Contents

I Overview

To inform Agency action toward providing an equitable degree of protection from environmental and health hazards, and to enhance the ability to focus on overburdened and vulnerable communities throughout the policy development process, EPA recently developed the Power Plant Screening Methodology described in this document. While there are several potential applications of this methodology and the associated components, the primary objective is to apply this methodology as a screening-level tool to quickly rank fossil steam electric generating units (coal-, oil-, and natural gas-fired boilers serving electric generators) in the contiguous US based on their relative potential to affect areas of potential EJ concern.

The methodology described in this document is intended to provide a screening-level look at the relative potential for power plants to affect areas with possible EJ concerns. Screening is a useful first step in understanding or highlighting locations and/or emissions sources that may be candidates for further review. However, it is essential to remember that screening-level results do not provide a complete assessment of risk and have significant limitations. Furthermore, this methodology is designed to be used as a starting point, to highlight the extent to which certain locations and/or emissions sources may be candidates for further review or outreach. Additional considerations and data, such as national, regional, or local information and concerns, along with appropriate analysis, should form the basis for any decisions.

This methodology does not consider the magnitude of the potential for each plant to affect nearby or downwind air quality. Rather, this methodology focusses on the potential for each fossil steam plant to impact communities with possible EJ concerns, and recognizes that any relative difference in air emissions or changes in emissions should be considered in secondary analyses. The intended purpose of this methodology is to score facilities based on potential to affect areas, while other analyses would evaluate other aspects of pollution from those facilities, including the magnitude and type of various pollutants.

There are two key components to this methodology: the identification of areas potentially affected by each power plant, and the relative potential for EJ concerns in those areas. In order to identify the areas that are potentially affected by air pollution from each facility, we look at a range of distances from each facility, informed by modeling that can estimate where air pollution from each source travels. Next, using environmental burden and demographic information, we identify the relative potential for EJ concern at a block group level across the country, utilizing both a cumulative impacts perspective as well as a vulnerability perspective. This information is combined to develop various scores for each facility that characterize the relative potential of that facility to affect either a greater number of overburdened people or the most vulnerable people on average. The relative scores can then be used to screen the facilities.

The remainder of this document is organized as follows:

Section II discusses the current scope of this analysis, detailing which power plants are currently included in the screening analysis. Section III discusses the various approaches for identifying the census block groups that are potentially affected by air pollution from each power plant. Section IV explains the two approaches used in this methodology to identify areas of potential EJ concerns. Section V describes how different scores are calculated for each facility, and Section VI presents results.

II Scope

This methodology evaluates the potential for two types of power plants, coal steam and oil/gas steam boilers, to affect nearby and farther downwind areas. Each power plant (or facility) is comprised of one or more electric generating units (EGUs),[1] and each of those EGUs has an associated stack through which combustion gases are exhausted into the air. The height of each stack is an important metric that plays a significant role in the downwind distribution of emissions.

The following sections discuss how various scores are developed for the 223 coal and 194 oil/gas steam facilities summarized in Appendix II. This list includes 473 coal EGUs which emit through 281 distinct facility/stack combinations, and 434 oil/gas steam EGUs which emit through 268 distinct facility/stack combinations.[2] This inventory is based on the National Electric Energy Data System (NEEDS) v6 January 24, 2022 database[3], which includes all grid-connected operational generation capacity. Note that the NEEDS database is forward-looking and excludes planned retirements as of January 2022. Geospatial coordinates and stack heights are added based on information available in the NEI as of March 2022.[4]

Finally, it is important to note that while this methodology develops facility- and unit-level scores for all EGUs listed in Appendix II, it is possible to conduct an analysis of any subset of those EGUs, which is discussed in further detail in Appendix IV.

III Identifying potentially-impacted areas

III.A Overview

This methodology utilizes two approaches to identify the areas that are potentially affected by each plant: proximity analysis and long-range downwind transport. Each of these approaches uses air quality modeling combined with GIS analysis to identify each census block group that is potentially affected by air pollution from each of the power plants discussed above. The proximity analysis approach focuses on the air quality impacts within 50 km of the source. The long-range downwind transport approach focuses on the *potential* air quality impacts at distances generally greater than 50 km from the sources. Each of these is described in the sections immediately below. It is important to note that the chemistry or deposition specific to any individual pollutant is not accounted for in this methodology. In Appendix V, for some example units, we have included some analysis of potential air quality concentrations of $PM_{2.5}$ and Ozone where we have accounted for the chemistry.

III.B Proximity Analysis

<u>Overview</u>

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[1] This analysis includes all fossil steam EGUs, and is not limited to EGUs greater than 25 MW.
[2] Note that some facilities may consist of more than one type of EGU
[3] https://www.epa.gov/power-sector-modeling/national-electric-energy-data-system-needs-v6
[4] https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei

Proximity screening analysis is a common approach used to identify areas that may be potentially affected by a source. In this approach, a radius of a certain distance is mapped around each facility to identify the census block groups that fall within the specified distance. The key variable in this approach is the distance value that defines the radius.

This methodology utilizes three alternative proximity analyses, each defined by a different radius: a 5 km radius that is consistent across all facilities (a commonly used distance for proximity analysis), and two radii that vary by facility based on near-field air quality modeling for each facility.

To determine the two variable radii for each individual unit, EPA used the AERMOD Modeling System, or AERMOD[5,6], which is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, along with detailed terrain and unit-specific characteristics, to estimate pollutant concentrations within 50 km from a source. AERMOD is EPA's preferred near-field modeling system of emissions for distances up to 50 km.[7] Using modeling for each coal- and oil-fired electric utility steam generating unit (EGU), we identified a distance associated with the area of maximum pollutant concentration, as well as an "intermediate concentration distance" where the concentrations are likely still impactful but have decreased substantially from peak values.

Identifying Distances for Proximity Analysis

In air quality programs, the initial screening methods used for environmental justice activities analyze a community's proximity to air pollutant sources using a pre-determined cut-off distance. In this methodology, a common 5 km distance is used as one approach to identify areas potentially affected by each facility. In addition to using a pre-determined cut-off distance, EPA used AERMOD dispersion modeling to determine two facility-specific screening distances to identify potentially-impacted census block groups within close proximity to a source: a "maximum concentration radius" and an "intermediate concentration radius."

The AERMOD modeling for EGUs used for this analysis was readily available resulting from the Air Toxics Screening Assessment module within the 2017 National Air Toxics Data Update performed by the Office of Air Quality Planning and Standards.[8] This modeling was initially used to support the estimation of ambient concentrations of air toxics for sources across the United States. Prognostic meteorological data from the Weather Research and Forecasting Model (WRF) was processed through EPA's Mesoscale Model Interface (MMIF) program to create AERMET ready meteorological input data and processed in AERMET (version 19191). Sources were then modeled in AERMOD (version 19191) using the processed meteorological data and source specific information regarding location, release characteristics, temporal

[5] Cimorelli, A.J., Perry, S.G., Venkatram, A., Weil, J.C., Paine, R.J., Wilson, R.B., Lee, R.F., Peters, W.D. and Brode, R.W. 2005. AERMOD: A Dispersion Model for Industrial Source Applications. Part I: General Model Formulation and Boundary Layer Characterization. Journal of Applied Meteorology, 44: 682–693.
[6] EPA. 2015. User's Guide for the AMS/EPA Regulatory Model – AERMOD. EPA-454/B-03-001. Addendum June 2015. EPA, Research Triangle Park, NC.
[7] EPA. 2017. Revisions to the Guideline on Air Quality Models: Enhancements to the AERMOD Dispersion Modeling System and Incorporation of Approaches To Address Ozone and Fine Particulate Matter. 82 Federal Register 10 (17 January 2017), pp. 5182-5231.
[8] Details regarding the 2017 National Air Toxics Data Update are available at: https://www.epa.gov/haps/air-toxics-data-update

variability, and source emissions.[9] Each source was modeled using "gridded" receptors (spaced at 1 or 4 km distances) out to 50 km from the source and census block centroid receptors out to 10 km.[10] The model results provide facility-level annual average concentrations (ug/m^3) for each receptor assuming a unit emission rate of 10,000 tons per year of $PM_{2.5}$ for all sources.[11] It should be noted than a unit $PM_{2.5}$ emission rate of 10,000 tons per year is an extremely conservative emission rate and exceeds the annual $PM_{2.5}$ rate of any EGU reported in the 2017 National Emission Inventory; therefore, all concentrations and distances resulting from this modeling are also conservative and should only be used in the context of this proximity screening analysis to identify a screening-level radius. [12] The annual average concentration results were spatially visualized (Figure 1) to gain a greater understanding of the concentration variability and gradients around each facility. Elevated concentrations were rarely evenly distributed around the source. As seen in Figure 1, there are multiple areas of elevated concentration around this source resulting from the effects of local meteorology and topography on pollutant dispersion. The distance between the source and each receptor was measured to generate a distribution of the annual average concentration at each receptor as a function of distance from the source shown in Figure 2. For all EGUs, the distributions generally paralleled an exponential decay function with the highest concentrations located within the first 5 km of the source and substantially decreased as the distance from the source increased.

A "maximum concentration radius" was determined for each source by averaging the distances to the ten highest concentrations around a source. By defining a radius based on the ten highest concentrations, it was inclusive of not only the location of the absolute maximum concentration in the modeling domain, but also additional areas of elevated concentration located at a variety of distances. The distribution of all maximum impact radii for coal- and oil-fired EGUs are shown in Figure 3. The median maximum impact radius for all coal-fired EGUs was 2.01 km, with distances ranging from 0.21 to 16.67 km. Distances to the maximum impact radius around oil-fired units were smaller, with a median of 1.22 km and ranging from 0.18 to 6.21 km.

Although the area of maximum concentration is of importance in proximity screening, it is not inclusive of all communities that may be impacted by a source. To allow users to screen for additional communities beyond the area encompassed using the maximum concentration radius, the 25th, 50th, and 75th percentile of the concentration distribution was calculated to provide additional screening distances for each facility. To determine the distance associated with each percentile rank, the concentration data for each facility were binned by distance into 50 bins (1 km in size, from the facility out to a distance of 50 km) and the median concentration within each distance bin was calculated. The median concentration percentile ranks and the associated distances are detailed in Table 1. To ensure the

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[9] Details regarding the AERMOD modeling used in this analysis be found in the Technical Support Document for EPA's Air Toxics Screening Assessment available at: https://www.epa.gov/system/files/documents/2022-03/airtoxscreen_2017tsd.pdf

[10] The equally spaced "gridded" receptors are set to 1 km in highly populated areas and 4 km otherwise.

[11] The chemistry or deposition specific to any individual pollutant is not accounted for when using a unit emission rate in AERMOD.

[12] This assumption of a uniformly high emission rate (which does not consider pollution controls or actual emissions rate) allows us to characterize *where* pollution may be transported and therefore which areas might be impacted, but it does not tell us about the *magnitude* of that impact.

distances were inclusive of the percentile rank concentration, the upper bound of the distance bin was selected for the radii.

In this screening methodology, EPA uses the 50th percentile distance at each facility to represent the "intermediate concentration distance" for purposes of proximity analysis. Figure 4 shows the distribution of the 50th percentile distances for all coal- and oil-fired EGUs. The distance associated with the 50th percentile concentration for coal-fired EGUs had the highest frequency between 25 to 35 km (Figure 4); whereas, the distances for oil-fired EGUs were more evenly distributed across various distances with a peak at 12 km. While the 50th percentile distance is used in this methodology, this intermediate proximity analysis can be extended to any percentile within the distribution to gain a better understanding of the relative potential for the facilities included in the analysis to affect areas based on higher or lower concentration levels at different distances.

