CHAPTER 3 | EMISSIONS AND AIR QUALITY MODELING UNCERTAINTY

3.1 INTRODUCTION

This chapter summarizes results from two quantitative sensitivity tests that characterize uncertainty in the emissions and air quality modeling steps of the second prospective analysis.

- **Sectoral emissions sensitivity analyses:** These analyses are designed to explore the relative importance of emitting sector in marginal benefits estimates, provide a sense of the shape of the marginal benefits curve around the point represented by the with-CAAA scenario emissions inventory, and explore spatial variability in benefits estimates with respect to the emitting sector. The approach adopted is to develop a standardized emissions increment for each of the five major emitting sectors (electric generating units, or EGUs; non-EGU point sources; on-road vehicles; nonroad engines; and area sources), and run the alternative scenarios through a reduced form air quality modeling tool and BenMAP to estimate changes in benefit estimates.
- **EGU sector alternative emissions model:** This analysis estimates model uncertainty for the EGU sector emissions estimation approach, using an alternative emissions estimation approach described in Appendix B of the primary emissions report, *Emission Projections for the Clean Air Act Second Section 812 Prospective Analysis*. The analysis compares the benefits estimates using the Integrated Planning Model (IPM)-based emissions outputs with comparable estimates using Continuous Emissions Monitor (CEM) data and an alternative approach to estimating counter-factual scenario emissions.

Note that, in addition to these quantitative analyses, IEc subcontractor Sonoma Technology, Inc (STI) conducted a three part literature review relating to the uncertainties in Integrated Air Quality Modeling Systems (IAQMSs). The first part of this literature review looks at the source of uncertainty and methods for quantifying these uncertainties. The second part looks at the literature relating to the evaluation and overall reliability of IAQMSs. The third part discusses the uncertainties specifically relating to the IAQM used in the Second Prospective Analysis (i.e., the Community Multiscale Air Quality, CMAQ, modeling system). This literature review can be found in its entirety in Appendix B. The literature review is part of our overall suite of uncertainty analyses that will be used to inform characterization of the costs and benefits of CAAA programs in the final project report.

3.2 DESCRIPTION OF ANALYTICAL TOOLS

The main tools used to develop these analyses are EPA's Particulate Matter Response Surface Model (PM RSM), a reduced form air quality estimation tool, and EPA's Environmental Benefits Mapping and Analysis Program (BenMAP). PM RSM estimates air quality outcomes from emissions inputs, and BenMAP estimates health effects and economic benefits outcomes from air quality inputs. The two tools are linked in our analyses to estimate the impact of uncertainties in emissions estimates.

3.2.1 RESPONSE SURFACE MODEL

The description of this tool is largely taken from EPA's *Technical Support Document for the Proposed PM NAAQS Rule: Response Surface Modeling*.[1] Response surface modeling provides a means to address the limitations of using complex air quality models for policy analysis. Air quality models such as CMAQ typically require complicated emission inputs and processing, and the resources needed to conduct model runs can be substantial. These requirements make such sophisticated models less well-suited for uncertainty analysis, where the analyst may want to conduct multiple model runs while varying key inputs or assumptions. Response surface modeling builds reduced form modeling tools by using advanced statistical techniques to characterize, in a more parsimonious manner, the relationship between the outputs of a complex model and its input parameters. The result is a more flexible, less resource intensive model of the original model (a "meta-model) that can be used as a reasonable proxy for conducting uncertainty analysis within the calibration range of the meta-model. This analysis makes use of a Particulate Matter Response Surface Model (PM RSM) developed by EPA to estimate results from the CMAQ Modeling System.

CMAQ is a three-dimensional regional grid-based air quality model designed to simulate particulate matter and ozone concentrations and deposition over large spatial scales (e.g., over the contiguous U.S.) over an extended period of time (e.g., up to a year). The CMAQ model includes state-of-the-science capabilities for conducting urban to regional scale simulations of multiple air quality issues, including tropospheric ozone, fine particles, air toxics, acid deposition, and visibility degradation. The PM RSM used in this analysis is based on air quality modeling using CMAQ version 4.4.

Response surface models are typically developed using a limited number of runs of the complex model at a set of statistically selected points in the design space. A total of 180 CMAQ model runs, meant to cover a change in baseline precursor emissions of zero to 120 percent, were conducted for development of the PM RSM. The response-surface method uses statistical techniques to relate a response variable from these runs (in this case, $PM_{2.5}$ concentration output from CMAQ) to a set of factors (in this case, $PM_{2.5}$

[1] U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Technical Support Document for the Proposed PM NAAQS Rule: Response Surface Modeling. February 2006.

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precursor pollutants from particular sources and locations). To develop a response surface approximation for CMAQ, EPA used an interpolation approach, implemented through the MIXED procedure in SAS software. The PM RSM models changes in $PM_{2.5}$ concentration at the grid cell level as a function of the weighted average of the modeled responses from the 180 CMAQ runs. Weights were assigned based on the distance between the factor levels defining the policy to be predicted and the factors defining the CMAQ experimental run.

The main purpose of the PM RSM is to demonstrate the impact on ambient $PM_{2.5}$ concentrations of reductions in $PM_{2.5}$ precursor emissions from different sources. EPA selected the precursor emission type and source combinations used as input factors into the model to provide maximum information for use in comparing relative effectiveness of different emission control strategies. Emission input factors are expressed as a percent of a 2015 baseline scenario that includes the Clean Air Interstate Rule (CAIR), Clean Air Non-Road Diesel Rule, Heavy Duty Diesel Rule, Tier 2, and the NO_x SIP Call. EPA selected the following 12 emission input factors for use in the PM RSM; users of the PM RSM can adjust these at a local or regional scale:

1) NO_x EGU – Nitrogen oxide (NO_x) emissions from Electric Generating Unit (EGU) point sources forecast using the Integrated Planning Model (IPM);
2) NO_x Non-EGU and Area – NO_x emissions from Non-EGU point sources forecast using IPM and from area sources, including agricultural sources;
3) NO_x Mobile – NO_x emissions from non-road and on-road mobile sources;
4) SO_x EGU – Sulfur oxide (SO_x) emissions from EGU point sources forecast using IPM;
5) SO_x Non-EGU – SO_x emissions from Non-EGU point sources forecast using IPM;
6) SO_x Area – SO_x emissions from area sources, including agricultural sources, and from non-road and on-road mobile sources[2];
7) NH_3 Area – Ammonia (NH_3) emissions from area source, including agricultural sources;
8) NH_3 Mobile – Ammonia emissions from non-road and on-road mobile sources;
9) POC/PEC Point – Particulate organic carbon (POC) and Particulate elemental carbon (PEC) emissions from EGU and Non-EGU point sources forecast using IPM;

[2] When it was developed by EPA this factor included only area-source emissions and mobile-source SO_x emissions were not included as an emission input factor in the model. Feeling that these emissions were significant, the Project Team elected to include them as part of this factor rather than leave them out of the model.

