Therefore, to fully evaluate the impact of environmental changes or government action, more local research would be needed to overcome and incorporate more granular information that these tools are missing. This is especially true for rural census tracts that represent geographically large spaces and have multiple small communities.

Conclusions

These mapping tools do not use perfect measures of exposures and risks for an individual or a community. However, *no perfect measures exist*. Given the data available these tools use some of the best measures relevant to environmental exposures, health, and disparities. They provide insight into some of the environmental harms present in a community and how well-equipped a community is to overcome those challenges. These limitations should not dissuade planners from using this tool as a starting point for understanding the potential environmental impact of their decision-making.

There will always be room for growth in these tools as data availability increases and methodology evolves. There is also the potential that new environmental exposures will be recognized, or preferences will change on what should be included in a model like the EHD Map. Over time, tool developers will need to regularly review and update their EJ modeling methodology, in addition to updating the data contributing to the model as it becomes available from secondary sources.

[44] University of Washington Department of Environmental & Occupational Health Sciences and Washington Department of Health (2022).

Appendices

Appendices

I. Comparison Tools Considered and Common Terms & Definitions

Exhibit A1 lists all the environmental health disparities or environmental justice mapping tools we found in our initial search but did not include in the comparison. It includes the name, geographic coverage, the owners or maintainers of the mapping tool, and a link to the website. The last column comments on the types of measures included in the mapping tool, and the tool’s sophistication or development process.

Exhibit A1

List of Environmental Justice Mapping Tools Found

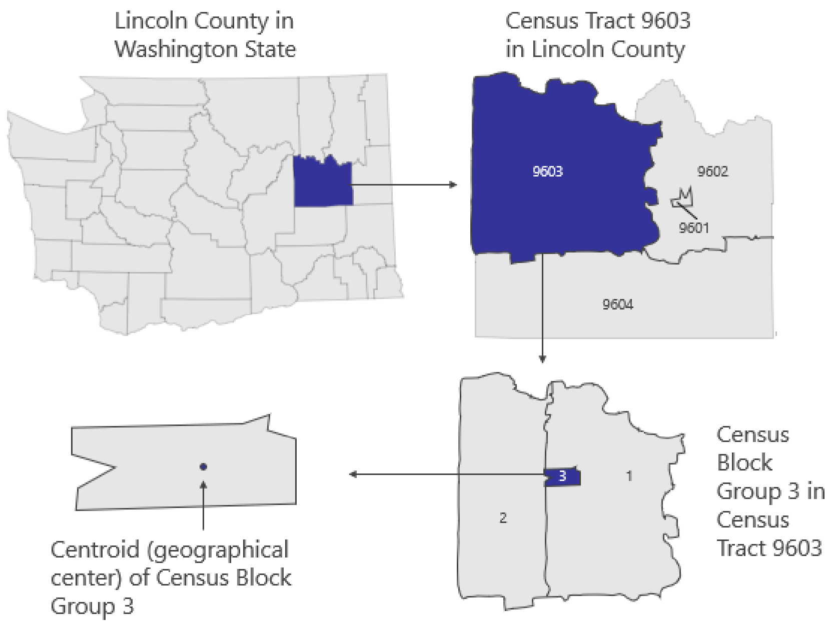
Name	State	Map maintainers	Notes
MDEJScreen	Maryland	Community Engagement, Environmental Justice, & Health Center	Follows CalEnviroScreen methods closely including composite score. The development includes community input. Version 2.0 coming soon.
Virginia MEJ Map	Virginia	MEJ from UC Berkeley	Follows CalEnviroScreen methods closely including composite score, development includes community input.
Colorado MEJ Map	Colorado	MEJ from UC Berkeley	Follows CalEnviroScreen methods closely including composite score.
VTEDI	Vermont	University of Vermont's Decolonial Science, Democracy & Just Futures Lab	Calculates a composite score using a slightly different formula, development does not include community input. Has limited documentation.
VA EJScreen+	Virginia	VA Department of Environmental Quality	Maps EJ communities and EPA's EJScreen Indexes. Does not present new data or combine into a score.
NC ENVIROSCAN	North Carolina	UNC Institute for Environmental Health Solutions	Maps sociodemographic data and EPA's EJScreen Indexes. Does not present new data or combine into a score.
EJ Mapper	New Mexico	New Mexico Environment Department	Maps demographic and environmental measures but does not combine them into a score.
EJMAP	New Jersey	NJ Department of Environmental Protection	Has separate maps on overburdened communities, environmental resources, and air quality but does not combine them into a score.
Understanding Environmental Justice	Minnesota	Minnesota Pollution Control Agency	Maps people of color and low-income populations. Has some separate air and soil & environmental measures. Does not combine measures in any way.
eMapPA	Pennsylvania	PA Department of Environmental Protection	Has multiple mapping tools for demographics and environmental measures. Does not combine them into a score.
DEQ North Carolina Community Mapping System	North Carolina	NC Department for Environmental Quality	The mapping tool has environmental measures, but no demographics or health measures. Does not combine measures in any way.
Environmental Justice Communities	Connecticut	CT Department of Energy and Environmental Protection	The mapping tool has environmental measures, but no demographics or health measures. Does not combine measures in any way.
Environmental Justice Viewer	Massachusetts	MA Executive Office of Energy and Environmental Affairs	Maps minority, low-income, and English isolation populations but no environmental measures. Does not combine measures in any way.
EJ Start	Illinois	IL Environmental Protection Agency	Maps minority and low-income populations but no environmental measures. Does not combine measures in any way.
Potential Environmental Justice Areas	New York	NYS Department of Environmental Conservation	Maps members of minority groups and low-income populations but no environmental measures. Does not combine measures in any way.

Geographical Terms

Exhibit A2 shows common geographic units that are used throughout the rest of the Appendix. Note that census tracts are within state counties, census block groups are within census tracts, and the term centroid refers to a geographic center.

Exhibit A2

Geographical Areas



Common Terms and Definitions for Validity, Reliability, and Clinical Importance

Exhibit A3 summarizes the minimum criteria we had for an indicator to be considered reasonably valid and reliable and describes how we defined clinical importance.

Exhibit A3

Validity, Reliability, & Clinical Importance Minimum Criteria

Term	Criteria and Interpretation
Validity	Indicators were considered to be reasonably valid if they came from a data source that was systematically collected, processed, and used by other researchers or government agencies, using statistical methods that were recommended by that data source, or had been subject to peer review.
Reliability	Indicators were considered reasonably reliable if there were no known or logically obvious patterns of measurement error or bias that would systematically impact the correct ranking of lower to higher environmental threats or vulnerabilities.
Clinical importance	Clinical importance was defined broadly to include importance or connection with health or something of public health importance. We did not require that the measure had to be correlated with a specific biometric or patient-reported outcome.

II. Individual Indicator Assessments: Environmental Exposures

The Washington Environmental Health Disparities (EHD) Map includes indicators for traffic density, diesel emissions, ozone, particulate matter 2.5, and toxic releases from facilities. Other tools also include other measures such as air toxic cancer risks, respiratory hazard index, drinking water contaminates, pesticide use, and noise. For each indicator that the EHD Map includes, there is a table directly comparing indicator features across each of the tools. For indicators that the EHD Map does not include, we summarize the potential value of that measure to an EJ model and the feasibility of the EHD Map to include it in future versions.

These measures also often rely on state-reported data required by the EPA. These data are then used in complex models and statistical analysis which led to estimates of concentrations at the census tract level.

A) Traffic Density

This indicator broadly captures the exposure of communities to heavy traffic and heavy roadways. High traffic density can expose nearby communities to noise, vibration, and less ideal industrial land use, in addition to greater traffic-related air pollution and the potential for more frequent car accidents, injuries to pedestrians, cyclists, and property.[45] Most use a measure of averaged annual daily traffic (AADT).

Clinical Importance

These environmental factors associated with high traffic density have been linked to sleep disturbances, poor cardiovascular and respiratory health, and an increased risk of low birth weight birth. This exposure and versions of these measures have been linked to worse health outcomes such as cardiovascular disease mortality, decreased respiratory health, and increased risk of low birth weight.[46] Populations at greater risk include those with respiratory diseases, young children, the elderly, and those communities living close to these sites, which are more likely to be low-income, communities of color, and speak another language besides English.[47]

[45] Boehmer, T., Foster, S., Henry, J., Woghiren-Akinnifesi, E., & Yip, F. (2013). Residential proximity to major highways - United States, 2010. *Morbidity and Mortality Weekly Report, 62(*3), 46-50.

[46] Kaufman et al. (2016), Berglind, N., Bellander, T., Forastiere, F., von Klot, S., Aalto, P., Elosua, R., . . . Nyberg, F. (2009). Ambient air pollution and daily mortality among survivors of myocardial infarction. *Epidemiology*, 110-118.; Ghosh, J.K.C., Wilhelm, M., Su, J., Goldberg, D., Cockburn, M., Jerrett, M., & Ritz, B. (2012). Assessing the influence of traffic-related air pollution on risk of term low birth weight on the basis of land-use-based regression models and measures of air toxics. *American journal of epidemiology*, *175*(12), 1262-1274.; Habermann, M., & Gouveia, N. (2012). Motor vehicle traffic and cardiovascular mortality in male adults. *Revista de saúde pública, 46,* 26-33.; Kan, H., Heiss, G., Rose, K.M., Whitsel, E., Lurmann, F., & London, S.J. (2007). Traffic exposure and lung function in adults: the Atherosclerosis Risk in Communities study. *Thorax*, *62*(10), 873-879.; Von Klot, S., Gryparis, A., Tonne, C., Yanosky, J., Coull, B. A., Goldberg, R. J., . . . Schwartz, J. (2009). Elemental carbon exposure at residence and survival after acute myocardial infarction. *Epidemiology*, 547-554.

[47] Garcia, E., Berhane, K. T., Islam, T., McConnell, R., Urman, R., Chen, Z., & Gilliland, F.D. (2019). Association of changes in air quality with incident asthma in children in California, 1993-2014. *JAMA, 321*(19), 1906-1915.; Ebisu, K., Malig, B., Hasheminassab, S., & Sioutas, C. (2019). Age-specific seasonal associations between acute exposure to PM2. 5 sources and cardiorespiratory hospital admissions in California. *Atmospheric Environment, 218,* 117029.; Gunier, R.B., Hertz, A., Von Behren, J., & Reynolds, P. (2003). Traffic density in California: socioeconomic and ethnic differences among potentially exposed children. *Journal of Exposure Science & Environmental Epidemiology*, *13*(3), 240-246.; Tian, N., Xue, J., & Barzyk, T.M. (2013). Evaluating socioeconomic and racial differences in traffic-related metrics in the United States using a GIS approach. *Journal of exposure science & environmental epidemiology*, *23*(2), 215-222.

Exhibit A4

Traffic Density Measures

Indicator attribute	**Washington EHD Map**	**California EnviroScreen**	**Federal EJScreen**	**Colorado EnviroScreen**	**Michigan MiEJScreen**
Concept being measured	**Proximity to heavy traffic roadways**: the maximum distance-weighted traffic (AADT) along Washington highways for each census tract	**Traffic impacts:** the sum of traffic volumes adjusted by road segment length (vehicle-kilometers per hour), divided by total road lengths within 150 meters of the census tract	**Traffic proximity**: the count of vehicles or AADT at major roads within 500 meters, divided by distance in meters	**Traffic proximity and volume:** the count of vehicles or AADT at major roads within 500 meters, divided by distance in meters	**Traffic density:** AADT within a buffered (150 meters) census tract, normalized to vehicles per day/adjusted length-based road (miles)
Geographical level of measurement/ presentation	Census Tract	Census Tract	Census Block / Census Tract	Census Block / Census Tract	Census Tract
Year(s) of data used in currently published tool	2019	2018 (TomTom), 2017 (TrafficMetrix)	2019	2017	2019
Data source(s)	Washington Department of Transportation	TomTom Find/Route/Display; Traffic Metrix®; University of California Riverside College of Engineering—Center for Environmental Research and Technology; US Customs and Border Protection, Border Crossing Entry Data	Highway Performance Monitoring System (HPMS)	EJScreen 2021	National functional classification (NFC) data files from the Michigan Department of Transportation
Calculation/model/ methods	For each census tract, a highway's AADT was divided by the distance between the closest point of the road and the census tract's border. Highways intersecting census tracts were divided by a minimum distance of 1 km.	Sum of all length-adjusted traffic volumes within buffered census tract divided by the sum of the length of all road segments (150 m buffer around census tract)	For a census block, each major interstate, principal arterial, and other large road's AADT is calculated and divided by the shortest distance from that road to the centroid of the census block. These values are summed if the distance is within 500 meters. Blocks are combined into block groups and census tracts using a population-weighted average.		Sum of all length-adjusted traffic volumes within buffered census tract divided by the sum of the length of all road segments (150 m buffer around census tract). Federal-aid road segments only.

Comparison

CalEnviroScreen and MiEJScreen use similar methods. They estimate traffic density within the border of a census tract plus a 150m buffer area, adjusting for the length of road in the area. However, MiEJScreen only includes federal-aid roads and may be an underestimate by not counting other major roads. Colorado EnviroScreen uses EJScreen data from an earlier year (2017 rather than 2019). This method uses a population-average of block exposure to traffic density within a 500-meter buffer; densities are divided by the distance to the centroid (geometric center) to down-weight traffic further away. Both methods capture cumulative traffic and cover a similar area, with an appropriate distance sensitivity backed by the literature (0-150 meters), at least for air pollution considerations. We were not able to determine differences in road coverage (highway only vs all roads vs federal-aid roads vs road included in the TomTom dataset) across tools.

The Washington EHD map method is the only one that does not use a cumulative measure of traffic for a geographical unit and instead takes the maximum of all highways' AADT, divided by the shortest distance to the edge of the census tract. The minimum distance of 1 kilometer, is larger than distances used by other methods but may be due to computational limitations. The Washington EHD Map also only includes highways and so may be systematically missing non-highway high traffic density.

Validity and Reliability

These are all reasonably valid measures using reputable data sources. A sophisticated methods analysis comparing these approaches and their ability to predict different health outcomes would be needed to be completed to determine the "best" approach. In addition to the geo-spatial differences, a study would also need to consider data sources and which kinds of roads would be most valuable to include.

This measure will not be consistent over long periods of time. With population growth and new communities growing, there will be an increase in traffic density in certain areas and a reduction in others. This measure is only as accurate as sampling as traffic volume will vary over seasons and holidays.

This indicator will not be consistent over census tracts. The traffic volume in census tracts in highly populated areas and major roadways will be more accurately represented across all tools compared to the less populated but larger census tracts. The EJScreen and Colorado method of using a 500-meter radius around the census block centroid will be less accurate at capturing the true traffic volume for a community in a geographically large census block if the most high-volume roads are not located within 500 meters from the centroid.

B) Diesel Emissions

This indicator broadly captures the exposure of particulate matter (PM) from diesel emissions. This is the particle phase of exhaust emitted by diesel engines that contain ultrafine particles that are a mix of harmful chemicals.

Clinical Importance

Exhaust from diesel engines is classified as carcinogenic in humans due to the association between exposure and increased risk of lung cancer.[48] These emissions are in high concentration near high-traffic roads and industrial sites. Exposure to high concentrations, or low/moderate but regular concentrations of diesel particulate matter has been linked with higher respiratory system inflammation, higher mortality (even in healthy adults), exacerbation of existing chronic conditions, and higher rates of respiratory-related hospitalizations.[49] Populations at greater risk include those with respiratory disease and those that work directly in the transportation industry.[50]

[48] IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. (2014). Diesel and gasoline engine exhausts and some nitroarenes. IARC monographs on the evaluation of carcinogenic risks to humans. *IARC monographs on the evaluation of carcinogenic risks to humans*, *105*, 9.

[49] Krishnan, R.M., Sullivan, J.H., Carlsten, C., Wilkerson, H.W., Beyer, R.P., Bammler, T., . . . Kaufman, J.D. (2013). A randomized cross-over study of inhalation of diesel exhaust, hematological indices, and endothelial markers in humans. *Particle and fibre toxicology*, *10*(1), 1-10.; Patel, M., Chillrud, S., Deepti, K., Ross, J., & Kinney, P. (2012). Traffic-related air pollutants and exhaled markers of airway inflammation and oxidative stress in New York City adolescents. *Environmental Research, 121,* 71-8.; Garshick, E., Laden, F., Hart, J.E., Rosner, B., Smith, T.J., Dockery, D. ., & Speizer, F.E. (2004). Lung cancer in railroad workers exposed to diesel exhaust. *Environmental Health Perspectives, 112*(15), 1539-1543.; Garshick, E., Laden, F., Hart, J.E., Rosner, B., Davis, M.E., Eisen, E.A., & Smith, T.J. (2008). Lung cancer and vehicle exhaust in trucking industry workers. *Environmental Health Perspectives, 116*(10), 1327-1332.; Löndahl, J., Swietlicki, E., Rissler, J., Bengtsson, A., Boman, C., Blomberg, A., & Sandström, T. (2012). Experimental determination of the respiratory tract deposition of diesel combustion particles in patients with chronic obstructive pulmonary disease. *Particle and Fibre Toxicology*, *9*(1), 1-8.; Spira-Cohen, A., Chen, L.C., Kendall, M., Lall, R., & Thurston, G.D. (2011). Personal exposures to traffic-related air pollution and acute respiratory health among Bronx schoolchildren with asthma. *Environmental health perspectives*, *119*(4), 559-565.