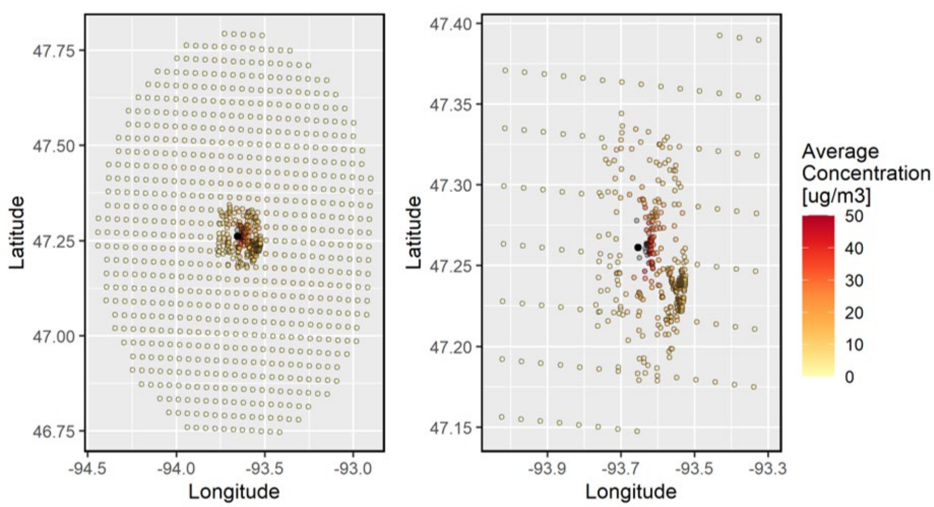

Figure 1. Spatial plots of 50 km modeling domain (left) and zoomed (right) of annual average concentration at each receptor surrounding an example coal-fired EGU.

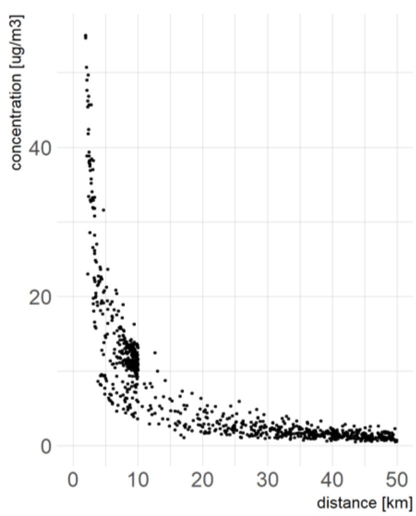

Figure 2. Distribution of annual average concentration (ug/m^3) as a function of distance (km) at an example coal-fired EGU.

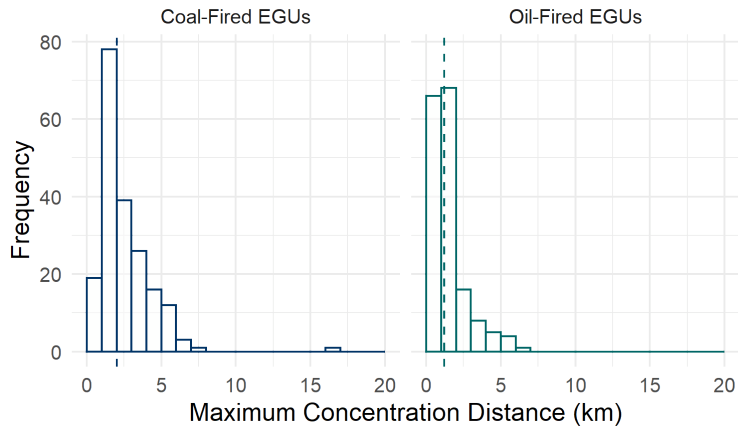

Figure 3. Distribution of all maximum concentration distances (i.e., averaged distance to top ten concentrations) for coal- and oil-fired EGUs. The median of the distribution is indicated by the vertical dashed line.

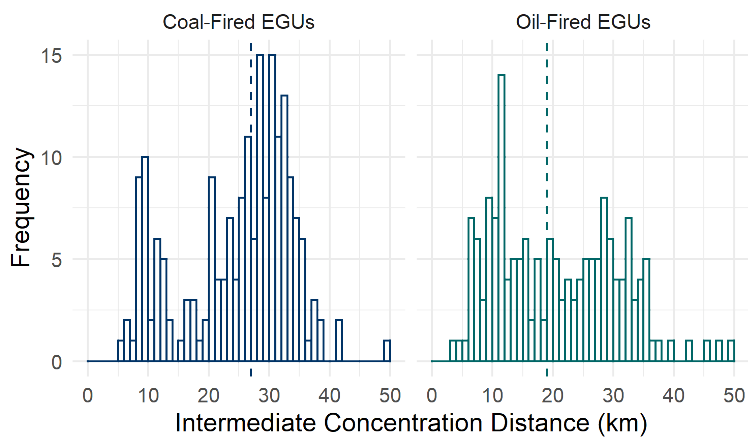

Figure 4. Distribution of all "intermediate concentration distances" (i.e., 50th percentile of total concentration distribution) for coal- and oil-fired EGUs. The median of the distribution is indicated by the vertical dashed line.

		25th Percentile	50th Percentile	75th Percentile
Coal-Fired EGUs	Concentration (ug/m^3)	0.614	1.28	3.202
	Distance (km)	49	28	15
Oil-Fired EGUs	Concentration (ug/m^3)	0.604	1.23	3.21
	Distance (km)	47	27	14

Table 1. Median intermediate concentration distances for the 25th, 50th, and 75th percentiles of the concentration distributions for all coal- and oil-fired EGUs.

Combining Distances with Census Block Groups

For each facility, and for each of the three radii identified above, EPA identified the census block groups and portions of those block groups located within the distance using a spatial analysis. The following process was completed for each facility included in this analysis. First, for each of the three radii discussed above, a circle with the center being the latitude and longitude of the facility was created using the ArcGIS 10.8 buffer command. Next, in order to identify all of the complete and partial block groups within each radius, each circle was spatially joined to the 2019 census block group spatial file[13] using an intersection. Finally, the total area included inside each circle was calculated for each block group, and converted to a share of the total area of that block group.

It is important to note that the spatial relationship analysis for each facility and radius was done separately, because some facilities are adjacent to one another, and their radii overlap (see Figure 5b). A block group could be split in the area where the two radii overlap, resulting in a divided census block group and an incorrect total area and percent if the evaluation was not conducted for each facility independently. The ArcPy command "arcpy.ListFeatureClasses" was used with the spatial join command to complete each join correctly.

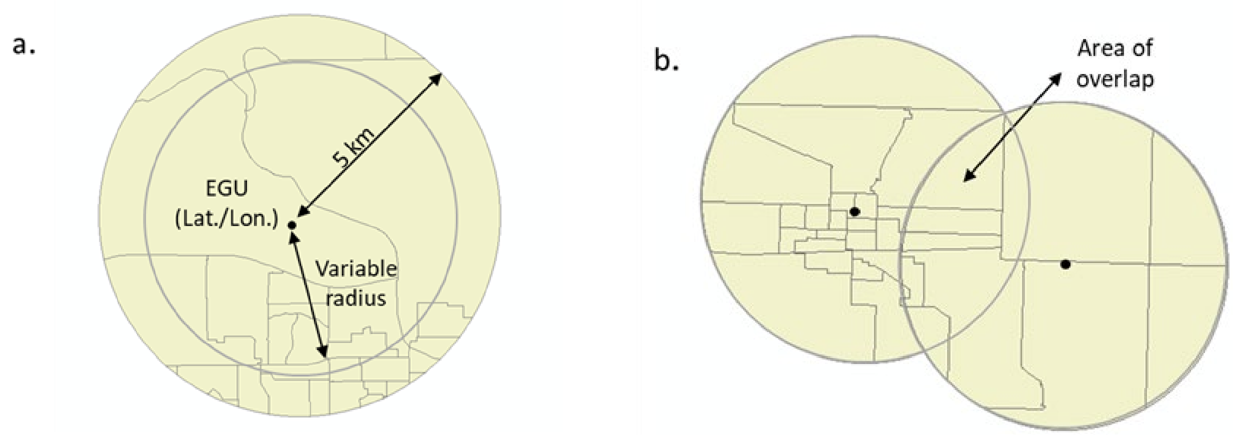

Figure 5. a. Illustration of the proximity analysis done for each EGUs, and b. an example of where two radii overlap. Census block groups are presented within each circle.

III.C Long-Range Downwind

Overview

In addition to identifying census block groups in the immediate vicinity of the facilities, this methodology also identifies census block groups located farther downwind that may also be impacted by each source. This long-range downwind approach is based on trajectory modeling, which provides potential path lines for each pollutant as it is transported through the atmosphere around the country. Associating these

[13] https://www.census.gov/topics/research/guidance/planning-databases/2019.html

trajectories with intersected census block groups enables the identification of census block groups that are potentially impacted by pollutants from each facility.

The sections below discuss the details of that modeling, and how those results are associated with census block groups

HYSPLIT methodology

To identify potentially-impacted census block groups located at greater distances from the sources, EPA used the "trajPlot" function within NOAA's Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model to generate forward trajectories for the set of large coal-fired and oil/gas steam-fired EGUs identified in the first section.[14,15] A forward trajectory is a modeled parcel of air that moves "forward" as time progresses (i.e., downwind) due to winds and other meteorological factors traveling over various parts of the country.[16] The HYSPLIT model uses gridded modeled meteorological fields. Neutrally buoyant "particles", or air parcels, are introduced into the gridded meteorological fields at the location of the "source".[17] In these simulations the starting location of the trajectory is the location (latitude and longitude) and the height of the stack (specified as the elevation above ground level) of the EGU. The transport of the simulated air parcels "emitted" at the source is then governed by the meteorology in the grid cell where the air parcel is located at that time step. As modeled time progresses, the meteorological fields are updated, and the air parcel moves (traveling from one grid cell to the other) as it responds to the updated meteorology within the grid cell that contains it. The output of the HYSPLIT model is a time-step by time-step list of point locations where the air parcel is located. In the simulations here, the location of the air parcels was recorded hourly.

The meteorological modeling used within HYSPLIT in these simulations was the NOAA's National Center for Environmental Information North American Mesoscale Forecast System 12 kilometer forecast gridded meteorology dataset (NAM-12)[18]. The horizontal resolution of this NAM-12 dataset is 12.191 kilometers, the vertical resolution is 26-layers from 1000 to 50 hectopascals, and the temporal

[14]Stein, A. F., Draxler, R. R., Rolph, G. D., Stunder, B. J. B., Cohen, M. D., and Ngan, F. (2015). NOAA's HYSPLIT Atmospheric Transport and Dispersion Modeling System. *Bulletin of the American Meteorological Society* 96, 12, 2059-2077, available from: < https://doi.org/10.1175/BAMS-D-14-00110.1> [Accessed 16 June 2022]
[15] Draxler, Roland & Hess, G.. (1998). An overview of the HYSPLIT_4 modeling system for trajectories, dispersion, and deposition. Australian Meteorological Magazine. 47. 295-308.
[16] The HYSPLIT model can also be run with "backward" trajectories, where air parcels located at a particular receptor at a particular time can be traced back in time to estimate where potential pollution contained in that air parcel may have originated. A trajectory path line connecting a source and a receptor can be found using either forward or backward trajectories.
[17] It is important to note that unlike the other models used to quantify downwind ozone concentrations, the HYSPLIT model is not a photochemical model – the model does not include chemical transformation and does not provide estimates of downwind pollutant concentrations.