10) POC/PEC Mobile – POC and PEC emissions from non-road and on-road mobile sources;

11) POC/PEC Area – POC and PEC emissions from area sources, including agricultural sources; and

12) VOC All – Volatile organic carbon (VOC) emissions from EGU point sources, non-EGU point sources, area sources including agricultural sources, non-road and on-road mobile sources.

The PM RSM includes an independent response surface for particular urban areas, as well as a generalized response surface for all other locations. A rigorous area-of-influence analysis was conducted for selection of PM RSM urban locations to discern the degree of overlap between different urban areas in terms of air quality impacts, and to tease out local versus regional impacts. The analysis concluded that ambient $PM_{2.5}$ in each of the nine selected urban areas is largely independent of the precursor emissions in all other included urban areas. The nine selected urban areas are New York/Philadelphia (combined), Chicago, Atlanta, Dallas, San Joaquin, Salt Lake City, Phoenix, Seattle, and Denver.

Potential limitations of the PM RSM are that:

- The PM RSM is designed to estimate $PM_{2.5}$ concentrations resulting from changes in precursor emissions between zero and 120 percent of 2015 baseline emission levels. The model has not been validated for accuracy outside of these bounds. The overall second prospective analysis does in many cases look at changes in precursor emission greater than 120 percent. The Project Team limits changes to 500 percent of the baseline to avoid straying too far outside the calibrated bounds of the PM RSM. The 500 percent limitation was developed based on Project Team analysis of results and inspection of the marginal response curves for PM outcomes relative to each of the twelve emissions inputs.

- The PM RSM is only capable of dealing with geographical differentiation of emission policies within the nine local areas. In general, our analysis is focused on National-level emissions policy, but the emissions changes are not uniform at the county-level resolution of our emissions inventories. Our sectoral emissions sensitivity analyses therefore focus on relative comparisons of uniform emissions changes, rather than absolute differences in PM RSM outcomes.

One result of these limitations is that core scenario air quality and benefit results are very different for PM RSM and CMAQ. For the same 2010 emissions scenarios, PM RSM results yield an estimated 31,000 avoided premature mortalities, while CMAQ results yield 102,000, a difference of more than three-fold. This large discrepancy in results is the main reason that our analyses focus mainly on relative comparisons of PM RSM runs, rather than hypotheses that depend on absolute air quality or benefits outcomes.

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3.2.2 BENMAP

EPA's BenMAP benefits modeling tool generates national-level estimates of avoided health effects due to changes in $PM_{2.5}$ between a baseline scenario (i.e., air pollution levels in the absence of control regulations) and a control scenario (i.e., air pollution levels after a control regulation is put into place). BenMAP applies health impact functions relating the change in $PM_{2.5}$ concentration to the change in the incidence of a health endpoint, taking into consideration the baseline incidence rate of the health endpoint and the exposed population in the target year of the analysis. BenMAP then applies valuation functions to estimate the economic benefits of the changes in the incidence of the health effect.

The $PM_{2.5}$ concentration output from CMAQ and PM RSM was used as input for BenMAP to generate health impacts and associated economic values for each emissions and air quality modeling scenario. Exhibit 3-1 presents the 27 BenMAP runs undertaken for this analysis grouped by scenario type. The PM RSM and/or CMAQ output for each scenario was converted into air quality grids that could be uploaded into BenMAP. Exhibit 3-1 also shows which scenario was used for the baseline and control scenarios in BenMAP. The Project Team then ran BenMAP using incidence and pooling/aggregation configuration files patterned after those used in the PM NAAQS Regulatory Impact Analysis (RIA).[3] However, we did not incorporate a population-level threshold in the $PM_{2.5}$ mortality impact functions from the Pope et al., 2002 and Laden et al., 2006 studies, as was done in that analysis.[4,5]

3.3 METHODS FOR QUANTITATIVE EMISSIONS UNCERTAINTY ANALYSES

The Project Team quantitatively analyzed uncertainty related to emissions by running various emissions scenarios through PM RSM and BenMAP and analyzing the results. We grouped these into three categories:

- Core scenarios – with- and without-CAAA scenarios for the three target years (2000, 2010, and 2020). These were essentially "control runs" to examine how PM RSM performed relative to the CMAQ.
- Sector-specific emission scenarios – these scenarios were developed in an attempt to estimate changes in $PM_{2.5}$ concentration and corresponding health benefits associated with small incremental changes in sector-specific emissions.

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[3] U.S. Environmental Protection Agency. (2006). *Final Regulatory Impact Analysis: PM2.5 NAAQS. Office of Air and Radiation*, Research Triangle Park, NC.

[4] Pope, C. A., R. T. Burnett, et al. (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *Journal of the American Medical Association* 287(9): 1132-1141.

[5] Laden, F., J. Schwartz, et al. (2006). Reduction in Fine Particulate Air Pollution and Mortality: Extended Follow-up of the Harvard Six Cities Study. *American Journal of Respiratory and Critical Care Medicine* 173: 667-672.

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- Alternative EGU emission scenarios – these scenarios assess model uncertainty by evaluating benefits results for an alternative method of estimating EGU emissions.

We describe each of these scenario categories in more detail below.

