



Defining Environmental Justice  
Communities and Distributional  
Analysis for Socioeconomic Analysis of  
2016 SCAQMD Air Quality Management  
Plan

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## CHAPTER 1. INTRODUCTION AND SUMMARY OF RECOMMENDATIONS

Addressing issues of environmental justice (EJ) is an important goal of U.S. environmental policy. That is, preferred policies will reduce the likelihood that environmental health risks are inequitably distributed and that particularly vulnerable and susceptible or otherwise disadvantaged populations do not bear a disproportionate burden of health risk. The U.S. EPA defines EJ as “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 (US EPA, 2015a).” In order to achieve environmental justice gains, policy makers must consider not only how regulations will impact average exposures across a population, but how they will impact the distribution of exposures in the affected population.

The South Coast Air Quality Management District (SCAQMD) develops air pollution control strategies to help California’s South Coast Air Basin (SCAB) achieve compliance with Federal and State air quality standards. As part of its upcoming 2016 Air Quality Management Plan (AQMP) Socioeconomic Analysis, SCAQMD plans to include considerations of expected impacts on EJ communities. SCAQMD currently defines an EJ community as “an area with at least 10% of the population below the federal poverty line and a PM<sub>2.5</sub> concentration greater than 11.1 µg/m<sup>3</sup> per year or a toxic cancer risk of greater than 894 in a million” (South Coast Air Quality Management District, 2015).<sup>1</sup> This definition captures locations with high percentages of poverty that are also within the top 15 percent of SCAB areas in terms of mean PM<sub>2.5</sub> concentrations and estimated toxic cancer risk. These values are updated over time, reflecting recent PM<sub>2.5</sub> concentration or cancer risk in the region. This definition, which is used for community grant allocation purposes, both incorporates communities that are exposed to greater than average air pollution exposures and addresses economic disadvantage. A review of existing EJ analyses suggests that there may be additional factors that warrant consideration when designating EJ communities in the SCAB, including other demographic and environmental factors that may serve to make a community particularly vulnerable to air pollution exposures. Alternative definitions of EJ should be explored for use in the Socioeconomic Analysis of the 2016 AQMP. This alternative definition should be “fit for purpose,” that is, it must be constructed to identify and appropriately characterize disadvantaged communities to best aid SCAQMD in analyzing differential impacts of proposed air quality management policies.

In addition to exploring alternative definitions of EJ, the SCAQMD wishes to analyze the distribution of impacts of the proposed AQMP on the SCAB population. Specifically, the agency wants to analyze how a policy may differentially impact areas that have been

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<sup>1</sup> This definition is most current as of July 2016, and does not reflect the definition included in the 2012 Air Quality Management Plan Socioeconomic Analysis.

designated as EJ communities relative to the rest of the SCAB population, using quantitative analysis methods to assess health risks in EJ and non-EJ designated communities before and after implementation of the AQMP. A quantitative distributional analysis of health risks will enable SCAQMD to examine impacts to both assess the magnitude of changes in air quality resulting from its 2016 AQMP and how those changes are distributed across the affected population. The agency can also examine how individual policies may influence health risk inequalities by analyzing distributions of risk pre- and post- implementation of the policy.

### 1.1 SUMMARY OF RECOMMENDATIONS

IEc describes in this report our recommended approach for a quantitative distributional analysis for the 2016 AQMP. First, we recommend alternative EJ definitions for use in a sensitivity analysis of the impact of the EJ definition on the socioeconomic impacts of the 2016 AQMP. This approach reflects our review of the existing literature for definitions of EJ communities, our evaluation of screening tools that have been developed to help identify EJ communities, and our assessment of how these definitions impact the policy maker's ability to compare and contrast regulations. Second, we recommend inequality indicators that can be used in distributional analysis of health risks associated with SCAQMD's 2016 AQMP policies between EJ and non-EJ communities. These recommendations reflect our review and analysis of the health inequality metrics literature, considering both the advantages and limitations of alternative distributional analysis methods. We also describe key questions to help guide SCAQMD in choosing appropriate methods for utilizing inequality indicators to perform distributional analysis of health risks in the SCAB region, based on exposure-related mortality and morbidity risk values calculated by the U.S. EPA's Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE).

Below we summarize our recommended approach to an EJ distributional analysis of health risks for the 2016 AQMP.

The overall process for SCAQMD's EJ analysis of the 2016 AQMP includes the following steps:

- Using quantitative indicators based on state-of-the-science literature guidance, define EJ communities in the SCAB region by census tract;
- Using the EPA's BenMAP-CE software in conjunction with local baseline mortality and morbidity incidence data and concentration-response functions, calculate exposure-related mortality and morbidity risk values at the census tract level associated with changes in PM<sub>2.5</sub> and O<sub>3</sub> exposure based on 2016 AQMP policy control scenarios. This step may be accomplished as part of the Benefits Analysis portion of the 2016 AQMP Socioeconomic Analysis, or may require some follow-up runs tailored to the EJ analysis;
- Applying appropriate inequality indicators to characterize changes in the distribution of BenMAP-calculated exposure-related mortality and morbidity risks associated with each 2016 AQMP policy, both for the SCAB population as a whole and comparing EJ and non-EJ SCAB communities.

To support the first step in this analysis, we developed five alternative EJ definitions described in this report and in Appendix A. SCAQMD has indicated that the alternative definitions should incorporate at minimum air quality and toxic cancer risk, along with relevant socioeconomic data. Race and ethnicity as an EJ indicator are considered, but its effects are analyzed and reported separately<sup>2</sup>. These definitions allow for every census tract in the SCAB region to be designated as either an “EJ community” or a “non-EJ community”. This designation is important for the next steps of the EJ analysis, as health risks will be calculated separately for EJ and non-EJ communities using BenMAP-CE. Our recommended EJ definition options are described in Table 1.

The maps shown in Table 1 demonstrate the geographic differences in designated EJ communities based on each alternative EJ definition. Compared with Definition 1, Definition 2 creates a more contiguous EJ community, whereas Definition 3 includes a greater number of rural census tracts than Definitions 1 and 2. As explained in Chapter 2, the alternative definition chosen by SCAQMD should be appropriate for the purpose of sensitivity analysis within their Socioeconomic Analysis of the 2016 AQMP.

To calculate health risks for EJ and non-EJ groups, we recommend SCAQMD uses the concentration-response functions and baseline incidence data provided by IEc under a separate contract. BenMAP-CE should be run separately for each control scenario or policy being analyzed within the 2016 AQMP. We recommend focusing the analysis on mortality risks from air pollution exposure and risks for a morbidity endpoint for which local-scale baseline health data are available. Furthermore, we recommend calculating mortality risk and asthma-related emergency department (ED) visit risk values separately by census tract for PM<sub>2.5</sub> and O<sub>3</sub> exposures, in order to capture the full distribution of health risks across the study area. Analyzing exposure-related mortality risk will provide information on the most extreme health impact associated with air pollution exposure that impacts older and more susceptible subgroups, while analyzing asthma-related ED visit risk will provide information on a common health impact that impacts younger subgroups. At this point, each census tract will be designated as an EJ community or a non-EJ community and will have an exposure-related mortality risk and morbidity risk value associated with each AQMP control scenario or policy.

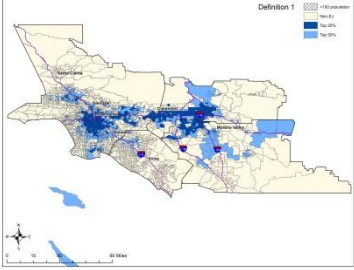
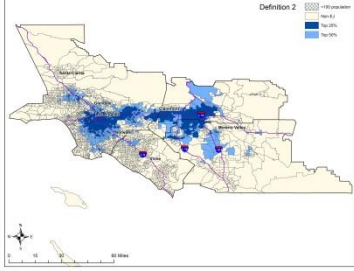
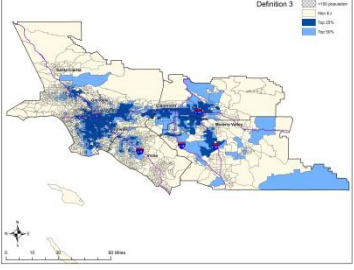
With the BenMAP-produced health risk outputs, we recommend SCAQMD calculates inequality indicator values for EJ communities for exposure-related mortality and morbidity risks, separately. We recommend SCAQMD uses the Atkinson index and Kolm-Pollak index for distributional analysis of inequality between EJ communities and the rest of the SCAB population. These measures can also be used to assess changes in the overall variability in risks pre- and post-AQMP implementation. Sensitivity analyses can be conducted through use of a set of inequality aversion parameters within the Atkinson and Kolm-Pollak indices, as well as use of other indicators, specifically Theil’s index, Gini coefficient, and mean log deviation. This recommendation is based on common practices used in the health risk distributional analysis literature. With the results of these distributional analyses, SCAQMD can determine whether each of the policies put forth in the 2016 AQMP increase or decrease inequality of exposure-related

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<sup>2</sup> SCAQMD states that this type of analysis is necessary to facilitate potential future use of an alternative EJ definition in other circumstances where race and ethnicity are legally prohibited from being included.

mortality and morbidity health risks across the EJ and non-EJ communities of the SCAB population.

TABLE 1. ALTERNATIVE EJ DEFINITIONS

	DEMOGRAPHIC INDICATORS		ENVIRONMENTAL INDICATORS		MAP OF ALTERNATIVE DEFINITION
	Income	Other Demographic	Air Quality	Other Environmental	
1	Poverty status		PM2.5, toxic cancer risk, ozone		
2	Poverty status	Age, asthma, education, linguistic isolation, low birth weight, unemployment	PM2.5, toxic cancer risk, ozone		
3	Poverty status	Age, asthma, education, linguistic isolation, low birth weight, unemployment	PM2.5, toxic cancer risk, ozone	Drinking water, pesticides, toxic releases, traffic, cleanup sites, groundwater threats, hazardous waste, impaired water bodies, solid waste	

Note: Appendix A presents the results for two additional definitions that add race and ethnicity to Definitions 2 and 3.



## 1.2 ORGANIZATION OF REPORT

In the remainder of this report, we provide detailed descriptions of the review and analysis underlying the recommendations above.

In Chapter 2, we begin by describing the literature, policy, and screening tool review of EJ definitions. We then describe the process by which we identified alternative EJ definition options for the 2016 AQMP EJ analysis and our rationale for recommending the proposed alternative EJ definitions. We conclude this chapter by recommending a set of alternative EJ definition options and affiliated analyses.

In Chapter 3, we perform a literature review of inequality indicators and distributional analyses of health risks. We describe qualities of inequality indicators commonly used in health literature and lay out guiding questions for choosing the appropriate inequality indicators to assess impacts of the 2016 AQMP's policies. We also recommend which inequality indicators SCAQMD should use and which health risk values should be assessed, and provide details of our recommended distributional analysis approach. Together, the analysis plan and recommendations laid out in Chapters 2 and 3 provide a comprehensive approach for assessing potential differences in health risks between EJ and non-EJ communities in the SCAB.

## CHAPTER 2. REVIEW OF EJ LITERATURE AND SCREENING TOOLS AND RECOMMENDATIONS FOR ALTERNATIVE EJ DEFINITIONS

In order to create alternative EJ definitions appropriate for SCAB communities, we performed a systematic review of literature, EJ screening tools, and definitions that are used by other government agencies across the U.S. This review enabled us to understand how EJ has been defined for an array of scenarios and applications.

### 2.1. METHODS

We began by consulting extensively with SCAQMD staff to understand their current approach and their goals for EJ-related analysis. Once we had a sound understanding of SCAQMD's needs and goals for an EJ analysis, we reviewed alternative working definitions of EJ communities using a three-step approach. First, we reviewed U.S. EPA guidance on EJ and studies identified by SCAQMD. Next, we conducted a supplemental review of the published literature based on the criteria provided in Table 2, below. Finally, we reviewed the EJ definitions employed by other state and local departments of environmental protection or air quality agencies across the U.S.

TABLE 2. EJ DEFINITION LITERATURE REVIEW CRITERIA

CRITERIA
<b>GENERAL:</b> <ol style="list-style-type: none"> <li>1. Study is peer-reviewed.</li> <li>2. Study is written in English.</li> <li>3. Study analyzes definition of environmental justice areas, vulnerable and sensitive areas, or environmental justice screening method.</li> <li>4. Study was published after 2010. Earlier studies were considered if they were in the South Coast Air Basin or California.</li> </ol>
<b>GEOGRAPHY AND STUDY POPULATION:</b> <ol style="list-style-type: none"> <li>5. Study uses a location whose characteristics are similar to the South Coast Air Basin. Order of preference of study location: <ol style="list-style-type: none"> <li>a. South Coast Air Basin (Los Angeles, Orange, Riverside, and San Bernardino Counties)</li> <li>b. Within State of California</li> <li>c. Within Western United States</li> <li>d. Within United States or Canada</li> </ol> </li> <li>6. Study uses study population with similar characteristics as found in Los Angeles, Orange, Riverside, and San Bernardino Counties.</li> </ol>

We began by searching existing SCAQMD documents and guidance documents that address EJ issues, including SCAQMD's 2012 Socioeconomic Report; and U.S. EPA's Guidance on Considering Environmental Justice during Development of Regulatory Actions (2015), Guidelines for Preparing Economic Analyses (2014), and Draft Technical Guidance for Assessing Environmental Justice in Regulatory Analysis (2013). We then conducted a literature review of studies that compared alternative definitions of EJ communities. We searched PubMed and Google Scholar for peer-reviewed articles from 2010 onward, using search terms "environmental AND justice AND definition" and "environmental AND justice AND define." We also included important studies that were referenced by those identified in our search, as well as studies that were recommended by our scientific advisors, Dr. Jon Levy of Boston University and Dr. Sam Harper of McGill University.

In addition to a literature review, IEc also reviewed relevant screening tools used to identify EJ communities. We analyzed tools identified by SCAQMD, as well as those previously identified by IEc. Tools were evaluated based on data resolution, data availability, ranking methods, and inclusion of environmental and demographic indicators as determined through the literature review.

IEc participated in a number of discussions with SCAQMD staff to assess their current practices regarding use of an EJ definition and how they intend to use an alternative definition in context of their future work. IEc then compiled a set of guidelines based on these calls to aid in creation of an alternate EJ definition.

## 2.2 RESULTS

In this section, we summarize the results of our research, first presenting our understanding of SCAQMD's needs for an EJ analysis; then presenting the results of our literature review on defining EJ and our EJ screening tool analysis; and, finally, recommending a set of potential EJ definitions.

Based on our conversations with SCAQMD staff, the goal of this analysis is to evaluate and compare alternative definitions of EJ communities that can be assessed for its 2016 AQMP EJ analysis. The alternative definitions incorporate at minimum air quality and the SCAQMD's toxic cancer risk matrices, along with relevant socioeconomic data. Race and ethnicity as an EJ indicator are considered, but its effects are analyzed and reported separately<sup>3</sup>. Other non-air quality environmental indicators may be included for alternative definitions that are for comparison purposes in sensitivity tests.

### 2.2.1 Review of Definitions of EJ Communities

Below, we analyze definitions of EJ communities based on common factors and themes identified throughout the literature review. We first describe federal guidelines for how EJ analyses should be incorporated in policy making, major findings of the literature review, and indicators of vulnerability and susceptibility, and then consider indicators to

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<sup>3</sup> The SCAQMD states that this type of analysis is necessary to facilitate potential future use of an alternative EJ definition in other circumstances where race and ethnicity are legally prohibited from being used.

which EJ community definitions are sensitive. Finally, we present currently used working definitions of EJ in other state and local government agencies.

