PLEASE NOTE - This is considered an intermediate contractor product for discussion purposes only and is not considered final.

The overall purpose of this effort was to take a second look at a recently promulgated rule and to see if we could perform any additional analysis that might inform questions related to the socio-demographic distributions affected by the regulation. This revised draft report does that. It addresses and answers some questions as it related to PM. The analysis focused on the 2006 PM NAAQS and attainment of the revised 15/35 suite of the NAAQS for PM2.5 by the year 2020. The analysis included race, ethnicity and poverty status.

Any comments and questions may be forwarded to Lillian Bradley, Environmental Economist, US Environment Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards Division, Health and Environmental Impacts Division, Air Benefits Cost Group. Email – bradley.lillian@epa.gov.

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Distributional

Abt Associates Inc.

Analysis of Environmental Benefits Using BenMAP: Revised Draft

Cambridge, MA
Lexington, MA
Hadley, MA
Bethesda, MD
Chicago, IL

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Prepared for
Lillian Bradley
US EPA / OAQPS

Prepared by
Anna Belova
Joanna Miles
Don McCubbin

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Distributional Analysis of Environmental Benefits Using BenMAP: Revised Draft

DRAFT

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Executive Summary

In this report, we address two types of potentially interesting questions for distributional analyses:

1. **Distribution of exposure/risk levels.** Are different socio-demographic subpopulations being exposed to significantly different pollution levels or health risks? Because each subpopulation is exposed to a distribution of pollutant levels (i.e., not all individuals in a subpopulation are exposed to the same level), answering this question would require comparing air quality exposure distributions. If inequalities are detected, a set of follow-up questions may include "why" and/or "what can be done about that."

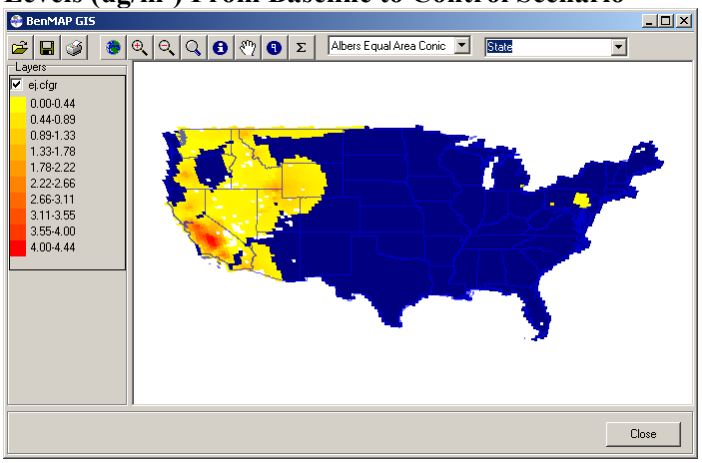
2. **Distribution of changes in exposures/risks.** When a given rule is implemented, do different socio-demographic subpopulations benefit differentially – i.e., do some groups enjoy significantly greater reductions in pollutant levels than others? If such an analysis is used in conjunction with a baseline pollution level analysis, we can also explore the effects of changes caused by a rule on the distribution of pollution levels – i.e. whether a given rule increases or reduces any disparities among the subpopulations.

The current analysis focuses on the National Ambient Air Quality Standards (NAAQS) for particulate matter (PM) – in particular, attainment of the revised 15/35 suite of NAAQS for $PM_{2.5}$ by the year 2020, and includes race, ethnicity, poverty status, education, location (urban/rural), and age as variables of interest. We used an updated version of BenMAP to generate population projections separately for each subpopulation within these categories, and then for each subpopulation, we estimated the baseline $PM_{2.5}$ level, the reduction in $PM_{2.5}$ between the baseline and control scenarios and then the associated reduction in premature mortality.

We examined annual average $PM_{2.5}$ levels in all of the maps, tables and figures in this report, as the underlying air quality data is at an annual level. The highest baseline $PM_{2.5}$ concentrations generally prevail in parts of California and the Midwest. These geographic differences have a strong impact on the average baseline levels experienced by each race and ethnicity. There are fewer differences in baseline levels by poverty, education and age. Generally, urban areas have higher PM2.5 levels than rural areas, although there are some notable exceptions, such as central California.

The reductions in 2020 annual average $PM_{2.5}$ levels are also not experienced uniformly across the U.S. As seen in Figure 1, most changes occur in the West, particularly in central California. No changes are observed in the areas shaded in blue, which covers the Eastern two thirds of the country. This has a significant impact on the results by race and ethnicity, because race and ethnicity subpopulations are not uniformly distributed across the U.S. Asian-Americans receive the greatest average benefit, followed by Native-Americans, Caucasians, and African-Americans.

Figure 1. Reduction in 2020 Annual Average $PM_{2.5}$ Levels (ug/m^3) From Baseline to Control Scenario



Similarly, Hispanics experience a greater reduction relative to Non-Hispanics. The differences by poverty, education and age subpopulations are smaller.

In addition to presenting results of the changes in $PM_{2.5}$ levels across different subpopulations, we present the associated change in premature mortality experienced by these same subpopulations. The changes in premature mortality generally mirror the changes in $PM_{2.5}$ levels. However, the premature mortality results need to be interpreted carefully. The calculated reductions in premature mortality that we observe may over- or under-state the true reductions, due to the fact that BenMAP does not currently have incidence rates specific to each of the subpopulations that we are comparing.

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1 Introduction

We prepared this report under Task 5 of Work Assignment No. 4-55 (Contract No. 68-D-03-002), which specifies that Abt Associates is to use an updated version of BenMAP to conduct a distributional analysis of the benefits of emission reductions achieved under Clean Air Act programs. In particular, we focused on scenarios developed for the analysis of the national ambient air quality standards (NAAQS) for particulate matter (PM). This report discusses the methods and results for a distributional analysis using an updated version of BenMAP that has more detailed socio-demographic data – updated population forecasts based on race, ethnicity, age, and gender, county-level data on poverty status and educational attainment. In addition, we discuss some additional modifications and enhancements to BenMAP that would be desirable to improve future distributional analyses.

Our analysis is based on baseline and control scenarios for attainment of the revised 15/35 suite of standards (NAAQS) for $PM_{2.5}$ by 2020. For exposure and premature mortality we present the distributions forecasted for 2020, as well as the distribution of changes. This is done for the general population, and for the sub-populations defined by race, ethnicity, income, and age categories.

In Section 2, we briefly discuss the methods that we used in this analysis. Section 3 presents the results by race, ethnicity, poverty status and educational attainment, as well as results of interactions of race and ethnicity, race and poverty, and ethnicity and poverty. In Section 4, we summarize our findings.

2 Methods

There are two types of potentially interesting questions for distributional analysis:

1. **Distribution of exposure/risk levels.** Are different socio-demographic subpopulations being exposed to significantly different pollution levels or health risks? Because each subpopulation is exposed to a distribution of pollutant levels (i.e., not all individuals in a subpopulation are exposed to the same level), answering this question would require comparing air quality exposure distributions. The analysis of exposures could include comparisons across several pollutants; it could also include several years, allowing us to look for trends in inequality across subpopulations, i.e. whether inequality in pollution exposures is increasing or decreasing. Likewise, the analysis of the distribution of health risks could include comparisons across different endpoints. If inequalities are detected, a set of follow-up questions may include "why" and/or "what can be done about that."

2. **Distribution of changes in exposures/risks.** When a given rule is implemented, do different socio-demographic subpopulations benefit differentially – i.e., do some groups enjoy significantly greater reductions in pollutant levels than others? An analysis to address this type of question would examine the distributional outcomes of a particular rule or regulation. It would require a baseline and a control scenario to calculate benefits that accrue to subpopulations. If such an analysis is used in conjunction with a baseline pollution level analysis, we can also explore the effects of changes caused by a rule on the distribution of pollution levels – i.e. whether a given rule increases or reduces any disparities among the subpopulations.

In this report, we propose an analytical approach that addresses both these questions by examining and comparing the distributions of individual-specific exposure (or health risk) levels and/or changes in these distributions in different (non-overlapping) subpopulations defined by race, ethnicity, poverty status, educational attainment, location (urban/rural), and age. In addition to exposure, we consider premature mortality.

Note that we could have examined additional health effects beyond premature mortality, however any additional health effects would tell qualitatively the same story. Moreover, since we have health incidence rates that, for the most part, just vary by age, and not by race, ethnicity, and other subpopulations of interest, the results may be suspect. To the extent that we see differences in adverse health impacts across different subpopulations, the results may be spurious, driven, for example, by differences in age structure. As a result, it is not worthwhile at this time to devote time to examine multiple health effects.[1] We examine reductions in premature mortality and point out potential anomalies as they appear in our results.

The remainder of this explanation of methods will focus on exposures; however, the same principles apply to premature mortality (or other health effects).

[1] In an earlier version of this report, we examined myocardial infarction and asthma-related emergency room visits; however, the results were not qualitatively different than those obtained from the analysis of premature mortality. See: Abt Associates (2007). Distributional Analysis of Environmental Benefits Using BenMAP. Prepared for Lillian Bradley, US EPA/OAQPS. September 10.

2.1 Distributions of Exposures/Risks

The analysis is based on the empirical distribution of annual average $PM_{2.5}$ exposures. This distribution is a set of frequencies with which different exposure levels occur in a given population. Thus, for all observed levels of exposures ($q_1, q_2, \ldots, q_Q$), we are interested in the following:

$$f_q = n_q / N, \qquad (1)$$

where n_q is the number of individuals who are exposed to pollution level q and N is the total number of individuals in the population. Correspondingly, f_q is the frequency with which exposure to pollution level q occurs in the population (i.e., the proportion of the population exposed to pollution level q). A distribution of the changes in pollution exposures can be similarly defined.

The frequency, f_q , may alternatively be thought of as a probability – the probability that a (randomly selected) individual in the population is exposed to pollution level q. Another name for the distribution described by equation (1) is therefore a *probability density function* (pdf).

In addition to the proportion of the population, f_q , that is exposed to a specific pollution level, q, we may be interested in the proportion of the population that is exposed to pollution levels that are no more than q. Using the notation above, this is

$$F_q = \sum_{i=0}^{q} \left(\frac{n_i}{N} \right) = f_0 + f_1 + f_2 + \ldots + f_q \ . \qquad (2)$$

Alternatively, this may be thought of as the probability that a (randomly selected) individual in the population is exposed to no more than pollution level q. As can be seen in equation (2), this is just the sum of the probabilities of being exposed to each pollution level less than or equal to q – i.e., it is just an accumulation of these probabilities. Another name for the distribution described by equation (2) is therefore a *cumulative distribution function* (cdf).

The same functions will be used to describe the distributions of changes in exposure. In addition, we will provide distributions of the positive changes in exposure, since often the distribution of all changes to exposure is dominated by zero-magnitude changes.

2.2 Inputs and Outputs of the Analysis

Our analysis is based on baseline and control scenarios for attainment of the revised 15/35 suite of standards (NAAQS) for $PM_{2.5}$ by 2020. We used an updated version of BenMAP (version 2.5) to generate total population projections and to create a configuration file to calculate benefits in terms of air quality improvements. The updated version of BenMAP is built on U.S. Census Bureau block data differentiated by race, ethnicity (Hispanic/Non-Hispanic), 19 different age groups, and gender. In addition, it has county-level data on poverty status and educational attainment.

The county-level poverty data measures the fraction of the population that is above and below the poverty line. In particular, BenMAP has poverty data for the general population as well as data broken down by race and separately by ethnicity. The data on educational attainment estimates the fraction of the population in five categories: no high school diploma, high school diploma, attended some college (no

degree), college degree, and graduate studies. As with the poverty data, the educational attainment data is for the general population, as well as by race and by ethnicity.

It is useful to know how BenMAP currently uses the county-level poverty status and educational attainment data. For example, to estimate the fraction of the population above and below the poverty line in a specific CMAQ gridcell, BenMAP uses a (simple) spatially weighted average of the one of more counties that might overlay the gridcell. (A similar approach is used for estimating educational attainment in a gridcell.) An alternative approach could (and probably should) be based on population-weighted averages, rather than the relatively simple spatially-weighted average used in BenMAP now.

The results of this analysis are presented in Section 3. For exposure and premature mortality we present the baseline distribution, as well as the distribution of changes. This is done for the general population, and for the subpopulations of interest.

2.3 Assessment of Uncertainty in the Estimates

There are a number of sources of uncertainty, including exposure estimates, population data, incidence rates, and health impact functions. We did not characterize uncertainty in the exposure estimates and simply recognize that there is uncertainty in these measures. It is difficult to determine how such uncertainty could affect the results. Similarly, we did not characterize uncertainty for population, health impact coefficients, and incidence data. We recognize that there are potentially significant sources of uncertainty.

As we discuss in the Results section, we have incidence rates that vary by age, however, we do not currently have incidence rates varying by race, ethnicity and income. We know there may be significant differences across different subgroups. For example, we note that state-level racial mortality rates differ significantly by race. Since BenMAP does not currently have incidence rates for each of the subgroups that we analyze, the result health estimates need to be evaluated cautiously. Similarly, there are a limited number of epidemiological studies that examine effect differentials, particularly by race. It is not unlikely that there are important differences that we are missing.