EXHIBIT 3-1 BENMAP RUNS FOR THE 812 UNCERTAINTY ANALYSIS

BENMAP SCENARIO	AIR QUALITY MODEL USED	BASELINE SCENARIO	CONTROL SCENARIO
CORE SCENARIOS			
2000	CMAQ and PM RSM	2000 without CAAA	2000 with CAAA
2010	CMAQ and PM RSM	2010 without CAAA	2010 with CAAA
2020	CMAQ and PM RSM	2020 without CAAA	2020 with CAAA
ALTERNATIVE EGU SCENARIOS			
2000 Alt EGU	PM RSM	2000 Ellerman Counterfactual	2000 CEM data
SECTOR-SPECIFIC EMISSION SCENARIOS			
2010 EGU hi	PM RSM	2010 with CAAA	2010 with CAAA, EGU hi
2010 Non-EGU hi	PM RSM	2010 with CAAA	2010 with CAAA, Non-EGU hi
2010 Area hi	PM RSM	2010 with CAAA	2010 with CAAA, Area hi
2010 On-Road hi	PM RSM	2010 with CAAA	2010 with CAAA, On-Road hi
2010 Non-Road hi	PM RSM	2010 with CAAA	2010 with CAAA, Non-Road hi
2010 EGU lo	PM RSM	2010 with CAAA	2010 with CAAA, EGU lo
2010 Non-EGU lo	PM RSM	2010 with CAAA	2010 with CAAA, Non-EGU lo
2010 Area lo	PM RSM	2010 with CAAA	2010 with CAAA, Area lo
2010 On-Road lo	PM RSM	2010 with CAAA	2010 with CAAA, On-Road lo
2010 Non-Road lo	PM RSM	2010 with CAAA	2010 with CAAA, Non-Road lo
2020 EGU hi	PM RSM	2020 with CAAA	2020 with CAAA, EGU hi
2020 Non-EGU hi	PM RSM	2020 with CAAA	2020 with CAAA, Non-EGU hi
2020 Area hi	PM RSM	2020 with CAAA	2020 with CAAA, Area hi
2020 On-Road hi	PM RSM	2020 with CAAA	2020 with CAAA, On-Road hi
2020 Non-Road hi	PM RSM	2020 with CAAA	2020 with CAAA, Non-Road hi
2020 EGU lo	PM RSM	2020 with CAAA	2020 with CAAA, EGU lo
2020 Non-EGU lo	PM RSM	2020 with CAAA	2020 with CAAA, Non-EGU lo
2020 Area lo	PM RSM	2020 with CAAA	2020 with CAAA, Area lo
2020 On-Road lo	PM RSM	2020 with CAAA	2020 with CAAA, On-Road lo
2020 Non-Road lo	PM RSM	2020 with CAAA	2020 with CAAA, Non-Road lo

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3.3.1 CORE SCENARIOS

The Project Team generated six “core scenarios” representing the ambient $PM_{2.5}$ concentrations in three target years (2000, 2010, and 2020) under each of two scenarios (a “with-CAAA” scenario and a “without-CAAA” scenario). The with-CAAA scenarios rely on emissions input data that reflects expected or likely future measures implemented since the 1990 CAAA. The counterfactual without-CAAA scenarios utilize emission input data that is derived by freezing the scope and stringency of emissions controls at their 1990 levels, while allowing for growth in population and economic activity. The core scenarios were also run through CMAQ and provide a base from which to compare the other scenarios used to gauge emission uncertainty. The CMAQ results provide the basis for the primary benefits estimates generated for the study. Because the PM RSM is much simpler to run, we use the PM RSM runs to evaluate a much broader range of alternative emissions outcomes.[6]

3.3.2 SECTOR-SPECIFIC EMISSION SCENARIOS

The sector scenarios attempt to estimate changes in $PM_{2.5}$ concentration and corresponding health benefits associated with small incremental changes in sector-specific emissions both above and below the emissions estimates used in the 2010 and 2020 core with-CAAA scenarios. It was difficult to select a fixed amount to increase or decrease emissions within each sector because emission levels and pollutant mix vary greatly over the five emitting sectors. For example, 2010 SO_x emissions from non-road sources equal approximately 16,900 tons, while SO_x emissions from EGU sources equal approximately 6,370,000 tons. Because of this variation, incremental changes were determined as a percentage of sector-specific emissions.

The Project Team determined that increasing/decreasing sector-specific emissions by ten percent results in changes large enough to impact $PM_{2.5}$ concentrations for all sectors, yet small enough to be considered incremental. The Project Team also determined that changes in precursor emissions should be limited to five times the 2015 baseline emission levels (i.e., limited factors to a value of five).[7] As is described above, the PM RSM is designed to cover changes in the baseline precursor emissions between zero and 120 percent. EPA has not validated the model for changes outside these bounds and the Project Team has found that changes above 500 percent may lead to unexpected results.

After determining how to calculate the incremental change, it was necessary to determine how to distribute the change over the local (Atlanta, Chicago, NYC/Philadelphia, Dallas, Denver, Salt Lake City, Phoenix, San Joaquin, and Seattle) and regional (East and West) PM RSM domains. The most straightforward manner in which to distribute the incremental change is based on a local area or region's share of the total sector-specific emissions. For example, if the Atlanta area has 25 percent of the SOx EGU emissions in 2010, then 25 percent of the incremental change in SOx EGU emissions was applied to the Atlanta area.

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[6] Note that the PM RSM was originally calibrated to CMAQ, but for a more limited range of emissions inputs than we ultimately need for the core comparison of the with-CAAA and without-CAAA scenario. As a result, it remains limited in its ability to assess the emissions changes implied by the without-CAAA core scenarios, because the absolute emissions in those scenarios are outside the range of calibration for the tool. As a result, in this chapter we rely on PM RSM only for those scenarios that most closely match its range of calibration.

[7] The Project Team initially analyzed scenarios that increased/decreased sector-specific emissions by 25 percent and limited emission input factor levels to ten times the 2015 baseline level (i.e., limited factors to a value of ten). After conducting this analysis, we determined that a smaller percentage change could be used and that, in some cases, factors above five lead to unexpected results.

Applying the ten percent incremental change both above and below the emissions estimates used in the 2010 and 2020 core with-CAAA scenarios resulted in 20 sector scenario PM RSM runs (five sectors per scenario per year). Exhibit 3-2 provides the resulting emissions changes for pollutant/sector combinations used to develop PM RSM inputs.

EXHIBIT 3-2 10 PERCENT CHANGE IN PRECURSOR EMISSIONS FROM WITH-CAAA SCENARIO EMISSIONS LEVELS (TONS)

SCENARIO	VOC	NO_X	SO_2	NH_3	POC AND PEC	TOTAL
2010						
EGU	4,266	243,722	636,546	82	3,096	890,809
NonEGU	143,550	224,660	217,706	17,392	4,078	611,462
Area	887,228	368,831	187,765	371,317	86,673	1,988,486
OnRoad	261,401	434,906	2,995	33,442	8,236	749,216
NonRoad	187,472	164,341	1,693	204	14,132	381,974
2020						
EGU	4,699	198,646	427,013	56	4,313	639,040
NonEGU	164,756	250,903	238,732	20,163	4,661	683,877
Area	971,557	372,498	194,175	398,677	88,595	2,114,096
OnRoad	167,062	191,584	3,646	39,532	5,732	413,288
NonRoad	148,964	99,892	275	240	9,164	267,698

3.3.3 ALTERNATIVE EGU EMISSION SCENARIOS

In response to differences between the spatial distribution of emissions as modeled by IPM and the actual spatial distribution from continuous emissions monitor (CEM) data, and differences in modeled versus actual fuel and allowance prices for the historical (with-CAAA) case, the Project Team has developed an alternative approach for modeling the effect of the CAAA on the EGU sector in the year 2000. The Project Team generated EGU point source emissions data for the with-CAAA scenario using continuous CEM data available on EPA's Clean Air Markets website.[8] We estimated EGU data for the without-CAAA scenario using an alternative counterfactual approach based on work done by Dr. A. Denny Ellerman of Massachusetts Institute of Technology.[9] The data for all other emission sources (non-EGU, on-road, non-road, and area) were held constant at levels consistent with the with-CAAA 2000 core scenario level.