[18] https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C00630

resolution is 3-hours.[19,20] The NAM-12 model domain is West: -152.9°, East: -49.4°, South: 12.1°, and North: 61.0° North. This covers the contiguous United States.

While fairly well-resolved, in areas of complex terrain or with multiple land use or land types, at this size-scale, the grid resolution of the meteorological fields may result in some uncertainty in the trajectory simulation. We limited the model results to the continental United States up to a maximum elevation of 10,000 meters above ground level. Trajectories traveling outside this domain were truncated. The coordinates of each trajectory were recorded along the entire 24-hour path, including all points at which the elevation was at ground level.

For each EGU, we used the HYSPLIT model to simulate the downwind path line trajectories of air parcels "released" at the locations of individual units four times per modeled day—12:00 AM, 6:00 AM, 12:00 PM, and 6:00 PM (local standard time) from June 1 to August 31 for the years 2017 to 2019.[21] The June to August time-period was selected because it represents days when some of the highest concentrations of some atmospheric pollutants (e.g., ozone, ammonium sulfate) are found. The time zone of each EGU was determined to ensure that the starting time of the trajectories in HYSPLIT, which is based on the Coordinated Universal Time (UTC) time zone from the meteorological model, coincides with the release times that are in local standard time.

We simulated trajectories each day across a 3-year time-period and followed the trajectories for the first 24-hours. [22,23] Consequently, we ran model simulations over 1,100 times for each facility (four simulations per modeled day across ninety-two days for each of three years). In essence, the HYSPLIT results here simply simulate the paths that the wind would carry a modeled parcel of air from the stack(s) of each EGU on each day. Consistent with the intent of this portion of the screening analysis, this HYSPLIT modeling provides information about where non-reactive, non-depositing pollutants might initially travel from each EGU over a limited 24-hour period but does not quantify the magnitude of impact at any given location.

From the model HYSPLIT simulation output, we extracted the geospatial coordinates for each of the modeled hourly locations of the air parcel along the trajectories. These points were then used to construct geospatial line segments in order to reconstruct 24-hour trajectories and estimate the

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[19]Stein, A. F., Draxler, R. R., Rolph, G. D., Stunder, B. J. B., Cohen, M. D., and Ngan, F. (2015). NOAA's HYSPLIT Atmospheric Transport and Dispersion Modeling System. *Bulletin of the American Meteorological Society* 96, 12, 2059-2077, available from: < https://doi.org/10.1175/BAMS-D-14-00110.1> [Accessed 16 June 2022]

[20] Draxler, Roland & Hess, G.. (1998). An overview of the HYSPLIT_4 modeling system for trajectories, dispersion, and deposition. Australian Meteorological Magazine. 47. 295-308.

[21] The HYSPLIT model is run assuming the air parcel is neutrally buoyant and inert (i.e., without any dispersion, deposition velocity, or atmospheric residence time constraints).

[22] While the 24-hour transport time used in this screening analysis identifies many of the near and more distant source areas that are the most frequently impacted, emissions can travel over larger distances and longer times and have substantive air quality impacts downwind (i.e., those impacts are typically analyzed in an RIA)

[23] For example, in 2016, the EPA used HYSPLIT to examine 96-hour trajectories and altitudes up to 1,500 meters in a corollary analysis to the source apportionment air quality modeling to corroborate upwind state-to-downwind linkages. Details of this analysis can be found in Appendix E ("Back Trajectory Analysis of Transport Patterns") of the Air Quality Modeling Technical Support Document for the Final Cross State Air Pollution Rule Update, which is available at: https://www.epa.gov/sites/default/files/2017-05/documents/aq_modeling_tsd_final_csapr_update.pdf

continuous spatial patterns of longer-distance pollutant transport from EGUs and to relate those trajectories to the census block group locations.[24]

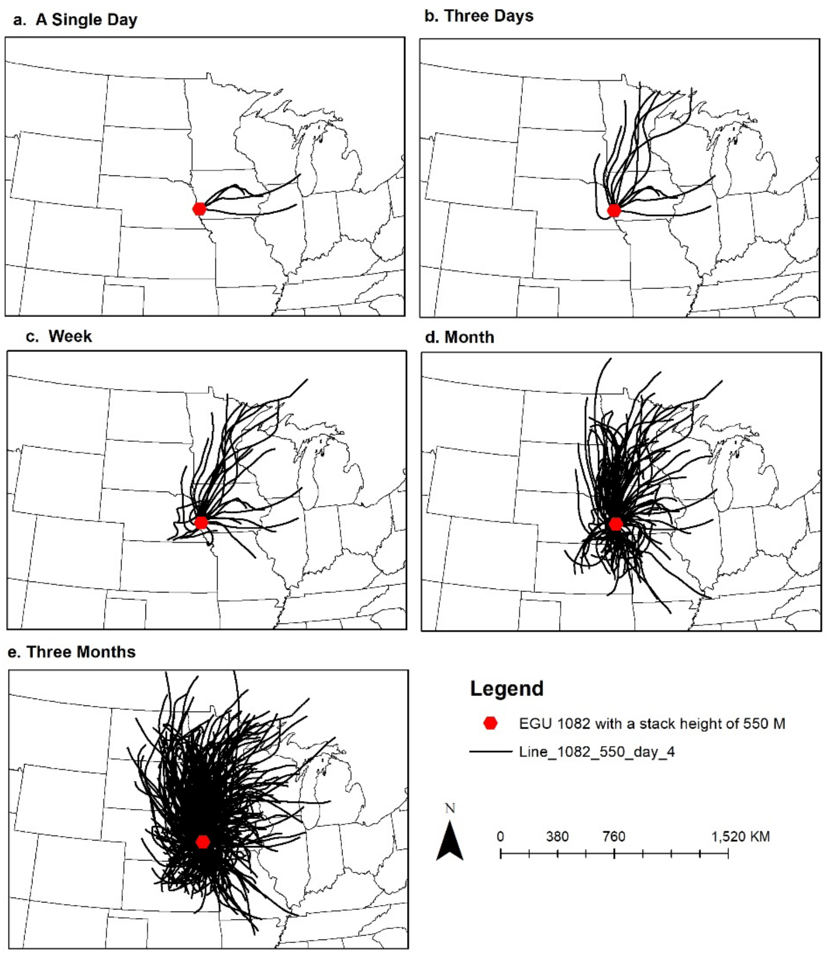

Figure 6. HYSPLIT output showing (a) a single day's four trajectories, (b) three days of trajectories, (c) twenty-eight trajectories (one week's worth), (d) 120 trajectories (one month's worth), and (e) 360 trajectories (three month's worth) from a coal-steam EGU (ORIS Code 1082 with stack height of 550 meters) in Iowa (MON DD, YYYY)

[24] In general, pollutant concentrations are the result of transport, dispersion, and transformation. As noted, this analysis does not consider photochemical transformations.

Associating HSYPLIT Results with Census Block Groups

In order to determine which census block groups were potentially affected by long-range pollution from each power plant stack included in this analysis, the 24-hour HYSPLIT trajectories were associated with the 2019 census block groups by a spatial analysis. This spatial analysis is summarized below.

It is important to understand the format of the HYSPLIT trajectories. Each 24-hour HYSPLIT trajectory consists of sets of coordinates that represent 1-hour time steps along the trajectory path. Each of these 1-hour time steps is characterized by a series of two point locations, one at the beginning of the hour and one at the end. A line segment is drawn between the starting and ending coordinate for each hour using the “XY to line Feature” command in ArcGIS 10.8.

In order to associate the trajectories with the block groups they pass through, the “Spatial Join” command was then used to identify all block groups[25] that intersect with each of the 1-hour time step lines of each trajectory. Finally, all 1-hour time steps were combined to represent the continuous 24-hour trajectory.

Conducting this association at the hourly segment level results in the potential for some block groups to be counted more than once along a trajectory. For example, if a trajectory is projected to move through a particular block group over multiple hours, that block group would be included once for each hour. This effectively weights that block group higher when calculating the facility-level scores discussed in section V below.

It is important to note that this screening-level approach identifies all of the census block groups that may be impacted by air pollution from each power plant for the period analyzed. This approach does not consider the magnitude[26] of that impact, the atmospheric residence time, chemical dispersion, nor atmospheric deposition of the pollutant.

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[25] The spatial join used the 2019 census block groups spatial data for only the CONUS (https://www.census.gov/topics/research/guidance/planning-databases/2019.html)

[26] This would require information about atmospheric residence time, chemical dispersion, and atmospheric deposition, none of which are estimated in this screening analysis.

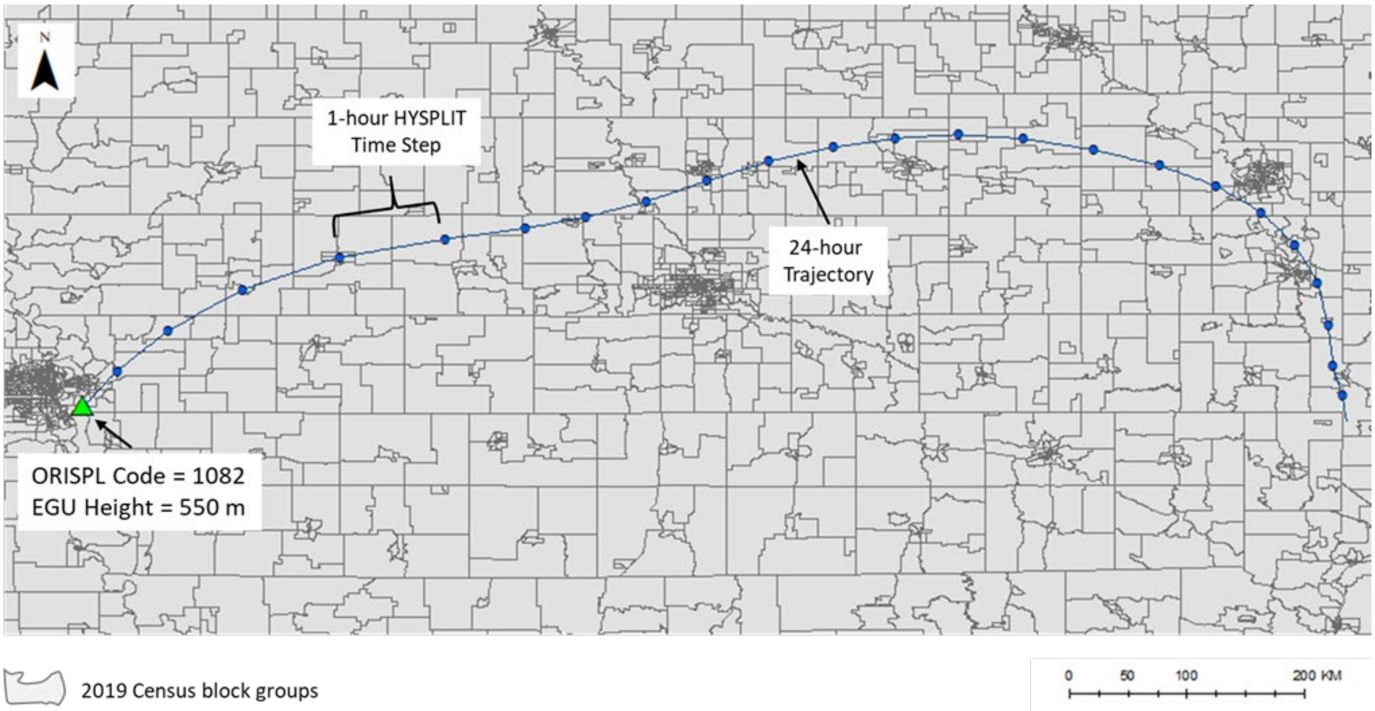

Figure 7. Example of the spatial analysis to identify census block group along the HYPSPLIT trajectories.