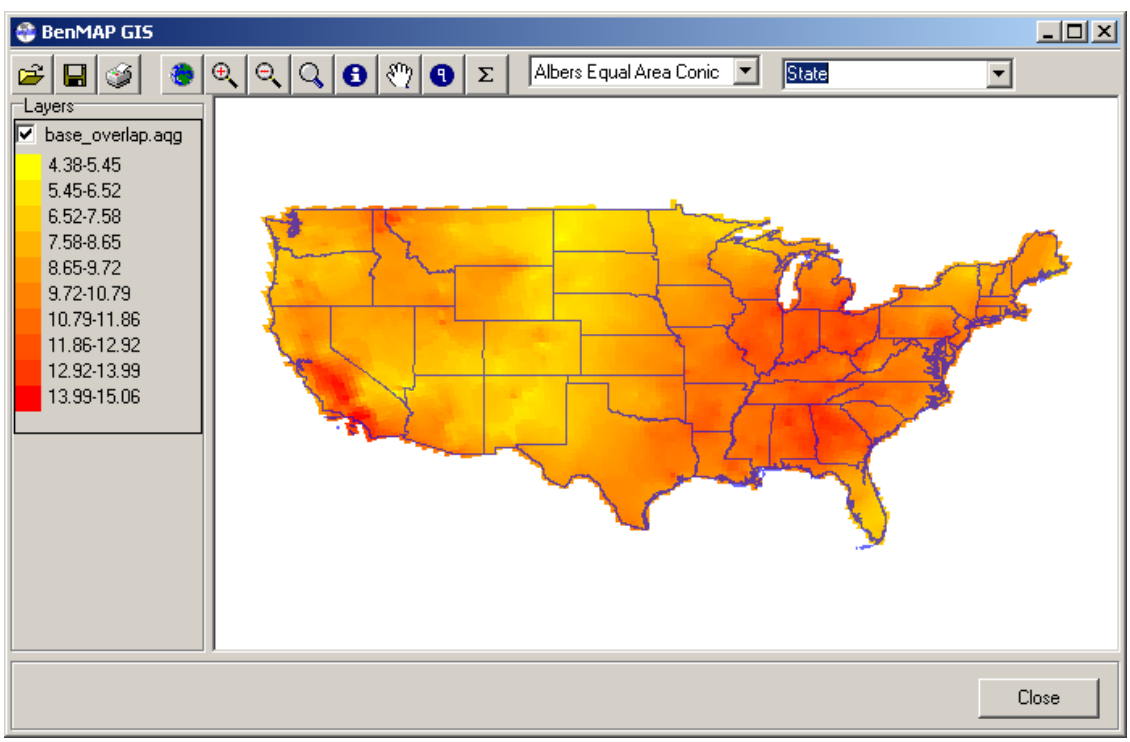
3 Results

The current analysis focuses on race, ethnicity, poverty status, educational attainment, and age, as well as differences between urban and rural areas. We used an updated version of BenMAP (version 2.5) to generate population projections separately for each subpopulation within these categories, and then for each subpopulation, we forecasted the 2020 annual average $PM_{2.5}$ level (measured in micrograms per meter cubed [ug/m^3]) that would occur without NAAQS-related pollution reduction programs – we refer to this 2020 scenario as the "**baseline**." The term baseline is used frequently in this report and should be thought of as the conditions that are estimated to prevail in the scenario that does not involve NAAQS-related emission reductions.

In addition to the baseline scenario, we examine the change (or improvement in air quality) from the baseline to the 2020 scenario that involves NAAQS-related emission reductions – we refer to this 2020 scenario as the "**control**." Finally, we examine the change (reduction) in premature mortality that is likely to occur in 2020 due to the change (reduction) in $PM_{2.5}$ levels. Dividing our results by subgroups of interest (e.g., race), we present in this section a variety of maps, tables, and graphs showing differences across subpopulations.

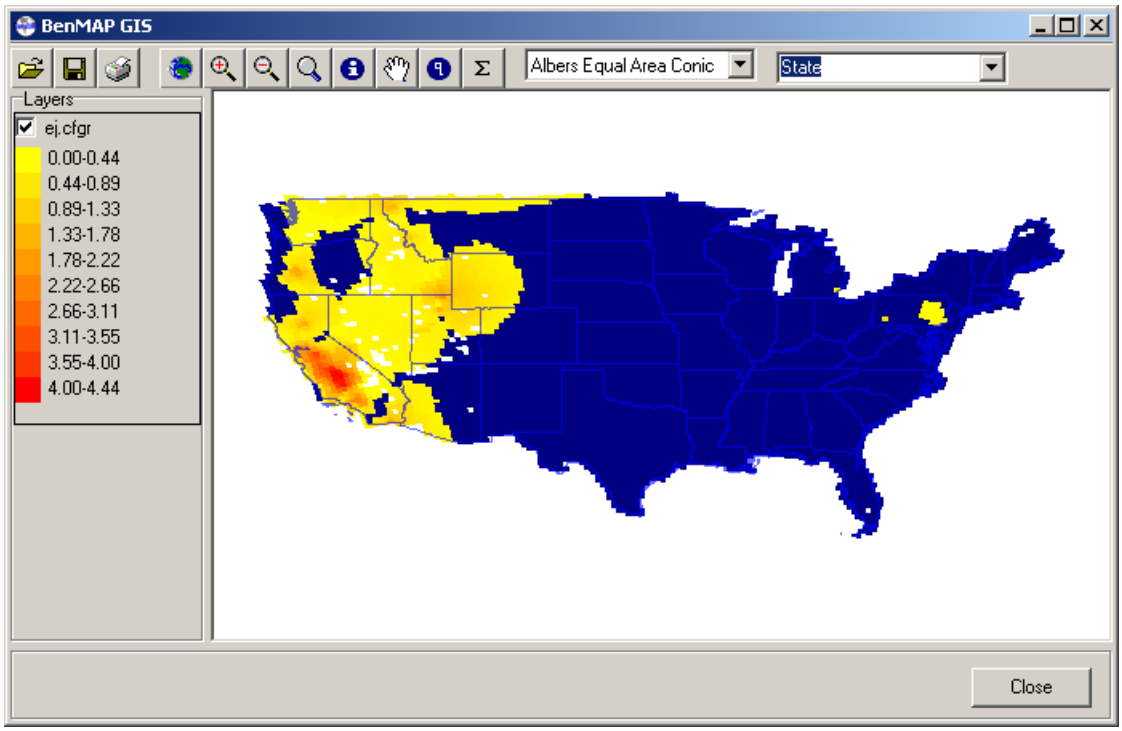
Figure 2 is a map of baseline air quality levels and shows that the highest $PM_{2.5}$ concentrations generally prevail in parts of California and the Midwest. These geographic differences have a strong impact on the average baseline levels experienced by different subgroups of interest, such as race.

Figure 2. Baseline 2020 Annual Average $PM_{2.5}$ Levels (ug/m^3)



The changes in $PM_{2.5}$ levels do not occur uniformly across the U.S. **Figure 3** presents the changes between the baseline and control scenarios. Most changes in air quality occur in the West, particularly in central California. No changes are observed in the areas shaded in blue, which covers the Eastern two thirds of the country.

Figure 3. Reduction in 2020 Annual Average $PM_{2.5}$ Levels (ug/m^3) From Baseline to Control Scenario



In addition to presenting reductions in $PM_{2.5}$ levels across different subpopulations, we also present the associated reductions in premature mortality experienced by these same subpopulations. The reductions in premature mortality generally mirror the reductions in $PM_{2.5}$ levels. However, the premature mortality results need to be interpreted carefully.

Some of the differences we observe may over- or under-state the true differences, due to the fact that BenMAP does not currently have incidence rates specific to each of the subpopulations that we are comparing. For example, we have mortality rate data by age, but we do not have mortality rates by race and ethnicity. Two subpopulations experiencing the same average change in $PM_{2.5}$ levels can have significantly different health effects changes if their baseline mortality incidence rates are different. We see this particularly when examining changes stratified by age – where the elderly generally enjoy considerably greater reductions in premature deaths than younger groups for similar reductions in $PM_{2.5}$ levels.

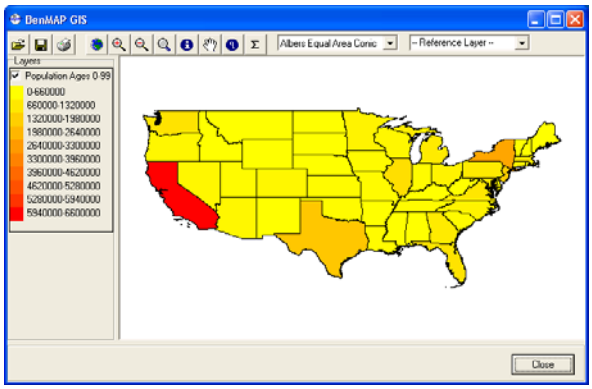
3.1 Examination of Results by Race

In this section, we present the baseline $PM_{2.5}$ levels and the changes in $PM_{2.5}$ levels experienced by each of the racial groups considered in our analysis – Caucasians, African-Americans, Asian-Americans, and Native Americans.

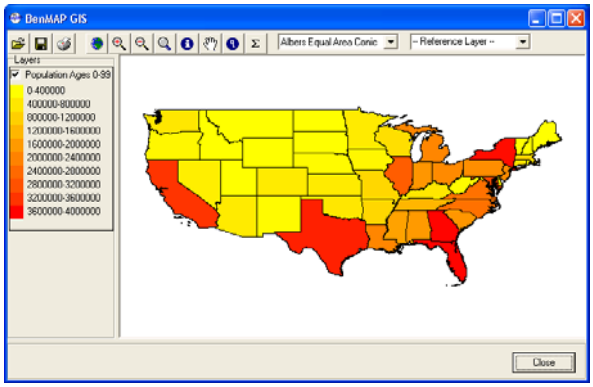
Figure 4 shows the state-level population of each of the racial groups. A cursory comparison of the population maps with the map showing baseline $PM_{2.5}$ levels (**Figure 2**) shows that the geographic distributions of Caucasians and African-Americans are roughly the same, with concentrations in the same geographic areas in which baseline $PM_{2.5}$ levels are highest. Native-Americans, in contrast, have substantial concentrations in rural areas in the central portion of the country, where baseline $PM_{2.5}$ levels are relatively low. Asian-Americans and Others, while generally much smaller in numbers, have substantial concentrations in California, where baseline $PM_{2.5}$ levels are high. A visual comparison of maps, however, is a "blunt tool" with which to make comparisons across racial groups. Below, we present quantitative comparisons of the baseline $PM_{2.5}$ levels, and the corresponding changes in $PM_{2.5}$ levels (from baseline to control scenario), to which people in each racial group are exposed.

Figure 4. Forecasted 2020 State Population by Race

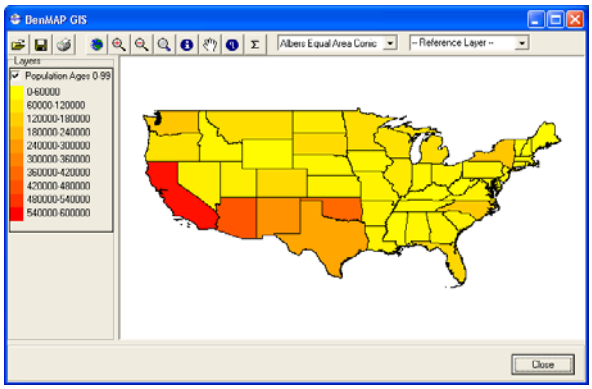
Asian-American



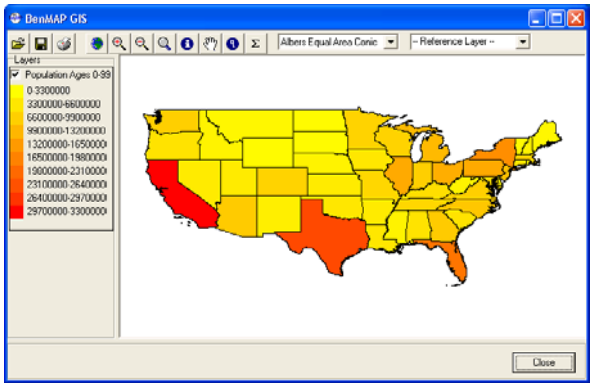
African-American



Native-American



Caucasian



3.1.1 Baseline $PM_{2.5}$ Levels by Race

Table 1 shows that, on average, African-Americans, Asians and Other are exposed to the highest baseline annual average $PM_{2.5}$ levels, and Native Americans are exposed to the lowest. It also presents the standard deviation of the population exposure that shows that Native Americans have the greatest variation in baseline exposure. Finally, it presents the 5th, 25th, 50th, 75th, and 95th percentiles, which show the variation in exposure. These results are consistent with the geographic population densities shown in **Figure 4**, which shows that Asians tend to have higher populations in California, which has some of the highest baseline $PM_{2.5}$ levels. Similarly, African-Americans have a relatively large population in the Eastern U.S., where baseline $PM_{2.5}$ levels are relatively high.

Table 1. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Race in 2020

Race	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	10.17	1.92	6.93	9.01	10.10	11.34	13.92
Asian-American	10.61	2.00	7.69	9.46	10.22	11.74	14.77
African-American	10.64	1.80	7.30	9.71	10.35	11.72	13.72
Native-American	9.21	2.25	6.07	7.46	9.19	10.28	13.96
Caucasian	10.07	1.91	6.87	8.81	10.01	11.27	13.43

Note: The 25th percentile is a level of PM2.5 such that 25% of population is exposed to lower levels of PM2.5 and 75% of population is exposed to higher levels of PM2.5. Percentiles are useful measures that describe the shape and location of the distribution of interest.

Figure 5 presents the cumulative density functions of baseline $PM_{2.5}$ levels by race. To interpret the cumulative distribution, consider that further to the right along the cumulative distribution indicates that a higher percentage of the subpopulation is exposed to relatively higher $PM_{2.5}$ levels. That is, any point along the cumulative distribution shows the percentage of each subpopulation exposed to no more than that level. We see that relatively greater proportions of Native Americans are exposed to relatively low $PM_{2.5}$ levels, whereas greater proportions of Caucasians, Asian-Americans, and African-Americans exposed to relatively high $PM_{2.5}$ levels.