[8] U.S. Environmental Protection Agency. Clean Air Markets – Data and Maps <http://camddataandmaps.epa.gov/gdm/> Accessed March 2009.

[9] Dr. A. Denny Ellerman's approach relies on multiplying a "baseline" pre-Title IV emissions rate by 2001 CEM heat input observations for each electric generating unit.

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3.4 RESULTS

3.4.1 CORE SCENARIOS

Exhibit 3-3 depicts the PM RSM results for each of the core scenarios. The core scenario PM RSM results are presented here mainly for context, because the results of the with-CAAA scenario are used as a baseline in evaluating the marginal effect of changes in emissions from major emitting sectors.

The PM RSM results match the general trends in the emissions inputs, as follows:

1. As expected, for each year in the analysis the without-CAAA scenario has higher $PM_{2.5}$ concentrations than the with-CAAA scenario.
2. Overall and on average $PM_{2.5}$ concentrations gradually decrease over time for the with-CAAA scenarios and the without-CAAA scenarios.
3. Over time, the gap between $PM_{2.5}$ concentrations in the with-CAAA and without-CAAA scenario widens.

The PM RSM results also provide a reasonable approximation of the results based on CMAQ, a much more complex and highly resolved model. There are nonetheless some important differences in the PM RSM and CMAQ results, as illustrated in Exhibit 3-4 for the target year 2010.[10] First, the PM RSM with-CAAA results indicate higher PM concentrations than CMAQ. This suggests that PM RSM may be somewhat less responsive to input changes than CMAQ, at least for our scenario. Second, PM RSM shows lower PM concentrations in the East, and higher concentrations in the West, particularly California, than CMAQ. This may be attributable to PM RSM's more limited ability to reflect complex interactive effects among pollutants, which could be important in the East where SO_x is affected by the ammonium levels, and in the West where precursors contribute to high levels of both PM and ozone (the PM RSM does not simulate ozone formation). Third, although differences between the two scenarios are not presented in Exhibit 3-4, the impact of the first two factors is that CMAQ estimates a much greater impact of the CAAA on air quality differences.

These factors suggestion caution is warranted in drawing conclusions based on the PM RSM estimates. We believe that comparisons of PM RSM runs provide insights into the marginal effect of emissions, and relative effect among emitting sectors, but also that PM RSM in general is likely to be less sensitive to emissions changes. As a result, the results we present in this chapter likely understate the absolute value of emissions differences among scenarios.

[10] The CMAQ results presented in Exhibit 3-4 reflect the impact of the MATS calibration procedure.

EXHIBIT 3-3 CORE SCENARIO PM RSM RESULTS FOR 2000, 2010, AND 2020

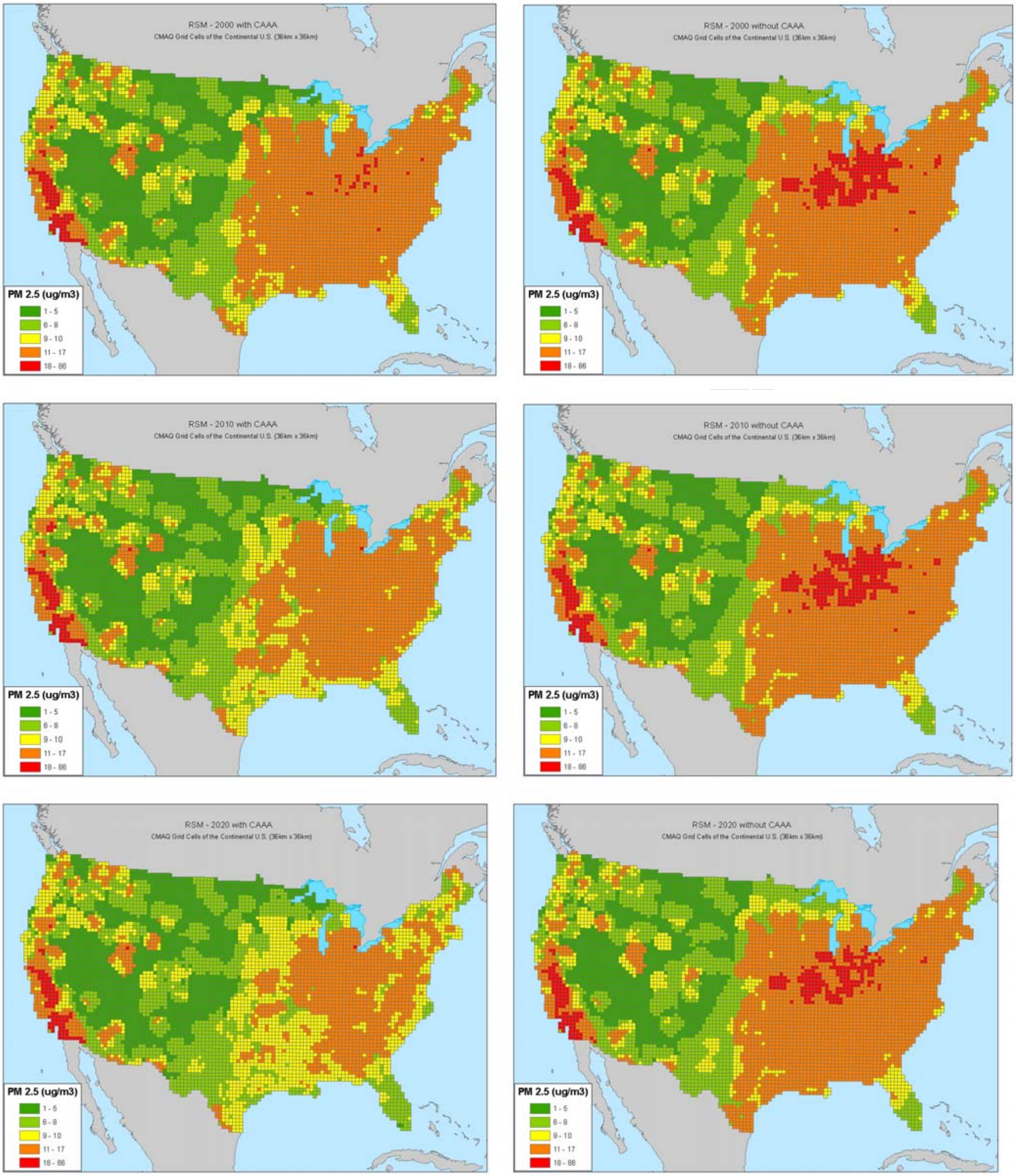
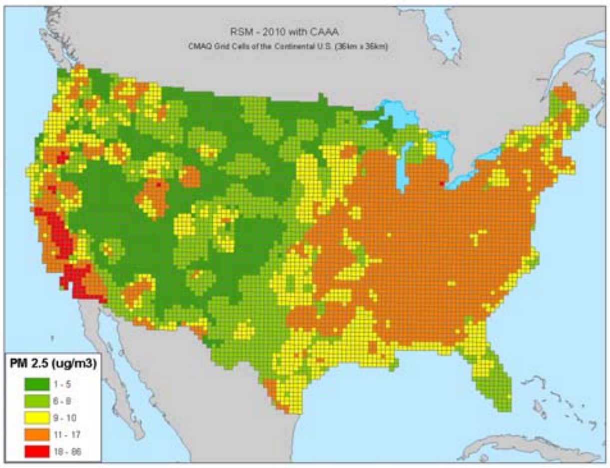
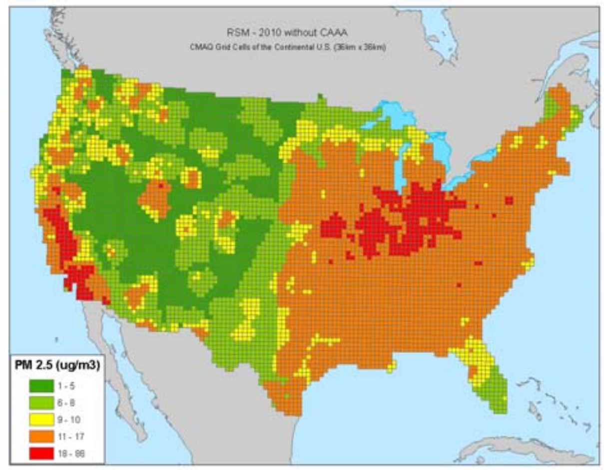