#### 2.2.1.1 How Do Federal Guidelines Suggest Incorporating EJ Analysis In Policy Making?

Executive Order 12898, issued by President Clinton in 1994, directs federal agencies to identify and address disproportionately high and adverse human health or environmental effects of policies on minority and low-income populations (*Executive Order 12898 - Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*, 1994). According to U.S. EPA's 2014 Guidelines for Preparing Economic Analyses, the purpose of analyzing distributional effects of a regulation is to examine how costs and benefits are distributed across population groups and life stages of interest, as it is challenging to assume that tighter regulatory standards improve environmental quality for everyone (US EPA, 2014). Policies may create disproportionate impacts on EJ communities or exacerbate existing inequalities (US EPA, 2015b).

Due to the variability in communities across the nation and within individual states or cities, it is both difficult and impractical to choose a single technical definition of an EJ community. The EPA's 2013 Draft Technical Guidance for Assessing Environmental Justice in Regulatory Analysis suggests that population groups should be defined within the context of particular regulatory actions such that the definition can inform necessary data collection and analysis.

According to these guidance documents, no single definition of EJ suits all regulatory scenarios, but rather the definition should be "fit for purpose." However, the Federal guidance suggests that when defining EJ communities, analysts should consider factors that allow for evaluation of combined risks from exposure to multiple chemical and nonchemical stressors, and include factors that influence susceptibility, potentially including genetics, diet, nutrition and disease status, other stress, co-exposure to similar toxics, making particular note of children, elderly, pregnant women, and those in high risk occupations (US EPA, 2013).

#### 2.2.1.2 How Have EJ Communities Been Defined in the Literature?

Major takeaways from the literature review include the importance of creating a "fit for purpose" definition of EJ for a particular area or policy analysis (as discussed above), the need for quantitative environmental and demographic indicators in a definition, and the vast variability in EJ definitions that are appropriate in different contexts. In a study analyzing inequalities of environmental health, Morello-Frosch et al. (2011) provided evidence that policy makers must analyze health disparities, environmental exposure disparities, intrinsic biological factors, and extrinsic social factors across different groups to address cumulative impacts of environmental and social stressors. These factors have been aggregated traditionally under the umbrella of vulnerability and susceptibility, where vulnerability is related to socioeconomic qualities and susceptibility is related to inherent qualities like age or genetics. Inclusion of quantitative indicators that describe a community's vulnerability and susceptibility is necessary for determining what kind of policies and mitigation strategies can be employed to improve public health for those who are most affected.

### *Vulnerability*

Vulnerability has been defined by the U.S. EPA as “differential exposure and differential preparedness,” and elsewhere, as “PM<sub>2.5</sub>-related effects due to factors including socioeconomic status” (Fann et al., 2011). The construct has been quantified most commonly through use of U.S. Census data for demographic factors affecting preparedness. In the literature, a community that may be made up of a particularly vulnerable population has been described by proportion minority or people of color (Gilbert & Chakraborty, 2011; Miranda, Edwards, Keating, & Paul, 2011; R. Morello-Frosch, Pastor, & Sadd, 2001; Sadd, Pastor, Morello-Frosch, Scoggins, & Jesdale, 2011), proportion below poverty level or median household income (Fann et al., 2011; Gilbert & Chakraborty, 2011; Kershaw, Gower, Rinner, & Campbell, 2013; Miranda et al., 2011; R. Morello-Frosch et al., 2001; Prochaska et al., 2014; Sadd et al., 2011), educational attainment status (Fann et al., 2011; Kershaw et al., 2013; Sadd et al., 2011), home ownership or renter status (Gilbert & Chakraborty, 2011; Kershaw et al., 2013; R. Morello-Frosch et al., 2001; Prochaska et al., 2014; Sadd et al., 2011), as well as other socio-demographic indicators. There is overlap between how vulnerable populations are defined and populations that are historically disadvantaged.

Studies in Southern California (Rachel Morello-Frosch, Pastor, Porras, & Sadd, 2002) and elsewhere have found that health risk outcomes including estimated lifetime cancer risk from environmental exposures and demographic factors (Gilbert & Chakraborty, 2011) proximity to toxic release facilities (Kershaw et al., 2013; Rachel Morello-Frosch et al., 2002), and air pollution exposure (Miranda et al., 2011; Schweitzer & Zhou, 2010) are significantly different between communities with different income characteristics. In the SCAB, Morello-Frosch et al. (2002) found that as household income increased, lifetime cancer risk decreased generally based on race and ethnicity (with cancer risk nearly 50% greater for Asian Americans, African Americans, and Latinos compared with Caucasians); whereas Gilbert and Chakraborty (2011) found using two different statistical methods that the proportion of owner-occupied housing units below poverty, and proportion minority were significant predictors of lifetime cancer risk. Low income communities tend to have greater sources of environmental risk (Miranda et al., 2011), though this tendency is inconsistent across type of risk and level of geographic aggregation (Ringquist, 2005). The results of these studies demonstrate a need for inclusion of both an income-related indicator and other non-income sociodemographic indicators in defining EJ communities.

Results of studies performed in the SCAB and in Southern California do not differ greatly from the results of other studies performed across the U.S. and Canada. In a study analyzing environmental inequality in the SCAB, Marshall (2008) found mean exposures to ambient air pollutants (including diesel particles) are 16% - 40% different between whites and nonwhites (Marshall, 2008). Both an older study of EJ in Southern California and a nationwide meta-analysis assessing evidence of environmental inequalities found that there is “ubiquitous” evidence of differences in exposure based upon race alone, after controlling for other economic, land-use, and population factors (R. Morello-Frosch et al., 2001) and irrespective of other indicators (Ringquist, 2005). The importance of race in defining an EJ community is described by Miranda et al. (2011), who found that EJ

concerns are more prominent along race and ethnicity lines. In U.S. counties whose air is monitored by U.S. EPA, those with the worst air quality are home to more predominantly black and Hispanic populations (Miranda et al., 2011). Ringquist's 2005 meta-analysis found that race-based environmental inequities exist and are unaffected by type of risk analyzed, level of geographic aggregation, or type of control communities, while class, income, and economic based inequities demonstrate weaker evidence. Due to the sensitive nature of reporting race and ethnicity in some jurisdictions, linguistic isolation has been used as a surrogate, attempting to capture the same underlying construct as proportion minority in a population. Linguistic isolation has been defined as the proportion of residents under age 4 living in households where no one over age 15 speaks English well (Sadd et al., 2011), and may serve as stand-in for the community's decreased resources to advocate for action on improving inequalities.

Another sociodemographic factor included in some EJ definitions is educational attainment, defined as proportion of the population over age 24 (or under age 25 (Kershaw et al., 2013)) with less than high school education (Sadd et al., 2011), or those with less than a high school education (Alexeeff et al., 2012; Fann et al., 2011). Using educational attainment to identify vulnerable populations, Fann et al. (2011) found that when comparing air quality management approaches, overall inequality across the population decreases, though they found greater inequalities within education groups than between education groups. Kershaw et al. (2013) found significant differences in educational attainment between census tracts hosting toxic air pollution emitters versus those that do not.

In addition to demographic indicators, a community also may be more vulnerable to the impacts of air pollutant exposures based on its members' exposures to environmental contaminants, including, but not limited to, air and water pollution and hazardous chemical exposures. In a study of a multi-pollutant risk-based approach to air quality management, Fann et al. (2011) analyzed different definitions of vulnerable and susceptible populations using combinations of baseline health, demographic, education, poverty, and air quality data. The largest differences in annual mean population-weighted PM<sub>2.5</sub> exposures per person were found between EJ and non-EJ communities when EJ communities were defined using both baseline PM<sub>2.5</sub> exposure and asthma hospitalization rates (Fann et al., 2011). A study assessing cumulative impacts in California included measures of PM<sub>2.5</sub> concentrations, ozone concentrations, toxic releases from industrial facilities, traffic volumes, and pesticide use in addition to other public health and socioeconomic factors (Alexeeff et al., 2012). The Environmental Justice Screening Method (EJSM), tested in the SCAB, includes measures of air quality hazards, sensitive land use, hazardous land use, and health risks and exposures, in addition to social and health vulnerability indicators (Sadd et al., 2011). While the potential correlation between indicators makes it difficult to determine which factors are important to include and which are not, there is evidence based on the above analysis of vulnerability to include air quality measures and potential environmental exposures when the goal of a potential regulation or policy is to improve air quality.

### *Susceptibility*

Susceptibility differs from vulnerability, because it is related to a person's underlying biology rather than social constructs. The U.S. EPA defines susceptibility as the “degree to which a given population experiences a greater or lesser biological response to exposure (US EPA, 2009).” Baseline health data, including mortality rates and hospital admissions rates, are commonly used surrogate susceptibility indicators (Fann et al., 2011), as well as age (Alexeeff et al., 2012; Kershaw et al., 2013; Miranda et al., 2011; Sadd et al., 2011). Fann et al. (2011) found that when paired with poverty and education status, both baseline rates of asthma-related hospital admissions and mortality indicate a common pattern of vulnerable and susceptible populations in Detroit. Young children (those under 5 years) and the elderly (those over 65 years) may be more susceptible to the health impacts of air pollution. Across U.S. counties, proportion of the population aged 65 and over was found to be a significant predictor of the worst 20% of counties for annual and daily PM<sub>2.5</sub> concentrations, while proportion of the population under age five is a significant predictor of the worst 20% of counties for ozone exposures (Miranda et al., 2011). When comparing the socioeconomic status of census tracts within two kilometers of the top ten highest emitting toxic release facilities with the rest of host census tracts, children under 14 years of age are significant predictors of differences in toxic equivalency potential scores (Kershaw et al., 2013).

#### 2.2.1.3 Are Analysis Results Sensitive to the Definition of EJ?

While some studies explicitly categorize the indicators used in defining EJ communities as related to vulnerability or susceptibility, others do not, instead simply employing different environmental, health, and demographic data to define communities. As is clear from IEc's review of relevant literature, there is not a one-size-fits-all working definition that can be employed to define particularly vulnerable and susceptible communities in different geographic areas across the US. However, certain definitions have been found to be more successful in appropriately designating potential EJ communities (Downey, 2005; R. Morello-Frosch et al., 2001; Ringquist, 2005; Sadd et al., 2011). Fann et al. (2011) analyzed use of different indicators for defining EJ communities, including a measure of vulnerability (poverty, education, and air quality) and a measure of susceptibility (mortality rate, hospital admissions due to asthma rate). Though they included no measures of race and ethnicity in their EJ definitions, they found that while education attainment and poverty status may be interchangeable as measures of vulnerability, highly resolved baseline asthma hospital admissions and mortality rates are not interchangeable measures of susceptibility. The largest population-weighted changes in air quality were observed when EJ communities were defined by health incidence rates and air quality exposure, more so than definitions based on health incidence rates and poverty or health incidence rates and education (Fann et al., 2011).

#### 2.2.1.4 Cumulative Impacts

A common thread among studies of EJ communities is the need for inclusion of cumulative impacts, or cumulative risks, in a community. Cumulative impacts include the aggregation of environmental and social stressors faced by vulnerable communities (US EPA, 2003). Consideration of cumulative exposure helps to determine what disparities in exposure mean for inequities in health risks, as the relationship between health risks and a



single environmental exposure is not direct. Sadd et al. (2011) employed an environmental justice screening method in the SCAB and analyzed 23 indicator metrics organized as hazard proximity and land use, air pollution exposure and estimated health risk, and social and health vulnerability measures. Areas with high cumulative impact scores had high minority proportion, low income populations, and were located near industrial activities (Sadd et al., 2011).

#### 2.2.1.5 How Do Other Agencies Define EJ Communities?

SCAQMD aims to assess and employ state of the science definitions for EJ communities. To ensure our recommended definitions are up to date, we also reviewed the definitions used by other State agencies to identify EJ communities. Table 3 below lists EJ definitions by agency. As described below, the California Environmental Protection Agency (CalEPA) has developed a tool, CalEnviroScreen 2.0, to identify communities that are disproportionately burdened by multiple pollutant sources (California Office of Environmental Health Hazard Assessment, 2015). The California Air Resources Board (CARB) employs the state definition of EJ, “The fair treatment of people of all races, cultures, and incomes with respect to the development, adoption, implementation, and enforcement of environmental laws, regulations, and policies,” and defers to the CalEnviroScreen 2.0 tool to define EJ communities.

**TABLE 3. EJ DEFINITIONS OR SCREENING TOOLS USED BY STATE AND LOCAL ENVIRONMENTAL AGENCIES**

AGENCY	EJ DEFINITION OR SCREENING TOOL USED
California EPA	CalEnviroScreen2.0
California Air Resources Board	Utilizes the state definition of EJ, “The fair treatment of people of all races, cultures, and incomes with respect to the development, adoption, implementation, and enforcement of environmental laws, regulations, and policies (California Air Resources Board, 2010).” CalEnviroScreen2.0 and EJSM
Massachusetts Department of Environmental Protection	If any of the following are true: <ul style="list-style-type: none"> <li>• Block group whose annual median household income is equal to or less than 65% of the statewide median; or</li> <li>• 25% or more residents identify as minority; or</li> <li>• 25% or more of households having no one over age 14 who speaks English only or very well (Massachusetts Department of Environmental Protection, 2014)</li> </ul>
Connecticut Department of Energy and Environmental Protection	Uses the list of distressed municipalities from the Department of Economic and Community Development, based on per capita income, % of poverty, unemployment rate, % change in population, % change in employment, % change in per capita income, % of house stock built before 1939, % population with high school degree or higher, and per capita adjusted equalized net grand list (Connecticut Department of Energy and Environmental Protection, 2015).
DC Department of Energy and Environment	Ensures “District citizens who are low-income, minority, or have limited English proficiency receive equal protection under environmental laws and have meaningful opportunities to participate in



AGENCY	EJ DEFINITION OR SCREENING TOOL USED
	environmental decision making undertaken by DOEE (DC Department of Energy & Environment, 2015).”
New York State Department of Environmental Conservation	<p>“Potential EJ Areas are 2000 U.S. Census block groups of 250 to 500 households each that, in the 2000 Census, had populations that met or exceeded at least one of the following statistical thresholds:</p> <ol style="list-style-type: none"> <li>1. At least 51.1% of the population in an urban area reported themselves to be members of minority groups; or</li> <li>2. At least 33.8% of the population in a rural area reported themselves to be members of minority groups; or</li> <li>3. At least 23.59% of the population in an urban or rural area had household incomes below the federal poverty level. (New York State Department of Environmental Conservation, 2003).”</li> </ol>
Pennsylvania Department of Environmental Protection	Any census tract where 20% or more live in poverty, and/or 30% or more is minority (Pennsylvania Department of Environmental Protection, 2014).
Michigan Department of Environmental Quality	Defined by U.S. EPA EJSEAT tool (Michigan Environmental Justice Working Group, 2010).
Rhode Island Department of Environmental Management	Based on 2000 census block groups, those with percentages in the top 15% for low income residents and/or non-white populations (Rhode Island Department of Environmental Management, 2014).
Tennessee Department of Environment and Conservation	Defined by U.S. EPA EJScreen Tool (Tennessee Department of Environment and Conservation, 2015).