Figure 5. Baseline Annual Average $PM_{2.5}$ Concentrations in 2020, Cumulative Density Function by Race

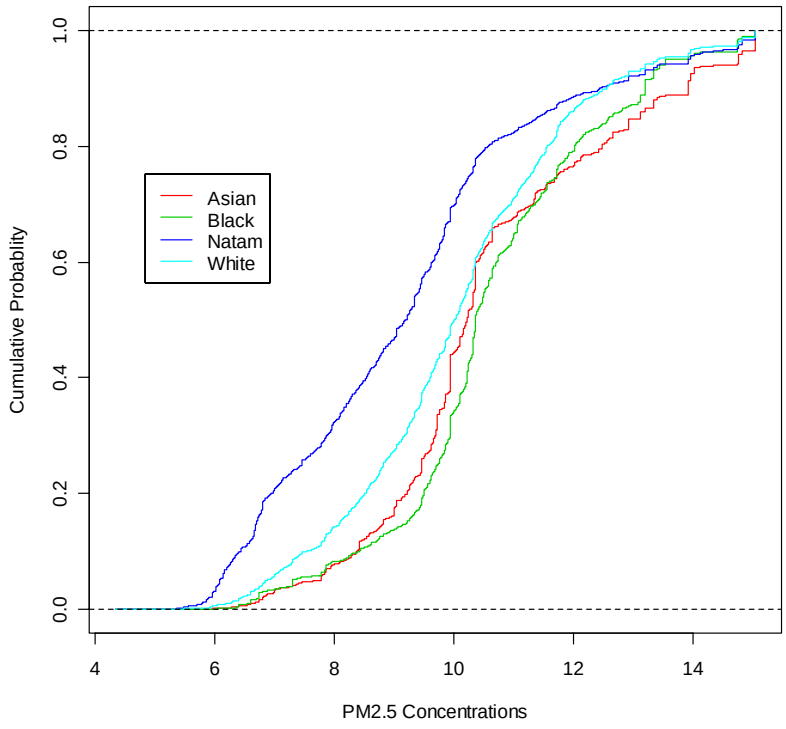


Figure 6 examines the cumulative density by urban and rural areas. Not surprisingly, rural populations have the least exposure across all racial groups. Rural Native Americans have much lower exposure than other groups, and in contrast urban Native Americans have some of the worst exposure.

Figure 6. Baseline Annual Average $PM_{2.5}$ Concentrations in 2020, Cumulative Density Function by Race and Urban/Rural Areas

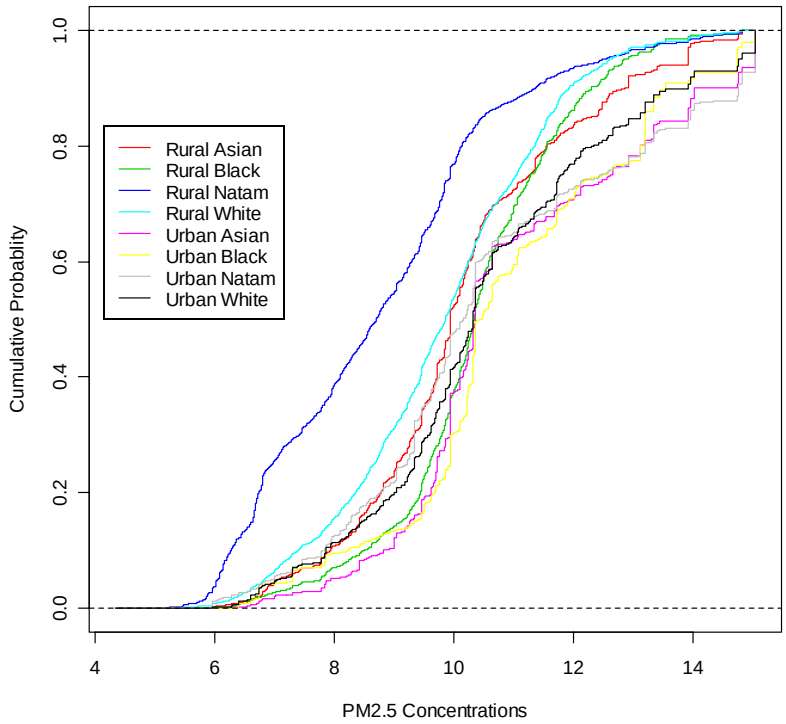


Table 2 focuses on the tails of the distribution of baseline $PM_{2.5}$ concentrations – the extremes of small concentrations (lower tail) and large concentrations (upper tail). This allows us to consider questions such as: Who are the people in the upper and lower tails of the exposure distribution – i.e., who are the people exposed to the lowest and the highest $PM_{2.5}$ levels? Are the socio-demographic patterns in the upper tail different from the overall socio-demographic patterns?

Table 2 presents the racial composition of the general population at different points on the baseline $PM_{2.5}$ distribution. The columns labeled 1st, 5th, 10th, 25th, 75th, 90th, 95th, and 99th give the racial composition at specific percentiles. The last column, labeled "All", gives the racial composition of the general population under all exposure levels (i.e., 79.21 percent Caucasians, 13.68 percent African-Americans, 6.05 percent Asian-Americans, and 1.05 percent Native-Americans). It is useful to compare the racial composition at any given percentile with the distribution in this final column. The upper tail is perhaps of most interest, as it examines the highest pollution levels.

Using **Table 2**, we can see if a racial group is under-represented or over-represented among people exposed to particularly high baseline $PM_{2.5}$ concentrations. For example, 79.21 percent of the general population is Caucasian, but only 73.94 percent of people exposed to baseline $PM_{2.5}$ concentrations at or above the 99th percentile baseline concentration (15..05 ug/m^3) are Caucasian – so Caucasians are under-represented among people exposed to the very highest baseline $PM_{2.5}$ concentrations. In contrast, Asian-Americans are only 6.05 percent of the general population but comprise 15.02 percent of those exposed to baseline $PM_{2.5}$ concentrations at or above the 99th percentile level – so Asian-Americans are over-represented among those exposed to the very largest baseline $PM_{2.5}$ concentrations.

Note that in a prior analysis by Abt Associates[2] found the "Other" racial group, which is comprised in large part of White Hispanics, made up 34 percent of the 99th percentile tail but only 8 percent of the general population, and Caucasians made up 42 percent of the 99th percentile but 72 percent of the general population. Now, with Other for the most part incorporated into the Caucasian group, there is much less under-representation of Caucasians at the highest pollution levels. In a later section, when we get to an analysis by race and ethnicity, we will see that Hispanics have much higher exposure relative to Non-Hispanics.

Table 2. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) in 2020, with Percentage of Population by Race at Each Percentile Value

	Statistics in Lower Tail				Statistics in Upper Tail				
Percentile	**1st**	**5th**	**10th**	**25th**	**75th**	**90th**	**95th**	**99th**	
Baseline $PM_{2.5}$ Level	6.28	6.93	7.72	9.01	11.34	12.68	13.92	15.05	**All***
Percent of Population by Race at Each Percentile Value **									
Asian-American	2.04	3.34	3.06	3.92	7.17	10.62	13.36	15.02	6.05
African-American	2.77	9.17	7.99	7.54	16.33	19.61	13.52	9.74	13.68
Native-American	8.50	4.15	2.92	1.96	0.64	0.96	1.19	1.31	1.05
Caucasian	86.69	83.33	86.02	86.58	75.85	68.81	71.93	73.94	79.21

* The fraction of the races in the population of all ages.

** The "Percentage of Population by Race at each Percentile Value" presents racial composition at each percentile. That is, it shows what percentage of the total population is in a particular racial group at each percentile. For example, in the 1st percentile, Caucasians comprise 86.69% of the total population, with African Americans at 2.77%, Asian-Americans 2.04%, and Native Americans 8.50%.

3.1.2 Reduction in $PM_{2.5}$ Levels by Race

Table 3 presents the unconditional mean change in $PM_{2.5}$ (*i.e.*, the average including individuals who received no change), the percentage of the population that received a non-zero change (*i.e.*, the percentage of a given population that benefited), and statistics for the conditional distributional (*i.e.*, descriptive statistics of individuals that benefited). Note that Asian-Americans enjoy the largest unconditional mean change between the baseline and control scenarios, followed by Native Americans, Caucasians and then African-Americans. Similarly, a greater percentage of Asian-Americans receive a non-zero change (35.52 percent). These results are consistent with the population densities that we see in **Figure 4**, which shows relatively greater proportions of Caucasians and African-Americans in the Eastern U.S.

[2] *See*: Abt Associates (2007). Distributional Analysis of Environmental Benefits Using BenMAP. Prepared for Lillian Bradley, US EPA/OAQPS. September 10.

Table 3. 2020 Projected Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Race

			Conditional Statistics						
Race	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	0.15	18.22	0.84	0.90	0.01	0.05	0.58	1.37	2.40
Asian-American	0.34	35.52	0.97	0.78	0.01	0.28	0.83	1.66	1.99
African-American	0.08	10.72	0.78	0.90	0.00	0.02	0.58	1.34	2.29
Native-American	0.20	23.46	0.86	0.97	0.01	0.09	0.55	1.37	2.88
Caucasian	0.15	18.13	0.83	0.92	0.01	0.05	0.58	1.37	2.40

* Mean change in $PM_{2.5}$ including individuals with zero changes.

** The column "Percent Above Zero" shows the percentage of the population that received a change greater than zero. For example, 18.13% of Caucasians had a change greater than zero (and by implication, 81.87% had no change).

*** The "Conditional Distribution" presents statistics showing the distribution of individuals that received a change greater than zero. For example, among Native-Americans that received a change, 25% received a change of 0.09 ug/m3 or less (and 75% had a change greater than 0.09 ug/m3).

Figure 7 presents the cumulative density functions of the changes in $PM_{2.5}$ levels by race. Any point along a cumulative distribution shows the percentage of a subpopulation that received no more than that change. A large percentage of all races received no change – about 90 percent of African-Americans, about 85 percent of Caucasians, about 80 percent of Native-Americans, and about 70 percent of Asian-Americans.

Figure 7. 2020 Projected Decrease in Annual Average $PM_{2.5}$ Concentrations (µg/m3), Cumulative Density Function by Race

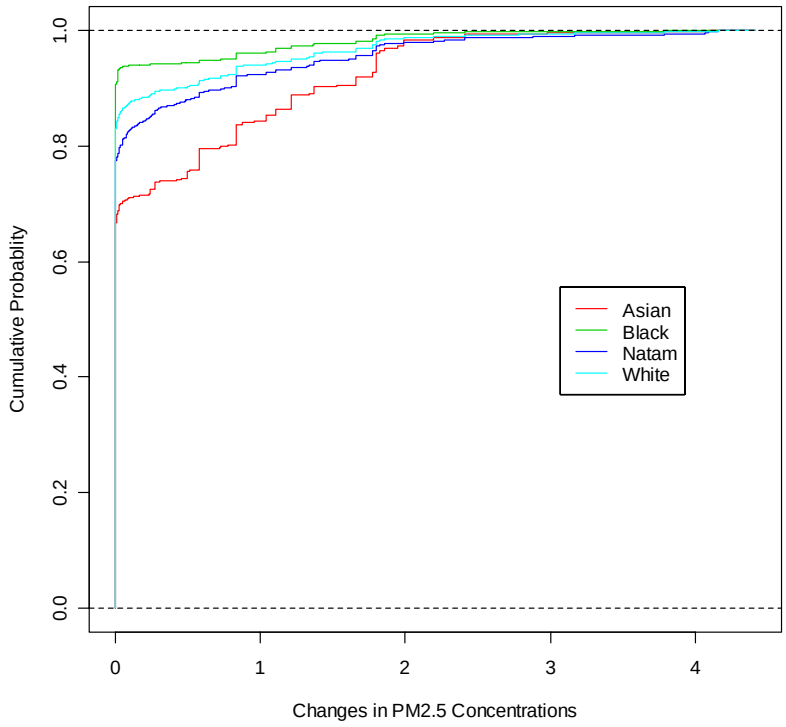


Figure 8 shows the cumulative density by race and urban/rural area. Rural areas generally have a greater population percentage that receives no change. An exception is Asian-Americans, which as a group show similar changes across urban and rural areas.

Figure 8. 2020 Projected Decrease in Annual Average $PM_{2.5}$ Concentrations (µg/m3), Cumulative Density Function by Race and by Urban/Rural Area

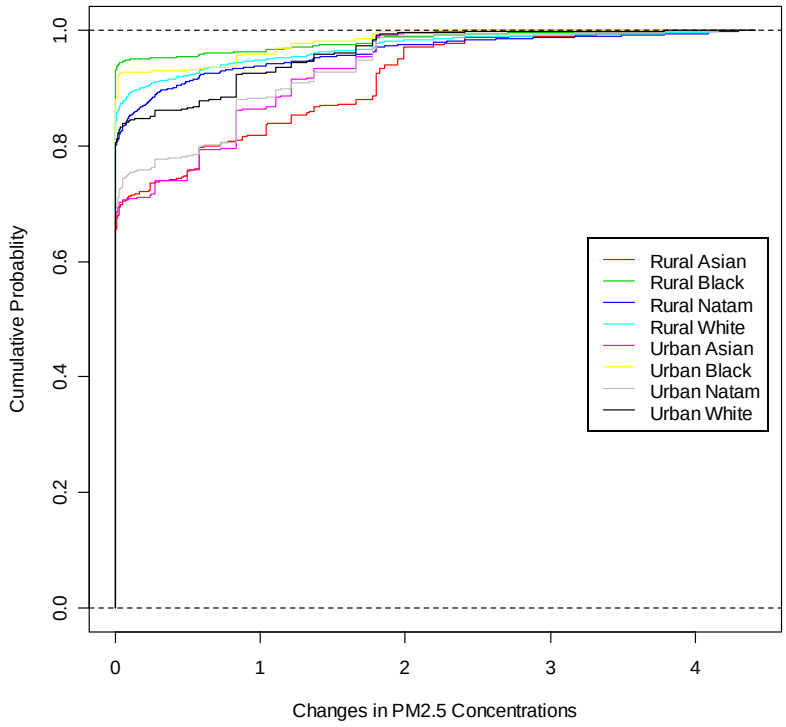


Table 4 presents the racial composition of the general population at different points on the distribution of $PM_{2.5}$ changes. At the 81st percentile the value is essentially zero, meaning that 81 percent of the population receives no change in $PM_{2.5}$ levels. We see that Asian-Americans and Native Americans tend to be over-represented, while Caucasians and African-Americans are under-represented. Caucasians vary between under- and over-representation.