EXHIBIT 3-4 2010 PM RSM AND CMAQ RESULTS

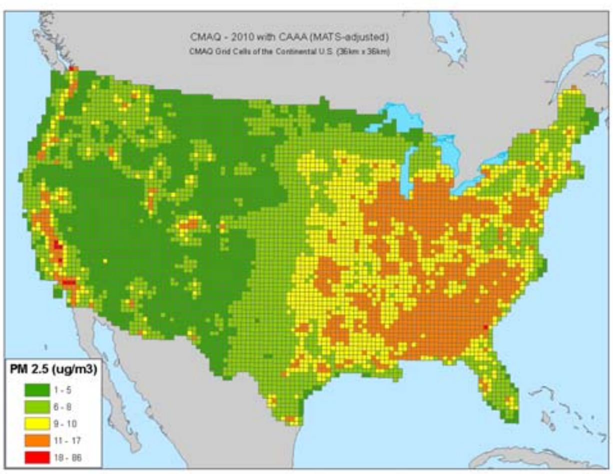
2010 with CAAA **2010 without CAAA**

PM RSM





CMAQ



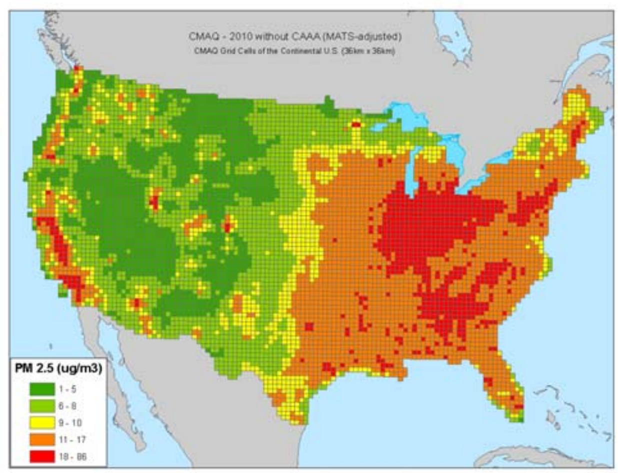


EXHIBIT 3-5 PM BENEFITS OF CAAA DERIVED USING RSM OUTPUT

ENDPOINT GROUP	INCIDENCE			VALUATION (MILLION 2006$)		
	PERCENTILE 5	MEAN	PERCENTILE 95	PERCENTILE 5	MEAN	PERCENTILE 95
2000						
Mortality – Pope et al., 2002	4,540	12,300	20,100	$32,700	$83,100	$141,000
			Total	$34,200	$89,200	$158,000
2010						
Mortality – Pope et al., 2002	11,600	31,300	51,000	$89,100	$225,000	$380,000
			Total	$93,100	$241,000	$426,000
2020						
Mortality – Pope et al., 2002	12,500	38,900	65,100	$109,000	$303,000	$525,000
			Total	$114,000	$324,000	$587,000

Notes:

1. Results are rounded to three significant figures.
2. The valuation totals represent low, central, and high estimates. The low and high estimates were calculated by taking the sum of the 5th and 95th percentiles of the valuation estimates for each health endpoint. An alternative would be to calculate actual percentiles for the aggregated valuation estimates, but this is not what is presented here.
3. 20-year distributed lag and five percent discount rate applied to mortality results.

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We generated benefits results for the PM RSM core scenarios as well, using PM RSM air quality outputs as BenMAP inputs. The summary results are illustrated in Exhibit 3-5. As expected, mortality benefits dominate the health benefit results. In addition, health benefits of the CAAA increase over time. This result is consistent with the increasing gap in $PM_{2.5}$ concentrations observed in the PM RSM results. Also consistent with the PM RSM results is the fact that there is a large increase in the number of avoided deaths (as well as other health benefits) between 2000 and 2010, but only a moderate increase between 2010 and 2020. Overall and on average the difference between $PM_{2.5}$ concentrations in the with- and without-CAAA scenarios also increases steeply between 2000 and 2010, but only moderately between 2010 and 2020. Comparing these PM RSM results to CMAQ results in Chapter 2 of the Benefits report, however, it is clear that PM RSM estimates much smaller benefits of the CAAA than CMAQ for the same emissions scenarios. This result provides further reason for interpreting the absolute PM RSM results with caution.

3.4.2 SECTOR-SPECIFIC EMISSION SCENARIOS

Exhibit 3-6 depicts the difference in $PM_{2.5}$ concentrations between each of the 10 sector scenarios for 2020 and the corresponding core with-CAAA scenario. Difference maps are used to depict these results because the differences in actual $PM_{2.5}$ concentrations over the scenarios are not noticeable on a map. In this exhibit, shades of green indicate that $PM_{2.5}$ concentrations are lower in the sector scenario than in the corresponding core scenario and shades of yellow, orange, and red indicate that $PM_{2.5}$ concentrations are higher in the sector scenario than in the corresponding core scenario.