Outside of California, the Massachusetts Department of Environmental Protection defines EJ communities as those where any of the following are true: a block group whose annual median household income is equal to or less than 65% of the statewide median (\$62,072 in 2010); or 25% or more of the residents identify as minority; or 25% or more of households having no one over the age of 14 who speaks English only or very well (Massachusetts Department of Environmental Protection, 2014). Connecticut’s Department of Energy and Environmental Protection utilizes the list of distressed municipalities from the Department of Economic and Community Development, which ranks 169 towns in Connecticut based on income, poverty, unemployment, population change, employment change, income change, housing characteristics, and education characteristics as described by the U.S. Census and ACS estimates, and defines the 25 towns with the highest scores based on those components as the distressed municipalities. Connecticut General Statute Section 32-9p indicates that a distressed municipality should be based on “high unemployment and poverty, aging housing stock, and low or declining rates of growth in job creation, population, and per capita income” (Connecticut Department of Energy and Environmental Protection, 2015). New York State Department of Environmental Conservation defines potential EJ communities as block groups that had populations that met or exceeded at least one of the following statistical thresholds: at

least 51.1% of the population in an urban area reported themselves to be members of minority groups, at least 33.8% of the population in rural areas reported themselves to be members of minority groups, or at least 23.59% of the population in an urban or rural area had household incomes below the federal poverty level (New York State Department of Environmental Conservation, 2003). The Pennsylvania Department of Environmental Protection defines EJ communities as a census tract where 20% or more individuals live in poverty and/or 30% or more of the population is minority (Pennsylvania Department of Environmental Protection, 2014).

While these states provide specific definitions for EJ communities, we can see that their definitions differ from one another. Some states consider a set of indicators and require multiple thresholds be met before an area is defined as an EJ community, while others allow an EJ community to be defined based on a single indicator. Other state agencies, including the Michigan Department of Environmental Quality and Tennessee Department of Environment and Conservation, utilize U.S. EPA's Environmental Justice Strategic Enforcement Assessment Tool (EJSEAT) tool and U.S. EPA's EJScreen tool, respectively, to define EJ communities. EJSEAT was created for the EPA Office of Enforcement and Compliance Assurance to identify areas with potentially high public health burdens, and uses federal databases to include environmental, human health, compliance, and social demographic indicators (EPA Office of Enforcement and Compliance Assurance, n.d.). Most state environmental protection departments do not specify EJ definitions publicly.

### **2.2.2 Environmental Justice Screening Tools**

To further inform our assessment of alternatives to enhance SCAQMD's current EJ analysis, we reviewed existing EJ tools and methodologies. The reviewed tools identify environmentally burdened communities, socially burdened communities, or both. We assessed common parameters across the tools, compared these parameters to the current SCAQMD EJ community definition, and ultimately assessed which tool would be most useful in choosing alternative EJ definitions. The tools are particularly useful as a means to compare and contrast how varying EJ definitions affect the identification of EJ communities within the SCAQMD.

This review included four tools or methods identified by SCAQMD: EJScreen, CalEnviroScreen 2.0, Environmental Justice Screening Method (EJSM), and Cumulative Environmental Vulnerabilities Assessment (CEVA), as well as several others IEC identified in its literature review above or from previous work. Tools were evaluated with a focus on the following parameters: data resolution, data availability, ranking methodology, and inclusion of key environmental and population indicators. Understanding that SCAQMD analyzes data at the sub-county level, preference was given to tools with sub-county data resolution. Also, tools with publicly available easy-to-use processed source data were preferred, as this both facilitates transparency with constituents and simplifies the process of tailoring the data analysis for SCAQMD's goals. A review of the 2012 Socioeconomic Assessment by Abt Associates suggested percentage-based thresholds replace quantitative thresholds; thus, we assessed each tool's methodology with particular attention to the threshold-defining steps. Finally, we

evaluated the inclusion of key environmental and population indicators identified both from the literature and from the current SCAQMD definition. As described below; the review resulted in the selection of CalEnviroScreen 2.0 as the preferred methodology for sensitivity testing of SCAQMD’s current EJ definition.<sup>4</sup>

EJScreen was developed by the U.S. EPA. Currently, the U.S. EPA uses EJScreen to “help to highlight geographic areas and the extent to which they may be candidates for further review, including additional consideration, analysis or outreach (US EPA, 2016).” Both the tool and the guidance documents were updated in 2016. This tool assigns a percentile to each census block in the United States, and allows for the combination of 11 environmental indicators and 7 demographic indicators in two ways:

- Any one environmental indicator may be combined with two pre-selected population indicators (% minority and % low-income); or
- Any one environmental indicator may be combined with all 7 population indicators.

The processed source data are available as GIS or Excel files (US EPA, 2016). Though the data are publicly available and resolved to census blocks, EJScreen guidance cautions that the tool should not be used to define an EJ community, consistent with Executive Order 12898 (US EPA). Additionally, the tool allows for combining population indicators with only a single environmental indicator, which is limiting for SCAQMD’s purposes.

The EJSM was developed by Rachel Morello-Frosch of UC Berkeley, Manuel Pastor of USC, and James Sadd of Occidental College; the most recent update was released in 2015. The method was initially developed for the California Air Resources Board, and provides no user-accessible tool. This method assigns a value (1-5) to each census tract for each of four categories, resulting in a cumulative score (0-20). Ten hazard proximity indicators and five sensitive land use indicators comprise the Hazard Proximity category; six indicators comprise the Health Risk & Exposure category; nine indicators comprise the Social & Health Vulnerability category; nine indicators comprise the Climate Change Vulnerability category. Though this analysis was originally ground-truthed and performed for the SCAB region, this is a method without readily available processed source data or results. Additionally, EJSM indicators may be highly correlated with one another (e.g., “housing value” and “% residents below twice national poverty level”).

CEVA was developed by UC Davis’s Center for Regional Change in November 2011 to provide spatial analysis identifying places subject to cumulative environmental hazards and social, economic, and political strains. Raw data are used to assign a mean value for each of six environmental hazard indicators, six social vulnerability indicators, and three health indicators to each census block. The means are averaged and normalized for both the cumulative environmental hazard indicators and social vulnerability indicators. The resulting environmental and social scores are mapped, with a different color assigned to each category bin based on percentiles (Low, Medium, and High). This analysis does not provide readily accessible source data or results. Additionally, the cumulative

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<sup>4</sup> SCAQMD has identified a potential concern regarding CalEnviroScreen 2.0’s percentile scoring method, as this method may not reflect potential skewness in nonparametric variable distributions.

environmental hazard indices (e.g., proximity to hazardous waste treatment facilities, chrome platers) do not align with SCAQMD's emphasis on air quality burdens.

U.S. EPA's Community-Focused Exposure and Risk Screening Tool (C-FERST) is a pilot tool currently in development that will help communities understand potential environmental public health issues in EJ communities. Currently, the beta-version is available upon request for pilot testing, and the full public release is not yet scheduled.

The University of South Carolina's Social Vulnerability Index (SoVI) 2006-10 measures the social vulnerability of U.S. counties to environmental hazards. However, the data are resolved to counties, and thus are inconsistent with the spatial requirements for SCAQMD's analysis, which need to be more resolved than the county level.

The 2010 Social Vulnerability Index (SVI) was developed by the Agency for Toxic Substances & Disease Registry to assess social vulnerability for each census tract, especially as it relates to disaster relief. Because the tool includes indicators customized to disaster relief (e.g., percent housing structures with 10 or more units or percent households with no vehicle available) and did not include environmental burden, the tool would require significant alterations to meet SCAQMD's analytic needs.

CalEnviroScreen 2.0 was developed by the California Environmental Protection Agency (CalEPA) and the Office of Environmental Health Hazard Assessment (OEHHA). Guidance documents were updated in October 2014, and the tool was updated in November 2015. An updated version of CalEnviroScreen 2.0 is expected in 2016. The tool was designed to aid in the identification of EJ communities for SB 535, which dictates that 25% of money from the Greenhouse Gas Reduction Fund must be directed to projects benefitting disadvantaged communities. Thus, both CalEPA and CARB currently use the tool to identify disadvantaged communities. CalEPA also uses the tool to aid in environmental justice grant administration, prioritizing clean-up sites, promoting compliance with environmental laws, and identifying opportunities for sustainable economic development. Raw data are used to assign each census tract a percentile for each indicator (indicators listed in Table 3 below), relative to the State of California. The percentiles are averaged and normalized for both the pollution burden indicators and the population indicators. The resulting pollution burden score and population score are multiplied. The product (0-100) is ranked against all census tract scores. The overall score is a percentile calculated using the ordered (0-100) values. The tool is accompanied by a thorough guidance document, and all processed source data are available as GIS or Excel files. Because all source data are available and resolved to census tracts, the methodology is consistent with SCAQMD's goals and is replicable, and key indicators are included, CalEnviroScreen 2.0 was identified as the preferred methodology for enhancing SCAQMD's EJ analysis.

### 2.2.3 EJ Definition Options

Through a series of discussions with SCAQMD staff, IEc aimed to create a set of alternative EJ definitions based on the following guidelines:

- An alternative definition of EJ must provide a sensitivity analysis for SCAQMD's current grant distribution definition of EJ,

- An alternative definition should include SCAQMD- generated data (including but not limited to toxic cancer risk) rather than values from another source when possible,
- An alternative definition of EJ must include air quality measures,
- An alternative definition of EJ should include relevant socio-economic data, and
- Race and ethnicity and other non-air quality environmental indicators may be included for alternative definitions that are for comparison purposes in sensitivity tests,

Multiple definitions with similar structure are recommended based on the ability to use these definitions as a sensitivity analysis for both the current grant distribution definition of EJ, and also as sensitivity analyses for one another. To best enhance SCAQMD's EJ analysis, we suggest tailoring CalEnviroScreen's source data, except for toxic cancer risk and race and ethnicity data, and methodology to the SCAB region and using it to identify EJ communities based on a series of alternative EJ definitions. Table 4 shows the indicators used by CalEnviroScreen and those that IEc proposes.

Comparing the list of indicators used by CalEnviroScreen and proposed by IEc, alternative definitions were created to best suit the needs of SCAQMD. Environmental indicators of potential hazard (e.g., proximity to hazardous waste facilities, groundwater threats, impaired water bodies, solid waste sites and facilities, and cleanup sites) were weighted half as much as indicators reflecting measured environmental contaminant concentrations. Toxic cancer risk values generated by SCAQMD were included in lieu of diesel PM emissions. Race and ethnicity values were generated from the 2010-2014 ACS 5-Year estimates. Because SCAQMD has jurisdiction only over the SCAB, percentiles are generated relative to the SCAB region (rather than relative to all of California). Census tracts with a population less than 100 are excluded from analysis. In the remainder of this section we present our recommendations for EJ definitions and how the CalEnviroScreen 2.0 methodology and data can be used to identify EJ communities based on the recommended alternative definitions.

For each indicator of interest, raw data from CalEnviroScreen (other than toxic cancer risk and race and ethnicity as explained above) are used to assign each census tract a percentile ranking. For example, the census tract with the highest PM<sub>2.5</sub> value in the SCAB region would fall into the 100<sup>th</sup> percentile for the PM<sub>2.5</sub> indicator. Gridded toxic cancer risk values modeled by the SCAQMD are joined to the census tracts layer using population-weighted averages by area. Race and ethnicity values were generated by the ACS for each census tract. Percentile rankings were calculated for each indicator separately – zero and one hundred percentiles are included, and if there are zero values in the raw data, those were equated to zero values in the percentile rankings, as well. In the event that census tract raw data was missing, the appropriate county mean value was used. For example, if a census tract in Orange County did not have associated poverty data, that census tract was allocated the Orange County poverty mean value. The environmental burden indicator percentiles are averaged, resulting in an average environmental burden percentile by census tract. This average percentile is divided by the

maximum environmental burden percentile in the SCAB region and subsequently multiplied by 10, resulting in a 0-10 environmental burden score. The above process is repeated for the demographic indicators, resulting in a 0-10 demographic score. The pollution burden score and demographic score are multiplied. The product (0-100) is ranked against all SCAB census tract scores. The overall score is a percentile calculated using the ordered (0-100) values. A census tract was designated a “Top 25%” EJ community if the overall score was greater than or equal to 75, and was designated a “Top 50%” EJ community if the overall score was greater than or equal to 50. Indicators marked with an asterisk (\*) and shown in *italics* in the table represent differences between CalEnviroScreen indicators and indicators proposed by IEC.

**TABLE 4. COMPARISON OF CALENVIROSCREEN INDICATORS AND INDICATORS PROPOSED BY IEC FOR ALTERNATIVE EJ DEFINITIONS**

INDICATOR TYPE	CALENVIROSCREEN INDICATORS	IEC PROPOSED INDICATORS
Environmental	Ozone concentration PM <sub>2.5</sub> concentration <i>*Diesel PM concentration</i> Drinking water contaminants Toxic releases from facilities Traffic density Pesticide use Cleanup sites Groundwater threats Hazardous waste generators and facilities Impaired water bodies Solid waste sites and facilities	Ozone concentration PM <sub>2.5</sub> concentration Drinking water contaminants Toxic releases from facilities Traffic density Pesticide use Cleanup sites Groundwater threats Hazardous waste generators and facilities Impaired water bodies Solid waste sites and facilities <i>*Toxic cancer risk</i>
Demographic	Children and elderly Asthma rate Low birth weight infants Educational attainment Linguistic isolation Poverty Unemployment	Children and elderly Asthma rate Low birth weight infants Educational attainment Linguistic isolation Poverty Unemployment <i>*Race and Ethnicity</i>
Note: Indicators marked with an asterisk (*) and shown in <i>italics</i> represent differences between CalEnviroScreen indicators and indicators proposed by IEC.		

When defining EJ communities in an effort to analyze regulation or control policies, it is important to utilize information at the highest geographic resolution possible. Based on both our literature and EJ screening tool review, we recommend the following set of definitions to determine which communities are particularly vulnerable or susceptible to air pollution exposures (Table 5). The definitions are created based on CalEnviroScreen’s



framework summarizing environmental and sociodemographic indicators separately, then multiplying their respective scores together for an overall score, based on percentile ranking. Scores are multiplied together rather than added because often these indicators are understood in scientific literature as effect modifiers, which amplify risk; risk assessment applies numerical multipliers to account for human susceptibility; and in the related field of emergency response, many priority rankings are created via multiplication of factors rather than addition (California Office of Environmental Health Hazard Assessment, 2015). These ranked percentiles are relative to the SCAB rather than the state of California or the United States, as the definition of EJ communities should be limited to the area that is subject to SCAQMD's authority. CalEnviroScreen uses census tracts to define EJ communities, whereas SCAQMD uses a 2km x 2km air quality grid. We constructed these definitions using census tracts because census tracts are created with an optimal average population size of 4,000 people, are intended to be maintained over time, generally follow visible features, and are updated by local participants (US Census Bureau, 2010).

**TABLE 5. RECOMMENDED ALTERNATIVE EJ DEFINITIONS FOR SENSITIVITY ANALYSIS**

ALTERNATIVE DEFINITION	DEMOGRAPHIC INDICATORS		ENVIRONMENTAL INDICATORS	
	Income	Other Demographic	Air Quality	Other Environmental
1	Poverty status		PM <sub>2.5</sub> , toxic cancer risk, ozone	
2	Poverty status	Age, asthma, education, linguistic isolation, low birth weight, unemployment	PM <sub>2.5</sub> , toxic cancer risk, ozone	
3	Poverty status	Age, asthma, education, linguistic isolation, low birth weight, unemployment	PM <sub>2.5</sub> , toxic cancer risk, ozone	Drinking water, pesticides, toxic releases, traffic, <i>cleanup sites, groundwater threats, hazardous waste, impaired water bodies, solid waste</i>

Definitions and data sources for the environmental and sociodemographic indicators included in the alternative EJ definitions are presented below.