Again we see a key difference between the current and the prior analysis by Abt Associates.[3] The prior analysis found the "Other" racial group, which is comprised in large part of White Hispanics, was over-represented at the higher percentiles and Caucasians were under-represented. Now, with Other for the most part incorporated into the Caucasian group, there is much less under-representation of Caucasians at the highest percentiles.

[3] *See*: Abt Associates (2007). Distributional Analysis of Environmental Benefits Using BenMAP. Prepared for Lillian Bradley, US EPA/OAQPS. September 10.

Table 4. Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) Projected for 2020, with Percentage of Population by Race at Each Percentile Value

	Statistics At or Above Zero		Statistics in Upper Tail of Unconditional Distribution			All*
Percentile	**<=81st****	**82nd**	**90th**	**95th**	**99th**	
Change in $PM_{2.5}$ Level	No Change	>0	0.53	1.32	2.34	
Percent of Population by Race at Each Percentile Value ***						
Asian-American	4.77	11.90	14.69	13.51	7.50	6.05
African-American	14.94	8.11	7.73	7.41	7.06	13.68
Native-American	0.98	1.35	1.25	1.33	1.76	1.05
Caucasian	79.31	78.64	76.33	77.74	83.68	79.21

* The fraction of the population of all ages.

** At the 81st percentile, the change is zero, so lower percentiles have the same value as the 81st percentile.

*** The "Percentage of Population by Race at each Percentile Value" presents racial composition at each percentile. That is, it shows what percentage of the total population is in a particular racial group at each percentile. For example, in the 95th percentile, Caucasians comprise 56% of the population, with African Americans at 7%, Asian-Americans 14%, Native Americans 1%, and Other 21%.

3.1.3 Reduction in Mortality Rate by Race

The changes in exposures (from baseline $PM_{2.5}$ levels to control scenario levels) are of interest primarily because of the corresponding changes in rates of those health effects that have been associated with $PM_{2.5}$. In this section, we examine the changes in premature deaths. However, as we noted at the beginning of this section, care must be taken in interpreting these results.

To a large extent, the changes in rates of the health endpoints we examined across the different racial groups reflect the confluence of geographical locations where the greatest changes in $PM_{2.5}$ levels occur and those geographical locations in which some racial groups are most concentrated.

However, some differences in health effects can arise because the underlying incidence rates vary. Since $PM_{2.5}$-related changes in health effect rates are most often calculated as a percentage of baseline rates, differences in these baseline rates imply that two subpopulations experiencing the same change in $PM_{2.5}$ can have different incidence (rate) reductions if their baseline incidence rates differ. The baseline mortality rates currently available in BenMAP vary by age and county, but not by race. We cannot currently capture all of these differences to the extent that BenMAP doesn't incorporate baseline incidence rates that are specific to the subpopulations in which we are interested.

If racial subpopulations differ in age structure (*e.g.*, one racial group is more elderly) or in geographic location (*e.g.*, concentrated in the West), however, health benefits can still differ between racial groups that otherwise have the same change in $PM_{2.5}$.

Table 5 shows that Asian-Americans have the greatest changes in rates of premature mortality, experiencing on average 2.86 fewer deaths per 100,000 people, followed by Native-Americans and Caucasians. African-Americans have the smallest change in mortality rates, experiencing on average 0.56 fewer deaths per 100,000 people, primarily because they tend to live in areas that experienced little decline in $PM_{2.5}$ concentration.

Table 5. Decline in Mortality Rate by Race (# fewer deaths per 100,000 people)

			Conditional Statistics****						
Race*	Unconditional Mean**	Percent Above Zero***	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	1.10	17.97	6.12	6.55	0.04	0.36	4.48	10.20	16.21
Asian-American	2.86	38.13	7.51	6.02	0.04	2.25	7.25	11.04	16.71
African-American	0.56	10.89	5.13	5.77	0.02	0.15	3.45	8.49	14.31
Native-American	1.29	23.51	5.48	6.51	0.05	0.63	3.40	8.83	21.62
Caucasian	1.04	17.41	5.99	6.72	0.05	0.37	4.46	9.78	17.34

* Premature deaths calculated for ages 35 and older.

** Mean change in death rate including individuals with zero changes.

*** The column "Percent Above Zero" shows the percentage of the population that received a change greater than zero. For example, 10.89% of African-Americans had a change greater than zero (and by implication, 89.11% had no change).

**** The "Conditional Distribution" presents statistics showing the distribution of individuals that received a change greater than zero. For example, among Native-Americans that received a change, 25% received a change of 0.63 deaths per 100,000 or less (in other words, 75% had a change greater than 0.63 deaths per 100,000).

Note that the changes in premature mortality rates are not strictly proportional to the changes observed in $PM_{2.5}$ because of differences in mortality rates. As seen in **Table 6**, Caucasians have a higher baseline mortality rate, and thus gain a greater benefit from a given reduction in $PM_{2.5}$. However, since BenMAP does not race-specific mortality rates, the differences we see in mortality rates in **Table 6** cannot be driven by differences in mortality rates by race *per se*, but rather are due to differences in age structures between races and population locations. As we can see in **Table 7**, mortality rates differ markedly by age.

The prior Abt report found even more pronounced differences across races.[4] The "Other" racial group experienced an air quality improvement (0.39 ug/m3 decline in annual average PM2.5 concentration) over three times greater than that for Caucasians (0.12 ug/m3), yet the change in mortality for Others (2.03 fewer deaths per 100,000 people) was just twice that for Caucasians (0.98 fewer deaths per 100,000 people). As we will see later, when we examine mortality effects by ethnicity, the Hispanic population has a much lower apparent mortality rate, and thus appears to benefit less from a given change in air pollution.

[4] *See*: Abt Associates (2007). Distributional Analysis of Environmental Benefits Using BenMAP. Prepared for Lillian Bradley, US EPA/OAQPS. September 10.

Table 6. Forecasted 2020 Mortality Rate by Race (deaths per 100,000 People)

Race	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	1483.49	293.49	1056.42	1283.17	1453.58	1644.31	2003.11
Asian-American	1126.15	266.50	697.65	942.61	1140.00	1292.41	1541.41
African-American	1244.21	278.55	753.17	1067.47	1275.18	1447.01	1662.33
Native-American	1136.95	329.23	657.75	924.67	1095.52	1335.69	1682.43
Caucasian	1549.68	322.97	1063.36	1335.86	1523.47	1738.48	2101.33

Note: Mortality rates calculated for ages 35 and older.

Table 7. Forecasted 2020 Mortality Rate by Race & Age (deaths per 100,000 People)

Race	Age	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	Total	1483.49	293.49	1056.42	1283.17	1453.58	1644.31	2003.11
Asian-American	Ages 35-54	230.54	44.42	165.16	197.98	233.12	254.04	301.82
	Ages 55-64	764.27	103.08	628.83	687.89	760.17	811.30	951.96
	Ages 65+	3458.40	380.06	2840.89	3206.89	3470.76	3712.06	3907.28
African-American	Ages 35-54	262.92	58.10	177.15	225.00	260.45	293.51	371.17
	Ages 55-64	878.38	154.38	670.27	769.36	857.31	958.15	1165.90
	Ages 65+	3844.61	478.45	3048.53	3529.70	3868.60	4072.28	4593.56
Native-American	Ages 35-54	249.13	68.71	164.68	207.93	238.81	276.56	375.09
	Ages 55-64	836.61	159.00	628.24	733.75	817.40	914.26	1129.64
	Ages 65+	3529.79	707.00	2524.60	3103.48	3447.79	3910.01	4653.44
Caucasian	Ages 35-54	234.88	51.06	160.66	198.19	231.66	264.03	320.03
	Ages 55-64	810.68	137.60	616.02	723.69	795.74	884.06	1050.88
	Ages 65+	4059.15	484.99	3301.78	3747.18	4054.67	4353.61	4837.05

Table 8 focuses on the tails of the distribution of changes in premature mortality rates – the extremes of small changes (lower tail) and large changes (upper tail). The upper tail is of particular interest. **Table 8** gives the racial breakdown of people experiencing $PM_{2.5}$-related changes in rates of premature mortality in progressively smaller sections of the upper tail and, in addition, the racial breakdown in the relevant portion of the general population. Since we calculated mortality rate changes for the general population ages 35 and older, this is the relevant portion of the general population here.

Using **Table 8**, we can see if a racial group is under-represented or over-represented among people experiencing particularly large $PM_{2.5}$-related declines in rates of premature mortality. For example, 11.87% of the relevant portion of the general population is African-American, but 7.90% of people experiencing changes in rates of premature mortality at or above the 99th percentile level (15.93 per 100,000) are African-Americans, which are thus under-represented among people who experience the very largest $PM_{2.5}$-related declines in mortality rates. In contrast, Asian-Americans are only 6.17 percent

of the relevant general population but 11.49 percent of people experiencing changes in mortality rates at or above the 99th percentile level – so Asian-Americans are over-represented among those experiencing the very largest declines in mortality rates.

Table 8. Decline in Mortality Incidence Rate, with Percentage of Population by Race at Each Percentile Value

	Statistics At or Above Zero		Statistics in Upper Tail of Unconditional Distribution			All**
Percentile	**<=82nd***	**83rd**	**90th**	**95th**	**99th**	
Change in Mortality	No Change	>0	3.75	9.99	15.93	
Percent of Population by Race at Each Percentile Value * **						
Asian-American	4.65	13.40	16.98	17.71	11.49	6.17
African-American	12.90	6.68	6.80	7.18	7.90	11.87
Native-American	0.86	1.23	1.18	1.17	1.52	0.92
Caucasian	81.59	78.68	75.04	73.94	79.10	81.04

* At the 82nd percentile, the change is zero, so lower percentiles have the same value as the 82nd percentile.

** The fraction of the population ages 35 and older.

*** The "Percentage of Population by Race at each Percentile Value" presents racial composition at each percentile. That is, it shows what percentage of the total population is in a particular racial group at each percentile. For example, in the 95th percentile, Caucasians comprise 73.94% of the population, with African Americans at 7.18%, Asian-Americans 17.71%, and Native Americans 1.17%.

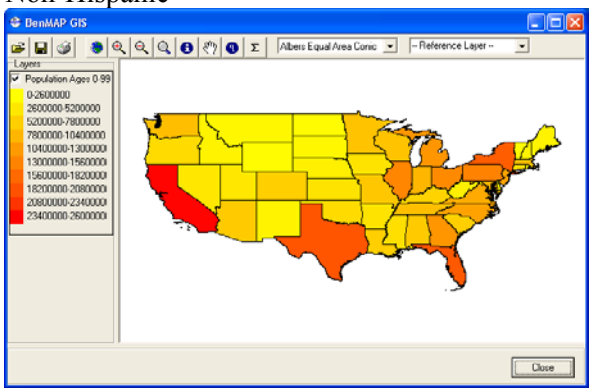
3.2 Examination of Results by Ethnicity

In this section, we present the baseline $PM_{2.5}$ levels and the declines in $PM_{2.5}$ levels and premature deaths experienced by Hispanics and Non-Hispanics. We find that Hispanic have generally higher baseline PM2.5 levels, but they also experience greater reductions in PM2.5 levels relative to the Non-Hispanic population. Hispanics also enjoy a greater reduction in premature mortality than Non-Hispanics, though the reduction is not as pronounced as it is for the reduction in PM2.5, because of apparent differences in mortality rates.

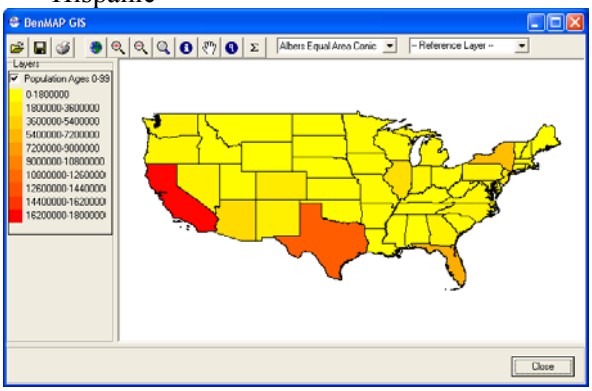
The higher baseline PM2.5 levels and the greater PM2.5 reductions are consistent with the distribution of the Hispanic and Non-Hispanic populations. In **Figure 9**, we see that Hispanics have a large population concentration in California, which experiences some of the highest baseline PM2.5 levels and also experiences some of the biggest reductions in PM2.5.

Figure 9. Forecasted 2020 State Population by Ethnicity

Non-Hispanic



Hispanic



3.2.1 Baseline $PM_{2.5}$ Levels by Ethnicity

Table 9 shows that, on average, Hispanics are exposed to higher baseline annual average $PM_{2.5}$ levels than Non-Hispanics, and Hispanics have greater variation in baseline exposure.