These maps indicate that increasing/decreasing EGU and Area emissions seem to have the greatest impact on $PM_{2.5}$ concentrations. These results are not surprising because the overall level of Area- and EGU-specific emissions are higher than the other sector-specific emissions (Non-EGU, On-Road, and Non-Road) and thus a ten percent change will necessarily lead to greater impacts.

Exhibit 3-7 provides the mean incidence and valuation results for sector-specific emission increases and decreases in 2010 and 2020. The full BenMAP incidence and valuation summary reports for the sector-specific emission scenarios are included in Appendix B. The BenMAP results are in line with the PM RSM results in that increases in Area- and EGU-specific emissions lead to the greatest damages, while conversely, decreases in these sector-specific emissions lead to the greatest benefits, consistent with the overall greater level of Area- and EGU-specific emissions. Damages and benefits are of approximately the same scale of magnitude, but differ across years and sector in a curious pattern. In 2010, the EGU and non-EGU sectors show very close agreement between damages and benefits, but in the non-road, onroad, and area source sectors, decreases in emissions yield larger benefits than the comparable increase in emissions yields damages. This might suggest that, at the margin in 2010, there is an increasing marginal benefit curve for additional reductions for these three sectors. By 2020, all the sectors except for area sources emissions show close agreement between damages from a 10 percent increase and benefits from a 10 percent decrease, which may suggest that the marginal benefits curve for most sectors is flat, but for area sources remains upward sloping.

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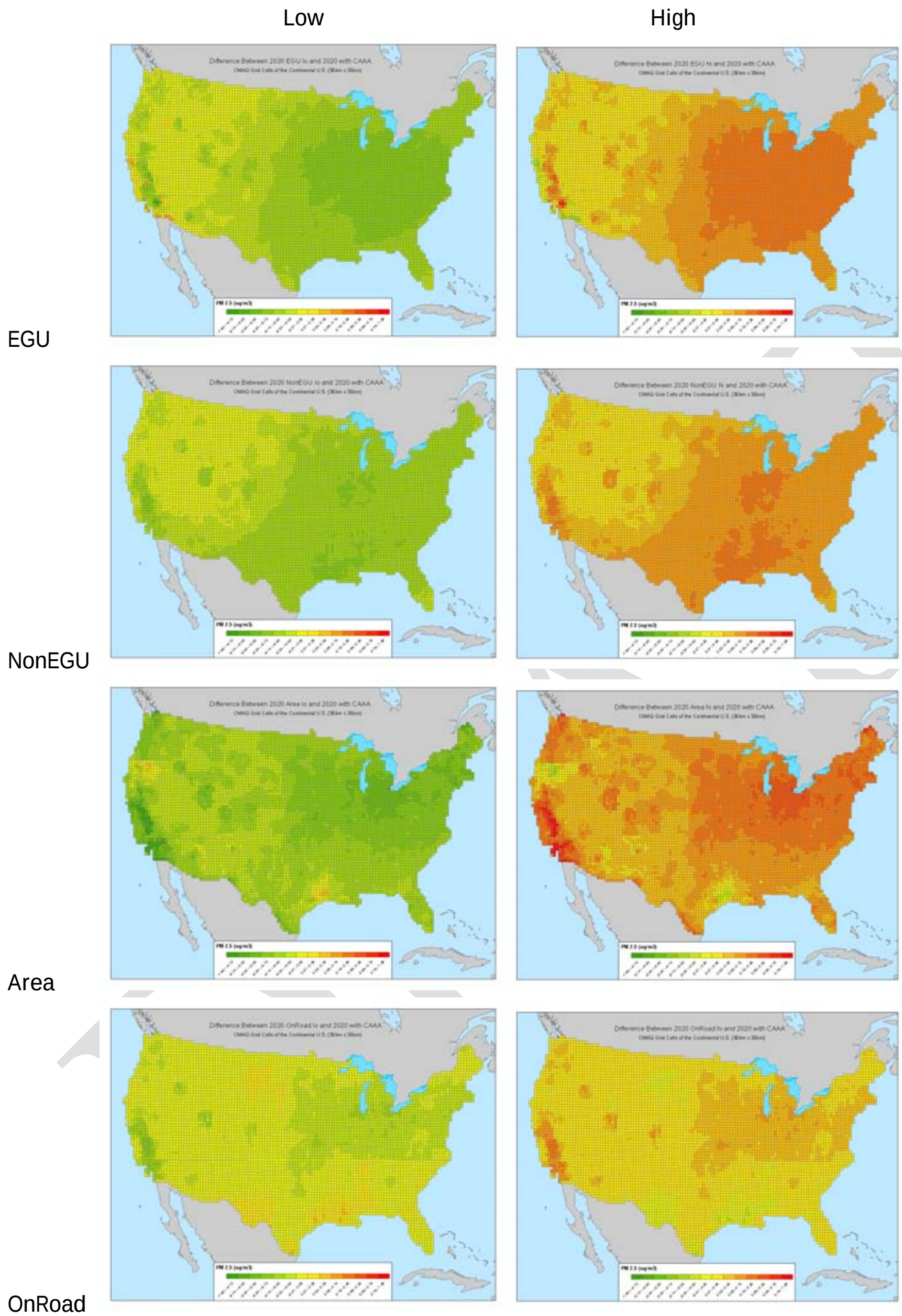
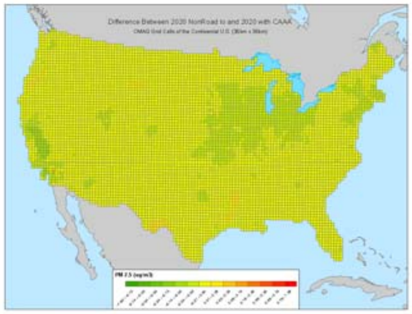
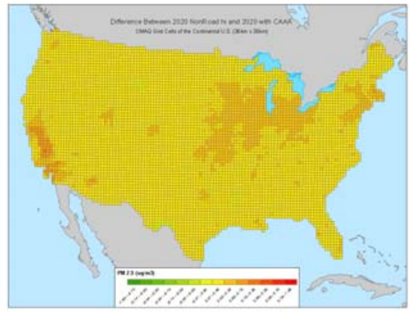
EXHIBIT 3-6 2020 SECTOR-SPECIFIC EMISSION SCENARIO DIFFERENCE MAPS