- Poverty status is the percent of the population within a census tract whose income is less than twice the federal poverty level, as low income populations are more likely than wealthier populations to face adverse environmental burden. In their grant allocation EJ definition, SCAQMD includes areas where at least 10% of the

population is below the federal poverty level. We recommend updating this to twice the federal poverty level to account for the higher than average cost of living in the SCAB and conservative federal poverty level value. Poverty data are from the ACS 5-year estimates for 2008-2012.

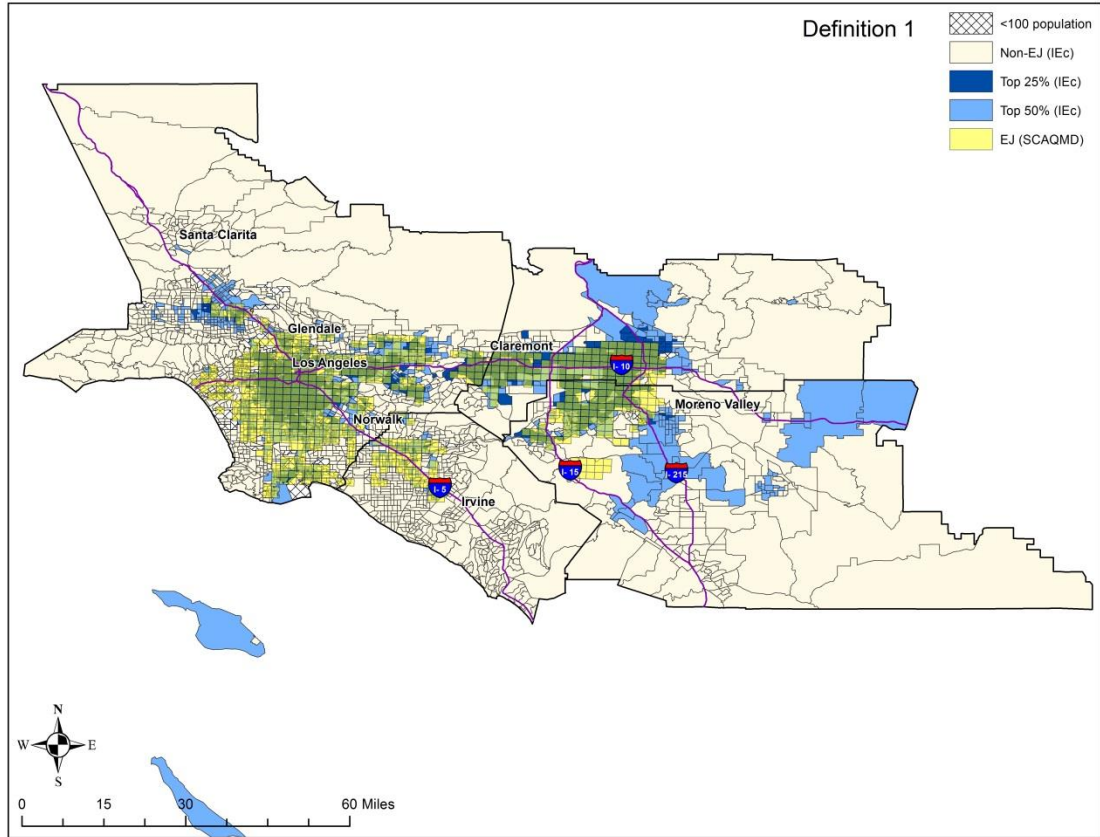
- Age is the percent of the population within a census tract under age 10 or over age 65. Children can be particularly sensitive to the effects of air pollution due to both their high activity levels and their developing body and organ systems, and the elderly can be particularly sensitive to air pollution effects due to preexisting health conditions. Data are from the U.S. Census Bureau's 2010 decennial census.
- Asthma is included as the age-adjusted rate of emergency department visits per 10,000 averaged between 2007 and 2009. These rates were modeled by the California Office of Statewide Health Planning and Development.
- Education is the percent of the population within a census tract over age 25 with less than a high school education, as derived from the ACS 5-year estimates for 2008-2012.
- Linguistic isolation is the percentage of households in which no one over age 14 speaks English very well or at all, as determined by the U.S. Census Bureau's 2008-2012 ACS estimates (California Office of Environmental Health Hazard Assessment, 2015).
- Low birth weight is the modeled percent of low birth weights (less than 2,500 grams) within a census tract, averaged from California Department of Public Health 2006-2009 data.
- Unemployment is the population over the age of 16 that is unemployed and eligible for the labor force. Unemployment data are from the ACS 5-year estimates for 2008-2012.
- PM<sub>2.5</sub> concentrations are the annual mean PM<sub>2.5</sub> concentrations, averaged 2009-2011 with data from the California Air Resources Board.
- Toxic cancer risks in the SCAB are modeled by SCAQMD, gridded to 2km x 2km grid cells. These risks are then mapped to census tracts to appropriately incorporate values into these definitions.
- Ozone is incorporated as the amount of daily maximum 8-hour ozone concentration over the California standard, averaged 2009-2011 with data from the California Air Resources Board.
- Drinking water contaminants are included as the drinking water contaminant index from the Drinking Water Systems Geographic Reporting Tool by the California Department of Public Health.
- Pesticides are the total pounds of active pesticide ingredients (filtered for hazard and volatility) used in production-agriculture per square mile with data from the California Department of Pesticide Regulation.



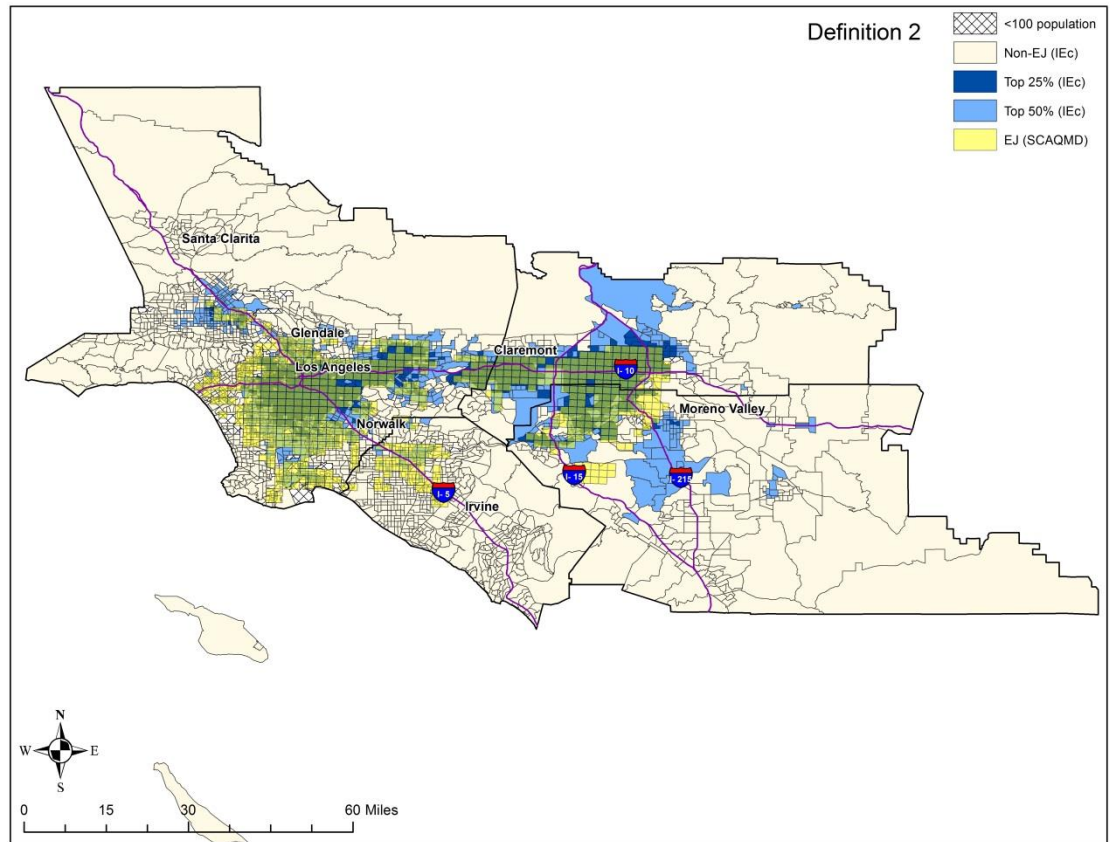
- Toxic releases from facilities are the toxicity-weighted concentrations of chemical releases from facility emissions and off-site incineration, with data from Risk Screening Environmental Indicators, U.S. EPA, and the Toxic Release Inventory.
- Traffic density is included as the sum of traffic volume (adjusted by road segment length) divided by total road length within 150 meters of the census tract boundary, with data from the California Environmental Health Tracking Program and the San Diego Association of Governments.
- Cleanup sites are the sum of sites within each census tract, with data from the U.S. EPA and the Department of Toxic Substances Control.
- Groundwater threats are the sum of scores for storage tank sites within each census tract, with data from the State Water Resources Control Board.
- Hazardous waste generators and facilities are the sum of permitted hazardous waste facilities and generators within each census tract, with data from the Department of Toxic Substances Control.
- Impaired water bodies are included as the summed number of pollutants across impaired water bodies with data from the State Water Resources Control Board.
- Solid waste sites and facilities are the sum of solid waste sites and facilities, with data from CalRecycle.

Based on SCAQMD's current EJ definition, it is most appropriate to begin with a definition inclusive of an income or poverty indicator and air quality metrics (Definition 1). We then expand upon this definition, including other sociodemographic indicators that may better capture the vulnerable and susceptible population by incorporating indicators such as age, asthma baseline rates, and linguistic isolation (Definition 2). We expand this definition further in Definition 3 to include additional environmental burden factors, such as drinking water and pesticides. The indicators retained (listed in Table 5 and described above) are based on our literature and screening tools review. The maps shown in Figures 1a, b, and c below show EJ communities identified by applying each proposed EJ definition.

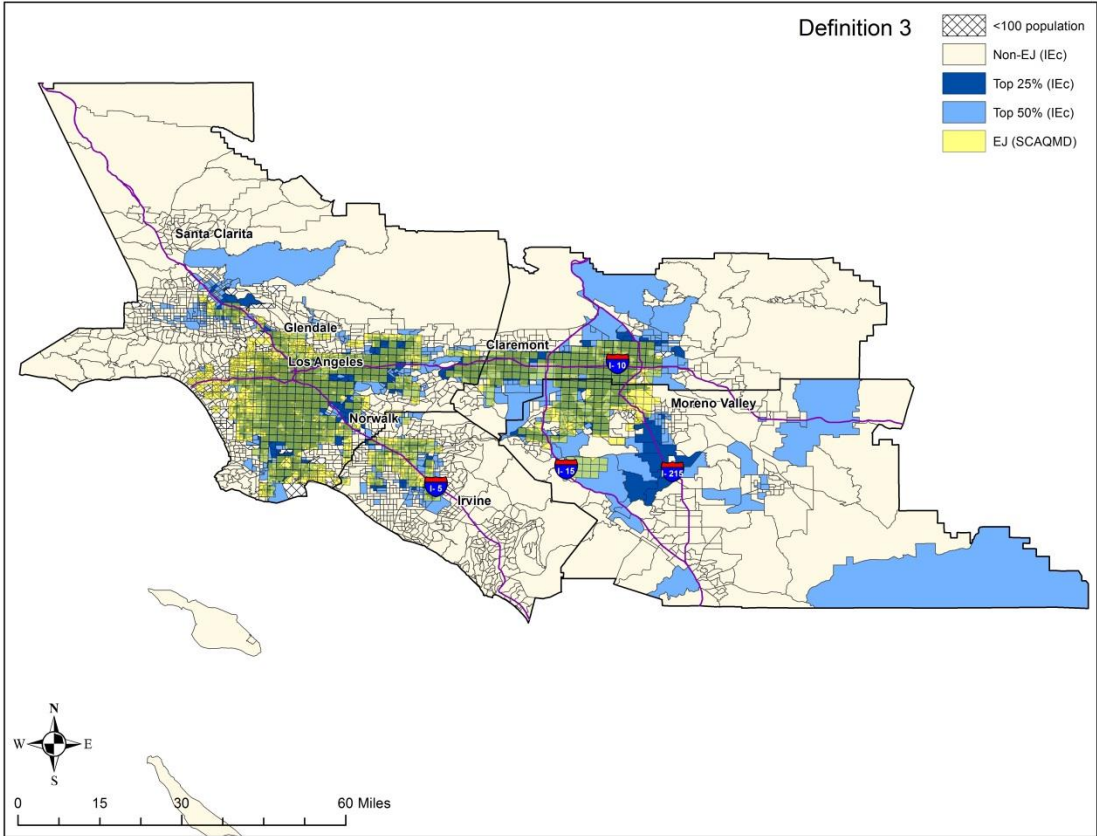
**FIGURE 1a. MAP OF CENSUS TRACTS IN SCAB DESIGNATED BY PROPOSED EJ DEFINITIONS (BLUE) WITH SCAQMD EJ DEFINITION OVERLAID (YELLOW). DEFINITION 1 INCLUDES INCOME AND AIR QUALITY INDICATORS**



**FIGURE 1b. MAP OF CENSUS TRACTS IN SCAB DESIGNATED BY PROPOSED EJ DEFINITIONS (BLUE) WITH SCAQMD EJ DEFINITION OVERLAID (YELLOW). DEFINITION 2 INCLUDES INCOME, OTHER SOCIODEMOGRAPHIC, AND AIR QUALITY INDICATORS**



**FIGURE 1c. MAP OF CENSUS TRACTS IN SCAB DESIGNATED BY PROPOSED EJ DEFINITIONS (BLUE) WITH SCAQMD EJ DEFINITION OVERLAID (YELLOW). DEFINITION 3 INCLUDES INCOME, OTHER SOCIODEMOGRAPHIC, AIR QUALITY, AND OTHER ENVIRONMENTAL BURDEN INDICATORS**



The findings in Figures 1a, b, and c are consistent with expectations based on the indicators included in each definition. SCAQMD defines its EJ communities based on a 2km x 2km grid, so EJ communities do not line up directly with those included in the proposed definitions by census tract. Generally, communities that have been defined as EJ communities by SCAQMD overlap with those defined as EJ communities by the proposed set of definitions in this report. Definition 1 is the most basic, including only poverty status and air quality indicators, but with a more inclusive definition of poverty than used in SCAQMD's current definition. EJ communities defined in this manner tend to be located along major roadways, and are spread fairly evenly across the center third of the SCAB. Definition 1's Top 50% overlaps largely with the SCAQMD definition, though also includes additional census tracts in the more rural eastern part of the basin. Definition 1's Top 25% generally falls in the Los Angeles city center. Definition 1 does not include some areas that have been defined by SCAQMD as EJ communities, including tracts along the outskirts of the dense EJ area of the city of Los Angeles and tracts in the eastern central area of SCAB.