Table 9. Baseline annual average $PM_{2.5}$ Concentrations (ug/m^3) by Ethnicity in 2020

Ethnicity	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	10.17	1.92	6.93	9.01	10.10	11.34	13.92
Hispanic	10.38	2.38	6.74	8.83	10.09	11.88	14.83
Non-Hispanic	10.13	1.79	7.00	9.03	10.11	11.27	13.21

When examining results by urban and rural areas in **Table 10** and in **Figure 10**, we see that mean $PM_{2.5}$ level in rural areas is similar between Hispanics and Non-Hispanics, but in urban areas Hispanics tend to have markedly higher levels. In both rural and urban areas, Hispanics have much greater variation in exposure.

Table 10. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Ethnicity & Urban/Rural Areas in 2020

Ethnicity	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total Rural	9.89	1.74	6.83	8.76	9.94	11.06	12.72
Hispanic	9.82	2.12	6.60	8.39	9.62	11.03	13.92
Non-Hispanic	9.90	1.66	6.94	8.79	9.96	11.06	12.56

Ethnicity	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total Urban	10.68	2.10	7.26	9.46	10.33	11.92	14.77
Hispanic	11.03	2.50	7.02	9.41	10.35	13.21	15.05
Non-Hispanic	10.57	1.95	7.27	9.46	10.33	11.75	14.03

Figure 10. Baseline Annual Average $PM_{2.5}$ Concentrations in 2020, Cumulative Density Function by Race & Urban/Rural Areas

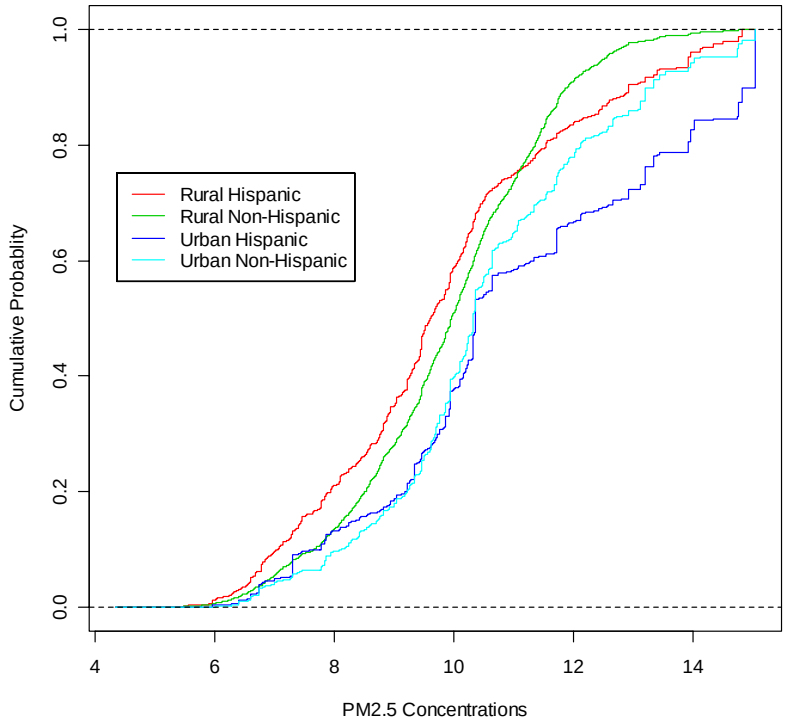


Table 11 presents the lower and upper tails of the distribution of baseline $PM_{2.5}$ exposures. The most marked result is the over-representation of urban Hispanics: they represent 8.46 percent of the total population, yet they comprise over 60 percent of the population exposed to the very highest (99th percentile) pollution levels.

Table 11. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) in 2020, with Percentage of Population by Ethnicty & Urban/Rural Areas at Each Percentile Value

		Statistics in Lower Tail				Statistics in Upper Tail				
Percentile		**1st**	**5th**	**10th**	**25th**	**75th**	**90th**	**95th**	**99th**	
Baseline $PM_{2.5}$ Level		6.28	6.93	7.72	9.01	11.34	12.68	13.92	15.05	**All***
Percent of Population by Ethnicity and Location at Each Percentile Value **										
Hispanic	Rural	20.44	17.52	16.74	13.72	8.68	11.72	12.65	0.61	9.83
	Urban	4.01	7.77	8.41	6.25	13.41	24.81	35.68	60.38	8.46
Non-Hispanic	Rural	69.27	53.59	56.97	60.73	43.53	21.06	12.19	0.39	54.13
	Urban	6.29	21.12	17.88	19.30	34.38	42.41	39.48	38.62	27.58

3.2.2 Reduction in $PM_{2.5}$ Levels by Ethnicity

Table 12 presents the change in $PM_{2.5}$ levels by ethnic group. Hispanics enjoy greater reductions, on average, than NonHispanics, moreover a larger percentage of Hispanics enjoy a decrease in $PM_{2.5}$ levels than Non-Hispanics.

Table 12. 2020 Projected Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Ethnicity

			Conditional Statistics***						
Ethnicity	**Unconditional Mean***	**Percent Above Zero****	**Mean**	**Standard Deviation**	**5th Pct**	**25th Pct**	**50th Pct (Median)**	**75th Pct**	**95th Pct**
Total	0.15	18.22	0.84	0.90	0.01	0.05	0.58	1.37	2.40
Hispanic	0.36	30.68	1.19	0.99	0.02	0.45	0.83	1.77	3.32
Non-Hispanic	0.11	15.44	0.69	0.81	0.00	0.03	0.42	1.14	1.99

* Mean change including individuals with zero changes.

** The column "Percent Above Zero" shows the percentage of the population that received a change greater than zero. For example, 30.68% of Hispanics had a change greater than zero (and by implication, 69.32% had no change).

*** The "Conditional Distribution" presents statistics showing the distribution of individuals that received a change greater than zero. For example, among Hispanics that received a change, 25% received a change of 0.45 or less (and by implication 75% had a change greater than 0.45).

As seen in **Table 13**, the difference between Hispanics and NonHispanics also holds across both rural and urban areas.

Table 13. 2020 Projected Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Ethnicity & Urban/Rural Areas

Rural			Conditional Statistics						
Ethnicity	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total Rural	0.14	16.40	0.87	1.02	0.01	0.05	0.51	1.41	3.17
Hispanic	0.40	29.75	1.33	1.18	0.02	0.25	1.21	1.82	4.07
Non-Hispanic	0.10	13.98	0.69	0.88	0.01	0.03	0.29	1.05	2.34

Urban			Conditional Statistics						
Ethnicity	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total Urban	0.17	21.46	0.80	0.71	0.00	0.05	0.83	1.21	1.80
Hispanic	0.33	31.76	1.03	0.68	0.02	0.73	0.83	1.66	1.80
Non-Hispanic	0.12	18.30	0.68	0.70	0.00	0.02	0.58	1.21	1.80

Figure 11 presents another view of the information in **Table 13**. A greater fraction of Hispanics enjoy a decline in PM2.5 levels and the change on average is greater than it is for Non-Hispanics. In particular, rural Hispanics enjoy relatively large changes.

Figure 11. 2020 Projected Decrease in Annual Average $PM_{2.5}$ Concentrations (µg/m3), Cumulative Density Function by Ethnicity & Urban/Rural Areas

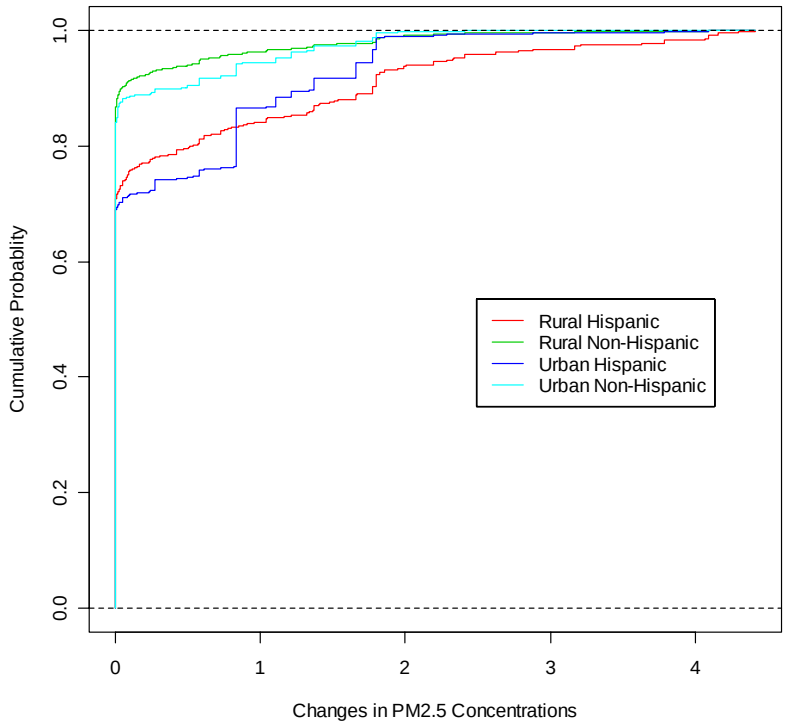


Table 14 presents a quantitative view of the population composition in the lower and upper tails of the $PM_{2.5}$ change distribution. Rural Hispanics comprise over 49 percent of the population with the largest changes (at least 2.34 ug/m^3), even though they represent less than 10 percent of the population. The other sub-groups tend to be under-represented at the highest percentiles, particularly urban Non-Hispanics.

Table 14. Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) Projected for 2020, with Percentage of Population by Race & Urban/Rural Areas at Each Percentile Value

		Statistics At or Above Zero		Statistics in Upper Tail of Unconditional Distribution			All**
Percentile		**<=81st***	**82nd**	**90th**	**95th**	**99th**	
Change in $PM_{2.5}$ Level		No Change	>0	0.53	1.32	2.34	
Percent of Population by Ethnicity at Each Percentile Value * **							
Hispanic		15.51	31.07	41.20	46.16	55.68	18.29
Non-Hispanic		84.49	68.93	58.80	53.84	44.32	81.71
Percent of Population by Ethnicity and Location at Each Percentile Value							
Hispanic	Rural	8.45	16.18	19.77	28.46	49.17	9.83
	Urban	7.06	14.90	21.43	17.71	6.51	8.46
Non-Hispanic	Rural	56.94	41.17	32.28	33.53	38.11	54.13
	Urban	27.56	27.75	26.52	20.30	6.21	27.58

* At the 81st percentile, the change is zero, so lower percentiles have the same value as the 81st percentile.

** The fraction of the total population all ages.

*** The "Percentage of Population by Ethnicity at each Percentile Value" presents racial composition at each percentile. That is, it shows what percentage of the total population is in a particular racial group at each percentile. For example, in the 95th percentile, Hispanics comprise 46.16% of the population and Non-Hispanics 53.84%.

3.2.3 Reduction in Mortality Rates by Ethnicity

As shown in **Table 15**, Hispanics experienced about a two-fold larger reduction in premature mortality rate than Non-Hispanics. However, recall from **Table 12** that Hispanics experienced over a three-fold greater reduction in $PM_{2.5}$ levels than Non-Hispanics. This suggests that Hispanics enjoy a smaller reduction in premature mortality per unit reduction in $PM_{2.5}$ levels.

This result appears to be driven by the relatively young age structure of the Hispanic population. When controlling for age, we see in **Table 16**, Hispanics experience about a three-fold decrease in mortality relative to Non-Hispanics, as would be expected if the reduction in premature mortality were strictly proportional to the change in $PM_{2.5}$.

Table 15. Decline in Mortality Rate by Ethncity (# fewer deaths per 100,000 people)

			Conditional Statistics						
Ethnicity	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	1.10	17.97	6.12	6.55	0.04	0.36	4.48	10.20	16.21
Hispanic	1.85	30.13	6.13	5.18	0.08	2.27	4.36	9.48	16.98
Non-Hispanic	0.97	15.83	6.11	7.41	0.03	0.27	3.88	10.04	17.86

Table 16. Decline in Mortality Rate by Ethncity & Age (# fewer deaths per 100,000 people)

				Conditional Statistics						
Ethnicity	Age	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	Total	1.10	17.97	6.12	6.55	0.04	0.36	4.48	10.20	16.21
Hispanic	Ages 35-54	0.49	30.10	1.62	1.45	0.02	0.60	1.09	2.33	4.88
	Ages 55-64	1.74	30.96	5.62	4.88	0.11	2.23	3.83	7.85	17.34
	Ages 65+	6.97	29.34	23.76	19.82	0.58	10.35	16.02	34.12	70.05
Non-Hispanic	Ages 35-54	0.15	15.66	0.96	1.20	0.00	0.04	0.55	1.60	2.71
	Ages 55-64	0.50	15.57	3.20	3.99	0.01	0.12	1.86	5.20	9.05
	Ages 65+	2.47	16.26	15.18	18.63	0.07	0.71	9.69	25.03	43.45

3.3 Examination of Results by Poverty

In this section, we present the baseline $PM_{2.5}$ levels and the changes in $PM_{2.5}$ levels and premature mortality experienced by the population above and below poverty. BenMAP uses county-level poverty data that measures the fraction of the population that is above and below the poverty line. To estimate the fraction of the population above and below the poverty line in a specific CMAQ gridcell, BenMAP uses a simple spatially weighted average of the one of more counties that might overlay the gridcell.[5]

3.3.1 Baseline $PM_{2.5}$ Levels by Poverty

In **Table 17** we see that the baseline $PM_{2.5}$ levels do not differ much, with somewhat higher PM2.5 levels in the below poverty group. When examining for differences between urban and rural areas, we see that this difference holds between urban and rural areas, though the difference is somewhat more pronounced in urban areas. This is reflected in **Figure 12**, which shows little difference by poverty status in rural areas.

[5] Using a simple spatially-weighted average does not take into account population density, so a large, sparsely population county may have a disproportionate influence on the results.