[50] Krivoshto, I.N., Richards, J.R., Albertson, T.E., & Derlet, R.W. (2008). The toxicity of diesel exhaust: implications for primary care. *The Journal of the American Board of Family Medicine, 21*(1), 55-62.; National Toxicology Program. (2021). Report on Carcinogens, Fifteenth Edition. *Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service*.; US EPA (2002). *Health assessment document for diesel engine exhaust*.; McCreanor, J., Cullinan, P., Nieuwenhuijsen, M. J., Stewart-Evans, J., Malliarou, E., Jarup, L., . . . Zhang, J. (2007). Respiratory effects of exposure to diesel traffic in persons with asthma. *New England Journal of Medicine*, *357*(23), 2348-2358.; Wargo, J., Brown, D., Cullen, M. R., Addiss, S., & Alderman, N. (2002). Children's exposure to diesel exhaust on school buses. *Environment & Human Health, Incorporated*.

Exhibit A5

Diesel Particulate Matter Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Diesel exhaust PM2.5 emissions:** Annual tons	**Diesel particulate matter:** The spatial distribution of gridded diesel PM emissions from on-road and non-road sources (ton/year)	**Diesel particulate matter**: the level in air (µg/m^3).	**Diesel particulate matter**: the level in air (µg/m^3)	**NATA diesel particulate matter**: the level in air (µg/m^3)
Geographical level of measurement/ presentation	4 x 4 km Grid Cells/ Census Tract	Census Tract	Census Tract	Census Tract	Census Tract
Year(s) of data used in currently published tool	2014	2016	2017	2017	2014
Data source(s)	Washington State Department of Ecology's 2014 Comprehensive Emissions Inventory and AIRPACT-5	On Road Emissions: California Air Resources Board (CARB) On Road Emission Model Non-Road Emissions: CEPAMv1.05 and 2012 CEIDARS	EPA's National Air Toxics Assessment (NATA and National Emissions Inventory (NEI)		
Calculation/model/ methods	AIRPACT uses data from the Emissions inventory and other sources (non-point and mobile) to model total emissions for 4x4 km grid cells across Washington. Census tracks are assigned the maximum emissions estimate of any grid cells that intersect it.	Estimates were based on a 1x1 km grid for both road and non-road sources. T*he gridded diesel PM estimates were allocated to census tracts using weighted apportionment.* The weighting is based on the proportion of the grids that intersect with populated census blocks. The weighted values were then summed across the census tracts.	The NATA model uses data from the National Emissions Inventory and other sources and feeds them into two models, CMAQ and AERMOD, and then combines them into a hybrid model to produce census block estimates. These estimates are area-weighted to create census tract estimates.		

Comparison

CalEnviroScreen and Washington's EHD Map rely on data from their state or region air quality models, while the others use the EPA's NATA air quality models. All tools use a single year of data, but the year used varies (2014, 2016, or 2017).

Validity and Reliability

All these measures are reasonably valid. They rely on models that have been well-vetted and are housed and maintained by government agencies and other agencies use and rely on data produced from these sources. They are the best available data sources for this kind of information. These methods rely on a mix of direct measurements from emissions site data, assigned standard emissions from small non-point sources (housing, dry cleaners, and other emissions-producing industries), and mobile sources (highways, ports, airports, and traveled waterways). The NATA model that EJScreen and states use is a national model so it may not capture all state nuances, but it will capture larger national weather patterns that may influence an individual state's estimates.

Air quality exposures can be sensitive to local geographies and forcing this measurement into a census tract level can be less precise for census tracts that are too big or too small. For example, large census tracts will have a measurement that is an average of all the small communities in that census tract, even if those communities are many miles apart. Conversely, if census tracts are smaller than the unit of air measurement (as can be the case for Washington) then small census tracts may be assigned an average for a larger area though their local concentrations are much higher or lower.

The data that are used for the estimates are generally 5+ years old and may not represent current air concentrations. However, this is less of a concern if changes over time are consistent across census tracts because the percentile rank would not be impacted. This indicator will vary with seasonality and temperature changes. All measures capture average values of diesel particulate matter but may not represent an individual's average daily exposure.

All sources use complex, validated models to make up for the lack of randomly sampled direct data and indirect data sources. Even under ideal data collection, an indicator like this may not be an accurate measure of exposure for small communities in large geographical census tracts.

C) Ozone

This indicator broadly captures the exposure of ozone for a census tract area. Ozone is an extremely reactive form of oxygen. When it is present at the ground level, it reacts with other pollutants to create smog; it is harmful to humans.

Clinical Importance

Exposure to high concentrations of ozone, or low/moderate but regular concentrations of ozone has been linked to worse health outcomes, specifically higher respiratory system inflammation, higher mortality, exacerbation of existing chronic conditions, and higher rates of respiratory-related hospitalizations.[51] Populations at greater risk include those with respiratory or cardiovascular disease, young children, the elderly, and those who are Black/African American.[52]

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[51] Alexis, N.E., Lay, J.C., Hazucha, M., Harris, B., Hernandez, M.L., Bromberg, P.A., . . . Peden, D.B. (2010). Low-level ozone exposure induces airways inflammation and modifies cell surface phenotypes in healthy humans. *Inhalation toxicology*, *22*(7), 593-600.; Fann, N., Lamson, A.D., Anenberg, S.C., Wesson, K., Risley, D., & Hubbell, B.J. (2012). Estimating the national public health burden associated with exposure to ambient PM2. 5 and ozone. *Risk Analysis: An International Journal, 32(*1), 81-95.; Crouse, D.L., Peters, P. A., Hystad, P., Brook, J.R., van Donkelaar, A., Martin, R.V., . . . Burnett, R.T. (2015). Ambient PM2. 5, O3, and NO2 exposures and associations with mortality over 16 years of follow-up in the Canadian Census Health and Environment Cohort (CanCHEC). *Environmental Health Perspectives*, *123*(11), 1180-1186.; Thurston, G.D., Lippmann, M., Scott, M.B., & Fine, J.M. (1997). Summertime haze air pollution and children with asthma. *American Journal of Respiratory and Critical Care Medicine, 155(*2), 654-660; and Malig, B.J., Pearson, D.L., Chang, Y.B., Broadwin, R., Basu, R., Green, R.S., & Ostro, B. (2016). A time-stratified case-crossover study of ambient ozone exposure and emergency department visits for specific respiratory diagnoses in California (2005–2008). *Environmental Health Perspectives, 124*(6), 745-753.

[52] Thurston, G.D., Lippmann, M., Scott, M.B., & Fine, J.M. (1997). Summertime haze air pollution and children with asthma. *American Journal of Respiratory and Critical Care Medicine*, *155*(2), 654-660; and Medina-Ramon, M., & Schwartz, J. (2008). Who is more vulnerable to die from ozone air pollution?. *Epidemiology*, 672-679.

Exhibit A6

Ozone Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Ozone:** the 3-year average of annual 4th highest 8-hour daily maximum concentrations of ozone (ppb)	**Air quality ozone:** the 3-year average of all 8-hour daily maximum concentrations during summer months (ppb)	**Ozone:** the annual average of all 8-hour daily maximum concentrations during summer months (ppb)	**Ozone:** the maximum 8-hour average model predictions over the U.S. for ozone in any month of the year (ppb)	**Ozone:** the annual average of all 8-hour daily maximum concentrations during summer months (ppb)
Geographical level of measurement/ presentation	4 x 4 km Grid Cells/ Census Tract	Census Tract	Census Tract	Census Tract	Census Tract
Year(s) of data used in currently published tool	July 2014–June 2017	2017-2019 (May-October)	2018 (May-September)	2017	2017 (May-September)
Data source(s)	AIRPACT NW-AIRQUEST Regional Background Design Values and 2010 ACS population estimates	California Resources Board (CARB)	EPA's Bayesian Space-time Downscaling Fusion Model	EPA's Bayesian Space-time Downscaling Fusion Model	EPA's Bayesian Space-time Downscaling Fusion Model
Calculation/model/ methods	AIRPACT models interpolated 3-year average measures from air quality monitoring sites into 4 km x 4 km grid cells using Empirical Bayesian Kriging Regression Prediction. Census tracks are assigned the value of the most populated grid cell in that tract, based on 2010 census block group population estimates for a grid cell.	An ordinary Kriging model used 8-hour daily maximum concentrations from monitoring sites to estimate concentrations for the centroid of each census tract. Then these daily estimates were averaged over 3 years for each centroid of each census tract.	A combination of SLAMS* data and output from the CMAQ** model were input into the EPA's Downscaler model to predict 8-hour daily maximum concentrations for the centroid of each 2010 census tract. Then these daily estimates were averaged from May to September.	A combination of SLAMS* data and output from the CMAQ** model were input into the EPA's Downscaler model to predict 8-hour daily maximum concentrations for the centroid of each 2010 census tract. The maximum value of the year was used.	A combination of SLAMS* data and output from the CMAQ** model were input into the EPA's Downscaler model to predict 8-hour daily maximum concentrations for the centroid of each 2010 census tract. Then these daily estimates were averaged from May to September.

Notes:

* Monitoring data from the State and Local Air Monitoring Stations.

** Environmental Protection Agency. *The Community Multiscale Air Quality Modeling System.*

Comparison

CalEnviroScreen and Washington's EHD Map rely on data from their state or region air quality models and use three years of data while the others use the EPA's national Downscaler model and only one year of data. The Washington EHD Map uses an annual average of the 4th highest daily maximums which is the EPA rule standard. The rest of the tools use an average of all the daily maximums over critical months of exposure.

Validity and Reliability

All these measures are reasonably valid. They rely on models that have been well-vetted and are housed and maintained by government agencies and other agencies use and rely on data produced from these sources. They are the best available data sources for this kind of information. The EHD Map and CalEnviroScreen are the only tools that use data at the grid cell level that must be converted into census tracts, rather than data modeled for a census tract's centroid. This approach can be beneficial for large census tracts where the centroid may not be representative of the population exposure. However, the centroid approach may be better for smaller areas because of the point precision, given that these air models are capable of that level of precision. CalEnviroScreen uses smaller grids and takes an average, while the EHD Map is limited to AIRPACT's larger grids and takes a maximum. The method using the Downscaler model is not a direct measurement of ozone concentration in each individual census tract. It is a national model, so it may not capture all small state nuances, but it will capture larger national weather patterns that may influence an individual state's estimates.

These methods rely on temporal-spatial data sources that are rich in the temporal sense (in that these sites produce many measurements each day), but less rich in the spatial sense (few locations that are measured). Ideally, the best case would be to get multiple samples within a census tract and have a population-weighted average of those samples. However, that many monitoring stations likely is not practical or feasible at the state or national level. All sources use complex, validated models to make up for the sparseness of spatial data. Even under ideal spatial sampling, an indicator like this may not be an accurate measure of exposure for small communities in large geographical census tracts.

Air quality exposures can be sensitive to local geographies and forcing this measurement into a census tract level can be less precise for census tracts that are relatively big or relatively small. For example, large census tracts will have a measurement that is an average for all the small communities in that census tract, even if those communities are many miles apart. Conversely, if census tracts are smaller than the unit of ozone measurement (as can be the case for WA) then small census tracts may be assigned an average for a larger area though their local concentrations are much higher or lower.

The data that are used for the estimates are generally 5+ years old and may not represent current ozone concentrations. However, this is less of a concern if changes over time are consistent across census tracts because the percentile rank would not be impacted, but the percentile rankings of the census tracts are still a reliable measure of the differences in concentration of ozone between census tracts. This indicator will vary with seasonality and temperature changes. All measures capture extreme critical values of ozone, but may not represent an individual's average, daily exposure to ozone.

D) Particulate Matter 2.5 (PM2.5)

This indicator broadly captures the exposure of particulate matter smaller than 2.5 micrometers (PM2.5). PM2.5 is not a specific substance or chemical but is a mix of noxious substances and a product of combustion activities (wildfire, industrial processes, woodburning). Its impact is directly related to the small size of the particles and their ability to penetrate and damage tissues deep in the lungs.

Clinical Importance

Studies show a well-documented relationship between exposure to PM2.5 and negative health outcomes; there are negative health effects observed at both long-term and short-term exposure to PM2.5. Exposure to PM2.5 has been linked with higher rates of respiratory disease, cardiovascular disease, adverse birth outcomes, higher respiratory system inflammation, higher mortality, general exacerbation of existing chronic conditions, and an association with lung cancer.[53] Populations at greater risk include those with respiratory or cardiovascular disease, young children, and the elderly.[54]

[53] Adar, S. D., Sheppard, L., Vedal, S., Polak, J.F., Sampson, P.D., Diez Roux, A.V., . . . Kaufman, J.D. (2013). Fine particulate air pollution and the progression of carotid intima-medial thickness: a prospective cohort study from the multi-ethnic study of atherosclerosis and air pollution. *PLoS medicine*, *10*(4); Bell, M.L., Ebisu, K., & Belanger, K. (2007). Ambient air pollution and low birth weight in Connecticut and Massachusetts. *Environmental health perspectives*, *115*(7), 1118-1124.; Kaufman, J.D., Adar, S.D., Barr, R.G., Budoff, M., Burke, G.L., Curl, C.L., . . . Watson, K.E. (2016). Association between air pollution and coronary artery calcification within six metropolitan areas in the USA (the Multi-Ethnic Study of Atherosclerosis and Air Pollution): a longitudinal cohort study. *The Lancet*, *388*(10045), 696-704; Fann et al. (2012); Morello-Frosch, R., Jesdale, B.M., Sadd, J.L., & Pastor, M. (2010). Ambient air pollution exposure and full-term birth weight in California. *Environmental Health*, *9*(1), 1-13; International Agency for Research on Cancer. (2015). IARC monographs on the evaluation of carcinogenic risks to humans: vol. 109, *Outdoor Air Pollution*. Lyon, France: IARC.; Dominici, F., Peng, R.D., Bell, M.L., Pham, L., McDermott, A., Zeger, S. L., & Samet, J.M. (2006). Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. *JAMA*, *295*(10), 1127-1134.; Ostro, B., Roth, L., Malig, B., & Marty, M. (2009). The effects of fine particle components on respiratory hospital admissions in children. *Environmental Health Perspectives, 117*(3), 475-480.

[54] U.S. EPA. (2019, December) Integrated Science Assessment (ISA) for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-19/188, 2019.

Exhibit A7

Particulate Matter 2.5 Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Particulate matter 2.5:** the 3-year average concentration combined with 24-hour 98th percentile concentration over three years PM2.5 in micrograms per cubic meter	**Air quality PM2.5:** the 3-year average concentration of annual particulate matter that is less than or equal to 2.5 micrometers in micrograms per cubic meter	**Particulate matter 2.5:** the annual average of 24-hour average particulate matter that is less than or equal to 2.5 micrometers in micrograms per cubic meter	**Fine particle pollution:** the annual average of 24-hour average particulate matter that is less than or equal to 2.5 micrometers in micrograms per cubic meter	**Particulate matter 2.5:** the annual average of 24-hour average particulate matter that is less than or equal to 2.5 micrometers in micrograms per cubic meter
Geographical level of measurement/ presentation	4 x 4 km Grid Cells/ Census Tract	1 x 1 km Grid Cells/ Census Tract	Census Tract	Census Tract	Census Tract
Year(s) of data used in currently published tool	July 2014-June 2017	2015-2017	2018	2017	2016
Data source(s)	Field PM2.5 2014 – 2017 estimates from the Washington State Department of Ecology, AIRPACT	Air Monitoring Network, Satellite Remote Sensing Data; California Air Resources Board (CARB)	EPA's Bayesian Space-time Downscaling Fusion Model		
Calculation/model/ methods	AIRPACT models interpolated 3-year average and 98th percentile measures from air quality monitoring sites into 4 km x 4 km grid cells using Empirical Bayesian Kriging Regression Prediction. Census tracks are assigned the value of the grid cell with the maximum concentration that intersects that tract. Means and 98th percentile values are combined by normalizing each estimate (0-1) and summing them.	Annual means from both satellite and monitoring stations were combined to compute a weighted average of every 1 km x 1 km grid cell over the three years of observation. Grid cell estimates were converted to census tract estimates by taking the average.	A combination of SLAMS* data and output from the CMAQ** model were input into the EPA's Downscaler model to predict 24-hour averages of PM2.5 for the centroid of each 2010 census tract. Then these daily estimates were averaged across the entire year.		