Definition 2, which includes poverty status, air quality indicators, and other demographic indicators, shows a similar pattern to Definition 1, with fewer tracts in the southeastern area of the SCAB included. Definition 2 overlaps largely with the SCAQMD definition, but also includes additional census tracts in the eastern part of the basin and in the central and eastern part of the city of Los Angeles. Among the three alternatives shown here, Definition 2 EJ communities appear to overlap most with EJ areas designated by SCAQMD, with the exception of some tracts in the eastern central part of the SCAB. Definition 3, which is the most expansive definition and includes poverty status, air quality indicators, other demographic indicators, and other environmental indicators, shows the greatest difference with the SCAQMD definition due to its inclusion of other environmental burden indicators. Definition 3 does not include as many tracts on the western coast of the SCAB that are defined as EJ by SCAQMD. Most notably, Definition 3 includes the southeastern most census tract, which is large and rural with low population density. Definitions 2a and 3a, which include race and ethnicity as an additional demographic indicator, are shown in Appendix A. Tables 6 and 7 show the percent of population identified as living within an EJ community by county for the Top 50% and Top 25% of EJ populations, respectively.

**TABLE 6. DISTRIBUTION OF TOP 50% EJ POPULATIONS FOR EACH PROPOSED DEFINITION BY COUNTY**

	DEFINITION 1	DEFINITION 2	DEFINITION 3
Los Angeles	70.6%	72.5%	68.1%
Orange	5.7%	3.9%	11.2%
Riverside	10.0%	9.5%	8.1%
San Bernardino	13.7%	14.1%	12.5%
Total	100%	100%	100%*
Note: Sum of county-specific values do not sum to 100% due to rounding error.			

**TABLE 7. DISTRIBUTION OF TOP 25% EJ POPULATIONS FOR EACH PROPOSED DEFINITION BY COUNTY**

	DEFINITION 1	DEFINITION 2	DEFINITION 3
Los Angeles	72.1%	72.0%	75.2%
Orange	1.0%	0.1%	4.8%
Riverside	7.2%	7.1%	6.6%
San Bernardino	19.7%	20.8%	13.5%
Total	100%	100%	100%*
Note: Sum of county-specific values do not sum to 100% due to rounding error.			

Los Angeles County contains the majority of the EJ populations in the SCAB based on each proposed definition. Definition 3 shifts more of the affected population to Orange County. Orange and Riverside Counties have the smallest percent of population identified by the proposed EJ definitions. Tables 8 and 9 show the percent of population in each county identified as living within an EJ area for the Top 50% and Top 25% of EJ populations, respectively. Los Angeles and San Bernardino are the counties with the highest proportions of population identified as living within EJ communities. Orange County exhibits the smallest percentage of its population living within EJ communities, though the percentage increases substantially under Definition 3.

**TABLE 8. PROPORTION OF COUNTY POPULATION LIVING IN A TOP 50% EJ COMMUNITY BY PROPOSED EJ DEFINITION**

	DEFINITION 1	DEFINITION 2	DEFINITION 3
Los Angeles	57.4%	59.3%	56.9%
Orange	14.5%	10.0%	29.5%
Riverside	44.1%	42.0%	36.6%
San Bernardino	69.0%	71.5%	64.8%
All Counties in SCAB	48.9%	49.1%	50.2%
Note: Values by definition for individual counties do not add up to 100%, as this table depicts the percent of county population affected.			

**TABLE 9. PROPORTION OF COUNTY POPULATION LIVING IN A TOP 25% EJ COMMUNITY BY PROPOSED EJ DEFINITION**

	DEFINITION 1	DEFINITION 2	DEFINITION 3
Los Angeles	28.3%	28.7%	31.3%
Orange	1.3%	0.1%	6.2%
Riverside	15.2%	15.4%	14.9%
San Bernardino	47.9%	51.2%	34.6%
All Counties in SCAB	23.6%	24.0%	25.0%
Note: Values by definition for individual counties do not add up to 100%, as this table depicts the percent of county population affected.			

These definitions can be used in sensitivity analyses to determine whether and how changing the definition of an EJ community may affect the assessment of the distributional impacts of the 2016 AQMP on mortality and morbidity health risks within the SCAB. Similar tables can be found in Appendix A showing Definitions 2a and 3a, which include race and ethnicity as a demographic variable.

It is important to note that an EJ screening analysis using these definitions would be based on a static snapshot of demographics across the SCAQMD. For example, the data on population age is from the U.S. Census Bureau's 2010 decennial census and data on education, poverty and employment are from the U.S. Census Bureau's American Community Survey 2008 – 2012. Therefore, the modeling tool being proposed here cannot reflect dynamic changes in demographics that may occur as a result of environmental improvements from implementation of new policies. Such changes could be related to environmental gentrification, the potential for which has been explored in published studies with mixed conclusions (Checker, 2011; Banzhaf and McCormick, 2006; Eckerd, 2011).



## CHAPTER 3. REVIEW OF INEQUALITY INDICATORS AND DISTRIBUTIONAL ANALYSIS METHODS

### 3.1. METHODS

Prior to beginning our review, IEc participated in a number of discussions with SCAQMD staff where we discussed how SCAQMD currently defines EJ communities; how SCAQMD has analyzed differential impacts on EJ communities in comparison with the rest of the population in previous studies, and what goals SCAQMD has established for an analysis of these differences in the upcoming 2016 Socioeconomic Assessment of the AQMP. We conducted a review of the literature describing inequality metrics and distributional analysis guided by the objectives SCAQMD laid out in these discussions. We began by reviewing the documents that SCAQMD specified in its statement of work, including papers by Maguire and Sheriff (2011), Post et al. (2011), Sheriff and Maguire (2013), and Harper et al. (2013). Then, we analyzed health and environmental inequality and distributional analysis literature, searching for both examples of use of inequality indicators in health benefits analysis as well as guidance or review articles recommending inequality indicators for health benefits analysis, paying particular attention to studies focused on risks from air pollutants. Finally, we analyzed literature specifically noted by our scientific advisors, Dr. Sam Harper of McGill University and Dr. Jon Levy of Boston University. Based on this literature review, we developed a set of potential indicators and criteria to serve as the basis for choosing the most appropriate inequality indicators for SCAQMD's analysis.

### 3.2 RESULTS

In this section, we summarize the results of our literature review in three parts. We first focus on the basics of distributional analysis and inequality indicators, and then we summarize guidance literature. Finally, we present criteria and considerations for SCAQMD to consider before choosing inequality metrics for the agency's distributional analysis. We describe case studies that utilized these indicators and consider critiques of the use of these indicators in the health context.

#### 3.2.1 Distributional Analysis

When comparing or analyzing air pollution control strategies, it is important to consider not just the magnitude but also the distribution of health benefits associated with those strategies. Distributional analysis provides a way to compare empirical distributions from different points in time for a broad assessment of health risk in populations generally, and between specific sub-populations such as EJ and non-EJ groups. Distributional analysis provides more information than an analysis comparing only the relationship between summary measures between groups. For example, it is feasible to compare health risks between EJ and non-EJ groups by comparing measures of central tendency or 95<sup>th</sup>



percentiles, but these measures do not provide information about variance within groups or the shape of the distribution. Distributional analysis of health impacts can inform policy makers regarding whether or not there is a difference in health impacts between EJ and non-EJ groups at various points within the risk distribution, and whether or not these groups will benefit from an air pollution control policy differentially in ways that improve or exacerbate inequality.

Regulatory impact analyses performed by the U.S. EPA, which focus on quantifying health and environmental benefits of policy options, have historically focused on aggregated health benefits rather than the demographic or spatial distribution of such health benefits (Levy, Wilson, & Zwack, 2007). Distributional analysis allows policy makers to formally analyze air pollution control strategies given tradeoff preferences between equality and efficiency characteristics of a given policy's health impacts (Levy, Greco, Melly, & Mukhi, 2009). For distributional analysis, an inequality index should be calculated for the baseline scenario and compared with the same inequality index for control scenarios to assess changes in inequality arising from different control strategies (Levy et al., 2007). The quantitative indicators utilized in distributional analysis provide information on inequality, but moving from a state of inequality to a state of equity or justice requires policy makers impose a social calculus of which inequalities are of greatest concern. As stated in Harper et al. (2013), "quantification of inequality in health or exposure to environmental hazards or benefits is necessary, but not sufficient, for determining whether or not a distribution is indeed inequitable." Other factors must also be considered.

### **3.2.2 Guidelines for Use of Inequality Indicators in Health Benefits Distributional Analysis**

An examination of distributional outcomes of EJ policies requires three separate analytical elements: the baseline distribution of an environmental outcome for one or more groups; the distribution of that environmental outcome under different regulatory options; and a metric to characterize how policy options change the distribution of the outcome within or between groups when compared to the baseline situation (Maguire & Sheriff, 2011). For SCAQMD's distributional analysis, the environmental outcomes being analyzed are exposure-related mortality risk and risk of asthma-related emergency department (ED) visits associated with fine particulate matter (PM<sub>2.5</sub>) and ozone exposure. PM<sub>2.5</sub>- and ozone-related mortality risk in adults is analyzed because it is the most severe health outcome associated with air pollution, local baseline data are readily available, and results would be expected to vary based on local demographic characteristics such as the percent of individuals aged 65 and older. The morbidity risk of asthma-related ED visits in children provides a useful complement to the exposure-related mortality risks, providing a measure of AQMP impacts on morbidity risks particularly affecting children. In analyzing these risk values, the baseline distributions of health risk from PM<sub>2.5</sub> and ozone constitute the baseline to which each air quality control strategy is compared. These health risk values for both PM<sub>2.5</sub> and ozone exposure can be produced with BenMAP-CE, using SCAQMD's modeled air quality values for baseline and control scenarios, SCAB baseline health data, concentration-response functions, and local population characteristics.

### 3.2.2.1 Necessary Criteria

A general set of guidelines is common throughout studies attempting to create or utilize inequality indicators for health risk or EJ analysis. An indicator should be able to:

- Convert a distribution to a single index value to provide a concise and easily utilized metric to order a set of outcomes (Maguire & Sheriff, 2011; Sheriff & Maguire, 2013). This is the basic principle behind using a single indicator or index value for distributional analysis.
- Define a reference group for comparison, whether it be comparing to an average member of the population, the best-off person in a population, or to all of those who are better off (Harper et al., 2013).
- Be defined as to whether it uses relative comparisons, and thus is unaffected by proportional changes across a population (scale invariance) (Levy, Chemerynski, & Tuchmann, 2006; Maguire & Sheriff, 2011), or whether it uses absolute comparisons between groups and thus is unaffected by a uniform shift (Maguire & Sheriff, 2011).
- Clearly indicate whether the groups being considered are ordinal (e.g., defined by income) or nominal (e.g., defined by race or ethnicity)(Harper et al., 2013). In this analysis, EJ classification can be considered nominal, as it is made up of an array of factors, or can be considered ordinal, if it is presumed that those in EJ groups experience more risk than those not in EJ groups.
- Fulfill the Pigou-Dalton transfer principle (Levy et al., 2006), which states that any transfer from a better-off person to a worse-off person, should cause the indicator value to decrease, signifying a reduction in inequality. This principle prevents an indicator from displaying a reduction in inequality if the health risk of an already low-risk person decreases even further.

### 3.2.2.2 Additional Considerations

The following characteristics are desirable of indicators, though not mandatory.

Indicators may:

- Make an explicit value judgment that evaluates changes in one part of the distribution differently than changes in another part of the distribution (Harper et al. 2013).
- Be decomposed for evaluation of within-group and between-group inequality (Harper et al., 2013; Levy et al., 2006; Maguire & Sheriff, 2011). Subgroup decomposability allows for analysis of within-group and between-group inequality, and consideration of how they relate to one another within the construct of a particular indicator. Analyzing between-group and within-group variation provides insight on whether overall inequality within the SCAB region is driven by EJ characteristics versus other factors. For example, where between-group inequality is greater than within-group inequality, the EJ versus non-EJ division between the groups does a sufficient job of explaining this variability. Where within-group inequality is greater than between-group inequality, the EJ versus non-EJ division between the groups does not do a sufficient job of

explaining this variability, as there is a greater difference in inequality within these groups than between them.

Based on these tenets and our review of relevant literature, we focus our analysis on the indicators in Exhibit 1, below.

### 3.3 INEQUALITY INDICATORS

The inequality indicators considered in this report have been used by economists traditionally to analyze the distribution of income or wealth (Atkinson, 1970; de la Vega & Urrutia, 2003; The World Bank, 2016). Previous studies have attempted to identify and quantify inequality and inequities in health benefits and regulatory impacts analyses using a suite of economic inequality indicators, including the Atkinson index (Post, Belova, & Huang, 2011), Gini coefficient (Bouvier, 2014), Theil's entropy index, mean log deviation (Levy et al., 2009, 2007), and the Kolm-Pollak index (Maguire & Sheriff, 2011; Sheriff & Maguire, 2013). These indicators are summarized in Table 10, adapted from Harper et al. (2013) and Levy et al. (2006). Other indicators, including concentration index, squared coefficient of variation, and variance of logarithms, which have been used in more limited contexts and not demonstrated for use in a health risk case study, are not included in this review. We also excluded Lorenz curves because they are not an index or indicator value, but rather a visualization tool for comparing outcome distributions (Sheriff & Maguire, 2013).

TABLE 10. INEQUALITY INDICATORS

INEQUALITY INDICATOR	REFERENCE GROUP	ABSOLUTE OR RELATIVE INEQUALITY?	ACCOMMODATES ORDERED SOCIAL GROUPS?	SUBGROUP DECOMPOSABLE?	ADJUSTABLE INEQUALITY AVERSION PARAMETER?
Atkinson Index	Average	Relative	Yes	Yes	Yes
Gini coefficient	Average/ those better off	Relative or Absolute	No	No	No
Theil index	Average	Relative	No	Yes	No ( $\epsilon = 1$ )
Mean log deviation	Average	Relative	No	Yes	No ( $\epsilon = 0$ )
Kolm-Pollak index	Average	Absolute	Yes	Yes	Yes

The parameters used to define these indicators in Table 10 are important for SCAQMD to consider in the context of their goals for policy analysis. In the next section, we describe different options for each parameter, and illustrate with examples how one option may impact the outcome as compared with another option. We review applications of these inequality indicators more thoroughly in section 3.5.

### 3.4 IMPLICATIONS OF PARAMETER CHOICES FOR POLICY ANALYSIS

The measures of inequality most appropriate for SCAQMD's analysis must reflect the aspects of health inequality that SCAQMD believes are most important to capture in its distributional analysis. There is no single "right" indicator that should be used in all cases, as these inequality indicators have attributes that are specific to the values indicated by policy makers. Deciding what aspects of health inequality are important to ensure as part of distributional analysis will affect conclusions regarding the trends and magnitude of health inequalities (Harper & Lynch, 2016). The parameter choices presented in this section result from our literature review and are not presented in a specific order of importance, though all should be considered by SCAQMD in context of its analysis and policy goals.

SCAQMD should consider whether it is interested in understanding effects on total inequality which measures variation in health risk across the entire SCAB population, effects on inequality between different social groups within the SCAB population, or effects on both. It is our understanding that SCAQMD wishes to analyze inequality between different social groups, defined as EJ communities and non-EJ communities. This decision provides a framework for SCAQMD to review the options below for the attributes of alternative inequality index parameters in performing distributional analysis.