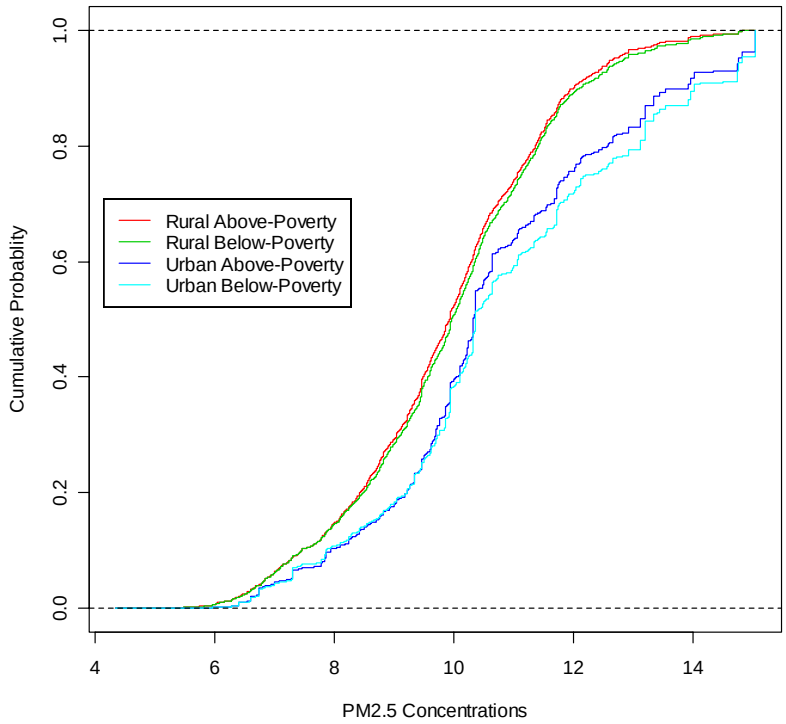
Table 17. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Race in 2020

Poverty Level	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	10.17	1.92	6.93	9.01	10.10	11.34	13.92
Above Poverty Level	10.16	1.91	6.92	9.00	10.10	11.34	13.55
Below Poverty Level	10.24	1.97	6.94	9.01	10.16	11.44	13.96

Rural Poverty Level	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	9.89	1.74	6.83	8.76	9.94	11.06	12.72
Above Poverty Level	9.88	1.74	6.83	8.75	9.93	11.06	12.68
Below Poverty Level	9.94	1.77	6.83	8.81	9.97	11.13	12.86

Urban Poverty Level	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	10.68	2.10	7.26	9.46	10.33	11.92	14.77
Above Poverty Level	10.66	2.09	7.24	9.46	10.33	11.92	14.77
Below Poverty Level	10.82	2.20	7.27	9.47	10.35	12.29	14.83

Figure 12. Baseline Annual Average $PM_{2.5}$ Concentrations in 2020, Cumulative Density Function by Poverty



In **Table 18** we see differences between rural and urban areas dominating any differences by poverty group. Not surprisingly, rural areas have low $PM_{2.5}$ levels relative to urban areas.

Table 18. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) in 2020, with Percentage of Population by Poverty & Urban/Rural Areas at Each Percentile Value

		Statistics in Lower Tail				Statistics in Upper Tail				
Percentile		**1st**	**5th**	**10th**	**25th**	**75th**	**90th**	**95th**	**99th**	
Baseline $PM_{2.5}$ Level		6.28	6.93	7.72	9.01	11.34	12.68	13.92	15.05	**All***
Percent of Population by Poverty Status and Location at Each Percentile Value **										
Above Poverty Level	Rural	78.44	62.07	64.28	65.18	45.26	27.92	21.01	0.86	55.80
	Urban	8.97	25.68	23.03	22.53	41.61	58.01	64.37	85.43	31.86
Below Poverty Level	Rural	11.27	9.03	9.43	9.27	6.94	4.86	3.84	0.14	8.16
	Urban	1.33	3.21	3.26	3.02	6.19	9.21	10.78	13.57	4.18

3.3.2 Reductions in $PM_{2.5}$ Levels by Poverty

In **Table 19**, we see that persons below the poverty line received a somewhat larger change in PM2.5 levels than those above the poverty line. This difference holds in both urban and rural areas. **Table 20** shows that persons both above and below the poverty line in rural are relatively over-represented in areas receiving the largest reductions.

Table 19. 2020 Projected Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Poverty and Urban/Rural Areas

All			Conditional Statistics						
Poverty Level	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	0.15	18.22	0.84	0.90	0.01	0.05	0.58	1.37	2.40
Above Poverty Level	0.15	18.23	0.82	0.88	0.01	0.05	0.58	1.37	2.40
Below Poverty Level	0.17	18.16	0.96	1.00	0.01	0.07	0.78	1.66	3.17

Rural			Conditional Statistics						
Poverty Level	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	0.14	16.40	0.87	1.02	0.01	0.05	0.51	1.41	3.17
Above Poverty Level	0.14	16.48	0.85	1.00	0.01	0.05	0.49	1.37	2.93
Below Poverty Level	0.16	15.87	1.03	1.15	0.01	0.07	0.58	1.77	3.78

Urban			Conditional Statistics						
Poverty Level	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	0.17	21.46	0.80	0.71	0.00	0.05	0.83	1.21	1.80
Above Poverty Level	0.17	21.30	0.79	0.71	0.00	0.05	0.83	1.21	1.80
Below Poverty Level	0.19	22.64	0.86	0.75	0.01	0.07	0.83	1.37	1.80

Table 20. Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) Projected for 2020, with Percentage of Population by Poverty and Urban/Rural Areas at Each Percentile Value

		Statistics At or Above Zero		Statistics in Upper Tail of Unconditional Distribution			All*
Percentile		**<=81st****	**82nd**	**90th**	**95th**	**99th**	
Change in $PM_{2.5}$ Level		No Change	>0	0.53	1.32	2.34	
Percent of Population by Poverty Status and Location at Each Percentile Value ***							
Above Poverty Level	Rural	56.99	50.27	45.08	53.02	71.40	55.80
	Urban	30.66	37.44	41.76	32.90	10.56	31.86
Below Poverty Level	Rural	8.40	7.08	6.97	8.97	15.88	8.16
	Urban	3.95	5.21	6.19	5.11	2.16	4.18

3.3.3 Changes in Mortality Rates by Poverty

As seen in **Table 21**, persons below the poverty line receive a somewhat smaller decline in premature mortality. Most likely this is due to a younger age structure for those below the poverty line. This is consistent with the results in **Table 22**, which shows a smaller effect in the elderly for persons below the poverty level.

Table 21. Decline in Mortality Rate by Poverty Level (# fewer deaths per 100,000 people)

			Conditional Statistics						
Poverty Level	**Unconditional Mean**	**Percent Above Zero**	**Mean**	**Standard Deviation**	**5th Pct**	**25th Pct**	**50th Pct (Median)**	**75th Pct**	**95th Pct**
Total	1.10	17.97	6.12	6.55	0.04	0.36	4.48	10.20	16.21
Above Poverty Level	1.11	17.99	6.17	6.68	0.04	0.37	4.37	10.14	16.09
Below Poverty Level	1.01	17.82	5.65	5.73	0.04	0.40	4.85	8.90	15.72

Table 22. Decline in Mortality Rate by Poverty Level & Age (# fewer deaths per 100,000 people)

				Conditional Statistics						
Poverty Level	Age	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	Total	1.10	17.97	6.12	6.55	0.04	0.36	4.48	10.20	16.21
Above Poverty	Ages 35-54	0.22	18.59	1.16	1.30	0.01	0.07	0.80	1.88	3.51
	Ages 55-64	0.64	17.49	3.69	4.26	0.02	0.20	2.53	6.17	9.96
	Ages 65+	2.89	17.60	16.40	18.93	0.12	1.09	11.17	26.65	44.54
Below Poverty	Ages 35-54	0.24	18.36	1.29	1.47	0.01	0.09	0.82	1.94	4.90
	Ages 55-64	0.72	17.52	4.12	4.81	0.02	0.28	2.66	6.17	13.67
	Ages 65+	2.63	15.50	16.96	19.73	0.07	0.80	11.20	26.73	44.42

3.4 Examination of Results by Education

In this section, we present the baseline $PM_{2.5}$ levels and the changes in $PM_{2.5}$ levels and premature deaths experienced by each of the education groups considered in our analysis – no high school diploma, high school diploma, attended some college (no degree), college degree, and graduate studies. We find that persons with no high school diplma experience generally higher $PM_{2.5}$ levels and received on average a somewhat larger reduction in $PM_{2.5}$ than other groups. The differences between the other groups are slight.

3.4.1 Baseline $PM_{2.5}$ Levels by Education

In **Table 23** we see that least educated group have somewhat higher baseline levels of $PM_{2.5}$. The differences among the rest of the groups are relatively small.

Table 23. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Education in 2020

Education	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	10.17	1.92	6.93	9.01	10.10	11.34	13.92
No High School Diploma	10.37	2.02	6.97	9.17	10.24	11.55	14.03
High School Diploma	10.14	1.87	6.92	9.00	10.11	11.32	13.41
Attended College (no degree)	10.09	1.95	6.83	8.79	10.01	11.31	13.55
College Degree	10.13	1.90	6.94	8.97	10.07	11.26	13.55
Graduate Studies	10.13	1.84	6.94	9.07	10.10	11.18	13.35

3.4.2 Reduction in $PM_{2.5}$ Levels by Education

Table 24 presents the reductions in PM2.5 levels by education. The reductions are similar across different groups, with a somewhat larger reduction for persons without a high school diploma.

Table 24. 2020 Projected Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Education Level & Urban/Rural Areas

All			Conditional Statistics						
Education	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	0.15	18.22	0.84	0.90	0.01	0.05	0.58	1.37	2.40
No High School Diploma	0.22	20.68	1.04	0.98	0.01	0.17	0.83	1.66	3.17
High School Diploma	0.13	15.96	0.80	0.91	0.00	0.03	0.58	1.37	2.40
Attended College (no degree)	0.16	19.33	0.81	0.89	0.01	0.05	0.58	1.36	2.40
College Degree	0.14	18.62	0.76	0.79	0.00	0.05	0.58	1.21	1.95
Graduate Studies	0.13	17.75	0.74	0.76	0.00	0.05	0.58	1.21	1.95

3.4.3 Changes in Mortality Rates by Education

Table 25 presents the decline in mortality experienced by education. The results appear consistent with the changes in $PM_{2.5}$.

Table 25. Decline in Mortality Rate by Education (# fewer deaths per 100,000 people)

			Conditional Statistics						
Education	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	1.10	17.97	6.12	6.55	0.04	0.36	4.48	10.20	16.21
No High School Diploma	1.54	20.28	7.60	7.28	0.07	1.30	5.85	10.63	23.99
High School Diploma	0.92	15.67	5.90	6.73	0.03	0.28	4.05	9.99	17.57
Attended College (no degree)	1.13	19.01	5.97	6.55	0.04	0.36	4.05	9.99	16.21
College Degree	1.03	18.42	5.61	5.81	0.03	0.36	4.05	9.99	15.46
Graduate Studies	0.97	17.58	5.49	5.60	0.03	0.35	4.05	9.99	15.04

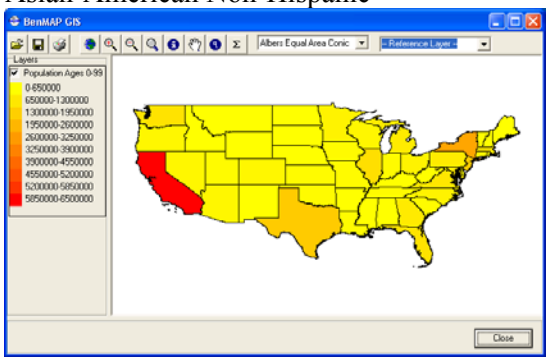
3.5 Examination of Results by Race and Ethnicity

In this section, we present the baseline $PM_{2.5}$ levels and the changes in $PM_{2.5}$ levels and premature deaths experienced by subgroups broken down by race and ethnicity.

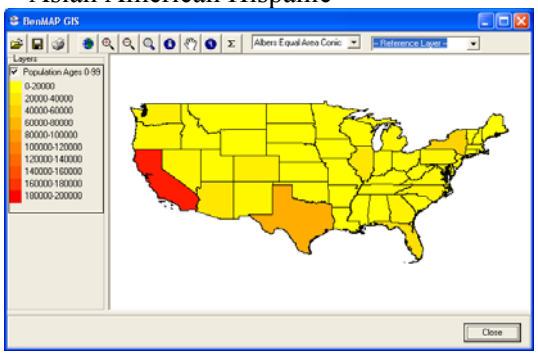
Figure 13 shows forecasted 2020 state-level population. The patterns for Asian-American Hispanics and Non-Hispanics are similar, with population concentrations in California, Texas, and New York. This pattern is, in fact, similar across all of the Hispanic subpopulations, with African-American Hispanic, Native-American Hispanics and Caucasian Hispanics having population concentrations in these three states. However, there are significant differences between Hispanic and Non-Hispanic populations. For example, African-American Non-Hispanics have large population centers in the South and NorthEast.