Difference Between 2020 NonRoad lo and 2020 with CAAA


Difference Between 2020 NonRoad hi and 2020 with CAAA

NonRoad

EXHIBIT 3-7 MEAN DAMAGES/BENEFITS ARISING FROM A 10% INCREASE/DECREASE IN SECTOR-SPECIFIC EMISSIONS

ENDPOINT GROUP	EGU		NON-ROAD		ON-ROAD		NON-EGU		AREA	
	INCIDENCE	VALUATION (MIL 2006$)	INCIDENCE	VALUATION (MIL 2006$)	INCIDENCE	VALUATION (MIL 2006$)	INCIDENCE	VALUATION (MIL 2006$)	INCIDENCE	VALUATION (MIL 2006$)
2010 - INCREASE										
Mortality – Pope et al., 2002	-2,860	-$19,400	-472	-$3,150	-648	-$4,380	-1,110	-$7,490	-4,050	-$27,200
Total	--	-$20,900	--	-$3,400	--	-$4,740	--	-$8,040	--	-$29,400
2010 - DECREASE										
Mortality – Pope et al., 2002	2,800	$20,200	450	$3,230	688	$4,970	1,170	$8,500	4,300	$31,100
Total	--	$21,600	--	$3,470	--	$5,350	--	$9,080	--	$33,400
2020 - INCREASE										
Mortality – Pope et al., 2002	-2,420	-$18,800	-388	-$3,000	-554	-$4,320	-1,570	-$12,200	-4,610	-$35,900
Total	--	-$20,100	--	-$3,210	--	-$4,640	--	-$13,000	--	-$38,500
2020 - DECREASE										
Mortality – Pope et al., 2002	2,310	$18,100	343	$2,650	557	$4,350	1,480	$11,600	5,050	$39,300
Total	--	$19,300	--	$2,840	--	$4,670	--	$12,300	--	$41,100

Notes:

1. Results are rounded to three significant figures.
2. The valuation totals represent low, central, and high estimates. The low and high estimates were calculated by taking the sum of the 5th and 95th percentiles of the valuation estimates for each health endpoint. An alternative would be to calculate actual percentiles for the aggregated valuation estimates, but this is not what is presented here.
3. 20-year distributed lag and five percent discount rate applied to mortality results.
4. Negative values reflect damages relative to the baseline and are the result of higher PM 2.5 ambient air quality concentrations in the control scenario than in the baseline. Control scenarios with lower concentrations than the baseline yield positive benefits.

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In order to better compare the relative damages/benefits associated with changes in sector-specific emissions the Project Team calculated dollar per ton values. The methodology used to calculate dollar per ton values is similar to that used in the Ozone Regulatory Impact Analysis to calculate benefit per-ton metrics that were used as the basis for estimating the $PM_{2.5}$ co-benefits.[11] After benefits/damaged were calculated using BenMAP, the Project Team divided these monetized values by the total precursor emission reductions/increases for each scenario.

Exhibit 3-8a presents a graph of the dollar per ton benefits associated with a 10 percent change in sector-specific emissions for 2010; Exhibit 3-8b shows comparable results for 2020. Overall, dollar per ton benefits are greater in 2020 than 2010. This means that further reducing emissions yields a greater benefit per ton in 2020 than 2010. Conversely, increasing emissions in 2020 leads to greater damages per ton than increasing emissions in 2010. In both 2010 and 2020 decreasing EGU-specific emissions has the highest dollar per ton value, followed by Area-specific and then Non-EGU specific. In 2010, decreasing Non-road-specific emissions has a higher dollar per ton value than on-road-specific, but the opposite is true in 2020.

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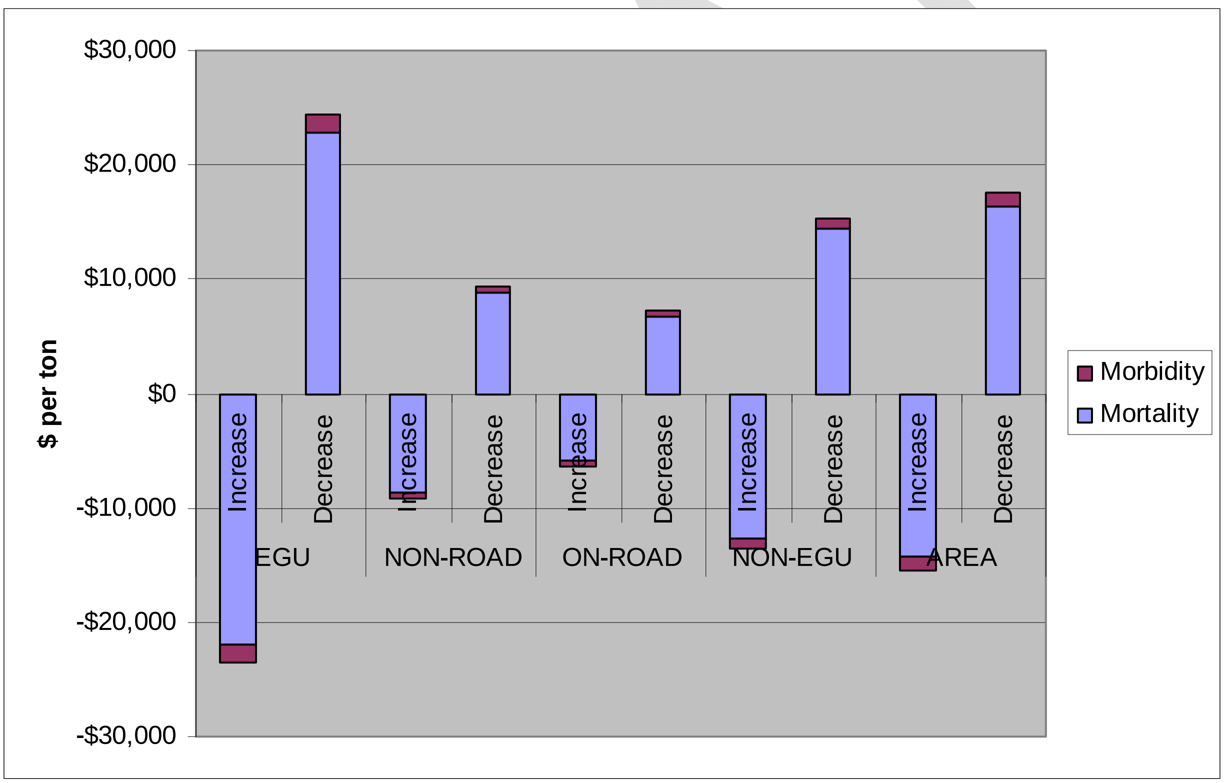
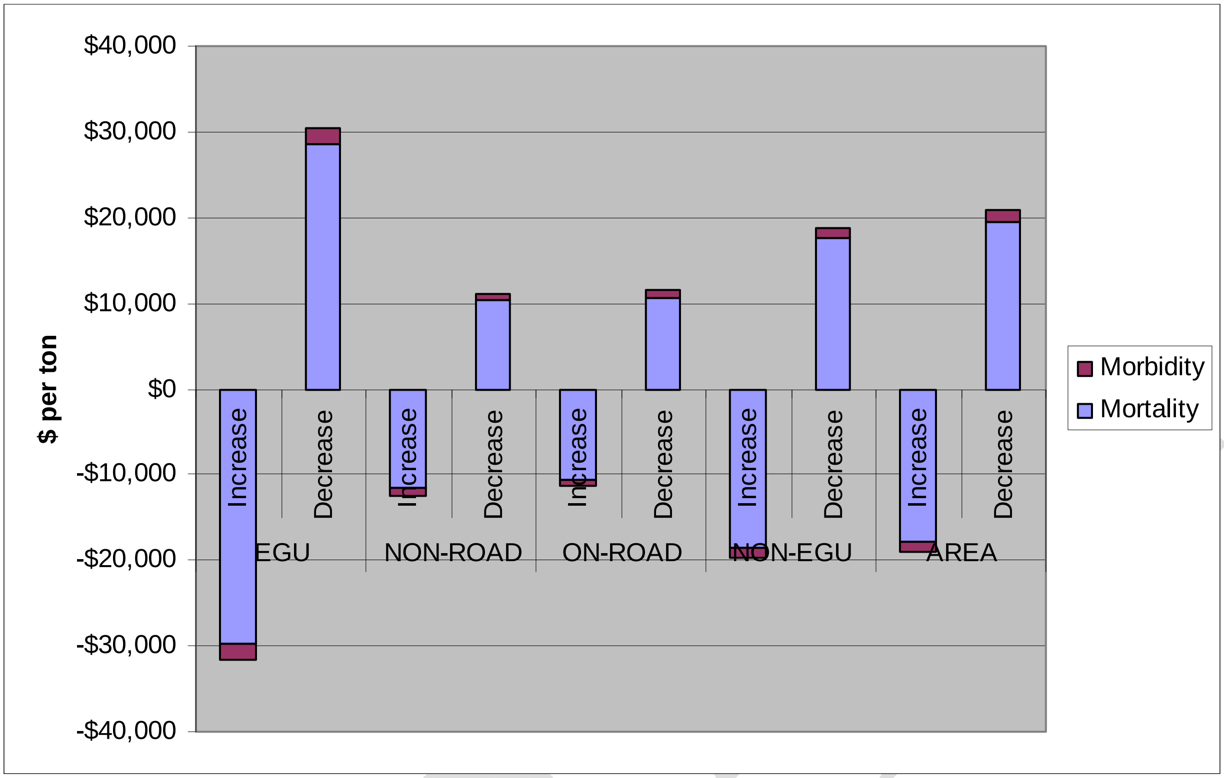
EXHIBIT 3-8A MEAN DOLLAR PER TON DAMAGES/BENEFITS ARISING FROM A 10% INCREASE/DECREASE IN SECTOR SPECIFIC EMISSIONS IN 2010