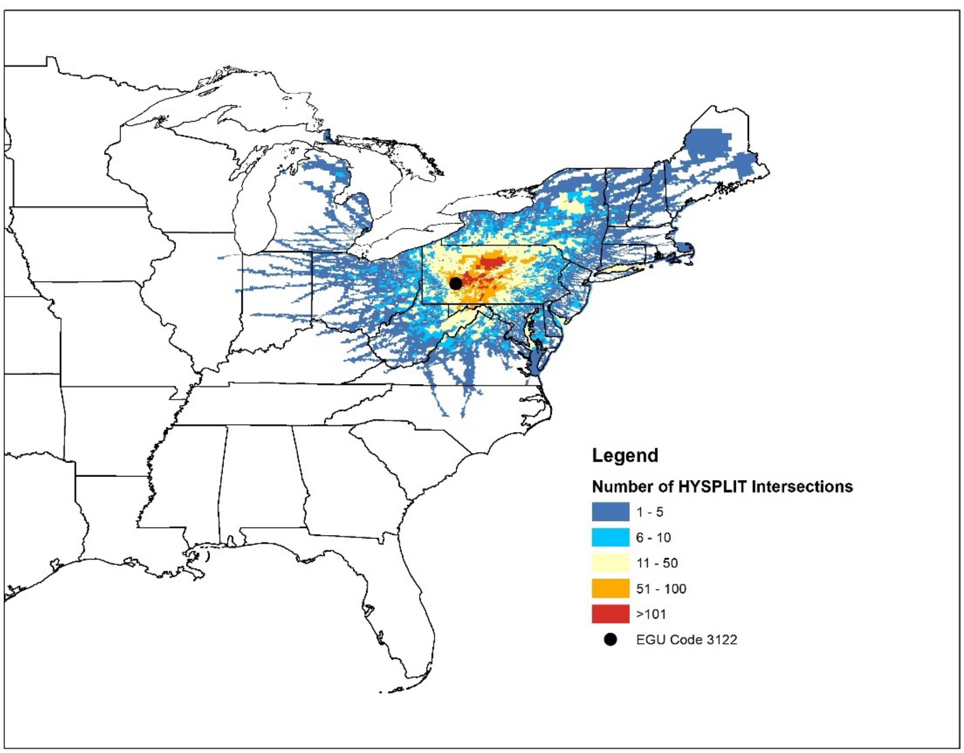

Figure 8. Frequency of HYSPLIT trajectory intersections with census block groups for one stack at one facility

IV Identifying areas with potential EJ concerns

IV.A Overview

This methodology applies two perspectives in order to determine which areas of the country might have EJ concerns, and the relative extent of those potential concerns: cumulative impacts and vulnerability. The cumulative impacts perspective considers the extent of existing pollution burden and vulnerability to that pollution. The vulnerability perspective focusses solely on potential vulnerability regardless of the amount of potential environmental burden.

It is important to recognize at the outset that our ability to quantify both cumulative impacts and vulnerability is an area of active research, and this methodology should be viewed as an initial screening-level effort to quantitatively evaluate these concepts nationally at a census block group resolution. Additionally, the methodology discussed below utilizes the best environmental burden and demographic data that is currently available nationally at this resolution. EPA intends to incorporate future advances in both the available indicators as well as our understanding of how those indicators can be combined to capture cumulative impacts and vulnerability.

The remainder of this section explains how two percentile values are developed for each block group based on these two different perspectives. As percentiles, these are relative values that simply provide a mechanism by which to rank the census block groups in order to facilitate comparison of those block groups. These values are not quantitative assessments of the total potential environmental burden, vulnerability, or risk of any block group.

IV.B Identifying Block Groups with Potential EJ Concerns: Cumulative Impacts Perspective

The cumulative impacts approach utilized in this methodology identifies block groups that might have environmental justice concerns by considering the existing pollution burden in each block group as well as the vulnerability to that pollution. This approach is based on the CalEnviroScreen[27] model, which is based on the CalEPA definition of "cumulative impacts":

> Cumulative impacts means exposures, public health or environmental effects from the combined emissions and discharges, in a geographic area, including environmental pollution from all sources, whether single or multi-media, routinely, accidentally, or otherwise released. Impacts will take into account sensitive populations and socioeconomic factors, where applicable and to the extent data are available.

Based on this definition, the CalEnviroScreen model separates indicators into two categories: Pollution Burden and Population Characteristics. Each of those categories is further separated into two components, which are groups of indicators. The Pollution Burden category consists of two components: Exposure indicators, which represent direct pollution exposure, and Environmental Effect indicators, which represent "adverse environmental conditions caused by pollutants."[28] The Population Characteristics category also consists of two components: Socioeconomic Factors, which are

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[27] https://oehha.ca.gov/calenviroscreen

[28] CalEnviroScreen 4.0 (October 2021). Available at: https://oehha.ca.gov/media/downloads/calenviroscreen/report/calenviroscreen40reportf2021.pdf

"community characteristics that result in increased vulnerability to pollutants," and Sensitive Populations, which are "populations with physiological conditions that result in increased vulnerability to pollutants."[29]

EPA's application of this methodology assigns EJScreen 2.0 indicators[30] to each of these components as summarized in Table 2.

Table 2. EPA Application of CalEnviroScreen Framework for the Cumulative Impact Screening Metric

Category	Components	EJScreen 2.0 Indicators Utilized by EPA
Pollution Burden	Exposure	•Ozone level in air •PM2.5 level in air •Diesel particulate matter level in air •Traffic proximity and volume •Air toxics cancer risk •Air toxics respiratory hazard index
	Environmental Effects	•Proximity to National Priorities List (NPL) sites •Proximity to Risk Management Plan (RMP) facilities •Proximity to Treatment Storage and Disposal (TSDF) facilities •% pre-1960 housing (lead paint indicator) •Wastewater discharge •Underground storage tanks (UST) and leaking UST (LUST)
Population Characteristics	Socioeconomic Factors	•% of households (interpreted as individuals) in linguistic isolation •% less than high school •% low-income •Unemployment rate
	Sensitive Populations	N/A

Note: additional information regarding each of these indicators is available in Appendix III

Note that, unlike CalEnviroScreen, EPA's application of this framework does not include any indicators within the Sensitive Populations component due to a limited number of relevant indicators[31] currently available nationwide at a block group level.

The numeric value for the each of the cumulative impact components is calculated as the average of all the indicators[32] within that component. For example, the value for the Exposure component is the average of the 6 exposure indicators. Going up one level to the category level, the value for the Pollution Burden category is the average of the two components within it: the Exposure value and the

[29] *Ibid.*

[30] 2021 release. Data available at: https://gaftp.epa.gov/EJSCREEN/2021/

[31] EJScreen 2.0 includes two relevant indicators: % under age 5 and % over age 64.

[32] This methodology uses EJScreen percentile values. To put indicator values in perspective, EJScreen converts raw indicator scores to population percentiles by dividing the number of US residents of block groups with the respective raw indicator value or lower by the total US population with known indicator values. The resulting percentile score describes the distribution of block group indicator scores across the population. For example, an 80th percentile score indicates that 20% of the US population reside in block groups with a higher value for the respective indicator. For further information, see: https://www.epa.gov/sites/default/files/2021-04/documents/ejscreen_technical_document.pdf

Environmental Effects value. In this case, the Environmental Effects component is half-weighted.[33] This is due to the fact that the environmental effects indicators within that component are considered to have less of an impact on a community's pollution burden when compared with the exposure indicators.[34] The Pollution Burden and Population Characteristics category values are then normalized (i.e., scaled) such that the range of values for each of the two factors falls between 0 and 10.[35]

The ultimate cumulative impact screening metric for each block group is calculated by multiplying the normalized Pollution Burden and Population Characteristics values together. The use of multiplication follows risk assessment guidelines and reflects the fact that population characteristics have the ability to modify a community's response to the pollution burden. Falling within a possible range from 0 to 100, each census block group is assigned a numeric vale which represents the relative cumulative impacts of multiple pollution sources on vulnerable people within each census block group. Finally, EPA ranked the block groups from lowest to highest based on the cumulative impact values, binning the block groups by the percentile rank. This percentile rank for each block group is the cumulative impact screening metric used in the facility-level scoring discussed in section V below.

It should be noted that the cumulative impact values are not meant to serve as quantitative assessments of the health impacts of pollution on communities or the vulnerability of communities to pollutants. Rather, these values provide a quantitative means by which to compare the burdens and vulnerabilities communities face from pollutants across these block groups. Higher values indicate that the respective block groups experience higher levels of pollution burden and/or may be more vulnerable to its impacts relative to block groups with lower cumulative impact values.

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[33] The exposure component therefore has a weight equal to 2/3, while the environmental effects component has a weight equal to 1/3.

[34] The CalEnviroScreen 4.0 (October 2021) documentation states: "This was done because the contribution to possible pollutant burden from the Environmental Effects component was considered to be less than those from sources in the Exposures component. More specifically, the Environmental Effects components represent the presence of pollutants in a community rather than exposure to them. Thus the Exposure component receives twice the weight as Environmental Effects component." Available at: https://oehha.ca.gov/media/downloads/calenviroscreen/report/calenviroscreen40reportf2021.pdf

[35] This is done by dividing each average by the maximum observed value for the respective factor and then multiplying that value by 10.