#### 3.4.1 Reference Group

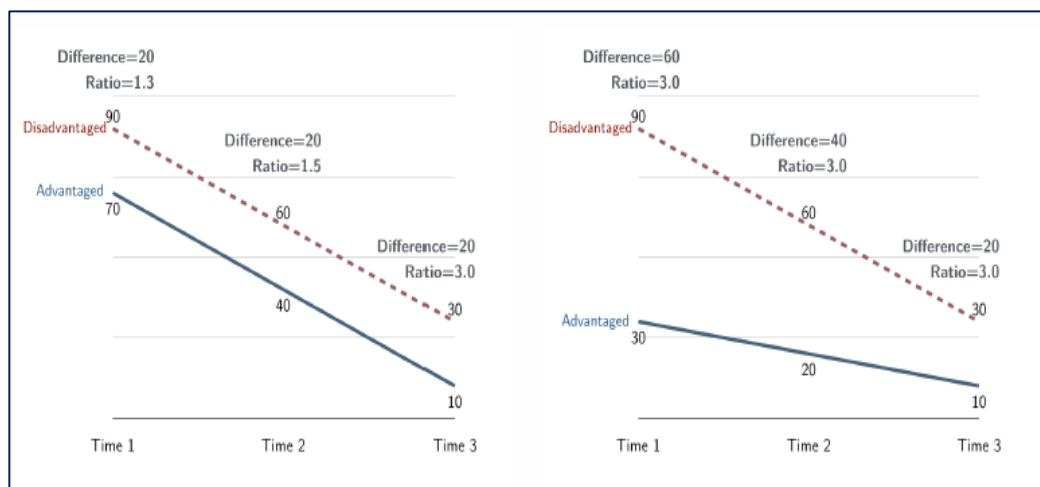
To measure inequality, a group of interest must be compared with a reference group. It is important to clearly define the rationale for choosing a reference group, as inequality conclusions may differ depending on the reference group chosen. For example, should the health risk of those in EJ communities be compared to the average health risk in the population, or to those with the least health risk, or to those in EJ communities in a different region of the country? Many different groups can be compared – EJ communities in SCAB region with EJ communities in the Bay Area; EJ communities in the SCAB region to non-EJ communities in the SCAB region; EJ communities in the SCAB region to the national average, or to the average of California, or the average of the SCAB region. There are many possible reference group choices (Harper & Lynch, 2016). Choosing the population average health risk as a reference group provides a comparison between an EJ group and the population average, an intuitive comparison, but the population average changes over time. Choosing the healthiest group or all those better off as the reference group provides information regarding the inequality between a group and maximum health potential. Another potential reference group is a target or goal health risk, which does not change over time as the other reference groups do. Choosing a target or goal health risk value provides a stable value as a goal, but without extensive research, this health risk value may be out of the realm of possibility for a group.

#### 3.4.2 Absolute or Relative Measure of Inequality

Inequality is a concept that depends on relationships between groups. An absolute comparison looks at the difference between two values, while a relative comparison looks at the ratio between two values. Absolute comparisons are translation invariant, that is, there is no absolute change if health risk values increase by a constant across a population or groups. Relative comparisons are scale invariant, as there is no relative change if

health risk values double for an entire population or group. For example, in the left panel of Figure 2, the outcomes decrease at the same absolute rate for both groups, but because the same absolute change will be proportionally larger for a group with lower baseline levels, relative inequality will increase while absolute inequality stays the same. In the right panel of Figure 2, the same relative decline with different starting points will lead to decreasing absolute inequality but constant relative inequality. If we consider health risk values for two different groups, we may arrive at different conclusions about inequality depending on whether it is measured relatively or absolutely. Both of these measures are valid, but policy makers must determine which type of measure is most appropriate for their analyses.

**FIGURE 2. DIVERGING SCENARIOS FOR ABSOLUTE AND RELATIVE INEQUALITY TRENDS (HARPER & LYNCH, 2016)**



### 3.4.3 Inequality Aversion Parameter

Inclusion of an explicit inequality aversion parameter ( $\epsilon$ ) as is found in the Atkinson index and the Kolm-Pollak index allows a policy maker to adjust the sensitivity of these metrics to changes in inequality, based on societal preferences. In these indices, higher values of the inequality aversion parameter indicate a society's stronger preference for equality, or aversion toward inequality. The Atkinson index and Kolm-Pollak index increase as  $\epsilon$  increases. Use of an inequality aversion parameter allows policy makers to place additional weight on transfers at the bottom of the distribution when measuring inequality of a good (health) rather than a bad (health risk) (Levy et al., 2007). The inequality aversion parameter can be any real number where higher values indicate a stronger preference for equality. To provide perspective, common indices of inequality with fixed aversion parameters are the Theil index, where  $\epsilon = 1$ , and the mean log deviation, where  $\epsilon = 0$ . That is, the Theil index is more sensitive to transfers at the bottom of the distribution than mean log deviation (Harper & Lynch, 2016). The magnitude of the Atkinson index increases as  $\epsilon$  increases, however, the overall impact of this change on a policy's effect on inequality depends on which part of the distribution (e.g., bottom, middle, top of the distribution) is being targeted by the policy.

Small differences in the magnitude of the inequality aversion parameters can be difficult to interpret; thus, inequality aversion parameters are best used in a sensitivity analysis context, where the analyst can evaluate potential impacts of broad increases or decreases in inequality aversion on distributional impacts.

#### **3.4.4 Subgroup Decomposable**

An inequality indicator that is subgroup decomposable allows the policy maker to assess between-group and within-group inequality, or the sources of total inequality differences across two groups. In this analysis, groups are geographical in nature and based on census tract. Subgroup decomposability is desirable, as it provides information beyond total inequality, including how between-group and within-group inequality is expected to change due to the policies being analyzed. For example, in some instances, between-group inequality may be greater than within-group inequality, providing information about the differences between the two groups and indicating similarity in risk within groups. In other instances, within-group inequality may be greater than between-group inequality, which provides the policy maker with information regarding the definition of the groups themselves, as members are not as similar in risk as was expected. A subgroup decomposable measure can incorporate risk assessment concerns like biological susceptibility with the distribution of impacts across EJ subgroups (Levy et al., 2006). However, this characteristic is not necessary in distributional analyses, as other measures provide information on total inequality across a population.

#### **3.4.5 Ordered Social Groups**

Policy makers should decide whether or not it is important that an indicator allows for inclusion of groups with inherent ordering, like income or education, or no inherent ordering, like race, ethnicity, or gender. Allowing for inclusion of ordered groups creates the opportunity to assess the gradient of risk as the group status changes. Some inequality measures quantify health gradients and whether health risks decrease or increase with social group ordering (e.g., health gradients with income), making them inappropriate for groups without inherent order. In an instance where judgments are made about nominal groups (like EJ and non-EJ groups) for use with an ordinal-type measure of inequality, the policy maker is including an important assumption that the ranking of groups by EJ status is associated with disadvantage. Using ordinal groups in conjunction with some indicators allows quantification of health gradients that follow increasing or decreasing health status by increasing group order. For example, using an indicator designed for ordinal comparisons for an analysis of neighborhoods ordered by proportion of minority population assumes that increasing proportions of minority population is directly associated with increasing disadvantage. However, there may be more well-off areas with large minority populations that do not adhere to this assumption. This assumption can be appropriate in cases where individual-level data are available for those within these neighborhoods to account for outlier situations, but may be inappropriate in contexts where only group data are available (Harper et al., 2013).



### 3.5 USE OF INEQUALITY INDICATORS IN HEALTH BENEFITS DISTRIBUTIONAL ANALYSIS

Inequality indicators have been used in a number of studies analyzing health risk (Levy et al., 2006, 2009, 2007) and EJ (Levy et al., 2006; Post et al., 2011). Additionally, a number of authors have both assessed and proposed methods regarding how these inequality measures are best utilized in health risk or EJ analyses (Harper et al., 2013; Maguire & Sheriff, 2011; Sheriff & Maguire, 2013). Below, we briefly describe each of these indices and how they have been used in relevant literature to inform how they may be used for SCAQMD.

#### 3.5.1 Atkinson Index

The Atkinson Index was constructed to assess income inequality and is derived from a social welfare function (Atkinson, 1970). The Atkinson index ranges from 0, representing perfect equality, to 1, representing maximum inequality. The Atkinson index value is based on the true outcome rather than a ranking of outcomes, and as such it is not dependent upon a third party variable or value outside of the distribution. While it is not additively decomposable, the Atkinson index is subgroup decomposable and can be broken down into between-group and within-group components (Harper et al., 2013). The Atkinson index can accommodate both ordered and non-ordered groups. The Atkinson index has been criticized as a health inequality indicator due to its inability to directly analyze a “bad” outcome (Maguire & Sheriff, 2011), or greater health risk, but it can be transformed to a “good” by analyzing the inverse of risk where theoretically appropriate (Harper et al., 2013). The Atkinson index is a generalized entropy indicator which utilizes an explicit parameter,  $\varepsilon$ , to allow greater sensitivity to the low end of a distribution (higher risk) over the high end in the distribution (low risk) with increasing  $\varepsilon$  (Levy et al., 2006). With inclusion of this inequality aversion parameter, the user can indicate societal concern for inequality, with higher values indicating a greater aversion to inequality. The Atkinson index is calculated as follows:

$$A(\varepsilon) = 1 - \left[ \frac{1}{n} \sum_{i=1}^n \left( \frac{y_i}{\bar{y}} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \quad \varepsilon > 0, \varepsilon \neq 1$$

$$A(\varepsilon) = 1 - \prod_{i=1}^n \left[ \frac{y_i}{\bar{y}} \right]^{\frac{1}{n}} \quad \varepsilon = 1$$

Where  $y_i$ ,  $\bar{y}$ , and  $n$  are the individual’s health, average health, and number of individuals and  $\varepsilon$  is the inequality aversion parameter.

In an analysis of the health impacts of public bus retrofits to decrease emissions in Boston, Levy et al. (2009) model the changes in emissions to determine age-adjusted mortality rates. Using the Atkinson index as their primary measure of inequality (both directly for mortality risk and for the inverse of mortality risk) between baseline and control scenarios, they find that higher mortality rates are found in lower socioeconomic

status census tracts, and also that more efficient control strategies tended to do better from an inequality perspective, as well. The Gini coefficient is used to test the sensitivity of the results, as the Gini coefficient is a commonly used income inequality measure (discussed below). The results of Levy et al. (2009) are corroborated by another study using the Atkinson index to quantify inequality between national power plant emissions reductions strategies, where health benefits are maximized in concordance with spatial inequality reduction. These conclusions were robust, as the optimal policy choice did not change with the choice of epsilon utilized in the Atkinson index (Levy et al., 2007). Similarly, Fann et al. (2011) utilized the Atkinson index to analyze differences in the results of different PM<sub>2.5</sub> reduction policies, finding that a multi-pollutant risk-based approach yielded the greatest health benefits and reduced inequality between vulnerable areas and elsewhere. Post et al. (2011) analyzed the health risks of the EPA's Heavy Duty Diesel rule for air quality for individuals living in EJ communities compared to other communities using the Atkinson index. Taking advantage of the decomposable nature of the Atkinson index, Post et al. (2011) found that inequality within racial and ethnic groups was greater than the inequality between the groups. While some of these studies looked at the distribution of risk (Levy et al., 2009, 2007) rather than EJ groups specifically (Fann et al., 2011; Post et al., 2011), all were able to analyze inequality of non-monetary (or non-income) distributions. Generally, when policy measures aim to reduce risk among EJ populations and the focus is on people who have higher environmental exposures and vulnerability attributes, greater total health benefits arise in the population as a whole.

### 3.5.2 Gini Coefficient

The Gini coefficient is a commonly used income inequality indicator, where 0 implies complete equality and 1 implies complete inequality. This index produces a value that is relative to all those better off, satisfies the Pigou-Dalton transfer principle, and does not utilize an explicit judgment parameter (Levy et al., 2006). The Gini coefficient can be derived from the Lorenz curve, which has percentiles of the population ranked by pollution exposure on the x-axis and percent of pollution exposed by percentile on the y-axis and where a 1-to-1 line indicates an equal distribution of exposure (Maguire & Sheriff, 2011). The Gini coefficient is equal to twice the area between the equality line and the Lorenz curve (Levy et al., 2006). This is depicted in Figure 3, below. The Gini coefficient is not subgroup decomposable in the context of health risk or EJ, as it can only be decomposed when values are ordered, and implicitly gives the most weight to the center of the distribution. While this coefficient is commonly used, transfer among the distribution is based on the ranks within the distribution rather than the difference in the outcome. Due to the use of rank differences, the Gini coefficient is impacted by third parties. For example, if there is a transfer in the distribution between two individuals, and there is a third unrelated individual between them, the transfer will have a greater impact than if there is no third individual between the two because there is a greater rank difference between the two individuals (Maguire & Sheriff, 2011).

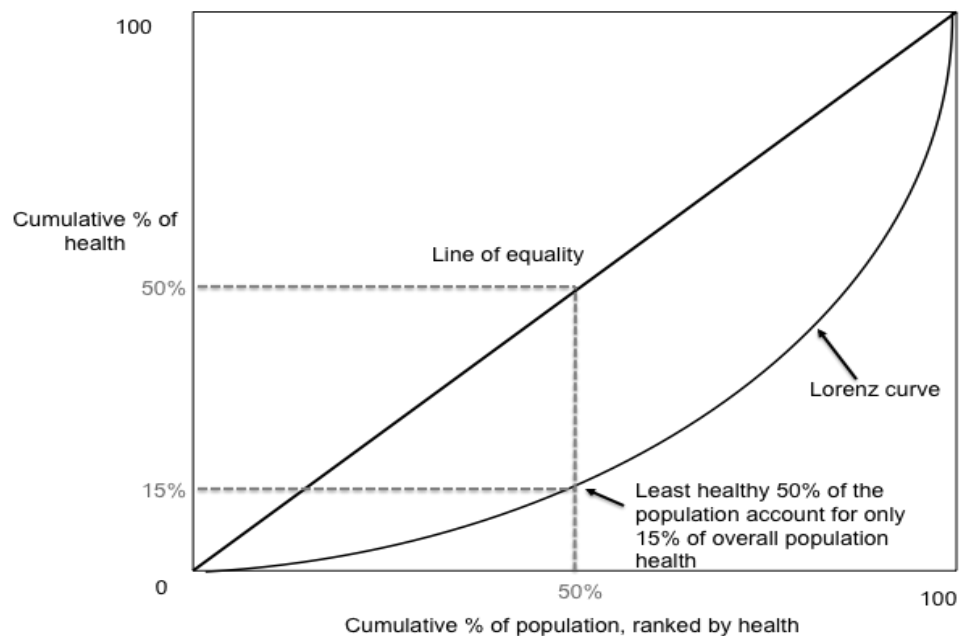
Some researchers have voiced broader concerns about the use of the Gini coefficient. According to Maguire and Sheriff (2011), the Gini coefficient can provide spurious results when comparing policy rankings. Because the Gini coefficient was created for



economic inequality analyses, they argue, it provides straightforward results when analyzing a “good,” like income, but is not well suited for use with health risk, which is inherently a “bad.” As a result, they do not recommend use of the Gini coefficient as a relative inequality measure (Maguire & Sheriff, 2011).

Other researchers, however, have applied the Gini in the context of health risks. For example, the Gini coefficient is used in an analysis of toxic air emissions and income in Maine, applying the index spatially to analyze the distribution of pollution, creating an environmental Gini coefficient. Bouvier (2014) also creates an emissions-adjusted income value, deriving an index based on income and pollution. She finds that the spatial distribution of pollution is more unequal than the distribution of income, and that a fraction of the population would experience a decrease in their income when adjusting for pollution (Bouvier, 2014). This paper presents a method much different than other related studies, and should be considered based on its novelty and incorporation of important factors in an EJ analysis – pollution and income distributions. In other studies, the Gini coefficient has been used as a sensitivity analysis when using the Atkinson index (Levy et al., 2009, 2007).