Notes:

* Monitoring data from the State and Local Air Monitoring Stations

** Environmental Protection Agency. *The Community Multiscale Air Quality Modeling System.*

Comparison

CalEnviroScreen and Washington's EHD Map rely on data from their state or region air quality models and use three years of data, while the others use the EPA's national Downscaler model and only one year of data. The Washington EHD Map measure includes both measures the EPA uses in their safety standards (mean and 98^{th} percentile), rather than just the average. CalEnviroScreen includes satellite data that helps to fill in the sparse air monitoring site data.

Validity and Reliability

All these measures are reasonably valid. They rely on models that have been well-vetted and are housed and maintained by government agencies and other agencies use and rely on data produced from these sources. They are the best available data sources for this kind of information. The EHD Map and CalEnviroScreen are the only tools that use data at the grid cell level that must be converted into census tracts, rather than data modeled for a census tract's centroid. This approach can be beneficial for large census tracts where the centroid may not be representative of the population exposure. However, the centroid approach may be better for smaller areas because of the point precision, given that these air models are capable of that level of precision. CalEnviroScreen uses smaller grids and takes an average, while WA is limited to AIRPACT's larger grids and takes a maximum. The method using the Downscaler model is not a direct measurement of PM2.5 concentration in each individual census tract. It is a national model so it may not capture all state nuances, but it will capture larger national weather patterns that may influence an individual state's estimates.

In general, these methods rely on temporal-spatial data sources that are rich in the temporal sense in that these sites are continuously monitoring and producing many measurements each day but less so in the spatial sense due to few locations (sparse sampling). Ideally, the best case would be to get multiple samples within a census tract and have a population-weighted average of those samples. However, that many monitoring stations likely is not practical or feasible at the state or national level. All sources use complex, validated models to make up for the sparseness of spatial data, and California supplements its monitoring data with satellite data. Even under ideal spatial sampling, an indicator like this may not be an accurate measure of exposure for small communities in large geographical census tracts.

Air quality exposures can be sensitive to local geographies and forcing this measurement into a census tract level can be less precise for census tracts that are too big or too small. For example, large census tracts will have a measurement that is an average for all the small communities in that census tract, even if those communities are many miles apart. Conversely, if census tracts are smaller than the unit of ozone measurement (as can be the case for Washington) then small census tracts may be assigned an average for a larger area though their local concentrations are much higher or lower.

The data that are used for the estimates are generally 4+ years old and may not represent current PM2.5 concentrations. However, this is less of a concern if changes over time are consistent across census tracts because the percentile rank would not be impacted. This indicator will vary with seasonality and temperature changes. It may not represent an individual's average, daily exposure to PM2.5.

E) Toxic Releases from Facilities

This indicator broadly captures the exposure of toxic releases from facilities into the air. These data are reported from industrial sites that are continuously monitored for a large set of specific toxic chemical emissions. These reports to the US EPA are mandatory. EJScreen, Colorado EnviroScreen, and MiEJScreen use different kinds of measures to capture toxic air emissions, see Section II. F of the Appendix for more information.

Clinical Importance

Exposure to these emissions is linked to a range of negative health outcomes impacting most major systems of the human body. The three major concerns are cancer, respiratory conditions, and child mortality.[55] Populations at greater risk include those communities living close to these sites which are more likely to be low-income and communities of color.[56] Studies show a well-documented relationship between exposure to these emissions and negative health outcomes. This relationship between emissions and poor health outcomes is the reason why the EPA requires reporting of these emissions.

Exhibit A8

Toxic Releases from Facilities Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Toxic releases from facilities:** the toxicity weighted concentrations of chemical release to air from facility emissions and off-site incineration	**Toxic releases from facilities:** the toxicity weighted concentrations of modeled chemical releases to air from facility emissions and off-site incineration	NA	NA	NA
Geographical level of measurement/ presentation	Census Tract	Census Tract	NA	NA	NA
Year(s) of data used in currently published tool	2018-2020	2017-2019 (TRI); 2014-2016 (RETC)	NA	NA	NA
Data source(s)	Risk Screening Environmental Indicators (RSEI), US EPA	Toxics Release Inventory (TRI), US EPA; Mexico Registry of Emissions and Transfer Contaminants (RETC); Risk Screening Environmental Indicators (RSEI), US EPA	NA	NA	NA
Calculation/model/ methods	A three-year average of TRI emissions data is input into the RSEI model to generate toxicity-weighted concentrations of chemical releases in the air.	TRI and RETC data are input into the RSEI model to generate toxicity-weighted concentration estimates at the census block level. Census blocks were combined into census tracts using an area-weighted average.	NA	NA	NA

Note:
* Regarding the RSEI model: studies have shown that the RSEI estimates of toxicity-weighted concentration in the air and the actual concentrations in the air are usually the same (McCarthy et al., 2009).

[55] Agarwal, N., Banternghansa, C., & Bui, L.T. (2010). Toxic exposure in America: Estimating fetal and infant health outcomes from 14 years of TRI reporting. *Journal of Health Economics*, *29*(4), 557-574.; Choi, H.S., Shim, Y.K., Kaye, W.E., & Ryan, P.B. (2006). Potential residential exposure to toxics release inventory chemicals during pregnancy and childhood brain cancer. *Environmental Health Perspectives*, *114*(7), 1113-1118; Hendryx, M., Luo, J., & Chen, B.C. (2014). Total and cardiovascular mortality rates in relation to discharges from toxics release inventory sites in the United States. *Environmental Research*, *133*, 36-41.

[56] Szasz, A., & Meuser, M. (1997). Environmental inequalities: Literature review and proposals for new directions in research and theory. *Current Sociology*, *45*(3), 99-120.

Comparison

Washington's EHD Map and CalEnviroScreen use similar sources and methods. CalEnviroScreen also includes data from Mexico to account for toxic releases that may impact areas near the border. EJScreen includes facility-level RSEI data as an overlay.

Validity and Reliability

These indicators and methods are reasonably valid. Values are from a commonly used, highly cited model created by the US EPA.[57] CalEnviroScreen goes a step further and includes data from Mexico for relevant regions of the state. However, these measures only look at air pollutants released by these facilities. While these pollutants can find their way into water sources and soil, these indicators do not capture any of those types of contamination. It is important to note that these indicators represent the amount of toxins released into the air from facilities, not the actual exposure that people in these census tracts experience.

Options for microdata exported from the RSEI model allow for the data to be consistent over time in terms of substances reported and methodology. Concentrations from the RSEI are calculated and reported at the census tract level and are available at the census block group level.

F) Other Measures

Air Toxics and Health Risks

EJScreen, MiEJScreen, and Colorado EnviroScreen also have measures of toxic air emissions, but they use different models that capture different toxins and different risks associated with those toxins (Exhibit A9).

Exhibit A9

Toxic Air Emissions Measures

Tool(s)	Measure(s)	Data source/model
WA EHD Map, CalEnviroScreen	Toxic Releases from Facilities	Risk-Screening Environmental Indicators (RSEI)
EJScreen, MiEJScreen	NATA Air Toxics Cancer Risk, NATA Air Toxics Respiratory Hazard Index	National Air Toxics Assessment (NATA)
Colorado EnviroScreen	Air Toxics Emissions, Other air pollutants (PM10)	Colorado Air Pollutant Emissions Notice (APEN) dataset

[57] Regarding the RSEI model: studies have shown that the RSEI estimates of toxicity weighted concentration into the air and the actual concentrations in the air are usually the same. McCarthy, M.C., O'Brien, T.E., Charrier, J.G., & Hafner, H.R. (2009). Characterization of the chronic risk and hazard of hazardous air pollutants in the United States using ambient monitoring data. *Environmental Health Perspectives, 117*(5), 790-796.

EJScreen and MiEJScreen use measures from NATA, which is a model that incorporates most of the same kind of emissions but incorporates estimated non-point and mobile sources of emissions, like their diesel emissions indicator. The NATA model has a more general set of inputs, but it is meant to be more specific in terms of health risks. They directly associate the specific chemical components of emissions with certain health risks, like cancer, respiratory hazards, and others.

The US EPA website has a summary of the differences between the two models.[58] Essentially, RSEI outputs a single general air toxic concentration measure that incorporates the level of health risk. It includes more chemical compounds, but only uses data from industrial facilities already required to report emissions data. It has consistent, yearly data releases, and the data is comparable over most years. NATA outputs measures for specific kinds of health risks associated with toxic air emissions, and it incorporates a more comprehensive set of sources of emissions (though fewer individual chemicals). The data are released less frequently and because of differences in methodology cannot be compared over time. Both tools capture health risks associated with toxic air emissions, but in different ways.

Colorado EnviroScreen developed its own emissions reporting system and selected toxins that were deemed most relevant for its state. Their method for computing this measure is very similar to the approaches for "proximity to site" measures in the environmental effects section. While it does not include modeling techniques for air behavior, the proximity to industrial sites could be interpreted as proximity exposure in general (air, water, land) rather than just air.

Drinking Water Contaminants

This indicator represents the proportion of time that a community had drinking water regulatory violations over a 10-year span. Drinking water contaminants can cause major health issues in communities that rely on that water source. CalEnviroScreen and Colorado EnviroScreen both use this measure. Colorado EnviroScreen has less coverage of water systems in that they only capture public water systems and aggregate those violations at the county level, though they do adjust for the duration of the violation and the population size affected. CalEnviroScreen uses more than five state-specific data sources and a complex calculation to incorporate public and private water sources (e.g., wells) at the census tract level.

If there is significant variability across census tracts this could be a valuable measure to include. Washington would have to develop its data source to include this measure but could use similar methods to the EnviroScreen tools. Based on earlier reports, this has been an indicator of interest for the Washington EHD Map since the tool's launch.

[58] Environmental Protection Agency. (2022). *Risk-Screening Environmental Indicators (RSEI) Model.*

Pesticide Use

CalEnviroScreen is the only state that includes this measure. This indicator represents the total pounds of pesticides used in production agriculture per square mile over three years (2017-2019). Its inclusion is due to California's large agricultural industry and therefore use of pesticides to increase production. Pesticides can drift into nearby communities and exposure can cause a range of illnesses, especially in children and agriculture workers.

Washington does have a significant agriculture industry but not at the level of California. If there is significant variability across census tracts this could be a valuable measure to include. Washington would have to develop its data source to include this measure but could use similar methods to the CalEnviroScreen tool. More work would also need to be done to determine if this would be a valuable and reliable measure across census tracts in Washington State.

Noise

Colorado EnviroScreen is the only state that includes this measure. This indicator represents the average daytime summer noise in decibels between 2013-2015 from the National Parks Service. The rationale for the inclusion of this indicator is that noise pollution has been associated with sleep disturbance, annoyance, stress, high blood pressure, diabetes, and cardiovascular health.

If there is significant variability across census tracts this may be a valuable measure to include. Washington could use the same data source and similar methods to the Colorado EnviroScreen tool. More work would also need to be done to determine if this would be a valuable and reliable measure across census tracts in WA state.

III. Individual Indicator Assessments: Environmental Effects

The Washington EHD Map includes indicators for lead exposure risk, wastewater discharge, and proximity to hazardous waste generators and facilities, Superfund sites, and sites with highly toxic substances. Other tools also include other measures such as impaired water bodies, solid waste sites and facilities, groundwater threats, and proximity to mines and oil and gas processing. For each indicator that the EHD Map includes there is a table directly comparing indicator features across each of the tools. For indicators that the EHD Map does not include, we summarize the potential value of that measure to an EJ model and the feasibility of the EHD Map to include it in future versions.

These measures often rely on state-reported data required by the US EPA. These data come from sites under monitoring and receiving funding for clean-ups. Data for proximity measures rely on point data that must be transformed into a census tract-level measure.

A) Lead Risk from Housing

This indicator captures the risk of lead exposure from housing. Buildings before 1970 were constructed using materials, like pipes and paint, that contained lead, and a fair number of those buildings are still around today. Exposure to lead can occur from contact with lead-based paint chips and dust, drinking from lead pipes, and other pathways.[59]

Clinical Importance

Exposure to lead is recognized by the EPA and CDC as a serious health risk. This is especially true in children, where the exposure is most commonly through older housing. Lead exposure can cause learning disabilities, behavior problems, stunt physical growth, and delay mental development.[60] There are no known safe levels of lead exposure, and levels that were previously considered safe are now known to cause subtle chronic health effects.[61] Although anyone who is exposed to lead can experience negative health outcomes, children are at a higher risk of developing long-term negative health outcomes due to exposure. Populations at greater risk include children, and those communities living in older housing, which are more likely to be low-income.[62]

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[59] Centers for Disease Control and Prevention. (2022). *Sources of Lead Exposure*. Centers for Disease Control and Prevention.

[60] American Academy of Pediatrics Committee on Environmental Health. (2005). Lead exposure in children: prevention, detection, and management. *Pediatrics*, *116*(4), 1036-1046.

[61] Centers for Disease Control and Prevention. (2019). *Childhood lead poisoning prevention: Blood lead levels in children*.

[62] CDC (2019a). Kim, D.Y., Staley, F., Curtis, G., & Buchanan, S. (2002). Relation between housing age, housing value, and childhood blood lead levels in children in Jefferson County, Ky. *American Journal of Public Health, 92*(5), 769-772.; Sargent, J.D., Brown, M.J., Freeman, J.L., Bailey, A., Goodman, D., & Freeman Jr, D.H. (1995). Childhood lead poisoning in Massachusetts communities: its association with sociodemographic and housing characteristics. *American Journal of Public Health*, *85*(4), 528-534.; and Schultz, B.D., Morara, M., Buxton, B.E., & Weintraub, M. (2017). Predicting blood-lead levels among US children at the census tract level. *Environmental Justice*, *10*(5), 129-136.

Exhibit A10

Lead Risk Exposure Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Lead risk from housing**: the percentage of households with a high likelihood of lead-based paint (LBP) hazards, including single homes and multiple residences	**Children's lead risk from housing:** an index combining the percentage of households with a high likelihood of lead-based paint (LBP) hazards and the percentage of households that are both low-income and have children under six years old	**Lead paint:** the number of occupied housing units built before 1960 divided by the total number of housing units in a block group	**Lead exposure risk:** the percentage of housing units built before 1960	**Lead paint indicator:** the percentage of houses built before 1960
Geographical level of measurement/ presentation	Census Tract	Census Tract	Census Block Group / Census Tract	Census Block Group / Census Tract	Census Block Group / Census Tract
Year(s) of data used in currently published tool	2015-2019	2017, 2015-2019, and 2013-2017	2015-2019	2015-2019	2015-2019
Data source(s)	American Community Survey	California Residential Parcel Data from Digital Map Products American Community Survey Comprehensive Housing Affordability Strategy (CHAS) data from the United States Department of Housing and Urban Development	American Community Survey	American Community Survey (ACS) via EJScreen 2021	American Community Survey (ACS) via EJScreen 2021
Calculation/model/ methods	Standard ACS calculation* for a count of houses built during a range of years. These counts were multiplied by a risk factor** to estimate the number of houses with a high likelihood of lead-based paint (LBP) hazards. These estimates for each range of years were summed and then divided by the total number of housing units.	Parcel data is used to estimate the count of houses built during a range of years. These counts were multiplied by a risk factor** to estimate the number of houses with a high likelihood of lead-based paint (LBP) hazards and this was divided by the total number of housing units. CHAS data was used to calculate the number of households with incomes less than 80% of the county median with 1 or more children under 6 years old. This data was then combined to form an index.***	Standard ACS calculation*	Standard ACS calculation* for census block groups. All block groups were averaged to calculate census tract values.	Standard ACS calculation* For each census tract, the block groups within the tract were summed.

Notes:

* U.S. Census. (2021). *Understanding and using American Community Survey Data: What all data users need to know.*

** Jacobs, D.E., Clickner, R.P., Zhou, J.Y., Viet, S.M., Marker, D.A., Rogers, J.W., Zeldin, D.C., Broene, P., & Friedman, W. (2002). The prevalence of lead-based paint hazards in U.S. housing. *Environmental Health Perspectives, 110*(10).

***If parcel data was deemed unreliable, they ACS survey data was used. The index was formed by converting each measure (proportion of housing with lead-based paint (LBP) hazards and proportion of households with low income and young children) into a percentile, then calculating a weighted average where the LBP measure received 0.6 weight and the low-income measure was weighed by 0.4.

Comparison

MiEJScreen and Colorado EnviroScreen use EJScreen data and similar methods to aggregate from the census block group to the census tract level. They use a simple measure from the ACS-the percentage of housing units built before 1960. The Washington EHD Map goes a step further and estimates the number of houses with lead-based paint (LBP) hazards from the number of houses built during different decades to get the proportion of houses with LBP hazards. CalEnviroScreen goes even further and combines this information with the proportion of households that are low-income with children less than six years old.

Validity and Reliability

These are all reasonably valid measures using reputable data sources. These indicators measure the potential risk of lead exposure from lead paint in residences, but not the true occurrence of lead paint in homes. Although not perfect, using the age of a residence to quantify the risk of lead paint exposure is the most accurate method to measure this indicator outside of testing all residences. These indicators use survey data collected by the American Community Survey. The California tool also includes administrative data.