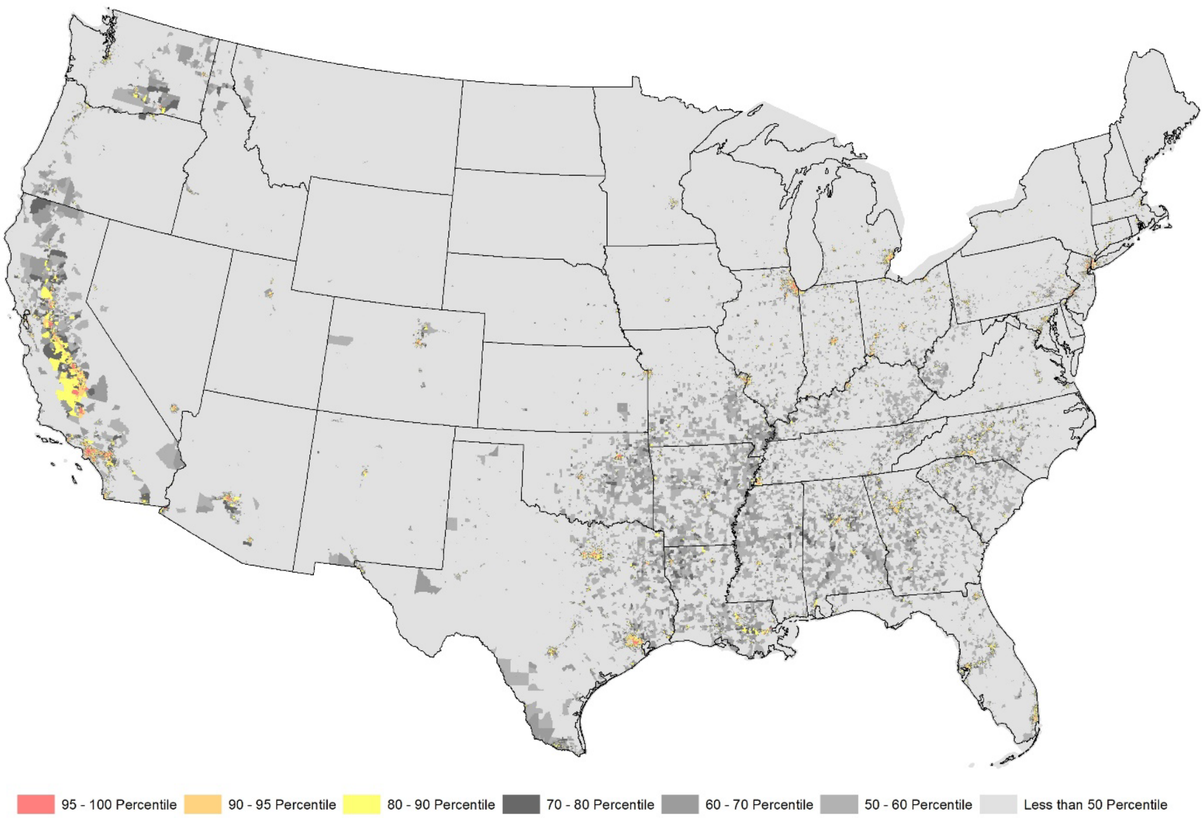

Figure 9. Block Group Cumulative Impact Screening Metric

IV.C Identifying Block Groups with Potential EJ Concerns: Vulnerability Perspective

The vulnerability approach utilized in this methodology identifies census block groups that might have environmental justice concerns by considering the potential vulnerability of that block group to any pollution.

The CalEnviroScreen documentation defines socioeconomic factors as "community characteristics that result in increased vulnerability to pollutants.[36] This document further states that:

> A growing body of literature provides evidence of the heightened vulnerability of people of color and lower socioeconomic status to environmental pollutants. For example, a study found that individuals with less than a high school education who were exposed to particulate pollution had a greater risk of mortality. Here, socioeconomic factors that have been associated with increased population vulnerability were selected.
>
> Data on the following socioeconomic factors have been identified and found consistent with criteria for indicator development: educational attainment, housing-burdened low-income households, linguistic isolation, poverty, unemployment.

[36] https://oehha.ca.gov/media/downloads/calenviroscreen/report/calenviroscreen40reportf2021.pdf

A vulnerability[37] screening metric is calculated for each census block group in a manner that is consistent with the development of the Socioeconomic Factors component value, as discussed in the preceding section (Table 2). First, the average of the following four EJScreen 2.0 indicators is calculated: percent of households in linguistic isolation, percent less than high school education, percent low-income, and percent unemployment rate. The average for each block group is then converted to a national percentile by ranking the census block group-level Socioeconomic Factors values from lowest to highest and then calculating the relative percentile of the block group relative to the total number of block groups. With a possible range from 0 to 100, this final value represents the relative vulnerability of each census block group throughout the US relative to all other block groups.

As with the cumulative impact values, the vulnerability values are not meant to serve as quantitative assessments of the vulnerability each block group to pollutants. Rather, these values provide a quantitative means by which to compare the potential vulnerability of people living within one block group to people living within another block group. Higher values indicate that the people living within that block group may be more vulnerable to pollution impacts than people living within a block group with lower values.

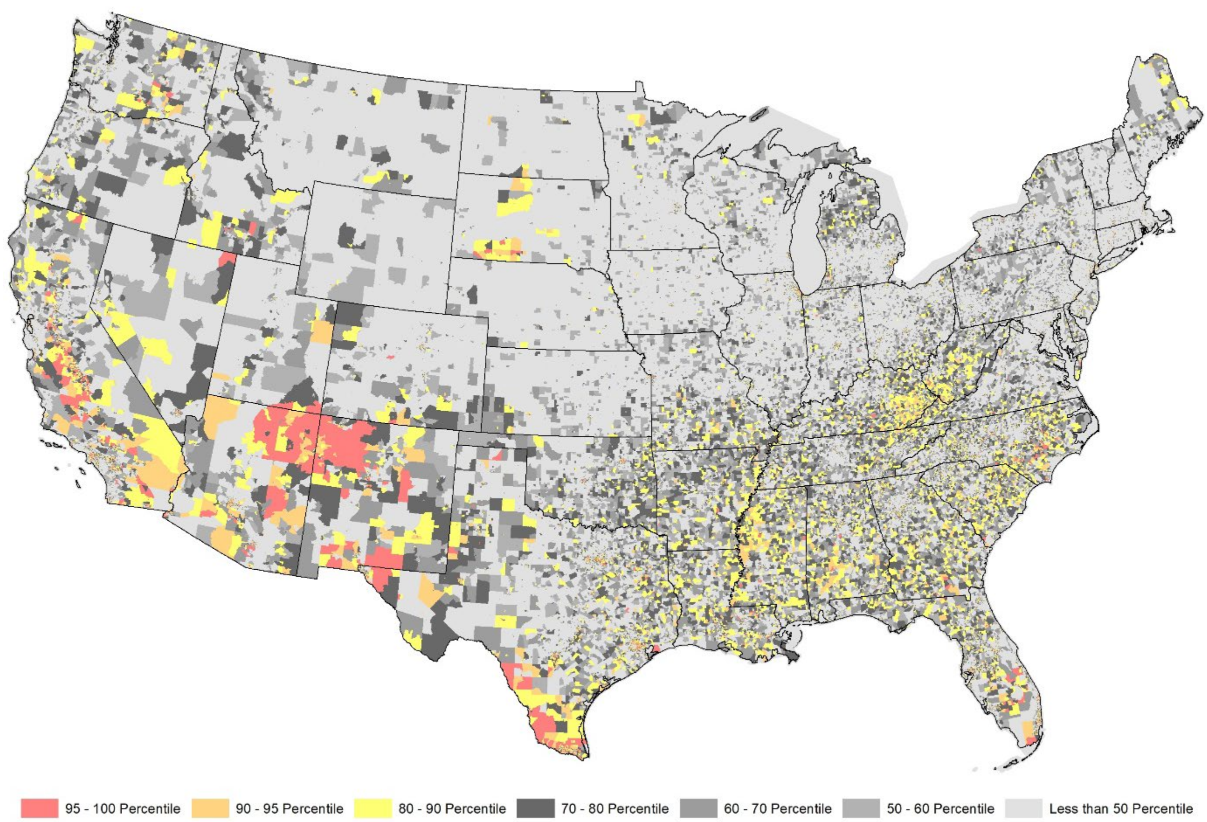

Figure 10. Block Group Vulnerability Screening Metric

[37] Note that this document uses the term vulnerability in a qualitative, general sense, to refer to what various authors have called susceptibility and/or vulnerability. Vulnerability in this report indicates the likelihood of a greater potential impact of one or more environmental burdens.

V Developing Facility-Level Scores

V.A Overview

This section discusses the facility-level scores developed for each power plant. These scores are developed using the information discussed in the preceding sections: section IV characterizes the relative potential for EJ concern within each census block group, and section III presents how the census block groups that are potentially affected by each power plant are identified. This section explains how that information is combined in different ways, resulting in various facility-level scores quantifying the relative potential for each plant to affect either the most overburdened people or the most vulnerable people on average.

As discussed in detail below, this scoring methodology employs two different approaches for ranking the facilities. The first approach considers how many people are potentially affected by each plant, and the current extent to which those people are both exposed to pollution and vulnerable to pollution exposure. The second approach considers the vulnerability of the average person living in an area that has the potential to be affected by each plant. For each of these two approaches, scores for each power plant facility are developed based on the four alternative methods for determining which census block groups might be affected (the uniform 5km proximity, AERMOD-based maximum impact and intermediate impact proximity methods, and the HYSPLIT-based long-range transport downwind method).

Here again, these are relative percentile scores ranging from 0 to 100 that rank the power plants based on the relative potential of each power plant to affect block groups, based on consideration of either the potential to affect the greatest number of overburdened people, or the potential to affect the most vulnerable people on average. These scores are not quantitative assessments of the total potential for any power plant to affect the environmental burden, vulnerability, or risk of any block group.

The following two sections discuss in detail the development of each type of score.

V.B Facility-Level Score Approach 1: Potential to Affect the Greatest Number of Overburdened People

This facility-level scoring approach ranks power plants based on their potential to affect the highest number of the most overburdened people. In this application, “overburdened” people are defined to be those who reside in census block groups with high cumulative impact values, which reflect a relatively high degree of exposure to pollution and vulnerability to that pollution (see discussion of the cumulative impact screening metric in Section IV.B). This approach considers:

- The number of overburdened block groups that are potentially affected by each power plant
- The total population of those block groups
- The relative difference in preexisting cumulative impacts (considering pollution burden and vulnerability together)

For this approach, we aggregate the population-weighted cumulative impact values of the block groups that are potentially affected by each power plant. The maximum aggregate values at each facility are then ranked relative to the other power plants from high to low and that ranking is converted to percentiles based on the plant type, facilitating screening-level comparisons across the coal fleet and separately across the oil/gas steam fleet.

The following equations summarize this scoring approach for each of the approaches[38] utilized in this methodology for identifying the block groups that are potentially affected by each power plant:

$$\text{Proximity Scores} = \sum_{block\ groups} CI\ metric\ \times\ population\ \times\ \%\ within\ radius$$

$$\text{Downwind Score} = \sum_{block\ groups} CI\ metric\ \times\ population$$

In this scoring approach, facilities that potentially affect more block groups with larger populations and higher cumulative impact values would generate a higher score. Conversely, power plants that potentially affect a smaller number of block groups with smaller populations and lower cumulative impact values would generate a lower score.

Four scores are developed using this approach for each facility: three scores based on proximity analysis (applying three different radii), and one score based on long-range downwind analysis.

V.C Facility-Level Score Approach 2: Potential to Affect the Most Vulnerable People on Average

In addition to identifying the facilities that might affect the greatest number of people, it is also important to identify the facilities that might affect areas where fewer people reside who are nevertheless vulnerable to the pollution emitted from each facility. This facility-level scoring approach ranks power plants relative to other plants based on their potential to affect people who are, on average, the most vulnerable to pollution. This approach:

- Considers the average vulnerability of the population that is potentially affected by the power plant
- Does not consider existing pollution burden

The following equations summarize this scoring approach for each of the for each of the approaches[39] utilized in this methodology for identifying the block groups that are potentially affected by each power plant.