Figure 13. Forecasted 2020 State Population by Race & Ethnicity

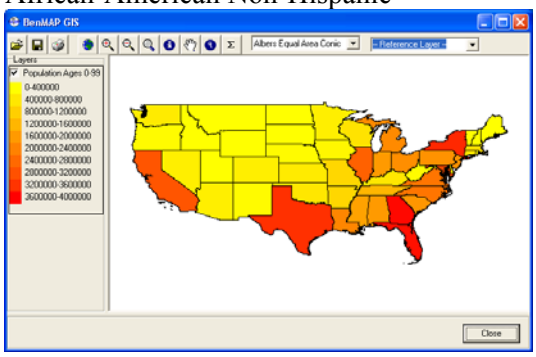
Asian-American Non-Hispanic



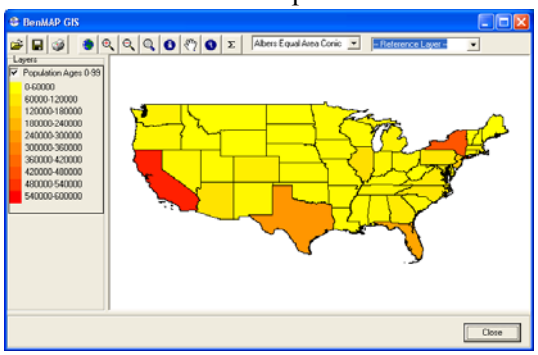
Asian American Hispanic



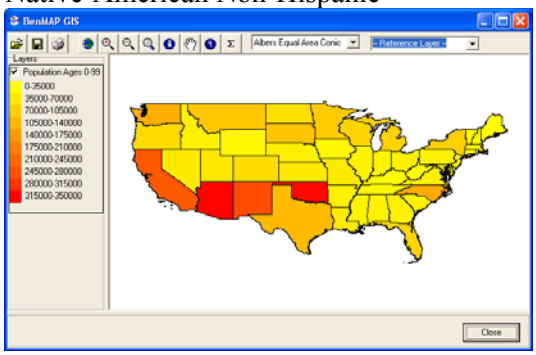
African-American Non-Hispanic



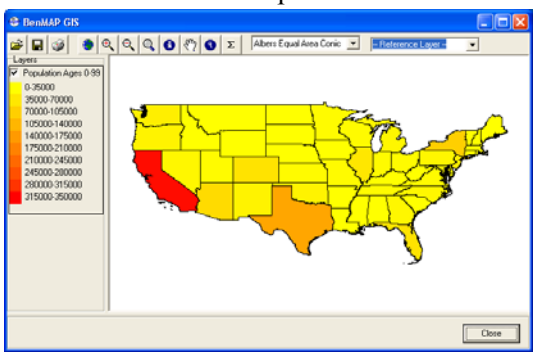
African-American Hispanic



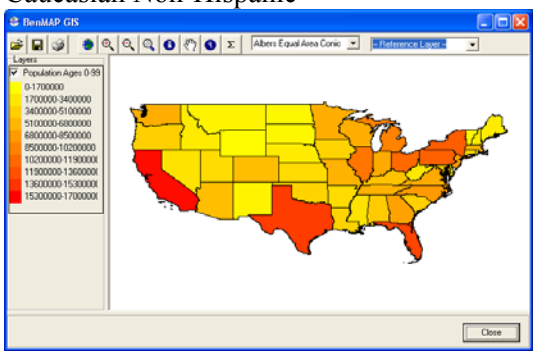
Native-American Non-Hispanic



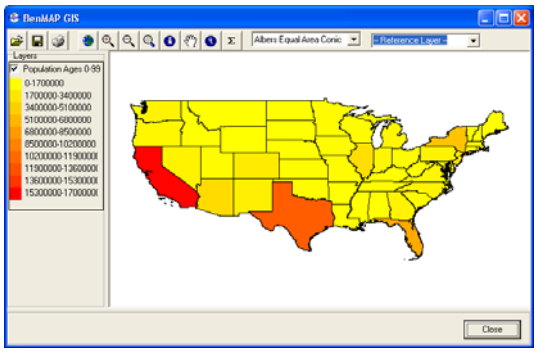
Native-American Hispanic



Caucasian Non-Hispanic



Caucasian Hispanic



3.5.1 Baseline $PM_{2.5}$ Levels by Race and Ethnicity

Table 26 and **Table 27** show that Hispanics experience generally higher $PM_{2.5}$ levels than Non-Hispanics.

Table 26. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Race and Ethnicity in 2020

Race	Ethnicity	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	Total	10.17	1.92	6.93	9.01	10.10	11.34	13.92
Asian-American	Hispanic	10.64	2.32	7.00	9.17	10.24	12.43	14.83
	Non-Hispanic	10.61	1.99	7.78	9.46	10.22	11.72	14.77
African-American	Hispanic	10.42	2.16	6.93	9.23	10.24	11.61	14.83
	Non-Hispanic	10.65	1.78	7.30	9.75	10.35	11.72	13.55
Native-American	Hispanic	10.47	2.43	6.79	8.78	10.09	12.29	14.83
	Non-Hispanic	8.75	1.99	6.03	6.94	8.73	9.94	12.47
Caucasian	Hispanic	10.37	2.39	6.74	8.81	10.07	11.90	14.83
	Non-Hispanic	9.99	1.74	6.96	8.81	10.00	11.17	12.80

Table 27. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) in 2020, with Percentage of Population by Race at Each Percentile Value

		Statistics in Lower Tail				Statistics in Upper Tail				
Percentile		**1st**	**5th**	**10th**	**25th**	**75th**	**90th**	**95th**	**99th**	
Baseline $PM_{2.5}$ Level		6.28	6.93	7.72	9.01	11.34	12.68	13.92	15.05	**All***
Percent of Population by Race and Ethnicity at Each Percentile Value **										
Asian-American	Hispanic	0.15	0.14	0.15	0.14	0.20	0.33	0.43	0.47	0.15
	Non-Hispanic	1.89	3.20	2.92	3.78	6.97	10.29	12.93	14.55	5.90
African-American	Hispanic	0.54	0.69	0.72	0.61	0.75	1.18	1.46	1.75	0.69
	Non-Hispanic	2.23	8.48	7.27	6.93	15.58	18.43	12.05	7.99	12.99
Native-American	Hispanic	0.47	0.34	0.35	0.31	0.36	0.61	0.82	0.97	0.28
	Non-Hispanic	8.03	3.81	2.57	1.65	0.29	0.34	0.37	0.34	0.77
Caucasian	Hispanic	23.29	24.12	23.92	18.92	20.78	34.40	45.61	57.80	17.17
	Non-Hispanic	63.40	59.21	62.10	67.66	55.07	34.41	26.32	16.14	62.04

3.5.2 Reduction in $PM_{2.5}$ Levels by Race and Ethnicity

In **Table 28** and **Table 29** we see that Hispanics experience a greater reduction in PM2.5 than Non-Hispanics. The differences are particularly large for African-Americans, Native-Americans, and

Caucasians. The differences between Hispanic and Non-Hispanic Asian-Americans is not as pronounced – not surprising given the similar locations of the two populations as seen in **Figure 13**.

Table 28. 2020 Projected Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Race and Ethnicity

				Conditional Statistics						
Race	Ethnicity	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	Total	0.15	18.22	0.84	0.90	0.01	0.05	0.58	1.37	2.40
Asian-American	Hispanic	0.45	37.67	1.20	0.98	0.01	0.49	1.04	1.77	3.17
	Non-Hispanic	0.34	35.46	0.96	0.77	0.01	0.28	0.83	1.66	1.99
African-American	Hispanic	0.29	25.18	1.15	1.01	0.01	0.28	0.83	1.77	3.63
	Non-Hispanic	0.07	9.96	0.73	0.87	0.00	0.02	0.57	1.21	2.19
Native-American	Hispanic	0.45	38.89	1.17	1.01	0.02	0.32	0.83	1.77	3.63
	Non-Hispanic	0.11	17.85	0.61	0.85	0.01	0.05	0.25	0.83	2.19
Caucasian	Hispanic	0.37	30.71	1.19	0.98	0.02	0.45	0.83	1.77	3.32
	Non-Hispanic	0.09	14.65	0.62	0.80	0.00	0.03	0.25	0.90	1.95

Table 29. Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) Projected for 2020, with Percentage of Population by Race and Ethnicity at Each Percentile Value

		Statistics At or Above Zero		Statistics in Upper Tail of Unconditional Distribution			All*
Percentile		**<=81st****	**82nd**	**90th**	**95th**	**99th**	
Change in $PM_{2.5}$ Level		No Change	>0	0.53	1.32	2.34	
Percent of Population by Race and Ethnicity at Each Percentile Value ***							
Asian-American	Hispanic	0.11	0.31	0.41	0.48	0.58	0.15
	Non-Hispanic	4.66	11.59	14.27	13.03	6.92	5.90
African-American	Hispanic	0.63	0.96	1.23	1.37	1.74	0.69
	Non-Hispanic	14.30	7.15	6.50	6.05	5.33	12.99
Native-American	Hispanic	0.21	0.60	0.77	0.86	1.13	0.28
	Non-Hispanic	0.77	0.75	0.48	0.47	0.64	0.77
Caucasian	Hispanic	14.55	29.20	38.78	43.46	52.25	17.17
	Non-Hispanic	64.76	49.44	37.55	34.29	31.43	62.04

3.5.3 Reduction in Mortality Rates by Race and Ethnicity

In **Table 30** we examine the reduction in mortality rates by race and ethnicity. Here the pattern changes somewhat, with the differences between Hispanics and Non-Hispanics narrowing (relative to **Table 29**) and in the case of Asian-Americans it appears that Non-Hispanics enjoy a greater reduction in mortality than Hispanics, even though Hispanics enjoy a greater reduction in PM2.5 levels.

This result is likely driven by the age structure of the population, with Hispanics having a younger age structure and thus lower mortality rates. However, it is important to recall that BenMAP does not race and ethnicity-specific mortality rates.

Table 30. Decline in Mortality Rate by Race & Ethnicity (# fewer deaths per 100,000 people)

				Conditional Statistics						
Race	Ethnicity	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	Total	1.10	17.97	6.12	6.55	0.04	0.36	4.48	10.20	16.21
Asian-American	Hispanic	1.97	38.15	5.16	4.24	0.06	1.93	4.14	8.04	11.42
	Non-Hispanic	2.88	38.13	7.55	6.08	0.04	2.27	7.33	11.07	16.83
African-American	Hispanic	1.27	23.71	5.34	5.03	0.03	1.49	3.77	8.33	18.48
	Non-Hispanic	0.53	10.29	5.11	5.93	0.02	0.15	3.26	8.80	14.46
Native-American	Hispanic	2.02	39.75	5.09	4.77	0.07	1.74	3.70	7.05	14.90
	Non-Hispanic	1.06	18.55	5.74	8.41	0.04	0.30	2.23	8.61	20.73
Caucasian	Hispanic	1.87	30.17	6.19	5.21	0.08	2.29	4.39	9.55	17.04
	Non-Hispanic	0.87	14.72	5.90	7.92	0.03	0.23	2.69	8.93	19.85

3.6 Examination of results by Race and Poverty

In this section, we present the baseline $PM_{2.5}$ levels and the changes in $PM_{2.5}$ levels and premature deaths experienced by subgroups broken down by race and poverty.

3.6.1 Baseline $PM_{2.5}$ Levels by Race and Poverty

In **Table 31** and **Table 32** we see some difference by poverty status for Native Americans, with individuals below the poverty line experiencing somewhat lower PM2.5 levels. However, for other races, there is little difference by poverty status. For example, Asian-Americans have generally higher exposure levels regardless of poverty status.

Table 31. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Race & Poverty in 2020

Race	Poverty Level	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	Total	10.17	1.92	6.93	9.01	10.10	11.34	13.92
Asian-American	Above Poverty Level	10.62	2.01	7.69	9.46	10.22	11.74	14.77
	Below Poverty Level	10.58	1.98	7.66	9.46	10.22	11.69	14.77
African-American	Above Poverty Level	10.62	1.80	7.30	9.71	10.35	11.72	13.92
	Below Poverty Level	10.70	1.79	7.30	9.75	10.49	11.72	13.55
Native-American	Above Poverty Level	9.36	2.27	6.13	7.73	9.35	10.35	14.03
	Below Poverty Level	8.77	2.13	6.03	6.81	8.62	9.95	12.96
Caucasian	Above Poverty Level	10.07	1.90	6.87	8.81	10.01	11.27	13.41
	Below Poverty Level	10.08	1.97	6.87	8.80	9.96	11.34	13.92

Table 32. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) in 2020, with Percentage of Population by Race & Poverty at Each Percentile Value

		Statistics in Lower Tail				Statistics in Upper Tail				
Percentile		**1st**	**5th**	**10th**	**25th**	**75th**	**90th**	**95th**	**99th**	
Baseline $PM_{2.5}$ Level		6.28	6.93	7.72	9.01	11.34	12.68	13.92	15.05	**All***
Percent of Population by Race and Poverty Status at Each Percentile Value **										
Asian-American	Above Poverty Level	1.82	2.98	2.73	3.50	6.42	9.54	12.02	13.51	5.41
	Below Poverty Level	0.22	0.36	0.33	0.42	0.74	1.08	1.35	1.51	0.64
African-American	Above Poverty Level	2.13	7.25	6.18	5.76	12.26	15.04	10.37	7.90	10.47
	Below Poverty Level	0.64	1.92	1.81	1.78	4.07	4.57	3.15	1.84	3.22
Native-American	Above Poverty Level	5.66	2.73	1.95	1.37	0.53	0.80	1.01	1.13	0.78
	Below Poverty Level	2.84	1.42	0.97	0.59	0.12	0.16	0.18	0.18	0.27
Caucasian	Above Poverty Level	77.71	74.95	76.89	77.50	68.04	61.02	63.11	65.38	71.28
	Below Poverty Level	8.98	8.38	9.13	9.08	7.81	7.79	8.82	8.56	7.93

3.6.2 Reduction in $PM_{2.5}$ Levels by Race and Poverty

Table 33 and **Table 34** present the reduction in $PM_{2.5}$ levels by race and poverty. Among Asian-Americans we see little difference. Among African-Americans we see a somewhat larger change for persons above poverty, and among Caucasians we see a somewhat larger change for persons below poverty. The biggest difference is found among Native-Americans, with persons above poverty enjoying the greatest change.