The EJScreen is the basic measure, while Washington captures more nuance in the LBP hazards with later decades, and CalEnviroScreen goes even further by using its state data and combining the nuanced LBP hazard with a measure for the most vulnerable group (young children in low-income households). There are strengths and limitations to CalEnviroScreen's specificity. It narrows in on a high-risk group but may not appropriately weigh the broader risk of LBP hazards to everyone in the census tract.

This indicator is fairly consistent over time and is likely to be consistent over census tracts (or blocks), though there is a fair amount of variability in how older housing units have been maintained and renovated to address lead hazards. Older neighborhoods that are more affluent or have been gentrified may have fewer lead hazards than similarly aged neighborhoods that have had fewer upgrades over time. For this reason, this indicator is not expected to be consistent over sub-populations. This indicator will not vary with seasonality.

B) Proximity to Hazardous Waste Generators and Facilities

This indicator captures a measure of the proximity of the census area to hazardous waste generators, also known as treatment, storage, and disposal facilities (TSDFs). These are specially recognized sites that the EPA monitors. Hazardous waste can come in solid, liquid, or gas form. It can be composed of manufacturing by-products and discarded materials, or pesticides and cleaning solvents. The contaminants from these sites are not limited to a small number of pollutants due to the broad range of sites that are included under the umbrella of hazardous waste. Pollutants have been found to reach individuals and communities in several ways including inhalation and airborne pollutants being deposited on surfaces, groundwater, and drinking water.[63]

Clinical Importance

The contamination from TSDFs is correlated with a multitude of negative health effects. Studies have linked living close to TSDFs to an increased risk of diabetes and increased risk of cardiovascular disease, increased risk of damage to the respiratory system and other organs, and an increased risk of cancers.[64] There is also an increased probability of ingesting or inhaling hexavalent chromium near these facilities which can cause damage to the respiratory system and other organs. While everyone living close to these sites has some degree of risk for adverse health effects, studies have found that TSDFs are more likely to be positioned near low-income and communities of color—specifically African American and Latino communities.[65]

[63] U.S. Environmental Protection Agency. (2019). *EJSCREEN Technical Documentation*.

[64] Kouznetsova et al. (2007); Sergeev & Carpenter (2005); and Pellerin, C., & Booker, S.M. (2000). Reflections on hexavalent chromium: health hazards of an industrial heavyweight. *Environmental Health Perspectives*, *108*(9), A402-A407.

[65] Aliyu, A.A., Kasim, R., & Martin, D. (2011). Siting of hazardous waste dump facilities and their correlation with status of surrounding residential neighbourhoods in Los Angeles County. *Property Management*.; Boer, J.T., Pastor, M., Sadd, J.L., & Snyder, L.D. (1997). Is there environmental racism? The demographics of hazardous waste in Los Angeles County. *Social Science Quarterly*, *78(*4), 793-810.

Exhibit A11

Proximity to Hazardous Waste Generators and Facilities Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Proximity to hazardous waste generators and facilities**: the count of commercial hazardous waste treatment, storage, and disposal facilities (TSDFs) within 5 km, divided by distance, presented as population-weighted averages in each census tract.	**Hazardous waste generators and facilities**: the sum of weighted permitted hazardous waste facilities, hazardous waste generators, and chrome plating.	**Proximity to TSDFs:** the count of all commercial TSDF facilities within 5 km, divided by distance	**Proximity to hazardous waste facilities**: the count of hazardous waste facilities (treatment, storage, disposal facilities, and large quantity generators) within 5 km each divided by distance in km	**Proximity to hazardous waste facilities**: the proximity to hazardous waste facilities (TSDFs and LQGs).
Geographical level of measurement/ presentation	Census Tract	Census Tract	Census Block / Census Tract	Census Tract	Census Tract
Year(s) of data used in currently published tool	2021	Permitted hazardous waste facilities 2021, Hazardous waste data 2018-2020, Chrome plating facilities 2018	2021	2021	2020
Data source(s)	EJScreen 2021	EnviroStor Hazardous Waste Facilities Database and Hazardous Waste Tracking System – Department of Toxic Substances Control (DTSC) & Chrome Plating Airborne Toxics Control Measure –California Air Resources Board The California Air Resources Board (CARB)	RCRAInfo (Resource Conservation and Recovery Act) database	EJScreen 2021	EJScreen 2020 and Michigan EGLE data from Material Management Division
Calculation/model/ methods	EJScreen Method*	Site Weight-Multi-Ringed Buffer Proximity Method**	EJScreen Method*	EJScreen Method*	Site Weight-Multi-Ringed Buffer Proximity Method**

Notes:
* Sites within 5 km of the centroid of a census block are given a weight of 1 and divided by the distance from the centroid to the point latitude and longitude of the site. These site values are summed for all sites in a census block and called a proximity score. If there are no sites within a 5-kilometer radius, the nearest site is given a 1/distance value and that is the block's proximity score. The proximity scores of individual blocks are combined in a population-weighted sum to the block group or census tract level.
** Sites are weighted based on size and level of "hazard." Higher weights indicate a mix of larger site size and more activity at the site that could lead to more leaching/spread/aerosolization of hazardous substances or the presence of more hazardous substances. For a census tract, sites are given a score that is a function of their site weight and proximity to populated blocks. These scores are then summed for a census tract.

Comparison

All tools include this indicator, but there are differences in data sources and methodology. The Washington EHD Map and Colorado EnviroScreen use data and methods from EJScreen. The EJScreen indicator pulls data on all commercial TSDF sites from the Resource Conservation and Recovery Act database, a national data source, and has a simple method to calculate proximity. CalEnviroScreen developed the "Site Weight-Multi-Ringed Buffer Proximity Method" and pulls its data on hazardous waste generators, hazardous waste facilities, and chrome plating facilities from multiple state-level sources.[66] MiEJScreeen uses both EJScreen data and state-level data and replicates the CalEnviroScreen method with small modifications to account for slightly less data availability.

Validity and Reliability

Both the EJScreen and CalEnviroScreen methodologies use administrative data and calculate a measure that is frequently used. California and Michigan use different methods to measure proximity to hazardous waste facilities incorporating site weights based on their type and status. Both methods are reasonably valid. The California method provides better information on the type of facilities that people may be exposed to, while the EJScreen method provides better insight into the actual proximity the population of a census block/tract is to a facility (regardless of the type of status).

California's method differs from EJScreen in two main ways. First, instead of finding a population-weighted average, the California tool instead only includes facilities that are within 1 kilometer of a populated census block, while EJScreen uses a 5-kilometer distance from every census block and then finds a population average. Secondly, CalEnviroScreen weights sites based on their type and status, while the EJScreen method does not. The California method provides better information on the type of facilities that people may be exposed to, while the EJScreen method provides better insight into the actual proximity the population of a census block/tract is to a facility (regardless of the type of status). With either method is it important to note that it is not an actual estimate of individual or community exposure to a specific substance but rather a proximity indicator that measures the number of facilities with a large range of hazardous substances and operational/clean-up statuses.

This indicator relies on the registration of sites on national and state-level databases and these databases are subject to change between data updates. Reporting is fairly standard and consistent because it is required but lacks greater detail on the size of facilities, types of hazardous waste, and their form (air, solid, liquid). Thus, while the reporting is standard the actual level and mode of exposure will vary. This is a proximity indicator that measures the number of facilities within a census block/tract. It does not predict actual, individual exposure or risk.

C) Proximity to Superfund Sites

This indicator captures a measure of the proximity of the census area to sites that are on the National Priorities List (NPL), also known as Superfund sites. The NPL is a list that identifies sites that need to be cleaned up, without assigning the actual task of cleaning up to a specific entity. The contaminants from these sites are not limited to a small set of chemicals or pollutants, due to the broad range of sites that are included in the NPL. Pollutants have been found to reach people/communities in several ways including inhalation, airborne pollutants being deposited on surfaces, airborne pollutants being deposited on agricultural land and entering the food supply, ground water, and drinking water.[67]

[66] Faust, J., August, L., Bangia, K., Galaviz, V., Leichty, J., Prasad, S., Zeise, L. (2017). *Update to the California Communities Environmental Health Screening Tool CalEnviroScreen 3.0. California* Office of Environmental Health Hazard Assessment.
[67] U.S. Environmental Protection Agency (2019).

Clinical Importance

The effects of the pollution from Superfund sites are correlated to a multitude of negative health effects. Studies have linked living close to Superfund sites with low birth weight, increased blood pesticide levels, increased toxic metals in house dust, increased occurrence of liver disease, elevated blood lead levels in children, and increased cognitive and behavioral problems with children conceived and brought to term close to Superfund sites.[68] While everyone close to these sites is at risk of adverse health effects, studies have found that these sites are more likely to be positioned near communities of color and low-income communities.[69]

[68] Ala et al. (2006).; Baibergenova et al. (2003); Gaffney, S.H., Curriero, F.C., Strickland, P.T., Glass, G.E., Helzlsouer, K.J., & Breysse, P.N. (2005). Influence of geographic location in modeling blood pesticide levels in a community surrounding a US Environmental Protection Agency Superfund site. *Environmental Health Perspectives*, *113*(12), 1712-1716; Zota, A.R., Schaider, L.A., Ettinger, A.S., Wright, R.O., Shine, J.P., & Spengler, J.D. (2011). Metal sources and exposures in the homes of young children living near a mining-impacted Superfund site. *Journal of Exposure Science & Environmental Epidemiology*, *21*(5), 495-505; Klemick, H., Mason, H., & Sullivan, K. (2020). Superfund cleanups and children's lead exposure. *Journal of Environmental Economics and Management, 100,* 102289; and Persico, C., Figlio, D., & Roth, J. (2020). The developmental consequences of Superfund sites. *Journal of Labor Economics*, *38*(4), 1055-1097.

[69] Kearney, G., & Kiros, G.E. (2009). A spatial evaluation of socio demographics surrounding National Priorities List sites in Florida using a distance-based approach. *International Journal of Health Geographics*, *8*(1), 1-10.

Exhibit A12

Proximity to Superfund Site Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Proximity to Superfund sites**: the count of NPL sites within 5 km, divided by distance, presented as population-weighted averages in each census tract	**Cleanup sites**: the sum of weighted sites within each census tract	**Proximity to NPL sites:** the count of all sites proposed and listed on the National Priorities List (NPL) within 5 km, divided by distance	**Proximity to National Proximity List (NPL) sites**: the count of proposed or listed NPL sites within 5 km, each divided by distance in km	**Proximity to cleanup sites**: the proximity to Part 201 cleanup sites, Part 213 leaking underground storage tank sites, and Superfund sites
Geographical level of measurement/ presentation	Census Tract	Census Tract	Census Block / Census Tract	Census Tract	Census Tract
Year(s) of data used in currently published tool	2021	2021	2021	2021	2020
Data source(s)	EJScreen 2021	EnviroStor Hazardous Waste Facilities Database and Hazardous Waste Tracking System – Department of Toxic Substances Control (DTSC) & Region 9 NPL Sites data from the EAP	EPA's Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) database	EJScreen 2021	EJScreen 2020 and Michigan EGLE data from Remediation and Redevelopment Division
Calculation/model/ methods	EJScreen Method*	Site Weight-Multi-Ringed Buffer Proximity Method**	EJScreen Method*	EJScreen Method*	Site Weight-Multi-Ringed Buffer Proximity Method**

Notes:

* Sites within 5 km of the centroid of a census block are given a weight of 1 and divided by the distance from the centroid to the point latitude and longitude of the site. These site values are summed for all sites in a census block and called a proximity score. If there are no sites within a 5-kilometer radius, the nearest site is given a 1/distance value and that is the block's proximity score. The proximity scores of individual blocks are combined in a population-weighted sum to the block group or census tract level.

** Sites are weighted based on size and level of "hazard." Higher weights indicate a mix of larger site size and more activity at the site that could lead to more leaching/spread/aerosolization of hazardous substances or the presence of more hazardous substances. For a census tract, sites are given a score that is a function of their site weight and proximity to populated blocks. These scores are then summed for a census tract.

Comparison

All tools include this indicator, but there are differences in data sources and methodology. The Washington EHD Map and Colorado EnviroScreen use data and methods from EJScreen. The EJScreen indicator pulls data on all proposed and listed sites on National Priorities List (NPL), a national data source, and has a simple method to calculate proximity. CalEnviroScreen developed the "Site Weight-Multi-Ringed Buffer Proximity Method" and pulls its data on cleanup sites from multiple state-level sources[70]. MiEJScreen uses both EJScreen data and state-level data and replicates the CalEnviroScreen method with small modifications to account for slightly less data availability. MiEJScreen is the only one to also include underground storage tanks/leaking underground storage tanks (UST/LUST). EJScreen includes UST/LUST information in a separate environmental indicator and index.

Validity and Reliability

Both the EJScreen and CalEnviroScreen methodologies use administrative data and calculate a measure that is frequently used. California and Michigan use different methods to measure proximity to hazardous waste facilities incorporating site weights based on their type and status. Both methods are reasonably valid. The California method provides better information on the type of facilities that people may be exposed to, while the EJScreen method provides better insight into the actual proximity the population of a census block/tract is to a facility (regardless of the type of status).

Specifically, CalEnviroScreen's method differs from EJScreen in two main ways. First, instead of finding a population-weighted average, the California tool instead only includes sites that are within 1 kilometer of a populated census block, while EJScreen uses a 5-kilometer distance from every census block and then finds a population average. Secondly, CalEnviroScreen weights sites based on their type and status, while the EJScreen method does not. The California method provides better information on the type of facilities that people may be exposed to, while the EJScreen method provides better insight into the actual proximity the population of a census block/tract is to a facility (regardless of the type of status). With either method is it important to note that it is not an actual estimate of individual or community exposure to a specific substance. This is a proximity indicator that measures the number of facilities with a large range of hazardous substances and operational/clean-up statuses.

This indicator relies on the registration of sites on national and state-level databases and these databases are subject to change between data updates. Reporting is fairly standard and consistent because it is required but lacks greater detail on the size of facilities, types of hazardous waste, and their form (air, solid, liquid). Thus, while the reporting is standard the actual level and mode of exposure will vary. This is a proximity indicator that measures the number of facilities within a census block/tract. It does not predict actual, individual exposure or risk.

[70] Faust et al. (2017).

D) Proximity to Facilities with Highly Toxic Substances

This indicator captures a measure of the proximity of census areas to sites that have a Risk Management Plan (RMP), or as Washington defines them, facilities with highly toxic substances.

These sites use highly toxic substances that have the potential to be flammable or explosive and the sites are required to create a Risk Management Plan (RMP) with the EPA. The main concerns that the EPA wants to mitigate with these facilities are the accidental release of substances, fires, and explosions.

Clinical Importance

The health risks associated with RMP sites are broad for the communities living close to these sites because the potential exposures from RMP sites can come from 72 different highly toxic chemicals and 60 substances that are highly flammable. The sudden release of highly toxic chemicals can result in death from inhalation or dermal exposure, in extreme cases. Explosions and fires can cause injuries and potential contamination from toxic smoke. Evacuations from such an incident may also result in damage to homes near the RMP site. All communities near these sites are at risk. Studies have found that communities of color are more likely to be located close to RMP sites.[71]

Exhibit A13

Proximity to Facilities with Highly Toxic Substances Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Proximity to facilities with highly toxic substances**: the count of RMP facilities within 5 km, divided by distance, presented as population-weighted averages in each census tract	NA	**Proximity to RMP sites**: the count of all RMP sites within 5 km, divided by distance	**Proximity to Risk Management Plan (RMP) sites**: the count of RMP sites within 5 km, each divided by distance in km	**Proximity to RMP sites**: the Proximity to facilities with Risk Management Plans
Geographical level of measurement/ presentation	Census Tract	NA	Census Block / Census Tract	Census Tract	Census Tract
Year(s) of data used in currently published tool	2021	NA	2021	2021	2020
Data source(s)	EJScreen 2021	NA	EPA's Risk Management Plan Database	EJScreen 2021	EJScreen 2020
Calculation/model/ methods	EJScreen Method*	NA	EJScreen Method*	EJScreen Method*	EJScreen Method*

Note:
* Sites within 5 km of the centroid of a census block are given a weight of 1 and divided by the distance from the centroid to the point latitude and longitude of the site. These site values are summed for all sites in a census block and called a proximity score. If there are no sites within a 5-kilometer radius, the nearest site is given a 1/distance value and that is the block's proximity score. The proximity scores of individual blocks are combined in a population-weighted sum to the block group or census tract level.

[71] Elliott et al. (2004).

Comparison

All tools, except CalEnviroScreen, include this indicator and use the same data source and methodology following EJScreen. Because of the federal requirement for RMPs for these sites, it is unclear if state-level data would contribute significantly more information. Like other proximity measures, is it important to note that it is not an actual estimate of individual or community exposure to a specific substance, this is a proximity indicator that measures the number of facilities with a large range of hazardous substances.