[38] Three proximity and one long-range downwind. See Section XX for discussion of each approach.
[39] Three proximity and one long-range downwind. See Section III for discussion of each approach.

$$\text{Proximity Scores} = \frac{\sum_{block\ groups} vulnerability\ metric \times population \times \%\ within\ radius}{\sum_{block\ groups} population \times \%\ within\ radius}$$

$$\text{Downwind Score} = \frac{\sum_{block\ groups} vulnerability\ metric \times population}{\sum_{block\ groups} population}$$

For this scoring approach, we calculate the population-weighted average vulnerability score of the block groups that are potentially affected by each power plant. As with the plant-level scores in scoring approach 1, the maximum values at each facility are ranked relative to the other power plants from high to low and that ranking is then converted to percentiles based on the plant type to facilitate screening-level comparison across the coal fleet and separately across the oil/gas steam fleet.

Four scores are developed using this approach for each facility: three scores based on proximity analysis (applying three different radii), and one score based on long-range downwind analysis.

It is important to highlight that the intent of this approach is to focus on areas where people who are the most vulnerable might live, rather than areas where the highest numbers of vulnerable people live. This approach is therefore limited to an evaluation of vulnerability scores (which do not consider existing pollution burden). The exclusion of pollution burden in this approach helps to reduce any potential bias in screening towards areas of high population density (which are generally correlated with areas of higher pollution burden) and facilitates an emphasis on identifying plants that affect people who are the most vulnerable to emissions.

VI Results

This methodology results in eight percentile-based scores for each facility. Table 3 and Table 4 below summarize the location of the figure summarizing the results of each score, as well as the location of that score in the full results table discussed in Appendix I.

Table 3. Summary of Facility-Level Score Figures and Tables for Coal Steam

	Proximity: 5km (Section III.B.)	**Proximity: Maximum (Section III.B.)**	**Proximity: Intermediate (Section III.B.)**	**Long-Range Downwind (Section III.C.)**
Approach 1: Greatest number of overburdened people (Section V.B)	Figure 11A Appendix I, Column C	Figure 11B Appendix I, Column D	Figure 11C Appendix I, Column E	Figure 11D Appendix I, Column F
Approach 2: Most vulnerable people on average (Section V.C)	Figure 12A Appendix I, Column G	Figure 12B Appendix I, Column H	Figure 12C Appendix I, Column I	Figure 12D Appendix I, Column J

Table 4. Summary of Facility-Level Score Figures and Tables for Oil/Gas Steam

	Proximity: 5km (Section III.B.)	**Proximity: Maximum (Section III.B.)**	**Proximity: Intermediate (Section III.B.)**	**Long-Range Downwind (Section III.C.)**
Approach 1: Greatest number of overburdened people (Section V.B)	Figure 13A Appendix I, Column C	Figure 13B Appendix I, Column D	Figure 13C Appendix I, Column E	Figure 13D Appendix I, Column F
Approach 2: Most vulnerable people on average (Section V.C)	Figure 14A Appendix I, Column G	Figure 14B Appendix I, Column H	Figure 14C Appendix I, Column I	Figure 14D Appendix I, Column J

Figure 11-Figure 14 below depict the facility-level scores discussed above. Each figure contains four maps, representing the four different approaches for identifying the areas that are potentially affected by each plant. Figure 11 and Figure 12 present the scores for coal facilities, showing approach 1 and approach 2, respectively. Figure 13 and Figure 14 present the scores for oil/gas steam facilities. Table 3 and Table 4 summarize the location of each score in the figures below.

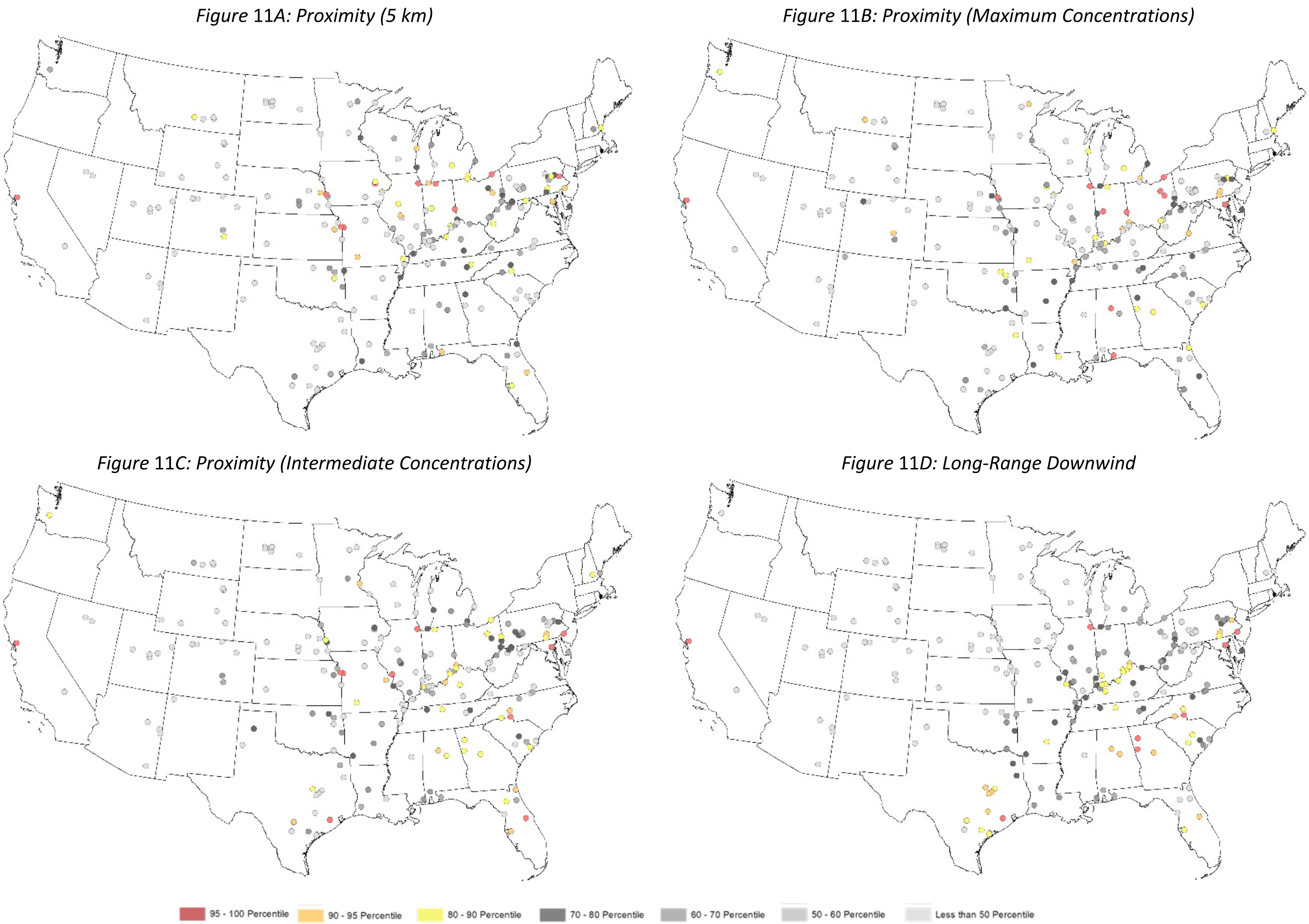

Figure 11. Maps depicting scores for coal facilities using Approach 1 (greatest number of overburdened people)

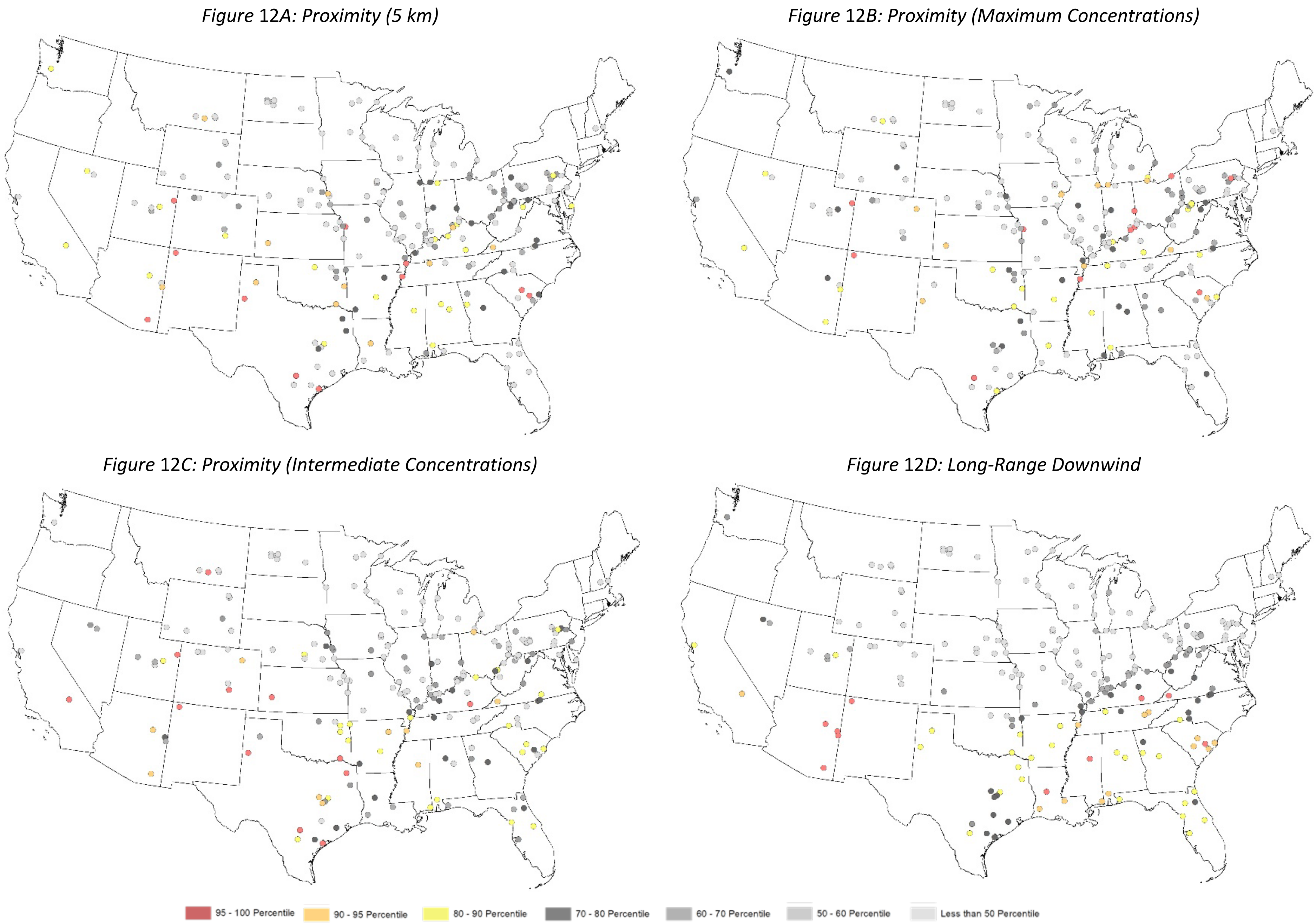

Figure 12. Maps depicting scores for coal facilities using Approach 2 (most vulnerable people on average)