Table 33. 2020 Projected Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Race & Poverty

				Conditional Statistics						
Race	Poverty Level	Unconditional Mean	Percent Above Zero	Mean	Std Dev	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	Total	0.15	18.22	0.84	0.90	0.01	0.05	0.58	1.37	2.40
Asian-American	Above Poverty	0.35	35.70	0.97	0.78	0.01	0.28	0.83	1.66	1.99
	Below Poverty	0.33	34.01	0.96	0.78	0.01	0.28	0.83	1.66	1.99
African-American	Above Poverty	0.09	10.94	0.80	0.88	0.00	0.02	0.61	1.36	2.27
	Below Poverty	0.07	10.03	0.74	0.94	0.00	0.02	0.24	1.21	2.40
Native-American	Above Poverty	0.22	24.93	0.90	0.98	0.01	0.10	0.58	1.37	3.17
	Below Poverty	0.13	19.19	0.70	0.92	0.01	0.05	0.28	1.04	2.40
Caucasian	Above Poverty	0.15	17.99	0.81	0.90	0.01	0.05	0.58	1.36	2.40
	Below Poverty	0.19	19.40	0.98	1.04	0.01	0.09	0.73	1.66	3.21

Table 34. Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) Projected for 2020, with Percentage of Population by Race & Poverty at Each Percentile Value

		Statistics At or Above Zero		Statistics in Upper Tail of Unconditional Distribution			All*
Percentile		<=81st**	82nd	90th	95th	99th	
Change in $PM_{2.5}$ Level		No Change	>0	0.53	1.32	2.34	
Percent of Population by Race and Poverty Status at Each Percentile Value ***							
Asian-American	Above Poverty Level	4.26	10.69	13.20	12.15	6.74	5.41
	Below Poverty Level	0.52	1.21	1.48	1.36	0.76	0.64
African-American	Above Poverty Level	11.40	6.33	6.19	5.91	5.32	10.47
	Below Poverty Level	3.54	1.78	1.54	1.50	1.74	3.22
Native-American	Above Poverty Level	0.72	1.07	1.05	1.12	1.46	0.78
	Below Poverty Level	0.27	0.28	0.21	0.22	0.30	0.27
Caucasian	Above Poverty Level	71.49	70.22	67.40	67.84	69.43	71.28
	Below Poverty Level	7.82	8.42	8.93	9.91	14.25	7.93

3.6.3 Reduction in Mortality Rates by Race and Poverty

Table 35 presents the reduction in mortality rates by race and poverty. The results generally mirror the changes in PM2.5 observed. Here again, however, we see the effect of mortality rates in Caucasians:

persons above the poverty line experience a somewhat smaller reduction in PM2.5 levels, nevertheless they experience a somewhat greater reduction in mortality.

Table 35. Decline in Mortality Rate by Race & Poverty (# fewer deaths per 100,000 people)

				Conditional Statistics						
Race	Poverty Level	Unconditional Mean	Percent Above Zero	Mean	Std Dev	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	Total	1.10	17.97	6.12	6.55	0.04	0.36	4.48	10.20	16.21
Asian-American	Above Poverty	2.88	38.33	7.52	6.02	0.04	2.25	7.26	11.05	16.72
Asian-American	Below Poverty	2.69	36.48	7.38	5.99	0.05	2.24	7.21	10.97	16.60
African-American	Above Poverty	0.59	11.11	5.36	5.96	0.02	0.15	4.13	9.29	14.57
African-American	Below Poverty	0.41	10.01	4.13	5.00	0.02	0.12	0.80	7.48	12.76
Native-American	Above Poverty	1.45	24.82	5.84	6.77	0.06	0.78	3.69	8.83	22.41
Native-American	Below Poverty	0.73	18.93	3.85	5.02	0.02	0.22	1.92	5.42	12.23
Caucasian	Above Poverty	1.05	17.35	6.03	6.84	0.05	0.37	4.42	9.92	17.75
Caucasian	Below Poverty	1.01	18.07	5.58	5.86	0.04	0.41	4.48	8.89	17.13

3.7 Examination of results by Ethnicity and Poverty

In this section, we present the baseline $PM_{2.5}$ levels and the changes in $PM_{2.5}$ levels and premature deaths experienced by subgroups broken down by ethnicity and poverty.

3.7.1 Baseline $PM_{2.5}$ Levels by Ethnicity and Poverty

Table 36 and **Table 37** present baseline PM2.5 levels by ethnicity and poverty status. The differences are more pronounced between Hispanic and Non-Hispanic groups than between persons above and below poverty. In the case of Hispanics, there is little difference by poverty status.

Table 36. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Ethnicity & Poverty in 2020

Ethnicity	Poverty Level	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	Total	10.17	1.92	6.93	9.01	10.10	11.34	13.92
Hispanic	Above Poverty	10.39	2.40	6.74	8.81	10.10	11.92	14.83
	Below Poverty	10.35	2.32	6.79	8.88	9.97	11.72	14.83
Non-Hispanic	Above Poverty	10.11	1.79	7.00	9.01	10.10	11.25	13.21
	Below Poverty	10.23	1.79	7.04	9.15	10.24	11.39	13.21

Table 37. Baseline Annual Average $PM_{2.5}$ Concentrations (ug/m^3) in 2020, with Percentage of Population by Ethnicity & Poverty at Each Percentile Value

		Statistics in Lower Tail				Statistics in Upper Tail				
Percentile		**1st**	**5th**	**10th**	**25th**	**75th**	**90th**	**95th**	**99th**	
Baseline $PM_{2.5}$ Level		6.28	6.93	7.72	9.01	11.34	12.68	13.92	15.05	**All***
Percent of Population by Ethnicity and Poverty Status at Each Percentile Value **										
Hispanic	Above Poverty Level	20.12	20.87	20.39	15.86	17.70	29.42	39.29	49.81	14.58
	Below Poverty Level	4.33	4.42	4.75	4.11	4.39	7.11	9.04	11.18	3.71
Non-Hispanic	Above Poverty Level	67.43	66.91	66.76	71.44	68.17	55.86	45.61	35.20	72.35
	Below Poverty Level	8.13	7.80	8.10	8.59	9.74	7.61	6.06	3.81	9.35

3.7.2 Reduction in $PM_{2.5}$ Levels by Ethnicity and Poverty

Table 38 and **Table 39** present the reduction in $PM_{2.5}$ levels by ethnicity and poverty. There are significant differences by ethnicity, but we see little difference by poverty status.

Table 38. 2020 Projected Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) by Ethnicity & Poverty

				Conditional Statistics						
Ethnicity	Poverty Level	Unconditional Mean	Percent Above Zero	Mean	Standard Deviation	5th Pct	25th Pct	50th Pct (Median)	75th Pct	95th Pct
Total	Total	0.15	18.22	0.84	0.90	0.01	0.05	0.58	1.37	2.40
Hispanic	Above Poverty	0.37	31.19	1.17	0.96	0.02	0.48	0.83	1.77	3.17
Hispanic	Below Poverty	0.36	28.68	1.25	1.09	0.01	0.42	0.85	1.80	3.78
Non-Hispanic	Above Poverty	0.11	15.66	0.68	0.81	0.00	0.03	0.42	1.14	1.99
Non-Hispanic	Below Poverty	0.10	13.70	0.69	0.86	0.00	0.02	0.33	1.17	2.19

Table 39. Decrease in Annual Average $PM_{2.5}$ Concentrations (ug/m^3) Projected for 2020, with Percentage of Population by Ethnicity & Poverty at Each Percentile Value

		Statistics At or Above Zero		Statistics in Upper Tail of Unconditional Distribution			All*
Percentile		**<=81st****	**82nd**	**90th**	**95th**	**99th**	
Change in $PM_{2.5}$ Level		No Change	>0	0.53	1.32	2.34	
Percent of Population by Ethnicity and Poverty Status at Each Percentile Value ***							
Hispanic	Above Poverty	12.27	25.18	33.49	37.17	41.70	14.58
	Below Poverty	3.24	5.89	7.71	8.99	13.99	3.71
Non-Hispanic	Above Poverty	74.62	61.93	52.93	48.26	39.01	72.35
	Below Poverty	9.87	7.00	5.87	5.57	5.31	9.35

3.7.3 Reduction in Mortality Rates by Ethnicity and Poverty

In **Table 40** we greater differences between Hispanics and Non-Hispanics, though the greater than three-fold differences in reductions seen in **Table 38** are muted by the higher assumed mortality rates for Non-Hispanics relative to Non-Hispanics. Similarly, we see some differences by poverty status, but again this is due to differences in age structure.

Table 40. Decline in Mortality Rate by Ethnicity & Poverty (# fewer deaths per 100,000 people)

				Conditional Statistics						
Ethnicity	**Poverty Level**	**Unconditional Mean**	**Percent Above Zero**	**Mean**	**Std Dev**	**5th Pct**	**25th Pct**	**50th Pct (Median)**	**75th Pct**	**95th Pct**
Total	Total	1.10	17.97	6.12	6.55	0.04	0.36	4.48	10.20	16.21
Hispanic	Above Poverty	1.89	30.63	6.18	5.21	0.08	2.33	4.40	9.32	17.41
Hispanic	Below Poverty	1.64	27.80	5.91	5.16	0.06	1.81	4.14	8.72	18.69
Non-Hispanic	Above Poverty	0.99	15.98	6.19	7.52	0.03	0.27	3.88	10.17	18.06
Non-Hispanic	Below Poverty	0.77	14.51	5.33	6.42	0.02	0.20	3.36	8.62	15.88

4 Summary

In the analyses discussed in this report, we looked for potential differences across socio-demographic subpopulations in the United States in:

- the distributions of baseline $PM_{2.5}$ levels to which individuals in the subpopulations are exposed;
- the distributions of changes in $PM_{2.5}$ levels to which individuals in the subpopulations are exposed resulting from a rule or regulation; and
- the distributions of changes in premature mortality corresponding to the changes in $PM_{2.5}$ levels.

The analysis focused on the National Ambient Air Quality Standards (NAAQS) for particulate matter (PM) – in particular, attainment of the revised 15/35 suite of NAAQS for $PM_{2.5}$ by the year 2020, and included race, ethnicity, poverty status, education, and age as variables of interest. We used BenMAP to generate population projections separately for each subpopulation within these categories, and then for each subpopulation, we estimated the baseline $PM_{2.5}$ level, the change between the baseline and control scenarios, and the associated change in premature mortality.

The highest baseline $PM_{2.5}$ concentrations generally prevail in parts of California and the Midwest. The greatest changes in $PM_{2.5}$ concentrations (from baseline to control scenario) are largely in California, with the Eastern two-thirds of the country experiencing virtually no changes. These results largely drive the distributional results, particularly when comparing racial groups. Those racial groups that are most highly concentrated in high-baseline-$PM_{2.5}$ areas – African-Americans, Asian-Americans– are exposed, on average, to the highest baseline $PM_{2.5}$ levels, and Native Americans are exposed, on average, to the lowest. Because the changes in $PM_{2.5}$ concentrations are so heavily concentrated in California, the extent to which racial groups are over- or under-represented among those experiencing the largest changes in $PM_{2.5}$ exposures is driven by the proportion of the racial group located in that area.

Asian-Americans, disproportionately located in California, experience the largest changes in $PM_{2.5}$ exposures and, correspondingly, the greatest reductions in premature mortality. Native-Americans, Caucasians, and African-Americans experience smaller changes. However, because BenMAP does not currently have incidence rates specific to each of the subpopulations that we are comparing, some of the observed differences in health effect rate changes may over- or under-state the true differences.

Differences across age and gender subpopulations were smaller. Some of the differences across age groups in health effect changes may be due in part to differences in baseline incidence rates (BenMAP does incorporate age group-specific rates of premature mortality and myocardial infarction). The same change in $PM_{2.5}$ exposure experienced by individuals in the oldest age group (65+) will result in a much larger reduction in the rate of premature mortality than in the younger age groups because the baseline mortality rate of the oldest group is so much larger. Similarly, the (small) differences observed between the two genders may be driven by their differing age distributions, since females are disproportionately represented in the oldest age group, whose baseline incidence rates are substantially higher than those of younger age groups.

4.1 Future Work

There are a number of areas that could be developed to further enhance distributional analyses carried out in BenMAP. As noted at various points in the report, it would be useful to increase the scope and specificity of the data in BenMAP for carrying out distributional analyses, such as incorporating greater detail for incidence rates (e.g., race-specific mortality rates).

It would be useful to revise how BenMAP currently uses the county-level poverty status and educational attainment data. As we noted in Section 2, to estimate the fraction of the population above and below the poverty line in a specific CMAQ gridcell, BenMAP uses a (simple) spatially weighted average of the one of more counties that might overlay the gridcell. (A similar approach is used for estimating educational attainment in a gridcell.) An alternative approach could (and probably should) be based on population-weighted averages, rather than the relatively simple spatially-weighted average used in BenMAP now.

It would be also useful to add inequality measures, which summarize in a single number the degree of inequality of the distributions (i.e., how far they are from the state of perfect equality). These measures can be decomposed to account for the sources of that inequality, which would allow us to determine which population characteristics contribute to the inequality. A summary measure of distributional inequality could be useful for comparisons across alternative policy options. It would allow us to analyze these options not only in terms of effectiveness, but in terms of equality across subpopulations as well. Levy (2006)[6] proposes the Atkinson index as the most appropriate indicator for health risk analysis. Another useful measure is a Generalized Entropy indicator, which is derived from information theory. Unlike the Atkinson measure, the Generalized Entropy indicator does not have a maximum of 1 – extreme inequality. On the other hand, the decomposition for the Generalized Entropy indicator is much more straightforward as compared to the Atkinson measure.

[6] Levy, J., Chemerynski, S., and Tuchmann, J. "Incorporating Concepts of Inequality and Inequity into Health Benefits Analysis" International Journal for Equity in Health. 200, 5:2.