Validity and Reliability

This indicator is reasonably valid. It relies on the registration of sites on national and state-level databases and these databases are subject to change between data updates. Reporting is fairly standard and consistent because it is required but lacks greater detail on the size of facilities, types of hazardous waste, and their form (air, solid, liquid). Thus, while the reporting is standard the actual level and mode of exposure will vary.

The EJScreen methodology uses administrative data from EPA's Facility Registry Service and calculates a measure that is frequently used by other government agencies and researchers. This is a proximity indicator that measures the number of facilities within a census block/tract.

E) Wastewater Discharge

This indicator captures the concentration of toxic contaminates from wastewater in downstream bodies of water. Wastewater can come from multiple sources: industrial (mining or oil and gas extracting), commercial (agriculture and production and processing of materials), and municipal (publicly owned treatment works and wastewater treatment plants).

Clinical Importance

Contaminated water from wastewater discharge can become an issue when it enters a drinking water or irrigation source, leading to exposure in humans, and local ecosystem disturbances.[72] Exposure to contaminated water can cause water-borne illnesses or adverse health effects, depending on the pathogen or chemical involved.[73]

This specific measure indicator has been correlated to worse health outcomes. However, since this indicator is composed of over 770 different chemicals that are considered toxic to humans, there is a wide range of negative health impacts that polluted water could cause. For this reason, the literature on this indicator is very general on the topic of specific health outcomes that can be impacted by polluted water. Water pollution can affect human health through other avenues outside of direct consumption including fish die-offs that affect both the food supply and cause water-born illnesses that will impact anyone who consumes the contaminated water. However, it is a well-respected proxy and gives the most accurate estimate of the possible levels of health risk.

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[72] Balazs, C.L., & Ray, I. (2014). The drinking water disparities framework: on the origins and persistence of inequities in exposure. *American Journal of Public Health*, *104*(4), 603-611.; Brender, J.D., Maantay, J.A., & Chakraborty, J. (2011). Residential proximity to environmental hazards and adverse health outcomes. *American Journal of Public Health*, *101*(S1), S37-S52.; VanDerslice, J. (2011). Drinking water infrastructure and environmental disparities: evidence and methodological considerations. *American Journal of Public Health*, *101*(S1), S109-S114.

[73] U.S. EPA. (2012a). *U.S. Census Bureau, Understanding and Using American Community Survey Data*.

Exhibit A14

Wastewater Discharge Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Wastewater discharge:** the estimate of the toxicity-weighted concentration of pollutants in downstream bodies of water	NA	**Wastewater discharge:** the Toxicity-weighted stream concentrations at stream segments within 500 meters, divided by distance in meters	**Wastewater discharge:** the estimated toxic chemical concentrations in stream segments within 500 meters of a geographic boundary, divided by meter distance	**Wastewater discharge:** the toxicity-weighted concentrations in stream segments within an area
Geographical level of measurement/ presentation	Census Tract	NA	Census Block / Census Tract	Census Tract	Census Tract
Year(s) of data used in currently published tool	2021	NA	2019	2019	2019
Data source(s)	EJScreen 2021	NA	EPA's Risk-Screening Environmental Indicators (RSEI), National Pollutant Discharge Elimination System (NPDES), Discharge Monitoring Report (DMR), and Toxic Releases Inventory (TRI)	EJScreen 2021	EJScreen 2021
Calculation/model/ methods	Data from DMR, NPDES, and TRI are inputted into the RSEI model to produce the toxicity-weighted concentration in a stream that reach segments within 500 meters of a block centroid, divided by the distance in meters. Census tract estimates are calculated using population-weighted averages of blocks.				

Comparison

All the state tools, except CalEnviroScreen, use this measure and receive their data from EJScreen. The Risk Screening Environmental Indicator Model used to create the estimates of the toxicity-weighted concentrations is a well-cited and respected model, though with some caveats (see validity and reliability below). All state tools note that this is a federal measure and may not be capturing all state-specific exposures.

Validity and Reliability

This indicator is reasonably valid. It measures the concept as specifically as it can considering the limitations of collecting the data needed to model this indicator. The RSEI model used to create the estimates of the toxicity-weighted concentrations is a well-cited and respected model. However, it does include the caveats that this indicator does not have a relationship to whether this is a discharge of pollutants, what body of water they were discharged into, and the actual potential for exposure. This indicator instead includes the pollutant loadings for the Discharge Monitoring Report Loading Tool for toxic chemicals reported to the Toxics Release Inventory.

This indicator provides a snapshot of the release of toxic chemicals into bodies of water. This includes 770 individually listed chemicals that are monitored by the EPA's Toxic Release Inventory (TRI) Program, but TRI does not include all the toxic chemicals that are used in the United States. The TRI also only collects release data annually in July. Thus, this indicator may not be capturing the actual amount of toxins released throughout the year. There may be seasonal variations for toxic releases into bodies of water, but this indicator does not capture it.

F) Other Measures

Impaired Water Bodies

The indicator of impaired bodies of water for a census tract is defined as the summed number of pollutants across all water bodies designated as impaired within a census tract. California and Michigan's proposed EJScreen map includes this indicator, with Michigan utilizing California's methods. They both use their state's respective 303(d) List of Impaired Water Bodies reports. These reports are required by the Federal Clean Water Act for each state and contribute to the process of tracking and measuring the quality of water, with the eventual goal that all water bodies are fishable and swimmable. Colorado EnviroScreen uses a similar measure for impaired streams and rivers where they calculate the proportion of streams or rivers impaired for a geographic area.

Measures of impaired bodies can signify environmental degradation in an area. If wildlife or plants from a contaminated environment are consumed, they can expose people living in that area to harmful substances. Bodies of water (streams, rivers, lakes, and coastal waters) have many uses including sources of drinking water, recreation, and fishing. When bodies are impaired or polluted it negatively impacts their usage as well as the surrounding environments and ecosystems.

Washington State collects similar information located on the Department of Ecology website, as mandated by the EPA. It is unclear if those data are in readily available format and could require significant time to create a similar indicator following CalEnviroScreen methodology. Washington State has an extensive number of water bodies and coastlines. If there is significant variability across census tracts this may be a valuable measure to include. More work would need to be done to determine if this would be a valuable and reliable measure across census tracts in WA state.

Solid Waste Sites and Facilities

This indicator is included in both the CalEnviroScreen and MiEJScreen tools. CalEnviroScreen defines it as the sum of weighted solid waste sites and facilities; MiEJScreen defines it as the proximity to Part 115 licensed landfills, old dumpsites, and scrap tire sites. Although this indicator has different definitions between the two tools, both tools are attempting to quantify the number of sites close to populated areas in their respective states. CalEnviroScreen uses the Solid Waste Information System (SWIS) and Closed, Illegal, and Abandoned (CIA) Disposal Sites Program and the California Department of Resources Recycling and Recovery. MiEJScreen uses EGLE, Material Management Division.

This indicator is included in these two tools because solid waste sites and facilities have been found to release toxins and pollutants that cause negative health outcomes for those who are exposed to them and this can continue for decades after a site has been closed.[74] Exposure to these sites has been associated with increased morbidity and mortality from respiratory disease, and increased rates of birth defects.[75]

This indicator applies to Washington, as it has solid waste sites and facilities throughout the state. If there is significant variability across census tracts this may be a valuable measure to include. Washington would have to find a state-specific data source for all solid waste sites and facilities throughout the state. More work would also need to be done to determine if this would be a valuable and reliable measure across census tracts in Washington State.

Groundwater Threats

This indicator is only included in the CalEnviroScreen tool and was calculated by finding the locations of cleanup sites, land disposal, underground storage tanks, produced water ponds, and dairy and feedlots across the state and calculating their proximity to populated census tracts using state-specific data. Groundwater can be contaminated by a large range of pollutants from the sites included in the list above. Contaminated groundwater can be a health threat to the communities that rely on it for drinking, bathing, cleaning, and local agricultural uses.

This indicator could apply to Washington. If there is significant variability across census tracts this may be a valuable measure to include. Washington would have to find a state-specific data source for types of sites within the state and may want to consider other threats. More work would need to be done to determine if this would be a valuable and reliable measure across census tracts in Washington State.

Mines, Oil, and Gas

These indicators are only included in the Colorado EnviroScreen tool. The mine measure is defined as the distance-weighted count of the total number of active coal, hard rock, and construction materials mining permits within a given geographic area. The oil and gas measure is defined as the distance-weighted count of the total number of active oil and gas locations, active pits, tank batteries, wells, and spills and releases within a given geographic area.

These indicators are included because these industries have a major presence in the state and pose a risk to human health and the environment around them. These indicators also rely on state-specific data resources. As these industries do not have a large presence in Washington State, this indicator is not likely pertinent to be included in Washington's tool.

[74] Lou, X.F., & Nair, J. (2009). The impact of landfilling and composting on greenhouse gas emissions–a review. *Bioresource Technology*, *100*(16), 3792-3798.; Ofungwu, J., & Eget, S. (2006). Brownfields and health risks—air dispersion modeling and health risk assessment at landfill redevelopment sites. *Integrated Environmental Assessment and Management: An International Journal*, *2*(3), 253-261.; Weitz, K.A., Thorneloe, S.A., Nishtala, S.R., Yarkosky, S., & Zannes, M. (2002). The impact of municipal solid waste management on greenhouse gas emissions in the United States. *Journal of the Air & Waste Management Association*, *52*(9), 1000-1011.

[75] Roelofs, D., de Boer, M., Agamennone, V., Bouchier, P., Legler, J., & van Straalen, N. (2012). Functional environmental genomics of a municipal landfill soil. *Frontiers in Genetics*, *3*, 85.; Palmer, S.R., Dunstan, F.D., Fielder, H., Fone, D.L., Higgs, G., & Senior, M.L. (2005). Risk of congenital anomalies after the opening of landfill sites. *Environmental Health Perspectives*, *113*(10), 1362-1365.; Mataloni, F., Badaloni, C., Golini, M.N., Bolignano, A., Bucci, S., Sozzi, R., . . . Ancona, C. (2016). Morbidity and mortality of people who live close to municipal waste landfills: a multisite cohort study. *International Journal of Epidemiology*, *45*(3), 806-815.

IV. Individual Indicator Assessments: Sensitive Populations

The Washington EHD Map includes indicators for cardiovascular disease and low birth weight. Other tools also include measures for asthma, life expectancy, cancer, diabetes, mental health, and blood lead levels in children. For each indicator that the EHD Map includes there is a table directly comparing indicator features across each of the tools. For indicators that the EHD Map does not include, we summarize the potential value of that measure to an EJ model and the feasibility of the EHD Map to include it in future versions.

These indicators are likely to rely on the availability of state-level data resources, which is why there is more variation in data sources and measurement across different tools. While the federal tool includes these measures in its map, they are not included in any of the index calculations.

A) Cardiovascular Disease (CVD)

This indicator broadly captures the burden of cardiovascular disease, the leading cause of death in the United States,[76] for a census tract's population. Cardiovascular disease refers to an array of conditions that affect the heart or the peripheral circulatory system of veins and arteries that move blood and oxygen throughout the body. Common cardiovascular conditions involve irregularities with the heart itself or blocked or narrowed blood vessels that can lead to events like acute myocardial infraction (AMI), as known as a heart attack, or other heart problems.

Clinical Importance

Environmental exposures, particularly different forms of air pollution, can contribute to developing cardiovascular disease,[77] and persons already living with cardiovascular disease, especially those that have survived a heart attack, have an even greater risk of mortality related to air pollution compared to healthier individuals.[78] While there have not been any conclusive studies on the effects of air pollution on AMI survivors over different races and ethnicities, Black Americans have higher rates of cardiovascular disease than White, Hispanic, and Asian or Pacific Islander groups.[79]

[76] Centers for Disease Control and Prevention. (2022). *National Center for Health Statistics.* Centers for Disease Control and Prevention.
[77] Brook, R.D., Rajagopalan, S., Pope III, C.A., Brook, J.R., Bhatnagar, A., Diez-Roux, A. V., . . . Kaufman, J.D. (2010). Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association. *Circulation, 121*(21), 2331-2378 and Pope III, C.A., Muhlestein, J.B., May, H.T., Renlund, D.G., Anderson, J.L., & Horne, B.D. (2006). Ischemic heart disease events triggered by short-term exposure to fine particulate air pollution. *Circulation, 114*(23), 2443-2448.
[78] Brook, R.D., Rajagopalan, S., Pope III, C.A., Brook, J.R., Bhatnagar, A., Diez-Roux, A.V., . . . Kaufman, J.D. (2010). Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from *the American Heart Association Circulation, 121*(21), 2331-2378; and Pope III et al. (2010).
[79] *Heart disease risk: How race and ethnicity play a role.* Cleveland Clinic.

Exhibit A15

Cardiovascular Disease Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Cardiovascular disease mortality:** age-adjusted mortality from cardiovascular disease per 100,000	**Cardiovascular disease:** age-adjusted rate of emergency department visits for AMI per 10,000	**Heart disease**: the prevalence of several types of heart conditions among adults 18 years and older	**Heart disease:** the predicted prevalence (% of persons) of coronary heart disease among adults	**Cardiovascular disease**: age-adjusted rate of hospitalization for cardiovascular per 10,000
Geographical level of measurement/presentation	Census Tract	ZIP code / Census Tract	Census Tract	State / Census Tract	Census Tract or Zip code / Census Tract
Year(s) of data used in currently published tool	2015-2019	2015-2017	2019	2014-2017	2016-2019
Data source(s)	Death Certificate Data from WA DOH Center for Health Statistics, Community Health Assessment Tool	Emergency Department and Patient Discharge Data from the State of California, Office of Statewide Health Planning and Development (OSHPD)	CDC Places Census Tract Data modeled from state BRFSS data	Colorado Department of Public Health and Environment Community Level Estimates modeled from state BRFSS data	Michigan Outpatient and Inpatient Databases prepared by the Division for Vital Records & Health Statistics
Calculation/model/ methods	Age-adjusted rates of death due to cardiovascular disease per 100,000 population are calculated at the census tract level.	Age-adjusted rates of AMI ED visits at the zip code level are combined* to form census tract estimates.	CDC Places predicted prevalence** of Coronary Heart Disease (CHD)	CDPHE predicted prevalence*** of Coronary Heart Disease (CHD)	Age-adjusted rates of cardiovascular disease hospitalizations at the census tract or zip code level are combined**** to form census tract estimates.

Notes:

* Age-adjusted rates of AMI ED visits per 10,000 people per year are calculated at the zip code level, then those estimates were spatially smoothed to improve the reliability of small rates. Census blocks were assigned the average zip code rate using areal apportionment, and those estimates are population-weighted to create measures for a census tract.

** Predictions were created for each census tract. First, by modeling the relationship between CHD and demographic information using state-specific BRFSS data using a multilevel logistic regression model. They modeled self-reported CHD data on age, race, gender, poverty, and location random effects. These relationship estimates were then applied to predict the number of people who have CHD in each census tract based on that census tract's sociodemographic data from the American Community Survey and the 2010 Census.

*** Predictions were created for each census tract. First, by modeling the relationship between CHD and demographic information using state-specific BRFSS data. They modeled self-reported CHD data on age, race, gender, poverty, education, location and health conditions, and risk behavior indicators. These relationship estimates were then applied to predict the number of people who have CHD in each census tract based on that census tract's sociodemographic information.

****Counts of hospitalization with cardiovascular disease (disease of the heart, stroke, or disease of the arteries) as the principle diagnosis were aggregated at the census tract level, or the zip code level, and then zip code estimates were geographically weighted to get to census tract estimates, depending on data availability. Age-adjusted rates were then calculated using census tract populations from PopStats to calculate CVD hospitalizations per 10,000 persons per year. Rates were then spatially smoothed using SpaceStat.

Comparison

While all tools use an indicator that can give a measurement of cardiovascular disease, there is a lot of variation in what the indicator is specifically measuring and what types of data sources they are using to estimate it. Measuring the rate and impact of cardiovascular disease at the census tract or smaller geographic levels can be done in multiple ways using a variety of different data sources. Most tools rely on administrative health data sources readily available in each respective state. California and Michigan use medical discharge records, and Washington uses death certificates to produce direct estimates of cardiovascular disease-related events. Colorado and EJScreen, instead, use state-level survey data to create a prediction of cardiovascular disease prevalence for each census tract. EJScreen does not include this indicator to calculate any of its EJ indexes, it only provides this measure as a map overlay for additional context and information.

Validity and Reliability

All these indicators are reasonably valid. They use well-established methods for measuring the burden of cardiovascular disease, though each approach has different strengths and weaknesses. Theoretically, all methods are capturing rates of important events for persons with CVD, a reasonable measure of disease burden, and presumably, each state is using the most reliable data available to them. The following paragraphs provide more about the strengths and limitations of each kind of CVD measure.

The Washington EHD Map uses death certificate data to estimate mortality rates. This approach reduces concern over sampling bias related to healthcare access, but it does not capture the underlying population with cardiovascular disease, especially for the cases that are not severe enough to cause death. However, it does capture nearly all death of Washingtonians, similar to a census, and is less likely to be biased regarding access to healthcare.