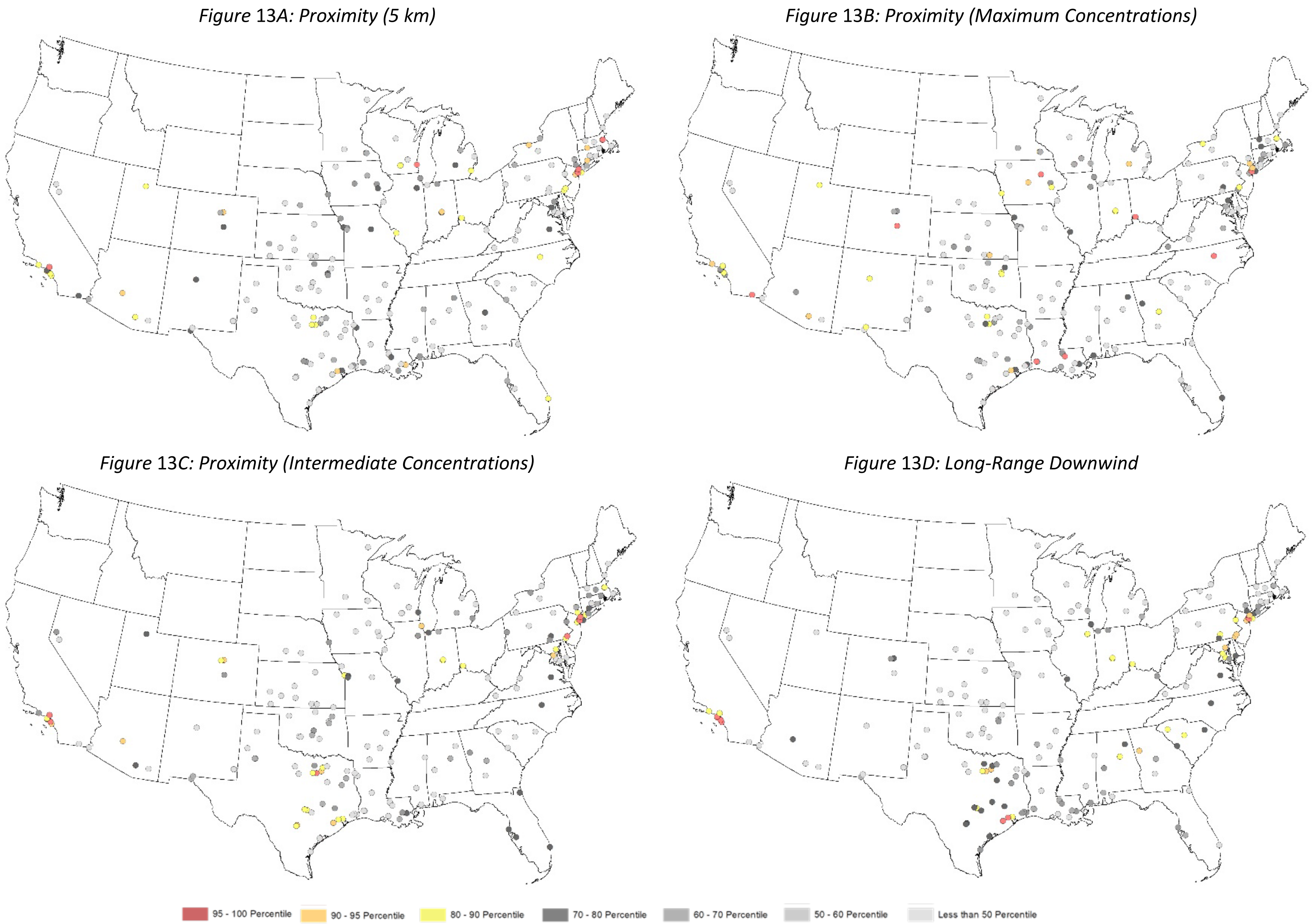

Figure 13. Maps depicting scores for oil/gas stean facilities using Approach 1 (greatest number of overburdened people)

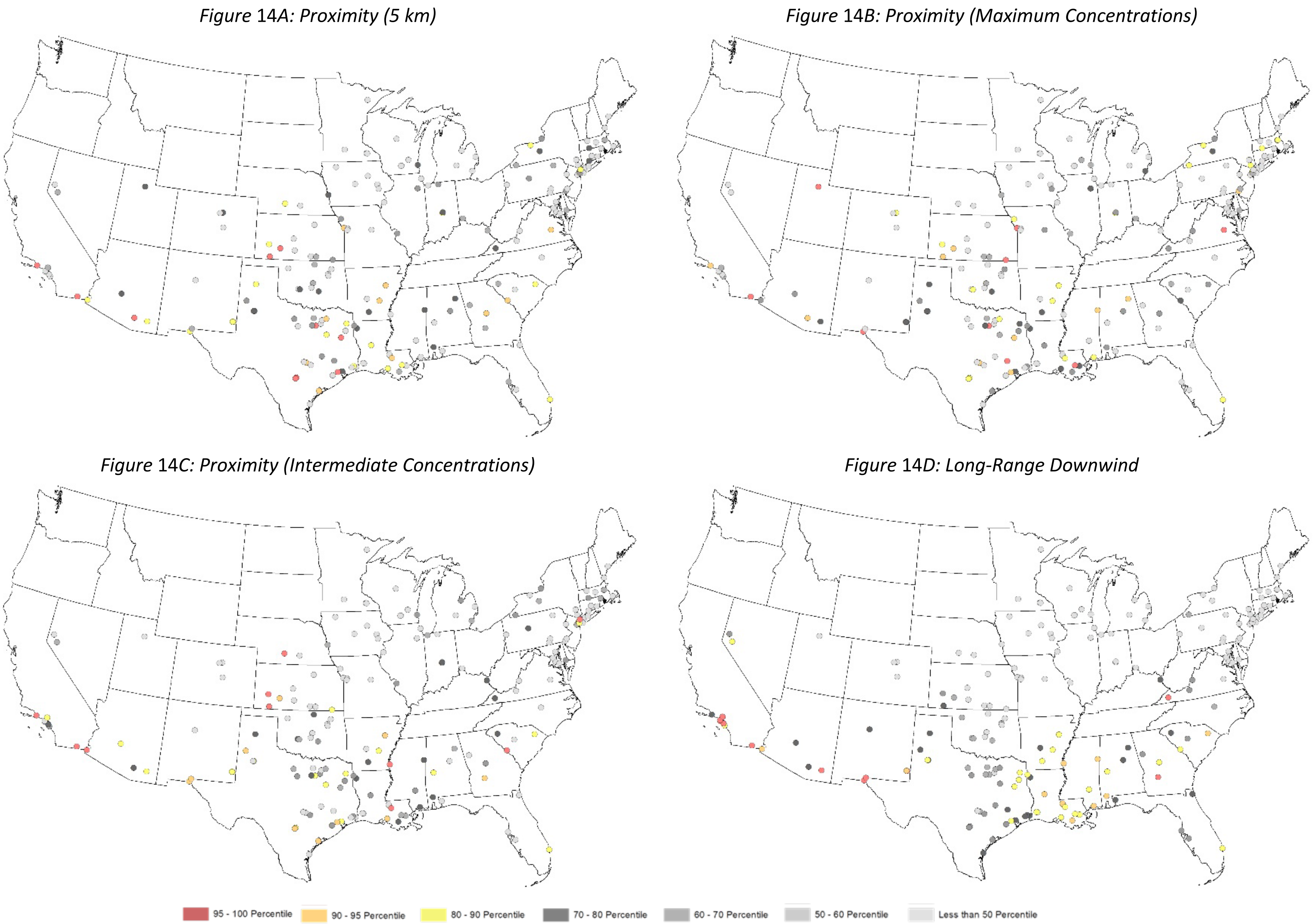

Figure 14. Maps depicting scores for oil/gas steam facilities using Approach 2 (most vulnerable people on average)

Appendix I. Comprehensive Results Tables

Each of the eight facility-level percentile scores are included in the accompanying spreadsheet titled: SCORES_ALL_PLANTS_for appendix.xlsx. This spreadsheet contains two worksheets: COAL and OG STEAM. Each of those sheets contains all of the coal or oil/gas steam facilities and facility-level scores, and are organized identically. The table below summarizes the organization:

Table 5. Summary of Facility-Level Score Spreadsheet

<table>
<tr><th colspan="2">Content</th><th>Column</th></tr>
<tr><td colspan="2">ORIS</td><td>A</td></tr>
<tr><td colspan="2">State Name</td><td>B</td></tr>
<tr><td rowspan="4">Approach 1: Greatest number of overburdened people (Section V.B)</td><td>Proximity: 5km (Section III.B)</td><td>C</td></tr>
<tr><td>Proximity: Max (Section III.B)</td><td>D</td></tr>
<tr><td>Proximity: Intermediate (Section III.B)</td><td>E</td></tr>
<tr><td>Long-Range Downwind (Section III.C)</td><td>F</td></tr>
<tr><td rowspan="4">Approach 2: Most vulnerable people on average (Section V.C)</td><td>Proximity: 5km (Section III.B)</td><td>G</td></tr>
<tr><td>Proximity: Max (Section III.B)</td><td>H</td></tr>
<tr><td>Proximity: Intermediate (Section III.B)</td><td>I</td></tr>
<tr><td>Long-Range Downwind (Section III.C)</td><td>J</td></tr>
</table>

Appendix II. Electric Generating Unit (EGU) Inventory

Each of the coal steam and oil/gas steam EGUs included in this analysis are included in the accompanying spreadsheet titled: ALL_UNITS_PEER_REVIEW.xlsx. This spreadsheet the stack heights and geospatial coordinates used in the HYSPLIT modeling (Section III.C) as well as the distances used for the proximity analysis discussed in section III.B.

The NEEDS database, which contains additional information about each EGU, is available at: https://www.epa.gov/system/files/documents/2022-01/needs-v6_01-24-2022-2.xlsx

Table 6. Summary of Facility-Level Score Spreadsheet

Field Name	Description	Column
NEEDS Unique ID	Unique identifier linking each EGU to the NEEDS database	A
ORIS Code	Facility-level identifier	B
Unit ID	Unit identifier	C
Plant Type	Coal Steam or Oil/Gas Steam	D
Latitude	Location of facility: coordinates	E
Longitude	Location of facility: coordinates	F
Stack Height (feet)	Height of stack associated with unit	G
State	Location of facility: state	H
Maximum Concentration distance (km)	Distance used in proximity analysis, based on maximum concentration (Section III.B)	I
Intermediate Concentration distance (km)	Distance used in proximity analysis, based on intermediate concentration (Section III.B)	J

Appendix III. EJScreen 2.0 Indicators

The follow two tables summarize the block group-level EJScreen 2.0 indicators.[40] Note that the indicators used in this analysis are summarized in Table 2.