**FIGURE 3. GRAPHICAL EXAMPLE OF A LORENZ CURVE IN THE CONTEXT OF HEALTH INEQUALITY (HARPER & LYNCH, 2016)**



#### 4.5.3 Theil's Index and Mean Log Deviation

Both Theil's index, also known as Theil's entropy index, and the mean log deviation are measures of entropy that can be used to measure inequality within and between groups. These measures allow for differential sensitivity of indices to different parts of the health distribution in the form of a constant which determines the relative sensitivity of the index. The sensitivity parameter constant indicates how sensitive the index is to the top end of the health distribution (Harper and Lynch, 2016). The mean log deviation constant

is equal to 0 and the Theil's index constant is equal to 1 (Levy et al., 2006). There are no explicit inequality aversion parameters included in either of these indices. Theil's index requires a comparison with the average and is a relative rather than absolute measure of inequality (Harper et al., 2013). Both measures are additively subgroup decomposable and fulfill the Pigou-Dalton transfer principle. Both Thiel's index and the mean log deviation measures have been used together as sensitivity analyses after utilization of the Atkinson index to determine the robustness of the results (Levy et al., 2009, 2007).

Theil's index or mean log deviation haven't been used in health risk or EJ analyses as the main inequality index to our knowledge, though they can provide important inequality information when used in tandem. Both Theil's index and mean log deviation have been used as part of sensitivity analyses in a study analyzing a tailpipe emissions control strategy (Levy et al., 2007) and in analyzing hypothetical policy control scenarios for power plants (Levy et al., 2009). In Levy et al. (2007), using the Atkinson index, Gini coefficient, mean log deviation, and Theil's index, they find that for each indicator, using policies which control risks for high-risk individuals decreased the inequality indicators, or decreased the inequality in risk. For the middle of the risk distribution, inequality increased according to the Theil index, Gini coefficient, mean log deviation, and Atkinson index at  $\epsilon = 0.5$ , though  $\epsilon$  values greater than 0.5 indicated decreasing inequality in the distribution (Levy et al., 2007).

#### 3.5.4 Kolm-Pollak Index

The Kolm-Pollak index is a measure of absolute inequality that allows for different levels of inequality aversion (Harper & Lynch, 2016), and has similar properties to the Atkinson index. Although the Kolm-Pollak index has not been used in practice to analyze health inequalities, both Maguire and Sheriff (2011) and Sheriff and Maguire (2013) suggest consideration of this index. Both the Kolm-Pollak and Atkinson indices satisfy the Pigou-Dalton transfer principle, can accommodate ordered and non-ordered groups, are not dependent upon a third party variable or value outside of the distribution being analyzed, and both indices allow for transfer of risk from high to low-risk individuals to have a greater impact on the index value than transfer of risk from low to high-risk individuals (Sheriff & Maguire, 2013). Both are in reference to the average member of the population and are subgroup decomposable. Similar to the Atkinson index, the Kolm-Pollak index does not readily accept "bad" values to be used directly, but can be manipulated to measure the distribution of its complementary "good". The Kolm-Pollak index provides an absolute rather than a relative measure of inequality, such that adding a value to the entire distribution does not change the index value (Maguire & Sheriff, 2011), which would change with a relative measure of inequality. The Kolm-Pollak index is calculated as follows<sup>5</sup>:

$$K(\alpha) = \frac{1}{\alpha} \ln \left[ \frac{1}{n} \sum_{i=1}^n e^{\alpha[\bar{y} - y_i]} \right] \quad \alpha > 0$$

<sup>5</sup> Harper, S., & Lynch, J. (2016). Health Inequalities: Measurement and Decomposition.

Where  $y_i$ ,  $y$ , and  $n$  are the individual's health, average health, and number of individuals and  $\alpha$  is the inequality aversion parameter (noted throughout the remainder of this document as  $\epsilon$ ).

### 3.6 CRITERIA FOR RECOMMENDATION

To determine which inequality indicator is the best choice for distributional analysis in SCAB, we first outline criteria that should be considered.

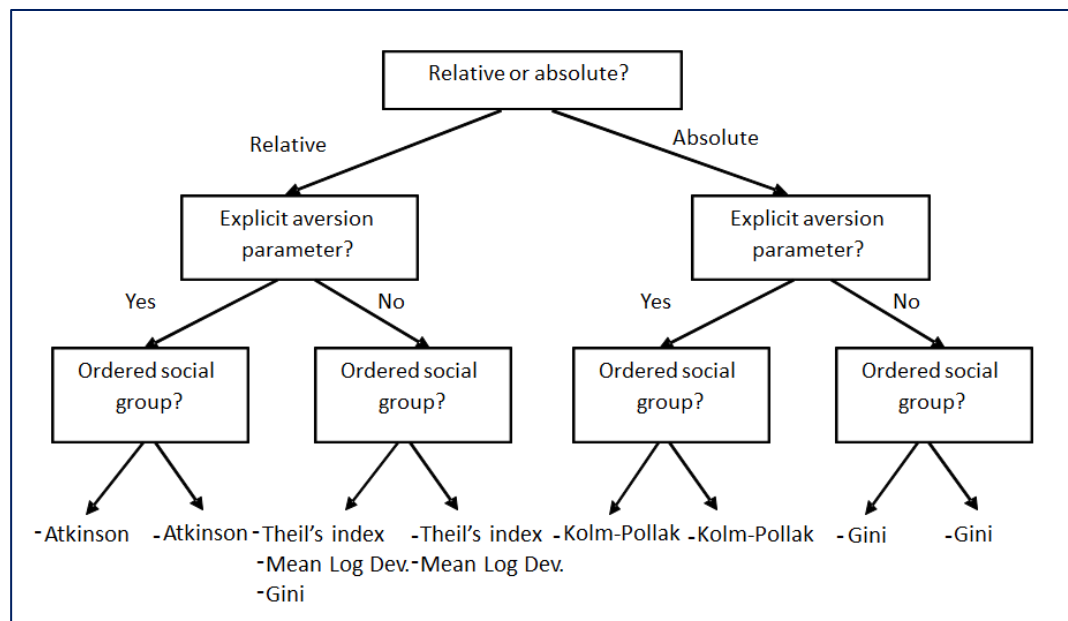
- What is the appropriate reference group or value for analysis of inequality in the SCAB region?

All indices discussed in this report have the ability to compare against the population average, or all those better-off in the case of the Gini coefficient. Indicators can generally be adapted to a chosen reference group or value.

- Should an indicator compare relative inequalities between groups or absolute inequalities between groups?
- Should an indicator include an explicit inequality aversion parameter to allow SCAQMD to determine the sensitivity of the indicator to different parts of the distribution?
- Should EJ and non-EJ groups be considered as ordinal or nominal?

These three questions are portrayed in the flow chart in Figure 4, below.

FIGURE 4. INEQUALITY MEASURE SELECTION FLOW CHART



Levy et al. (2006) sought to develop recommended methods to quantify inequality within a health benefit context, performing a systematic analysis of EJ and equity measures, ultimately providing axioms for inequality indicators for health benefits analysis. Based

on a set of 9 predefined axioms, Levy et al. (2006) recommends use of the Atkinson index generally to best address inequality assessment as part of health benefits analyses. Fann et al. (2011) analyzed two air quality management approaches in Detroit and their impacts on the distribution of health benefits across vulnerable and susceptible subpopulations. They applied the Atkinson index to quantify health risk inequality at baseline and for both air quality management approaches. Using the Atkinson index, they found their multipollutant risk-based approach yielded less inequality across the population than the traditional air quality management approach (Fann et al., 2011). Post et al. (2011) performed a distributional benefits analysis of U.S. EPA's Heavy Duty Diesel Rule in 2030, using modeled air quality data for 2030 as the control scenario, and analyzing the distribution among EJ subgroups. This goal is similar to that of SCAQMD, with the exception of analyzing PM<sub>2.5</sub> exposures rather than mortality risk in the affected population. In this study, they used the Atkinson index to determine if there are differences in air quality due to this rule and understand the inequality between and within EJ subgroups.

Maguire and Sheriff (2011) argue against use of the Atkinson index to analyze “bad” outcomes. They argue that, similar to the problem with the Gini coefficient discussed above, input of a “bad” into the Atkinson index violates economic principles. Replacing a “bad” with its complement (e.g., parts per billion “clean” air rather than parts per billion PM<sub>2.5</sub>) may create a very small Atkinson index value. When there is a very small change in health risk, the Atkinson index may be difficult to interpret, as a small percent change in health risk may be related to a significant valuation. They indicate that alternatively, multiplying the Kolm-Pollak index by negative one accommodates “bad” outcomes like health risk, preserving the social evaluation function ranking, similar to measuring the complementary “good” (Maguire & Sheriff, 2011). Other researchers have used the Atkinson index by applying a transformation to the health measure (e.g., using the inverse of health risk) to characterize health as a “good,” ensuring the increased weight placed on the bottom of the distribution by the inequality aversion parameter is weighting the appropriate end of the distribution. Alternatively, a small range of inequality aversion parameters can be used to provide sensitivity analysis of using the Atkinson measure with health or inverse of health risk as a “good” to avoid extreme interpretations (Harper et al., 2013).

### 3.7 RECOMMENDATIONS

Based on literature review and discussion with SCAQMD, the SCAQMD EJ working group, and STMPR group, we recommend the inequality indicator attribute preferences for use in distributional analysis of exposure-related mortality and morbidity risks between EJ and non-EJ communities in the SCAB listed in Table 11.

TABLE 11. PREFERRED INEQUALITY INDICATOR ATTRIBUTES

INDICATOR ATTRIBUTE	ATTRIBUTE TYPE
Reference Group	Average
Absolute or relative inequality?	Both Absolute and Relative
Accommodates ordered social groups?	Not needed
Subgroup decomposable?	Yes
Adjustable inequality aversion parameter?	Yes

An inequality indicator should have a reference group which is based on the average value in the population. This distributional analysis should include both an inequality aversion parameter to analyze absolute inequality and another to analyze relative inequality between groups. An inequality indicator does not need to accommodate ordered social groups since this analysis will be comparing EJ and non-EJ groups only, so no gradient can be determined. An inequality indicator should be subgroup decomposable to provide information on total inequality, within-group inequality, and between-group inequality. An inequality indicator should include an adjustable inequality aversion parameter to allow for sensitivity analyses and ensure that the designation of equality or inequality is consistent regardless of the indicator used.

Based on these preferences, we recommend the primary use of the Atkinson index, which uses the average of the population as the reference group, analyzes relative inequality, is subgroup decomposable, and includes an adjustable inequality aversion parameter. We also recommend the primary use of the Kolm-Pollak index, which uses the average of the population as the reference group, analyzes absolute inequality, is subgroup decomposable, and includes an adjustable inequality aversion parameter. These indices are similar to one another, with the exception of considering relative (Atkinson) and absolute (Kolm-Pollak) inequality.

In applying these inequality indicators, we recommend calculation of the risk of PM<sub>2.5</sub>- and ozone- exposure-related mortality and asthma ED visits across the study area using local baseline incidence rates and health impact functions. To calculate baseline risks, we recommend consideration of risks attributable to PM<sub>2.5</sub> and ozone rather than overall risk, as these exposure-related values are more relevant to SCAQMD policies. This will enable estimation of the change in mortality and asthma ED incidence related to AQMP policy-related changes in PM<sub>2.5</sub> and ozone exposure. The aforementioned inequality indicators can be applied to assess inequality between EJ and non-EJ communities before and after policy implementation.

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## APPENDIX A. ANALYSIS OF INCLUDING RACE AND ETHNICITY AS A DEMOGRAPHIC INDICATOR

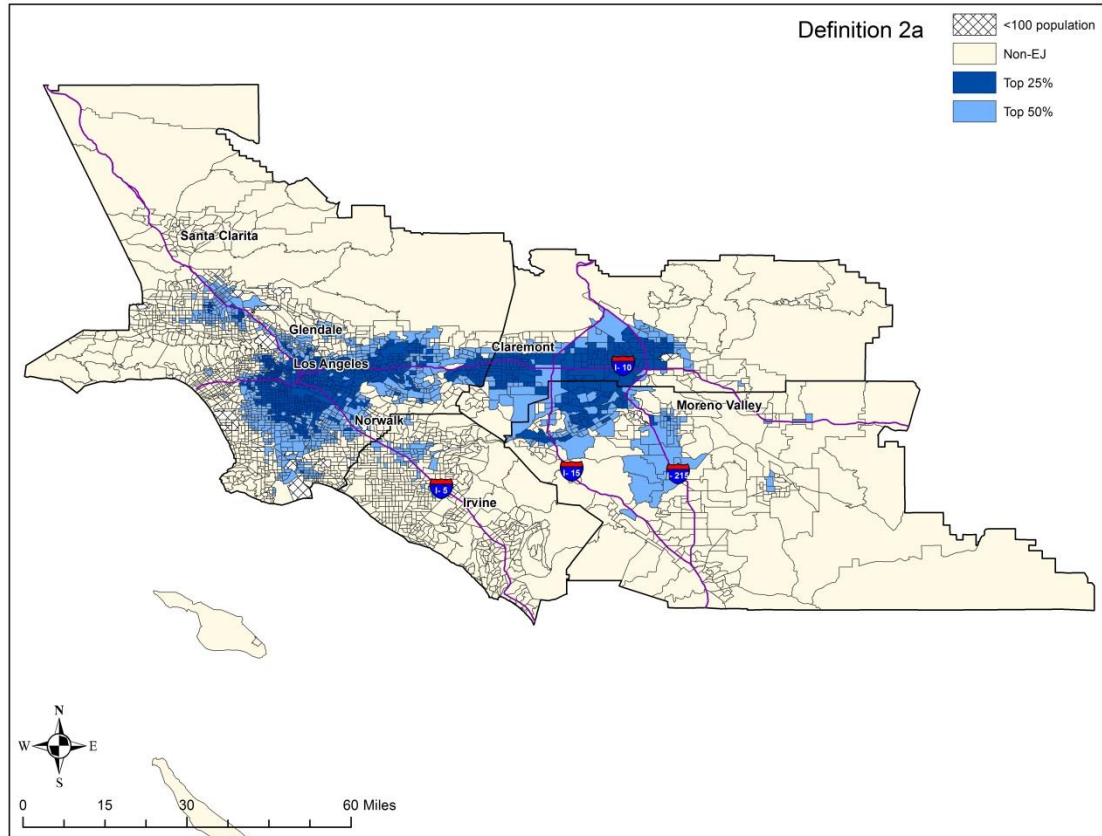
The definitions presented in this appendix are based on Definitions 2 and 3 in Chapter 3. These definitions expand upon Definitions 2 and 3 by adding race and ethnicity as an additional demographic variable. EJ scores are calculated by including race and ethnicity as one of the demographic variables, as shown in Table A1. Race and ethnicity expressed as is the percent of the population within a census tract with minority status (defined as non-Hispanic/Latino non-white alone), as derived from the U.S. Census Bureau's ACS 5-year estimates for 2010-2014.