CalEnviroScreen's measure of healthcare utilization does not account for those who do not seek regular health care or those that do not make it to the hospital before death. California only counts AMI events, which still only counts extreme events related to specific forms of cardiovascular disease rather than the underlying CVD population. It is also more likely to capture only certain subpopulations with CVD and may be underestimating the presence of other subpopulations that are less likely to experience AMI or other acute CVD events.

EJScreen and Colorado EnviroScreen use a method that aims to estimate the underlying population with CVD, specifically coronary heart disease, but these are not direct estimates. To produce their indicator, they model state-level relationships using BRFSS survey data and then make predictions for each census tract. These predictions rely heavily on assumptions of homogeneity between census tracts and may not reflect the true underlying population with CVD. However, multiple case studies and validation studies support the soundness of this method.[80]

MiEJScreen's measure of healthcare utilization does not account for those who do not seek regular health care or those that do not make it to the hospital and die in the community, similar to CalEnviroScreen. However, it does have a broader definition of specific forms of cardiovascular disease, though still does not capture the underlying CVD population.

[80] Zhang et al. (2014); Zhang et al. (2015); and Wang et al. (2017).

These indicators are consistent over time and geographic regions and should not have any variance with seasonality that would impact yearly estimates. There may be some concern that healthcare utilization measures may be underestimated in census tracts with low-income and low healthcare access.

B) Low Birth Weight (LBW)

This indicator captures the percentage of babies born at a low birth weight (LBW), which is a standard way to measure the general health of a population. This measure can indicate the health status of women of childbearing age and what conditions they experience while pregnant.

Clinical Importance

This indicator is relevant because a mother's exposure to environmental harms, before and during pregnancy can increase the risk of having an LBW birth.[81] Rates of LBW births also indicate the health status and future health status of young children. Those born at low birth weight are more likely to develop asthma and wheezing disorders during childhood, coronary heart disease, attention deficit hyperactivity disorder (ADHD), or other behavioral problems, and are more likely to grow up with delayed motor and social development or learning disabilities.[82] Furthermore, most of these conditions are risk factors for having a greater sensitivity to the harms of environmental exposures. This means that children born and raised to mothers in areas with high environmental exposures are potentially directly impacted before birth and throughout their life. These relationships can be even stronger when considering other factors like age, race, ethnicity, socioeconomic status, and access to prenatal care.[83]

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[81] Bekkar, B., Pacheco, S., Basu, R., & DeNicola, N. (2020). Association of air pollution and heat exposure with preterm birth, low birth weight, and stillbirth in the US: A systematic review. *JAMA Network Open*, *3*(6).

[82] Belbasis, L., Savvidou, M.D., Kanu, C., Evangelou, E., & Tzoulaki, I. (2016). Birth weight in relation to health and disease in later life: an umbrella review of systematic reviews and meta-analyses. *BMC Medicine, 14*(1), 1-15. Franz, A.P., Bolat, G.U., Bolat, H., Matijasevich, A., Santos, I.S., Silveira, R. C., . . . Moreira-Maia, C.R. (2018). Attention-deficit/hyperactivity disorder and very preterm/very low birth weight: a meta-analysis. *Pediatrics, 141*(1).

[83] Almeida, J., Bécares, L., Erbetta, K., Bettegowda, V.R., & Ahluwalia, I.B. (2018). Racial/ethnic inequities in low birth weight and preterm birth: The role of multiple forms of stress. *Maternal and Child Health Journal*, *22*(8), 1154-1163. Harley, K.G., Huen, K., Aguilar Schall, R., Holland, N.T., Bradman, A., Barr, D.B., & Eskenazi, B. (2011). Association of organophosphate pesticide exposure and paraoxonase with birth outcome in Mexican-American women. *PLoS One, 6*(8); and Ratnasiri, A.W., Parry, S.S., Arief, V.N., DeLacy, I. H., Halliday, L.A., DiLibero, R.J., & Basford, K.E. (2018). Recent trends, risk factors, and disparities in low birth weight in California, 2005–2014: A retrospective study. *Maternal Health, Neonatology and Perinatology, 4*(1), 1-13.

Exhibit A16

Low Birth Weight Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Low birth weight:** the percentage of live-born singleton infants born at term with a birth weight less than 2,500 grams	**Low birth weight:** the percentage of singleton infants, with low birth weight defined as infants weighing less than 2,500 grams	NA	**Low birth weight infants:** the percentage of singleton births weighing under 2,500 grams at birth	**Low birth weight infants:** the percentage of live, singleton births weighing less than 2,500 grams
Geographical level of measurement/ presentation	Census Tract	Census Tract	NA	Census Tract	Census Tract
Year(s) of data used in currently published tool	2015-2019	2009-2015	NA	2013-2017	2014-2019
Data source(s)	Birth Certificate Data from Washington State's DOH Center for Health Statistics, Community Health Assessment Tool	Birth Certificate Data from California's Department of Public Health (CDPH)	NA	Vital Records Birth Dataset from Colorado's Department of Public Health and Environment	Michigan Birth Files. Division for Vital Records & Health Statistics
Calculation/model/ methods	Count of LBW infants divided by total live-born singleton infants born at term (37 weeks).	Count of LBW infants divided by total live-born singleton infants born at term (37 weeks).	NA	The number of singleton low-weight births, divided by the number of all singleton births.	The number of live singleton births weighing less than 2,500 grams divided by the number of all singleton births.

Comparison

The Washington EHD Map defines the LBW indicator differently than the other tools. They exclude pre-term births, which are more likely to be LBW. There are no differences in the definition of the LBW indicator across the rest of the state EJ mapping tools. EJScreen does not include this indicator. All states use their birth certificate data, and the years of data used vary. Each state tried to use a range of years that was recent but combined enough years that small census tracts still had robust estimates, which ranged from five to seven years.

Validity and Reliability

All these indicators are reasonably valid. There is a long history of using the LBW measure and birth certificate data for public health and health policy research in the United States. It is widely considered a reliable and important measure of general health. Birth certificate data is collected, maintained, and owned by each state, district, or territory.[84] Historically, there has been some variation in data collection practices of birth certificate data across states; by 2015, all states have adopted the latest Standard Certificate of Live Birth.[85] There may still be minor differences in systematic data collection and processing across states depending on underlaying data collection systems and how each state chooses to fund and organize its vital records.

[84] National Research Council. (2009). *Vital statistics: summary of a workshop.*

[85] Howell, E. M., Morgan, J., Potamites, C.C.B.E., & Kranker, K. (2021). *How Reliable Are the Birth Certificate Variables for Mothers with Medicaid Coverage?. Mathematica Policy Research.*

All four of the state tools use state birth certificate data, which is an excellent source of LBW information. Birth certificate data is filled out by medical providers for nearly every birth in the US. It is essentially a full census rather than just a sample. All tools also use a standard definition and cut-off (2,500 grams at birth) that is well-regarded by experts in the public health and medical fields. This measure excludes multiple birth events (twins etc.) which are rare but have been slightly increasing over time. Babies of multiple births are more likely to have a low birth weight, so this measure is likely a slight underestimate of all LBW births. Washington's criteria of the birth being at-term (> 37 weeks of gestation) are likely undercounting the overall LBW population that is more sensitive to environmental exposures.

This indicator is consistent over both time and geographic location and should not vary with seasonality after averaging over multiple years of data. This measure may vary between racial groups and socioeconomic status. Washington's measure that excluded pre-term births may not be capturing this real variance. Pre-term births can be tied to low maternal socioeconomic status and other social and health stressors, which could lead to overestimates of LBW in more affluent census tracts and underestimates in less affluent census tracts.

C) Other Measures

Asthma

This indicator broadly captures the burden of asthma, a common chronic respiratory disease, for each census tract's population. Asthma can be life-threatening, but it is treatable and can be managed with a mixture of taking medications and avoiding certain triggers for asthma attacks. The development of asthma can be caused by environmental exposures and, for those that already have the condition, the symptoms can be worsened by environmental exposures. Proper management of asthma requires reliable access to healthcare, and the socioeconomic resources to live in an environment that has minimal asthmatic triggers like air pollutants, pesticides, and mold. So, the impact of environmental exposures on populations with high asthma might be even stronger when considering other factors like age, race, ethnicity, socioeconomic status, and access to healthcare.[86]

Washington is the only state that does not include this indicator due to a lack of data availability, though the inclusion of asthma is a priority of the tool's developers, and the indicator is relevant in terms of clinical importance. They are currently exploring options to include this kind of measure using discharge data from the Comprehensive Hospital Abstract Reporting System (CHARS) or syndromic surveillance data from the Rapid Health Information NetwOrk (RHINO). These are rich data sources, but work needs to be done to determine if an indicator using these data would be calculable at the census tract level and a reliable measure across census tracts in Washington State.

Life Expectancy

This measure is a general indicator of population health. Life expectancy represents a continuous measure of longevity. Therefore, a shorter life expectancy indicates the presence of barriers to longevity, such as the presence of poor or dangerous living conditions, and the development of chronic conditions. A community with shorter life expectancy could mean that there are already environmental harms or that the community may be more susceptible to environmental harms due to their health and other factors, in addition to other social conditions and health conditions that contribute to morbidity and mortality.

[86] Wendt, J.K., Symanski, E., Stock, T.H., Chan, W., & Du, X.L. (2014). Association of short-term increases in ambient air pollution and timing of initial asthma diagnosis among medicaid-enrolled children in a metropolitan area. *Environmental Research, 131,* 50-58. CDC, 2013; Grineski, S.E., Staniswalis, J.G., Peng, Y., & Atkinson-Palombo, C. (2010). Children's asthma hospitalizations and relative risk due to nitrogen dioxide (NO2): Effect modification by race, ethnicity, and insurance status. *Environmental Research, 110*(2), 178-188; and CDC (2013). *Centers for Disease Control and Prevention Asthma facts: CDC's National Asthma Control Program grantees.*

These indicators are included in the Colorado EnviroScreen and MiEJScreen tools and as a separate overlay in EJScreen. All these tools use the same data source, the U.S. Small-area Life Expectancy Estimates Project (USALEEP) for 2010-2015, and the same definitions. The USALEEP is a reputable and common source for these kinds of data.

Washington and California do not include these indicators. If there is significant variability across census tracts this could be a valuable measure to include. Washington could use the same data source as the other tools. This is a rich data source, but work needs to be done to determine if this would be a valuable and reliable measure across census tracts in Washington State.

Blood Lead Level

This indicator represents the proportion of young children (< 6 years old) that had a blood lead level higher than or equal to 5 µg/dL. This can be an indicator of an existing presence of environmental harm or that the community may be more susceptible to environmental harm due to their health and other factors. Michigan's MiEJScreen is the only tool that includes this indicator and may be the only state that has developed the regular data collection and capacity to measure this at the census tract level at this time. They include this in addition to the lead housing indicator.

If there is significant variability across census tracts this could be a valuable measure to include, though Washington already has a lead indicator. Washington would have to develop its data source to include this measure. More work would also need to be done to determine if this would be a valuable and reliable measure across census tracts in Washington State (in addition to or as a substitute for the existing lead measure).

Other Health Conditions: Cancer, Diabetes, and Mental Health

These measures represent a range of health conditions that indicate that there may already be environmental harms present or that the community may be more susceptible to environmental harms due to their health and other factors. Colorado's EnviroScreen is the only tool that includes these indicators. They use CDC Places as their data source, which relies on making predictions based on BRFSS data and ACS estimates of socio-demographic factors, similar to their heart disease measure.

If there is significant variability across census tracts this could be a valuable measure to include. Washington could use the same data source, CDC Places, as Colorado EnviroScreen or try creating indicators using the Comprehensive Hospital Abstract Reporting System (CHARS) or syndromic surveillance data from Rapid Health Information NetwOrk (RHINO). These are rich data sources, but work needs to be done to determine if an indicator using this data would be calculable at the census tract level and a reliable measure across census tracts in Washington State. These measures are relevant in terms of clinical importance. Again, sensitivity work would be required to determine if these indicators provided value additional information to the existing model. Note that Colorado also includes sensitive age groups (under 5 years and 65+ years old) in this group of indicators. See Section V. G of the Appendix for more information.

V. Individual Indicator Assessments: Socioeconomic factors

The Washington EHD Map includes indicators for low educational attainment, housing burden & transportation expenses, linguistic isolation, poverty, race, and unemployment. Other tools also include measures for certain age groups (<5 years and > 65 years) and disabilities. For each indicator that the EHD Map includes there is a table directly comparing indicator features across each of the tools. For indicators that the EHD Map does not include, we summarize the potential value of that measure to an EJ model and the feasibility of the EHD Map to include it in future versions.

A) Low Educational Attainment

This indicator captures the percentage of the population over the age of 25 that has not completed a high school level of education.

Clinical Importance

Low educational attainment is an important predictor of health. It can lead to poor health outcomes through decreased access to occupational opportunities, increased economic hardship, increased stress, decreased social support, decreased access to medical services, and decreased access to nutritious foods. Although this indicator by itself may not be a causal predictor of exposure to environmental harms, those with low education can have a higher vulnerability in the presence of environmental exposures and exacerbate circumstances that lead to poorer health. Low education attainment can reduce health status in the following ways: economic hardship, stress, fewer occupational opportunities, lack of social support, and reduced access to health services. Higher education attainment is positively correlated with health, though the health benefits gained from higher education attainment are not uniform across racial and ethnic groups. People of color are less likely to gain health benefits from increased education attainment.[87]

[87] Assari, S. (2018). Blacks' diminished return of education attainment on subjective health; mediating effect of income. *Brain Sciences, 8*(9), 176 and Bell, C.N., Sacks, T.K., Tobin, C.S.T., & Thorpe Jr, R.J. (2020). Racial non-equivalence of socioeconomic status and self-rated health among African Americans and Whites. *SSM-Population health, 10,* 100561.

Exhibit A17

Low Education Attainment Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**No high school diploma:** the percentage of the population over age 25 with less than a high school education	**Educational attainment:** the percentage of the population over age 25 with less than a high school education	**Less than high school education:** the percentage of people age 25 or older in a census block group whose level of educational attainment is less than a high school diploma	**Less than high school education:** the percentage of people age 25 or older in a census block group whose level of educational attainment is less than a high school diploma	**Educational attainment:** the percentage of the population over the age of 25 with less than a high school education
Geographical level of measurement/presentation	Census Tract	Census Tract	Census Block Group or Census Tract	Census Block Group / Census Tract	Census Tract
Year(s) of data used in currently published tool	2015-2019	2015-2019	2015-2019	2015-2019	2015-2019
Data source(s)	American Community Survey (ACS)	American Community Survey (ACS)	American Community Survey (ACS)	American Community Survey (ACS) via EJScreen 2021	American Community Survey (ACS) via ESRI Living Atlas of the World
Calculation/model/methods	Standard ACS calculation*	Standard ACS calculation, plus a reliability criterion**	Standard ACS calculation*	Standard ACS calculation* for census block groups. All block groups were averaged to calculate census tract values.	Standard ACS calculation*

Notes:

* Using methods from the U.S. Census. (2021). *Understanding and using American Community Survey Data: What all data users need to know.*

** California's EnviroScreen required a census tract's estimate have either 1) A relative standard error less than 50, or 2) A standard error was less than the mean of standard errors of all California census tract estimates.

Comparison

This indicator is consistent across all five tools in terms of definition and data source. The federal tool and Colorado's EnviroScreen are the only tools that use census blocks as the geographic unit of measurement, while all others use census tracts. Most of the tools use the same calculation for the indicator, but California's EnviroScreen also includes an additional reliability criterion for estimates to be included in the overall score. As Colorado starts with census block groups, those measures must be averaged to obtain the census tract values. EJScreen does not include this indicator to calculate any of its EJ indexes, it only provides this measure as a map overlay for additional context and information.

Validity and Reliability

This indicator is reasonably valid. It accurately measures the percentage of the population over 25 that does not have a high school degree. All the tools draw data from the same indicator in the ACS, which is composed of survey data. The ACS is a highly regarded and highly used data source for national and local data in the United States.

This indicator is consistent over time. However, it can be inconsistent over different levels of geographic measurements. Estimates from small portions of the population are less reliable than those based on large populations. The California and Maryland tools account for this by excluding census tracts where the standard error is more than half of the estimate or if the standard error is more than the mean of all the census tracts in the state. The reliability of this indicator over sub-populations is also dependent on the quality of the sample. There is no variance in seasonality with this indicator.

B) Unaffordable Housing and Transportation Expenses

These indicators capture the extent to which households are financially burdened by their housing expenses.

Most tools just use a measure of housing costs, but Washington also includes transportation expenses to capture those that may live further away from work with potentially lower housing costs but high commute costs. Transportation expenses are covered in this section in addition to housing burden even though they are treated as separate indicators in the EHD Map because they are highly related.