Table 7. Demographic and Socioeconomic Indicators

Indicator and Variable Name	Description and Metric	Source
People of Color "MINORPCT"	People of color are considered anyone other than non-Hispanic white individuals and is measured as the percent of individuals in a block group who identify as a person of color	2015-2019 ACS 5-year summary file data
Low-income "LOWINCPCT"	Low-income is defined as individuals whose ratio of household income to the poverty level in the past 12 months was less than 2 and is measured as the percent of a block group's population living in low-income households.	2015-2019 ACS 5-year summary file data
Unemployment Rate "UNEMPPCT"	Unemployment rate is defined as all who did not have a job during the reporting period, made at least one specific active effort to find a job during the prior 4 weeks, and were available for work (not ill) measured as percent of a block group's population that was unemployed	2015-2019 ACS 5-year summary file data
Linguistic Isolation "LINGISOPCT"	Linguistically isolated is defined as all household members who speak a non-English language and speak English less than "very well" measured as a percentage of people in a block group over age 14 who live in a linguistically isolated household	2015-2019 ACS 5-year summary file data
Less than High School Education "LESSHSPCT"	Defined as "short" of a high school diploma and is measured by the percent of people in a block group with less than a high school education who are over age 25	2015-2019 ACS 5-year summary file data
Under age 5 "UNDER5PCT"	Percentage of people in a block group under the age of 5	2015-2019 ACS 5-year summary file data
Over age 64 "OVER64PCT"	Percentage of people in a block group over the age of 64	2015-2019 ACS 5-year summary file data

Source: https://www.epa.gov/ejscreen/ejscreen-map-descriptions
https://www.epa.gov/system/files/documents/2022-02/ejscreen_fact_sheet_2022.pdf

[40] The data used in this analysis is available at: https://gaftp.epa.gov/EJSCREEN/2021/EJSCREEN_2021_USPR.csv.zip

Table 8. Environmental Indicators

Indicator and Variable Name	Description and Metric	Source
$PM_{2.5}$ "PM25"	Particulate matter that is 2.5 microns or less in diameter in air (µg/m^3 annual average in air)	OAR, fusion of model and monitor data (2018)
Ozone "Ozone"	Ozone created at ground level during ozone season (May-Sept) measured as seasonal average of daily-maximum (8-hour-average ozone concentrations, in ppb)	OAR, fusion of model and monitor data (2019)
Diesel PM "DSLPM"	Diesel particulate matter concentration in air (µg/m^3)	EPA Hazardous Air Pollutants (2017)
Air Toxics Cancer "CANCER"	Estimated lifetime cancer risk from the 187 EPA analyzed hazardous air pollutants (HAPs) with risk measured by inhalation exposure	EPA Hazardous Air Pollutants (2017)
Air Toxics Respiratory Hazard "RESP"	Ratio of exposure concentration to a health-based reference concentration expressed as an index	EPA Hazardous Air Pollutants 2017
Traffic "PTRAF"	Traffic proximity and # of vehicles per day within 500 meters of a block centroid, divided by distance	Department of Transportation traffic data 2019, retrieved 9/2021
Lead Paint "PRE1960PCT"	Potential lead exposure or likelihood of having significant lead-based paint hazards in the home measured as a percent of occupied housing units built before 1960	ACS 2015-2019, retrieved 4/2021
Superfund Proximity "PNPL"	Proximity to National Priorities List (NPL) sites measured as the count of sites within 5 km of the average resident in a block group, each divided by distance	EPA CERCLIS 2021, retrieved 9/2021
RMP Proximity "PRMP"	Facilities required by the CAA to file risk management plans (RMPs) measured as the count of RMP facilities within 5 km, each divided by distance	EPA RMP database 2021, retrieved 9/2021
Hazardous Waste Proximity "PTSDF"	Hazardous waste treatment, storage or disposal facilities (TSDFs) measured as a count of hazardous waste facilities within 5 km, divided by distance, presented as population-weighted averages of blocks in each block group	TSDF data from EPA RCRA 2021, retrieved 9/2021
Underground and leaking tanks "UST"	Underground and leaking storage tanks (UST & LUST) measured as # of LUSTs (multiplied by a factor of 7.7) and # of USTs within a 1,500-foot buffered block group	EPS UST Finder 2021, retrieved 9/2021
Wastewater "PWDIS"	Pollutant loadings from the Discharge Monitoring Report (DRM) Loading Tool for toxic chemicals reported to the Toxics Release Inventory measured as toxic concentrations (chemical toxicity and fate and transport) at stream segments within 500 meters, divided by distance	RSEI modeled concentrations to stream reach segments 2021, retrieved 9/2021

Source: https://www.epa.gov/ejscreen/overview-environmental-indicators-ejscreen

Appendix IV. Potential Future Work

As described above, this screening methodology evaluates the relative potential power plants to areas of possible EJ concern. It is possible to develop additional applications by applying the components discussed above with different objectives.

For example, while the methodology above develops percentile-based scores that enable screening by plant type at the national level, it is possible to apply the same methodology to a subset of those plants or EGUs.

Additionally, it is possible to perform a screening-level assessment of the census block groups based on number of power plants potentially affecting each block group. This screen could assess whether particular areas are potentially impacted by more power plants, or by power plants without advanced pollution controls.

Using the dispersion modeling-based radii in Section III.B, it is also possible to conduct proximity analyses that evaluate one or more indicators within a certain distance of each plant. Unlike most of the proximity analysis that has been conducted previously, this approach would allow for an emphasis on the areas around each plant that are most likely affected by air pollution from that plant. Additionally, the distance characterizing the proximity analysis for each facility could be focused on a particular pollutant. For example, the distance associated with average maximum concentrations is more indicative of the likely area impacted by one particular pollutant, whereas the distance associated with the intermediate concentration is more indicative of the area most likely to be affected by another pollutant.

Appendix V. Secondary $PM_{2.5}$ and Ozone

As described above in Section III.B, we are not accounting for emission magnitude, chemistry for the emissions at it transforms to pollution, or deposition. More in-depth air quality modeling of individual sources (or groups of sources) can be used to understand these processes. Here, we provide some additional analysis where chemistry has been accounted for to help contextualize this methodology.

Photochemical grid modeling of hypothetical single sources was used to provide a technical basis of downwind extent of impacts of precursors to secondarily formed pollutants O3 and PM2.5 and provided as part of the EPA guidance document "Guidance on the Development of Modeled Emission Rates for Precursors (MERPs) as a Tier 1 Demonstration Tool for Ozone and PM2.5 under the PSD Permitting Program" (https://www.epa.gov/sites/default/files/2020-09/documents/epa-454_r-19-003.pdf). This database was developed to inform anticipated permit applications for non-EGU industrial point sources and includes surface and aloft (90 m stack height) hypothetical sources emitting 500, 1000, and 3000 tpy of precursor emissions. An important limitation of the existing photochemical model hypothetical source impact database is that the modeling was done using 12 km sized grid cells which means that relationships can not be extrapolated to finer resolution scales.

Impacts from NOX and SO2 to secondary PM2.5 and NOX and VOC to O3 are typically highest near the source and decrease as distance from the source increases. The distance from the source of maximum daily and annual average secondary PM2.5 impact is shown in Figure 5. Peak impacts tend to be in close proximity to the source. For NOX precursor, the peak 24-hour PM2.5 impacts are typically within 20 to 50 kilometers, while peak annual average PM2.5 impacts are typically within 20 kilometers of the source. For SO2 precursor, the peak 24-hour PM2.5 impacts are shown to be mostly within 10 to 40 kilometers, while peak annual average PM2.5 impacts are largely within 20 kilometers. These peak impacts become less common as distance from the source increases. Like maximum daily PM2.5 impacts, maximum daily 8-hr average O3 impacts tend to be in close proximity to the source and are less frequent as distance from the source increases.

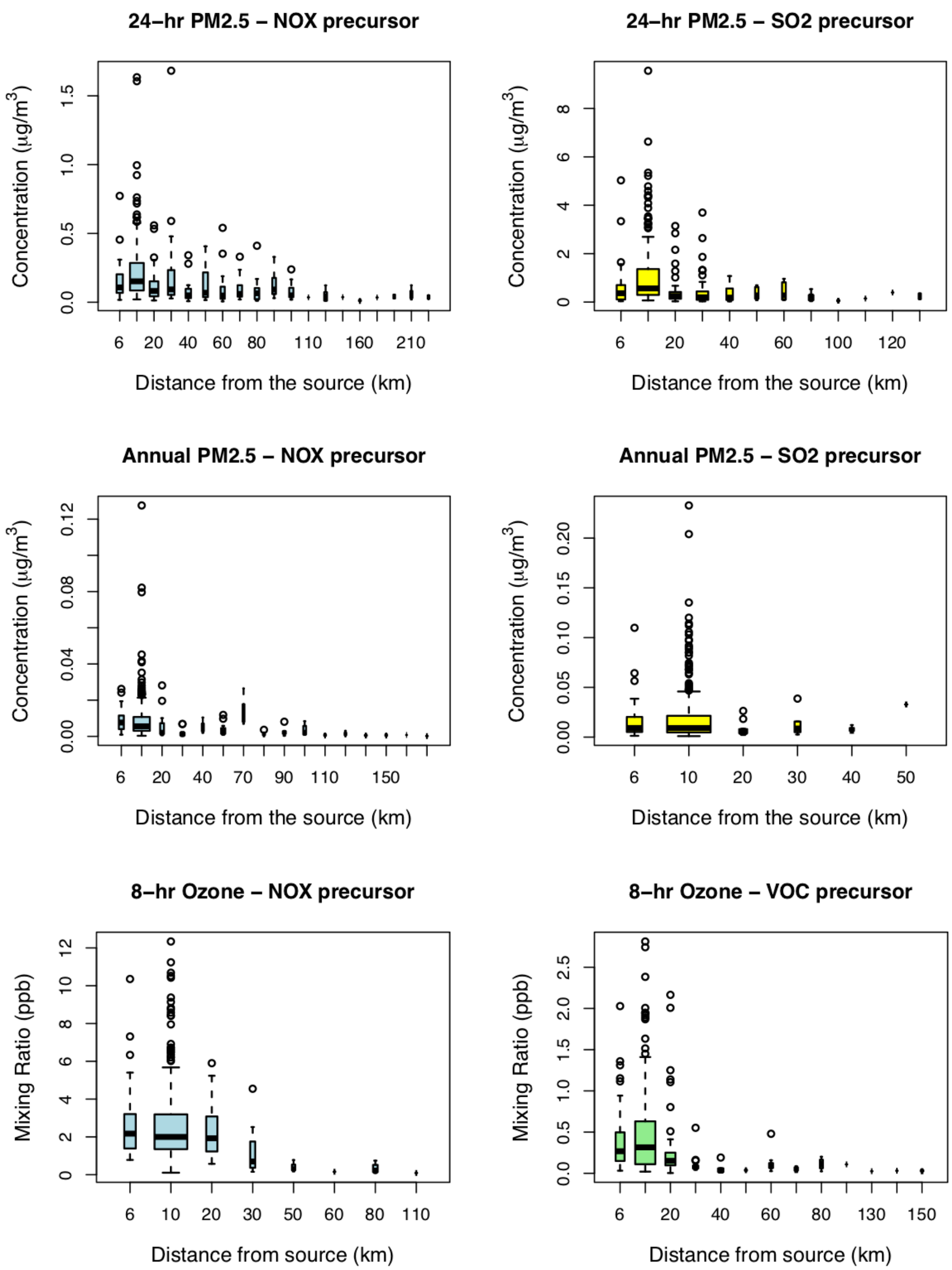

Figure 15. Maximum daily and annual average secondary $PM_{2.5}$ nitrate ion impacts from NO_X emissions and $PM_{2.5}$ sulfate ion impacts from SO_2 emissions shown by distance from the source. Also shown are maximum 8-hr ozone impacts from NO_X emissions and from VOC emissions by distance from the source.