**TABLE A1. ALTERNATIVE EJ DEFINITIONS FOR SENSITIVITY ANALYSIS INCLUDING RACE AND ETHNICITY**

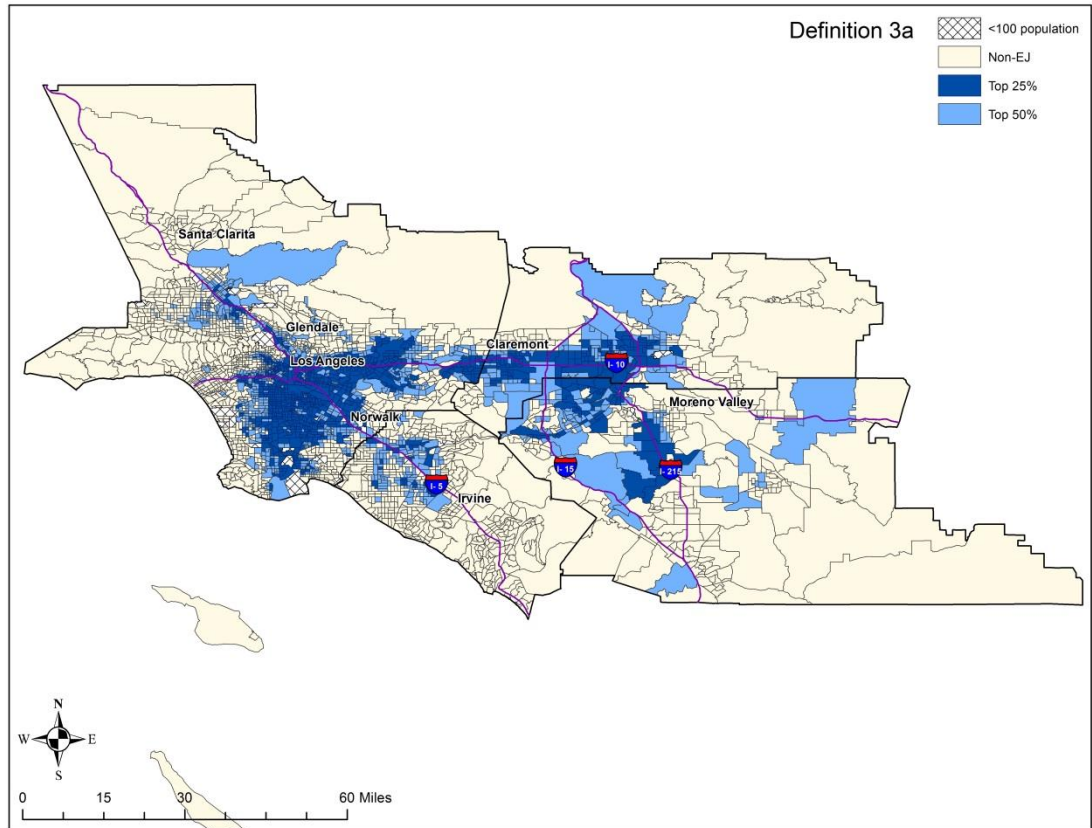
ALTERNATIVE DEFINITION	DEMOGRAPHIC INDICATORS		ENVIRONMENTAL INDICATORS	
	Income	Other Demographic	Air Quality	Other Environmental
2a	Poverty status	Age, asthma, education, linguistic isolation, low birth weight, unemployment, race and ethnicity	PM <sub>2.5</sub> , toxic cancer risk, ozone	
3a	Poverty status	Age, asthma, education, linguistic isolation, low birth weight, unemployment, race and ethnicity	PM <sub>2.5</sub> , toxic cancer risk, ozone	Drinking water, pesticides, toxic releases, traffic, <i>cleanup sites, groundwater threats, hazardous waste, impaired water bodies, solid waste</i>

The maps shown in Figures A1 and A2 below show EJ communities identified by applying each proposed EJ definition that contain race and ethnicity as a demographic variable (Definitions 2a and 3a) in addition to the base variables that make up Definition 2 and 3.

**FIGURE A1. MAP OF CENSUS TRACTS IN SCAB DESIGNATED BY PROPOSED EJ DEFINITIONS (BLUE). DEFINITION 2A INCLUDES INCOME, OTHER SOCIODEMOGRAPHIC INCLUDING RACE AND ETHNICITY, AND AIR QUALITY INDICATORS**



**FIGURE A2. MAP OF CENSUS TRACTS IN SCAB DESIGNATED BY PROPOSED EJ DEFINITIONS (BLUE). DEFINITION 3A INCLUDES INCOME, OTHER SOCIODEMOGRAPHIC INCLUDING RACE AND ETHNICITY, AIR QUALITY, AND OTHER ENVIRONMENTAL BURDEN INDICATORS**



The findings seen for Definitions 2a and 3a in Figures A1 and A2, respectively, are similar to those for Definitions 2 and 3 in Figures 1b and 1c in Chapter 3, respectively. Changes associated with inclusion of race and ethnicity are depicted in Figures A3 and A4, below. With race and ethnicity included in Definition 2, census tracts outside of the main contiguous EJ area are removed, and tracts within the contiguous area from central Los Angeles east along the I-10 corridor are included. Similarly, with race and ethnicity included in Definition 3, the large census tract in the southeastern corner of the region and other outlying tracts are removed, and tracts closer to the I-10 corridor are included as EJ communities.

**FIGURE A3. MAP OF CENSUS TRACTS IN SCAB DESIGNATED BY PROPOSED EJ DEFINITION 2 (BLUE). CENSUS TRACTS DESIGNATED AS EJ AREAS BY INCLUSION OF RACE AND ETHNICITY ARE SHOWN IN GREEN; CENSUS TRACTS DESIGNATED AS NON-EJ AREAS BY INCLUSION OF RACE AND ETHNICITY ARE SHOWN IN ORANGE.**

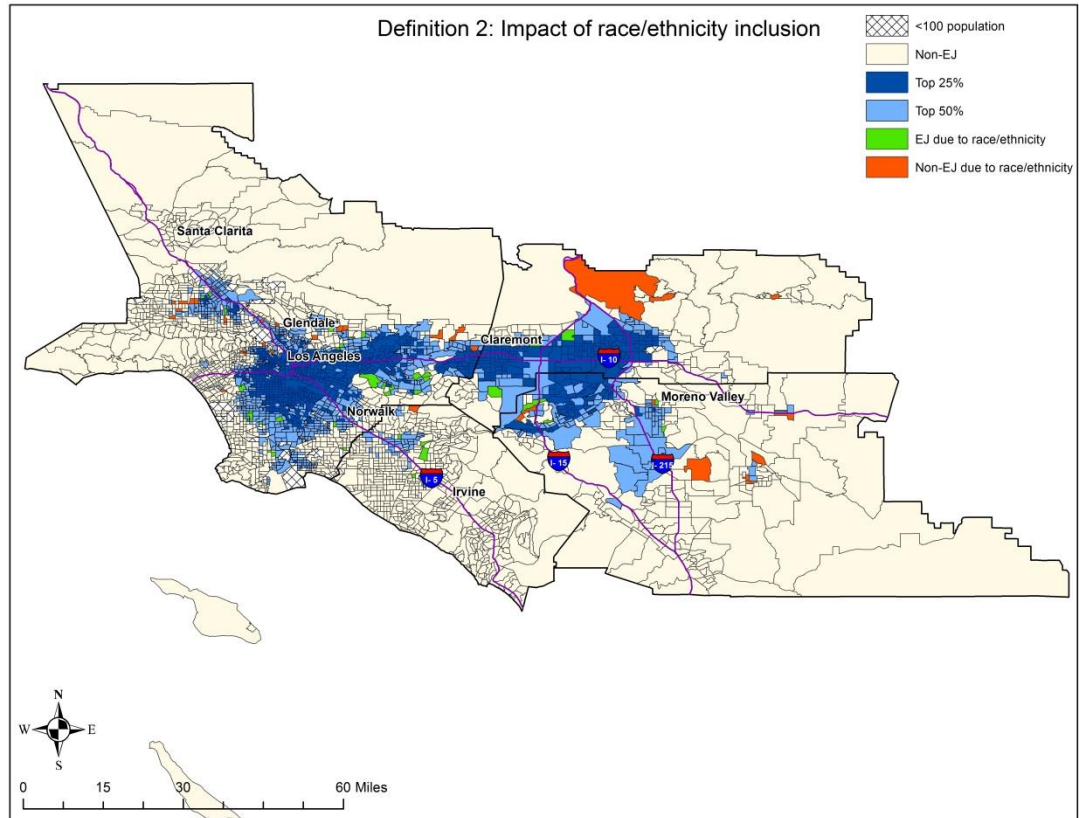




FIGURE A4.

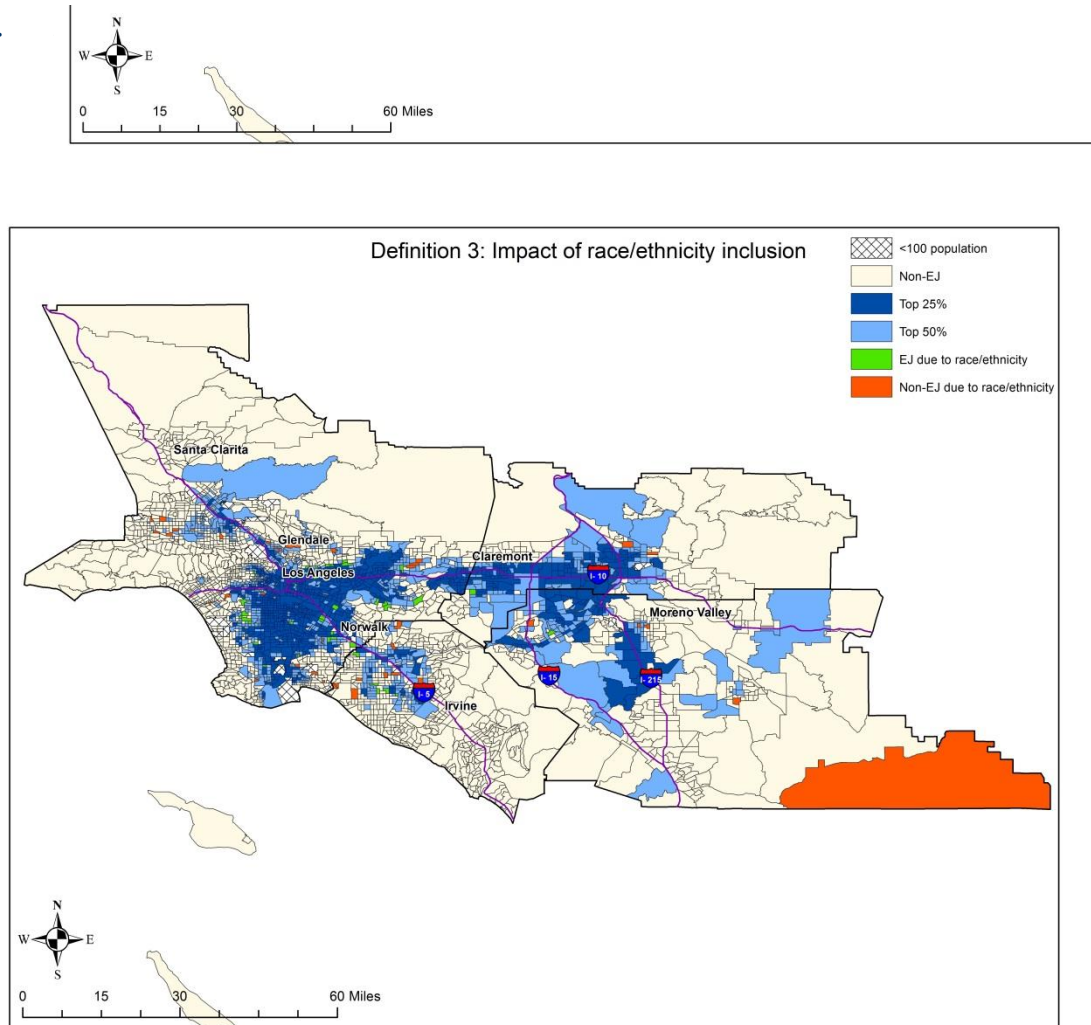


Table A2 indicates the changes in EJ-defined areas based on moving from Definition 2, which does not include race and ethnicity, to Definition 2a, which does include race and ethnicity. Table A3 indicates the changes in EJ-defined areas based on moving from Definition 3, which does not include race and ethnicity, to Definition 3a, which does include race and ethnicity.

TABLE A2. CHANGE IN POPULATIONS DEFINED AS EJ BETWEEN DEFINITION 2 AND DEFINITION 2A

NON-EJ TO TOP 50%	NON-EJ TO TOP 25%	TOP 50% TO TOP 25%	TOP 50% TO NON-EJ	TOP 25% TO NON-EJ	TOP 25% TO TOP 50%
Census Tracts					
40 (1.2%)	0	27 (0.8%)	40 (1.2%)	0	27 (0.8%)
Population					



214,302 (1.4%)	0	116,533 (0.7%)	153,968 (1.0%)	0	122,710 (0.8%)
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**TABLE A3. CHANGE IN POPULATIONS DEFINED AS EJ BETWEEN DEFINITION 3 AND DEFINITION 3A**

NON-EJ TO TOP 50%	NON-EJ TO TOP 25%	TOP 50% TO TOP 25%	TOP 50% TO NON-EJ	TOP 25% TO NON-EJ	TOP 25% TO TOP 50%
Census Tracts					
40 (1.2%)	0	31 (0.9%)	40 (1.2%)	0	31 (0.9%)
Population					
187,295 (1.2%)	0	131,825 (0.8%)	178,424 (1.1%)	0	125,079 (0.8%)

Here, we see that no census tracts moved from non-EJ designations to Top 25% designations or Top 25% to non-EJ designations for Definition 2 or 3. For both definitions, less than two percent of the population was impacted by inclusion of race and ethnicity. Tables A4 and A5, below, show the distribution of Top 50% and Top 25% EJ populations across counties within the SCAB. Tables A6 and A7, below, show the proportion of those counties that have population living in a Top 50% EJ community and Top 25% EJ community for each proposed definition which includes race and ethnicity.

**TABLE A4. DISTRIBUTION OF TOP 50% EJ POPULATIONS FOR EACH PROPOSED DEFINITION BY COUNTY**

	DEFINITION 2A	DEFINITION 3A
Los Angeles	72.2%	68.6%
Orange	4.2%	11.1%
Riverside	9.2%	7.9%
San Bernardino	14.3%	12.4%
Total	100%	100%

**TABLE A5. DISTRIBUTION OF TOP 25% EJ POPULATIONS FOR EACH PROPOSED DEFINITION BY COUNTY**

	DEFINITION 2A	DEFINITION 3A
Los Angeles	72.8%	76.4%
Orange	0.0%	4.6%
Riverside	6.4%	6.3%
San Bernardino	20.8%	12.7%
Total	100%	100%

**TABLE A6. PROPORTION OF COUNTY POPULATION LIVING IN A TOP 50% EJ COMMUNITY BY PROPOSED EJ DEFINITION**

	DEFINITION 2A	DEFINITION 3A
Los Angeles	59.6%	57.3%
Orange	10.9%	29.1%
Riverside	41.3%	35.8%
San Bernardino	73.1%	64.4%
All Counties in SCAB	49.5%	50.2%
Note: Values by definition for individual counties do not add up to 100%, as this table depicts the percent of county population affected.		

**TABLE A7. PROPORTION OF COUNTY POPULATION LIVING IN A TOP 25% EJ COMMUNITY BY PROPOSED EJ DEFINITION**

	DEFINITION 2A	DEFINITION 3A
Los Angeles	29.2%	31.6%
Orange	0.0%	6.3%
Riverside	13.3%	14.0%
San Bernardino	51.1%	34.2%
All Counties in SCAB	23.9%	25.0%
Note: Values by definition for individual counties do not add up to 100%, as this table depicts the percent of county population affected.		

The values in Table A4 fall within less than half of a percent of the distribution seen in Table 6 in Chapter 2; the values in Table A6 fall within two percent of the proportion of population living in a Top 50% EJ community for each of the four counties seen in Table 8 in Chapter 2. Similar patterns are observed for the Top 25% EJ communities.