Clinical Importance

These indicators are relevant because they provide additional and different information than a general poverty measure, specifically, the financial burden households face when living in communities with higher or lower costs of living. Households spending a high percentage of their income on housing (and/or transportation) are more likely to have increased levels of stress and report lower levels of health and depression.[88] This population is also more likely to delay medical care due to the high costs. This indicator does not actually measure the increased risk to health or exposure to pollution. Instead, it tracks the number of people above the threshold of having a high housing burden and thus more at risk of incurring the negative health effects associated with environmental exposures due to a lack of resiliency resources. Those with low income and people of color are more likely to face a higher housing burden.[89]

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[88] Slatter, M., & Beer, A. (2003). Housing Evictions in South Australia: A study of bailiff-assisted evictions; and Beer, A., Slatter, M., Baulderstone, J., & Habibis, D. (2006). Evictions and housing management.

[89] Hess, C., Colburn, G., Crowder, K., & Allen, R. (2020). Racial disparity in exposure to housing cost burden in the United States: 1980–2017. *Housing Studies,* 1-21

Exhibit A18

Housing Burden Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Unaffordable housing:** the percentage of households spending greater than 30% of their income on housing costs. **Transportation expense:** the average percentage of household income spent on transportation costs in a census tract.	**Housing-burdened low-income households:** the percentage of households in a census tract that is both 1)_low income (making less than 80% of the HUD Area Median Family Income), and 2) severely burdened by housing costs (paying greater than 50% of their income to housing costs)	NA	**Housing cost-burdened communities:** the percentage of households within an area that spends more than 30% of household income on housing	**Housing burden**: the percentage of households paying more than 30% of their income on shelter costs
Geographical level of measurement/ presentation	Census Tract	Census Tract	NA	Census Block Group / Census Tract	Census Tract
Year(s) of data used in currently published tool	**Unaffordable housing:** 2015-2019l **Transportation expense:** 2015	2013-2017	NA	2015-2019	2014-2018
Data source(s)	**Unaffordable housing:** American Community Survey (ACS) **Transportation expense:** 2017 Center for Neighborhood Technology (CNT) based on 2015 ACS estimates	Comprehensive Housing Affordability Strategy (CHAS) data from Housing and Urban Development based on American Community Survey (ACS) data	NA	American Community Survey (ACS)	American Community Survey (ACS) via ESRI Living Atlas of the World
Calculation/model/ methods	**Unaffordable housing:** Standard ACS calculation* **Transportation expense:** CNT predicted** average household transportation costs, divided by 80% of the median household income	Standard ACS calculation, plus a reliability criterion***	NA	Standard ACS calculation*	Standard ACS calculation*

Notes:

* Using methods from the U.S. Census Bureau, Understanding and Using American Community Survey Data: What All Data Users Need to Know, U.S. Government Publishing Office, Washington, DC, 2020.

* has multiple housing and cost models to predict transportation costs from built environments (population density and roadways) and other relevant indexes (job index and transit access indexes). Their latest data available is 2017 using 2015 data.

*** California's EnviroScreen required a census tract's estimate to have either 1) a relative standard error less than 50, or 2) a standard error was less than the mean of standard errors of all California census tract estimates.

Comparison

The unaffordable housing measure is consistent across Washington, Colorado, and Michigan. These tools use the same data and threshold (30% of income), though Michigan uses 2014-2018 rather than 2015-2019. CalEnviroScreen has stricter criteria; households must be spending a higher percentage of their income on housing, and the household income must be less than 80% of the median HUD household income. Washington also includes a separate transportation expense indicator in tandem with its housing burden measure, citing the inverse relationship between housing burden and transportation costs as the reason for including this additional indicator. The federal tool and Colorado's EnviroScreen are the only tools that use census blocks as the geographic unit of measurement, while all others use census tracts. EJScreen does not include this indicator to calculate any of its EJ indexes, it only provides this measure as a map overlay for additional context and information.

Validity and Reliability

This indicator is reasonably valid. It accurately measures the percentage of households that are paying greater than a certain threshold of their income on housing or shelter. The methods used by the ACS for data collection and calculating estimates at the census tract/block levels are well established and widely used in EJ tools, government planning, and economics, public health, and education research literature. Thirty percent is a common threshold used in health planning tools such as Healthy People 2030 and is commonly used when individuals apply for housing. The 50% threshold for California does seem high but may be more appropriate for high-cost areas, like many in California. The main limitation of this housing measure would be that it does not capture the trade-off between housing costs and commuting, which Washington addresses by including transportation expenses.

This indicator is consistent over time but may vary between urban and rural communities due to the high differential cost between living in cities and their surrounding suburbs compared to the rural census tracts.

C) Linguistic Isolation

This indicator captures the percentage of limited English-speaking households.

Clinical Importance

This indicator is relevant because it inhibits an individual's ability to access healthcare, participate in key national health surveys (including the American Community Survey), and participate in civic engagement—including surveys and engagement which apply to public health and environmental policies. Linguistic isolation is tied to worse medical outcomes because it can limit a family's ability to obtain health insurance and access quality medical care. Linguistic isolation is also linked to increased stress and decreased socioeconomic status which are both correlated with poorer health outcomes as well. Although this indicator by itself may not be a causal predictor of exposure to environmental harms, those with linguistic isolation can have a higher vulnerability in the presence of environmental exposures.

This measure does not capture the actual exposure or increased risk to health that these linguistically isolated households have to pollution, but it captures the percentage of households that will be more at risk/affected by exposure.

Exhibit A19

Linguistic Isolation Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Percentage of limited English-speaking households**: the percentage of households where no one aged 14 and older speaks English well	**Percentage of limited English-speaking households:** the percentage of households where no one aged 14 and older speaks English well	**Linguistically isolated households**: a household in which all members aged 14 years and over speak a non-English language and speak English less than "very well" (have difficulty with English)	**Linguistic Isolation:** the percentage of households in which all members 14 years old and older speak a non-English language and speak English less than "very well"	**Linguistic Isolation:** the percentage of households in which all members 14 years old and older speak a non-English language and speak English less than "very well"
Geographical level of measurement/ presentation	Census Tract	Census Tract	Census Block Group or Census Tract	Census Block Group / Census Tract	Census Tract
Year(s) of data used in currently published tool	2015-2019	2015-2019	2015-2019	2015-2019	2015-2019
Data source(s)	American Community Survey (ACS)	American Community Survey (ACS)	American Community Survey (ACS)	American Community Survey (ACS) via EJScreen 2021	American Community Survey (ACS) via ESRI Living Atlas of the World
Calculation/model/ methods	Standard ACS calculation*	Standard ACS calculation, plus a reliability criterion**	Standard ACS calculation*	Standard ACS calculation* for census block groups. All block groups were averaged to calculate census tract values.	Standard ACS calculation*

Notes:
* Using methods from the U.S. Census Bureau, Understanding and Using American Community Survey Data: What All Data Users Need to Know, U.S. Government Publishing Office, Washington, DC, 2020.
**California's EnviroScreen required a census tract's estimate have either 1) a relative standard error less than 50, or 2) a standard error was less than the mean of standard errors of all California census tract estimates.

Comparison

This indicator is consistent across all five tools in terms of definition and data source. The federal tool and Colorado's EnviroScreen are the only tools that use census blocks as the geographic unit of measurement, while all others use census tracts. Most of the tools use the same calculation for the indicator, but California's EnviroScreen also includes an additional reliability criterion for estimates to be included in the overall score. Because Colorado starts with census block groups, those measures must be averaged to obtain the census tract values. EJScreen does not include this indicator to calculate any of its EJ indexes, it only provides this measure as a map overlay for additional context and information.

Validity and Reliability

This indicator is reasonably valid. It comes from a widely cited and well-respected source. The methods used by the ACS for data collection and calculating estimates at the census tract/block levels are well-established and widely used. One potential issue with this indicator is that households that are linguistically isolated are more likely to be excluded from national surveys—like the American Community Survey—so the estimates provided by the ACS may be underrepresenting the true number of linguistically isolated households.

This indicator is consistent over time, however, it can be inconsistent over different levels of geographic measurements. Estimates from small portions of the population are less reliable than those based on large populations. The California and Maryland tools account for this by excluding census tracts where the standard error is more than half of the estimate or if the standard error is more than the mean of all the census tracts in the state. The reliability of this indicator over subpopulations is also dependent on the quality of the sample.

D) Poverty

This indicator captures the percentage of persons living in a low-income household or below a specified level of poverty.

Clinical Importance

This indicator is relevant because it approximates how many individuals may have limited access to resources allowing one to achieve and maintain good health outcomes in general and lower access to resources that would increase resilience in the presence of environmental exposures. Living in a low-income area itself does not directly determine one's health status, but it is a very good proxy for access to resources to a) achieve and maintain good health, b) be resilient in the presence of environmental exposures, and c) effect change in a person's living situation to prevent more environmental exposures. For example, households with higher incomes are more likely to have access to better healthcare, adequate nutrition, time for healthy activities, and time to be involved in community planning and decision-making. Low income is correlated with already having a chronic disease that requires care and a higher level of stress that can compound existing conditions and lead to worse health outcomes.

Exhibit A20

Poverty Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Population living in poverty:** the percentage of the total population whose income was less than or equal to 185% of the federal poverty level within the past 12 months	**Poverty:** the percentage of the population living below two times the federal poverty level	**Percentage low income:** the percentage of individuals whose ratio of household income to the federal poverty level in the past 12 months is less than 2	**Percentage low income:** the percentage of the population living in households where income is less than or equal to twice the federal poverty level	**Low-income population:** the percentage of the population living below 185% of the federal poverty level
Geographical level of measurement/ presentation	Census Tract	Census Tract	Census Block Group or Census Tract	Census Block Group / Census Tract	Census Tract
Year(s) of data used in currently published tool	2015-2019	2015-2019	2015-2019	2015-2019	2015-2019
Data source(s)	American Community Survey (ACS)	American Community Survey (ACS)	American Community Survey (ACS)	American Community Survey (ACS) via EJScreen 2021	American Community Survey (ACS)
Calculation/model/ methods	Standard ACS calculation*	Standard ACS calculation, plus a reliability criterion**	Standard ACS calculation.* This measure is part of their Demographic Index	Standard ACS calculation* for census block groups. All block groups were averaged to calculate census tract values.	Standard ACS calculation*

Notes:

* Using methods from the U.S. Census Bureau, Understanding and Using American Community Survey Data: What All Data Users Need to Know, U.S. Government Publishing Office, Washington, DC, 2020.

** California's EnviroScreen required a census tract's estimate have either 1) a relative standard error less than 50, or 2) a standard error was less than the mean of standard errors of all California census tract estimates.

Comparison

Washington and every other tool include this indicator in their socioeconomic factors and use the same data sources. Washington and Colorado are the only tools that use the 185% threshold, while all the others use 200%. At least for Washington, this is done to match the requirement in Washington's WIC program that families must be below 185% FPL. The federal tool and Colorado's EnviroScreen are the only tools that use census blocks as the geographic unit of measurement, while all others use census tracts. Most of the tools use the same calculation for the indicator, but California's EnviroScreen also includes an additional reliability criterion for estimates to be included in the overall score. Colorado's measure must scale up the block group estimates to obtain the census tract values. This measure is one of two indicators used in the federal tool's demographic index, along with the percentage minority. This demographic index is then used to calculate each environmental index.

Validity and Reliability

This indicator is reasonably valid. The ACS poverty measure at the census tract level is the most reputable and feasible measure for the needs of these tools. This measure is the official poverty measure for the United States. The methodology for data collection and calculating estimates at the census tract level are well established and widely used in EJ tools, government planning, economics, public health, and education research literature.

The measure has critiques, but the limitations are well-documented in the literature. One critique is the design. The 100% poverty line was built to represent 3x the cost of a minimum food diet in 1963 in current dollars and that may not represent the dollar amount needed to supply the basic needs of a household. This limitation is likely why all states choose a threshold over 100% of the poverty line. Whether 185% or 200% is enough to adequately capture the percentage of the population facing the challenges of poverty is hard to tell, though 200% seems to have become the common standard for EJ tools.

This indicator is self-reported and may be subject to recall bias. The survey only counts certain kinds of income and only counts household members with familial bonds. It also does not count persons institutionalized, in college, or living in non-conventional housing.

The indicator is consistently measured over time in terms of survey methods and data availability. It is adjusted with the consumer price index each year to adjust for inflation. However, there are concerns that this may not be an adequate adjustment for the changing needs of a household over time. This indicator does not adjust for costs of living in urban vs rural areas. In cities, this indicator may be an underestimate of the proportion of persons living in poverty while in rural towns it may be an overestimate.

E) Race (People of Color)

This indicator captures the percentage of the population that is Black, American Indian/Alaskan Native, Asian, Native Hawaiian/Other Pacific Islander, and two or more races. It can also be defined as a sum of all race/ethnicity categories except non-Hispanic White.

Clinical Importance

This indicator is relevant because the racial and ethnic groups included in this indicator are at higher risk for environmental risk factors. Due to racial discrepancies that people of color face they are more likely to have limited access to safe housing, healthcare, and wealth. Certain racial groups within this indicator are also more likely to have health conditions such as asthma and more likely to have adverse birth outcomes. This indicator is included not only because people of color have an increased vulnerability to pollutants due to lower health status, but communities of color are also historically more likely to be located by a Superfund or other hazardous sites. Although this indicator groups all races and ethnicities other than White together, the level of discrimination, stress, and negative health effects will vary between racial groups.

Exhibit A21

Race (People of Color) Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Race (people of color)**: those identifying as any race/ethnicity category except non-Hispanic White. It includes Black, American Indian/Alaskan Native, Asian, Native Hawaiian-other Pacific Islander, two or more races, and the ethnicity grouping of Spanish/ Hispanic/Latino.	NA	**Minority/people of color:** the percentage of individuals in a block group who list their racial status as a race other than White alone and/or list their ethnicity as Hispanic or Latino	**Percentage people of color:** the percentage of individuals who list their racial status as a race other than non-Hispanic White	**Black, Indigenous, or people of color population:** the percentage of people belonging to any race/ethnicity category except non-Hispanic White. It includes Black, American Indian/Alaskan Native, Asian, Native Hawaiian-Other Pacific Islander, and two or more races.
Geographical level of measurement/presentation	Census Tract	NA	Census Block Group or Census Tract	Census Block Group / Census Tract	Census Tract
Year(s) of data used in currently published tool	2019	NA	2015-2019	2015-2019	2015-2019
Data sources)	Washington State Office of Financial Management (OFM) population estimates.	NA	American Community Survey (ACS)	American Community Survey (ACS) via EJScreen 2021	American Community Survey (ACS) through ESRI Living Atlas of the World
Calculation/model/methods	OFM uses models of birth, death, and migration to make forecasts based on numbers obtained from the U.S. Census Bureau.	NA	Standard ACS calculation.* This measure is part of their Demographic Index	Standard ACS calculation* for census block groups. All block groups were averaged to calculate census tract values.	Standard ACS calculation*

Note:

* Using methods from the U.S. Census Bureau, Understanding and Using American Community Survey Data: What All Data Users Need to Know, U.S. Government Publishing Office, Washington, DC, 2020.

Comparison

All four of the tools that include a measure for race have the same definition of population. All tools, except Washington, use data from the American Community Survey (ACS). The federal tool and Colorado's EnviroScreen are the only tools that use census blocks as the geographic unit of measurement, while all others use census tracts. The Washington EHD Map instead uses forecasts made by the Washington State Office of Financial Management based on 2019 data from the Census Bureau. The California tool does not formally include an indicator for a race. It publishes a separate racial analysis alongside its reports, but race is not an indicator included in the calculation of a census tract's overall score in the CalEnviroScreen tool.

Validity and Reliability

These indicators are reasonably valid. The measure Washington uses is from an official resource for Washington State government planning and resource allocation. These estimates are predicted using different models of birth, death, and migration. While it is not a direct count of persons or a sample of persons, the source of data used in the models is the U.S. Census Bureau.

The indicator that the other tools use is an official measure for multiple environmental justice tools including Justice40. The methodology for data collection and calculating estimates at the census tract level for the ACS are well established and widely used.

All indicators are consistently measured over time in terms of methods and data availability. There are concerns about the ACS data that the people of color are being underestimated since undocumented individuals and those who are not English speakers are less likely to partake in the survey. Because Washington's source relies on similar data, there might be similar concerns about underestimates. A critique that can be made for all four of the indicators is that an indicator that groups all races and ethnicities outside of White/non-Hispanic into one group will miss the nuances between the groups.

F) Unemployment

This indicator captures the percentage of the population over the age of 16 that is in the labor force and is unemployed. For an individual to be defined as unemployed, that individual must be actively searching for work.

Clinical Importance

This indicator is relevant because unemployment has a wide range of negative health effects on both physical and mental health, including increased risk for developing diseases associated with aging, increased risk of coronary heart disease, and higher overall mortality. Unemployment has also been linked to the biological effects of stress which can also result in poor health outcomes and higher vulnerability to environmental impacts. Unemployed individuals often lack resources that would enable them to access quality healthcare in a timely manner, resulting in treatable health conditions having worse outcomes than if they had been addressed earlier. Although this indicator by itself may not be a predictor of exposure to pollutants, the decreased health status and increased stress seen in individuals who are unemployed can increase vulnerability to pollutants.

Exhibit A22

Unemployment Measures

Indicator attribute	Washington EHD Map	California EnviroScreen	Federal EJScreen	Colorado EnviroScreen	Michigan MiEJScreen
Concept being measured	**Unemployment:** the population of people 16 years and older who are in the labor force and are unemployed	**Unemployment:** the percentage of the population over the age of 16 who are unemployed and in the labor force	**Unemployment:** all those who did not have a job at all during the reporting period, made at least one specific effort to find a job during the prior 4 weeks, and were available for work	NA	**Unemployment:** The percentage of the population over the age of 16 who are unemployed and in the labor force
Geographical level of measurement/ presentation	Census Tract	Census Tract	Census Block Group or Census Tract	NA	Census Tract
Year(s) of data used in the currently published tool	2015-2019	2015-2019	2015-2019	NA	2015-2019
Data source(s)	American Community Survey (ACS)	American Community Survey (ACS)	American Community Survey (ACS)	NA	American Community Survey (ACS) via ESRI Living Atlas of the World
Calculation/model/ methods	Standard ACS calculation*	Standard ACS calculation, plus a reliability criterion**	Standard ACS calculation*	NA	Standard ACS calculation*

Notes:

* Using methods from the U.S. Census Bureau, Understanding and Using American Community Survey Data: What All Data Users Need to Know, U.S. Government Publishing Office, Washington, DC, 2020.

** California's EnviroScreen required a census tract's estimate have either 1) a relative standard error less than 50, or 2) a standard error was less than the mean of standard errors of all California census tract estimates.

Comparison

Washington and three other tools included this indicator in their socioeconomic factors, using the same data from the American Community Survey. This indicator is consistent across all tools that include unemployment in terms of definition and data source. The federal tool and Colorado's EnviroScreen are the only tools that use census blocks as the geographic unit of measurement, while all others use census tracts. Most of the tools use the same calculation for the indicator, but the CalEnviroScreen tool also includes an additional reliability criterion for estimates to be included in the overall score.

Validity and Reliability

This indicator is reasonably valid. The ACS unemployment measure is one of the most reputable and feasible measures for this indicator. It uses the same definition as the official unemployment measure for the United States, computed using the Current Population Survey. The methodology for data collection and calculating estimates at the census tract level are well established and widely used in EJ tools, government planning, economics, public health, and education research literature. The indicator is consistently measured over time in terms of survey methods and data availability. However, the actual unemployment rate may vary seasonally and by location due to changes in weather, harvest seasons, holidays, and school schedules. These causes of seasonal employment fluctuation will differ by rural and urban census tracts/blocks. Because this measure is surveyed over the entire year, these variations should not impact the reliability of the measure.

The critiques surrounding this indicator are not about the ACS measure of unemployment; they are about the definition of unemployment excluding discouraged workers (workers who are unemployed but not actively searching for work) and potentially underestimating the true number of unemployed workers. This measure also excludes retirees, students, homemakers, institutionalized persons except for prisoners, those not looking for work, and military personnel on active duty.

G) Other Measures

Age Groups, 65+ Years Old & Under 5 Years Old

These age groups represent populations that have specific healthcare and resource needs and may be more vulnerable to environmental exposure due to their physical susceptibilities. Young children’s bodies are developing and exposure to harmful pollutants could have life-long consequences. On the opposite end of the spectrum, older adults are more likely to have developed conditions that are sensitive to environmental exposures.

These indicators are included in the Colorado EnviroScreen and MiEJScreen tools and included as a separate overlay in EJScreen. Colorado includes this indicator in with their sensitive populations rather than socioeconomic factors theme. All these tools use the same data source, the American Community Survey (ACS), and the same definitions. The ACS is a reputable and common source for these kinds of data.

Washington and California do not include these indicators. If there is significant variability across census tracts this could be a valuable measure to include. Washington could use the same data source as the other tools or the OFM’s population estimates like what is used for their race (people of color) indicator. These are rich data sources, but work needs to be done to determine if this would be a valuable and reliable measure across census tracts in Washington State.

Disability Status

This indicator represents populations that have a higher proportion of people living with disabilities. Specifically, it includes those who have impaired or low vision, are deaf or hard of hearing, have limited or incomplete physical mobility, or are experiencing developmental disabilities. Colorado’s EnviroScreen is the only tool that includes this indicator, citing that people living with disabilities could have less capacity to respond to environmental hazards.

If there is significant variability across census tracts this could be a valuable measure to include. Washington could use the same data source (ACS) as Colorado EnviroScreen. This is a rich data source, but work needs to be done to determine if this would be a valuable and reliable measure across census tracts in Washington State.

VI. Composite Score Assessment

This section walks through the differences in each state tool's approach to calculating the composite score and creating the final cumulative impact ranks. We start with the individual indicators and how they are combined into themes, how the themes are combined into component scores, then finally how the component scores are combined into the composite score. The section finishes with a small discussion of sensitivity completed by other researchers and a comparison of how changes in methods would impact Washington's rankings.

A) Indicators and Themes

Once indicator measures have been calculated for each census tract, those measures are ranked across census tracts from the lowest to the highest value. All indicators are set up so low values are indicative of lower environmental exposures and lower vulnerability and high values are indicative of higher environmental exposures and higher vulnerability. Differences across tools are outlined in Exhibit A23.

Ranking

Colorado EnviroScreen and MiEJScreen follow CalEnviroScreen's method of ranking the census tracts into percentiles for each indicator. The Washington EHD Map does rank a little differently and ranks the indicators into 10 bins (or deciles). If two census tracts have the same value across the bin cut-off, they are both placed in the lower bin of the cut-off. This method preserves the general ranking but loses some of the exact precision of ranking between census tracts with very close values.

There are pros and cons to this approach. Precision is something to value in a mathematical process. However, for any ranking method, the distance between each rank varies. The difference from the 2nd to 3rd rank can be much more or much less than the difference between the 8th to the 9th. One could argue that preserving the rank to the hundredths (percentiles) place is unnecessary and gives the impression that there is a meaningful and standard difference from say the 45th to 46th place, when in fact there is not. However, the difference between the 80th percentile and the 90th percentile (roughly a decile) likely is meaningful, though not a standard difference.

Exhibit A23

Indicators and Themes

Methods for composite score	Washington EHD Map	California EnviroScreen	Colorado EnviroScreen	Michigan MiEJScreen
Reliability checks	Zeros are included in the ranking, due to the WTN IBL ranking no indicator is given a missing value, instead they are assigned a zero rank.	Zeros are included in the ranking, reliability criteria are applied, and if "unreliable," that indicator does not receive a percentile rank	Zeros are included in the ranking, if data are missing or NA, that indicator does not receive a percentile rank	Zeros are included in the ranking, if data are missing or NA, that indicator does not receive a percentile rank
Individual indicator ranking method	Deciles (1-10)	Percentiles (1-100)	Percentiles (>0-100)	Percentiles (1-100)
Themes (# of indicators)	**1.** Environmental Exposures (5) **2.** Environmental Effects (5) **3.** Sensitive Populations (2) **4.** Socioeconomic Factors (7)	**1.** Exposures (7) **2.** Environmental Effects (5) **3.** Sensitive Populations (3) **4.** Socioeconomic Factors (5)	**1.** Environmental Exposures (9) **2.** Environmental Effects (7) **3.** Climate Vulnerability (4) **4.** Sensitive Populations (9) **5.** Demographics (6)	**1.** Environmental Exposures (6) **2.** Environmental Effects (7) **3.** Sensitive Populations (5) **4.** Socioeconomic Factors (8)
Theme score method	Arithmetic mean of indicator deciles	Arithmetic mean of indicator percentiles	Geometric mean of indicator percentiles	Arithmetic mean of indicator percentiles
Theme score ranking method	Deciles (1-10)	Percentiles (1-100)	Percentiles (>0-100)	Percentiles (1-100)

Data Variability Checks

CalEnviroScreen also employs reliability checks on indicators from sample populations, which are mostly measures from the American Community Survey (ACS) or health data sources. For ACS they apply the following criteria: A census tract's estimate must have either 1) a relative standard error less than 50 or 2) a standard error less than the mean of standard errors of all census tract estimates. They applied similar criteria to census tracts with small counts for rates of health outcomes. When data were categorized as unreliable or missing for a geographic area, such as census data with large uncertainties, it was excluded from the percentile calculation and was not assigned any score for that indicator. This ensures that the census tract's estimate and rank are based on a certain standard of reliability.

The rest of the state tools do not include this check to censor values. Instead, raw indicator values, are included in that census tract's indicator value and the percentile ranking for that indicator if they are not missing. Colorado EnviroScreen and Michigan MiEJScreen indicators with missing values did not receive a rank for that percentile. For the Washington EHD Map, if values are missing, that census track was assigned a rank of zero for that indicator and that rank was included in the theme score.

For most tools after ranking individual indicators, the indicator percentiles are then combined into a theme score by taking the average of the indicator percentiles. However, Colorado's EnviroScreen approach is different. Rather than take the typical arithmetic mean (Eqn 1), they instead take the geometric mean (Eqn 2) to calculate the theme score. They cite this as a more appropriate way to combine indicators that are related, or correlated, which many indicators are.

Equation 1. Arithmetic Mean

$$\frac{x_1 + x_2 + \cdots + x_n}{n}$$

Equation 2. Geometric Mean

$$\sqrt[n]{x_1 * x_2 * \ldots * x_n}$$

Tools also vary by how many indicators they have in each theme and the mixture of indicators included in each theme. Depending on the theme or the tool, the number of indicators ranges from two to nine. This dynamic comes into play when considering how much each indicator contributes to the overall score. The more indicators in a theme, the less each indicator contributes, and some tool themes are more diverse than others. For example, the sensitive population's theme in the Washington EHD Map only has two indicators (cardiovascular disease and low birth weight), while Colorado's EnviroScreen has nine indicators that capture a wider range of conditions and health-sensitive populations, all of which are given equal weight. Depending on the relative concern or level of vulnerability of these populations, the assumption of equal weight and equal importance may not be a proper one. More information is good, but any addition of an indicator to an established tool should be done thoughtfully to make sure that the down-weighting of relevant information is not traded off for a greater number of measures.

Indicator Placement and Weights

Another difference to note is that in some instances, indicators are included in different themes. Colorado includes the age group indicators (percent under 5 years & percent 65 years and older) in their sensitive populations rather than their demographics or socioeconomic factors theme like MiEJScreen. In this case the difference may be minimal because there are at least five indicators without the age groups in each theme. Both tools include the age groups in the theme with a greater number of indicators, so the age groups' relative weight in each is approximately the same. However, if Washington added these measures, their placement in various themes will have different impacts. The impact of including both age groups in the socioeconomic factors theme (seven indicators) would be relatively small but adding them to the sensitive population's theme would drop the current contribution of the cardiovascular and low birth weight indicators by half.

Another instance of differential placement is in the CalEnviroScreen and Colorado EnviroScreen tools, lead-based paint is in the environmental exposures theme rather than the environmental effects theme like the Washington EHD Map and MiEJScreen. This gives the lead-based paint indicator roughly double the weight that it would have in the environmental effects theme due to the differential weighting of those themes in the component score which is discussed in the next section.

B) Component Scores and Composite Scores

Once theme scores are calculated, the census tracts are ranked and then combined into an average to get two component scores: pollution burden and population characteristics. The pollution burden score has slightly different weights depending on the tool, but in general, it is common to weight environmental effects by half compared to environmental exposures. Colorado's EnviroScreen also includes an additional theme, climate vulnerability, that also receives a half weight compared to environmental exposures. Washington divides their pollution burden score by 2 though the sum of weights is 1.5. This is different from other tools and is not the proper calculation of a weighted average, but it does not impact the ranking of the final composite score.

Once component scores are calculated, most other tools scale that score to a 1-10 range by dividing the component score by the maximum value of a census tract in that state and multiplying by ten. This forces the final composite score to be in a range between 1-10. The Washington EHD Map is the only tool that does not do this. However, completing this extra step does not change the final scores' rank percentile or decile, which is ultimately what is presented in the mapping tools.

Exhibit A24

Components, Scores, and Scaling

Methods for composite score	Washington EHD Map	California EnviroScreen	Colorado EnviroScreen	Michigan MiEJScreen
Components (# of themes)	**1.** Pollution burden (2) **2.** Population characteristics (2)	**1.** Pollution burden (2) **2.** Population characteristics (2)	**1.** Pollution & climate burden (3) **2.** Health & social factors (2)	**1.** Environmental conditions (2) **2.** Population characteristics (2)
Component score (CS) method	**Pollution burden score** = $\frac{E\ Exp + \left(\frac{1}{2} E\ Eff\right)}{2}$ **Population characteristics score** = $\frac{S\ Pop + Soc\ F}{2}$	**Pollution burden score** = $\frac{E\ Exp + \left(\frac{1}{2} E\ Eff\right)}{1.5}$ **Population characteristics score** = $\frac{S\ Pop + Soc\ F}{2}$	**Pollution & climate burden score** = $\frac{E\ Exp + \left(\frac{1}{2} E\ Eff\right) + (\frac{1}{2} Cl\ V}{2}$ **Health & social factors score** = $\frac{S\ Pop + Demo}{2}$	**Environmental conditions score** = $\frac{E\ Exp + \left(\frac{1}{2} E\ Eff\right)}{1.5}$ **Population characteristics score** = $\frac{S\ Pop + Soc\ F}{2}$
Component score scaling	None	**Scaled CS** = (CS ÷ CS_{max}) × 10	**Scaled CS** = (CS ÷ CS_{max}) × 10	**Scaled CS** = (CS ÷ CS_{max}) × 10
Composite score method	Pollution burden × Population characteristics	Scaled pollution burden × Scaled population characteristics	Scaled pollution & Climate burden × Scaled health & social factors	Scaled environmental conditions × Scaled population characteristics
Composite score ranking method	Deciles (1-10)	Percentiles (1-100)	Percentiles (1-100)	Percentiles (1-100)

C) Sensitivity Analyses Reported

California and Washington have published multiple sensitivity analyses to explore the robustness and prediction power of the composite score methodology. This section summarizes those analyses to date.

In the first publication describing the development of the EHD Map, a series of Spearman's correlation tests found that only linguistic isolation and race/ethnicity indicators were *highly* correlated. [90] They also conducted a principal components analysis (PCA) to determine what combination of indicators most contribute to the composite score. In PCA, the indicators are combined in new ways to form the principal components-the concepts that most explain why the composite score would be high or low. In this case, they found that five principal components accounted for 66.26% of the variance in the composite score. The components corresponded approximately to (1) pollution related to urbanized areas, (2) socioeconomic factors, (3) traffic-related pollution, (4) hazardous waste, and (5) peri-urban related pollution, with each accounting for 28.71%, 14.43%, 8.41%, 7.77%, and 6.95% of the variance, respectively. One of CalEnviroScreen's first papers (related to version 3.0) also conducted a PCA that found that two principal components explained 43% of the variance in the composite score.[91] The components were affiliated with 1) industrial activity and air pollution and 2) ozone, particulate matter 2.5, and drinking water contamination.

In later publications, Washington tool creators found that communities of color and low-income communities face a disproportionate burden of cumulative environmental threats, which matches the results of CalEnviroScreen's Analysis of Race/Ethnicity and CalEnviroScreen 4.0 Scores.[92]

With each update, CalEnviroScreen compares the new version to the previous version of the rank and census tract ranks. Washington also conducted a comparison of Version 2.0 to 1.0 summarized at the end of their 2.0 technical report.[93] This included an analysis examining the relationship between the cumulative ranks (deciles) and life expectancy, where they demonstrated a relationship between higher cumulative impact ranks and lower life expectancy.

Alternative models are being explored. The CDC's Environmental Justice Index was just released that utilized Sadd's Environmental Justice Screening Method and another group has just proposed a new index called the Environmental Burden Index[94]

[90] Min et al. (2019).
[91] Ibid.
[92] Min, E., Piazza, M., Galaviz, V.E., Saganić, E., Schmeltz, M., Freelander, L., . . . Seto, E.Y. (2021). Quantifying the distribution of environmental health threats and hazards in Washington State using a cumulative environmental inequality index. *Environmental Justice, 14*(4), 298-314.; Office of Environmental Health Hazard Assessment and California Protection Agency. (2021). *Analysis of Race/Ethnicity and CalEnviroScreen 4.0 Scores*.
[93] University of Washington Department of Environmental & Occupational Health Sciences and Washington Department of Health. (2022). *Washington environmental health disparities map: Cumulative impacts of environmental health risk factors across communities of Washington state: Technical report version 2.0*.
[94] Sadd et al. (2011).
Owusu, C., Flanagan, B., Lavery, A.M., Mertzlufft, C.E., McKenzie, B.A., Kolling, J., . . . Dent, A. (2022). Developing a granular scale environmental burden index (EBI) for diverse land cover types across the contiguous United States. *Science of The Total Environment, 838*, 155908.

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