[11] U.S. Environmental Protection Agency. Technical Support Document: Calculating Benefit Per-ton Estimates. Final Ozone Regulatory Impact Analysis.

EXHIBIT 3-8B MEAN DOLLAR PER TON DAMAGES/BENEFITS ARISING FROM A 10% INCREASE/DECREASE IN SECTOR SPECIFIC EMISSIONS IN 2020

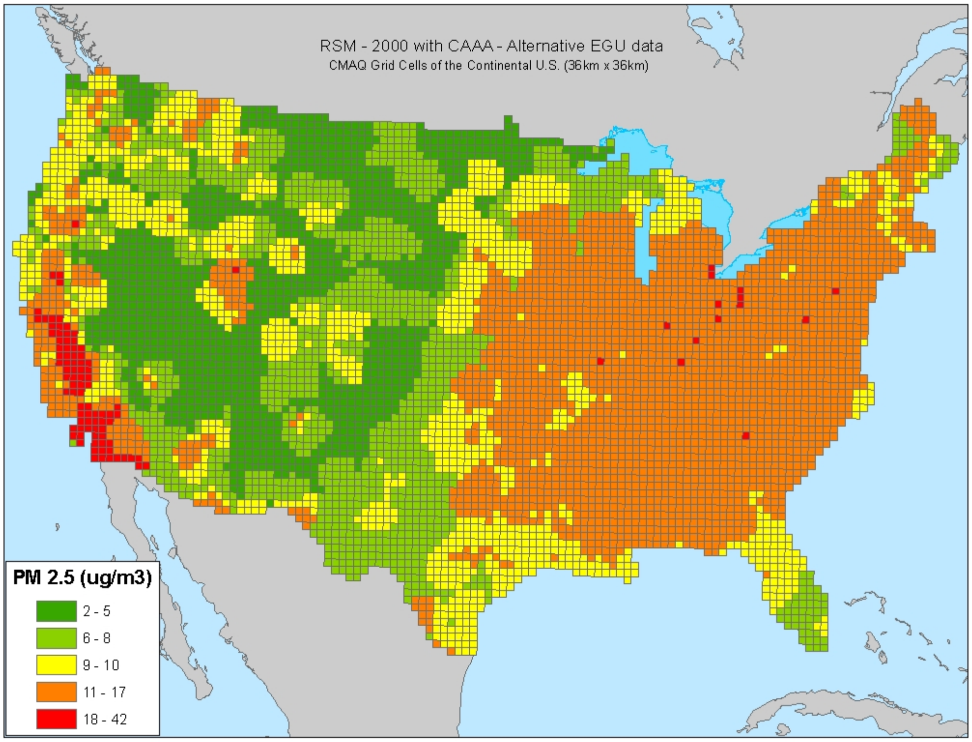


3.4.3 ALTERNATIVE EGU EMISSION SCENARIOS

Exhibit 3-9 depicts the PM RSM results for the 2000 alternative EGU scenarios, and Exhibit 3-10 shows the differences in PM RSM estimated air quality between the primary and alternative EGU emissions estimation methods. The results in Exhibit 3-9 using the alternative EGU data appear very similar to the results using the IPM EGU data, but the difference maps indicate that overall and on average $PM_{2.5}$ concentrations are slightly lower using the CEM data for the with-CAAA scenario in 2000, and slightly higher using the data derived using the Ellerman counterfactual method for the without-CAAA scenario compared to the corresponding core scenarios.

These results carry over into the benefits calculations. Exhibit 3-11 provides summary BenMAP results for the alternative EGU scenarios, and provides a comparison of the mean BenMAP incidence and valuation results for the 2000 core scenario and the 2000 scenario using the alternative EGU data. This exhibit shows that the health benefits of the CAAA in 2000 arrived at using the alternative EGU emissions are approximately 50 percent greater than the benefits in the 2000 core scenario. This result is consistent with the PM RSM results.

EXHIBIT 3-9 ALTERNATIVE EGU EMISSION SCENARIOS PM RSM RESULTS



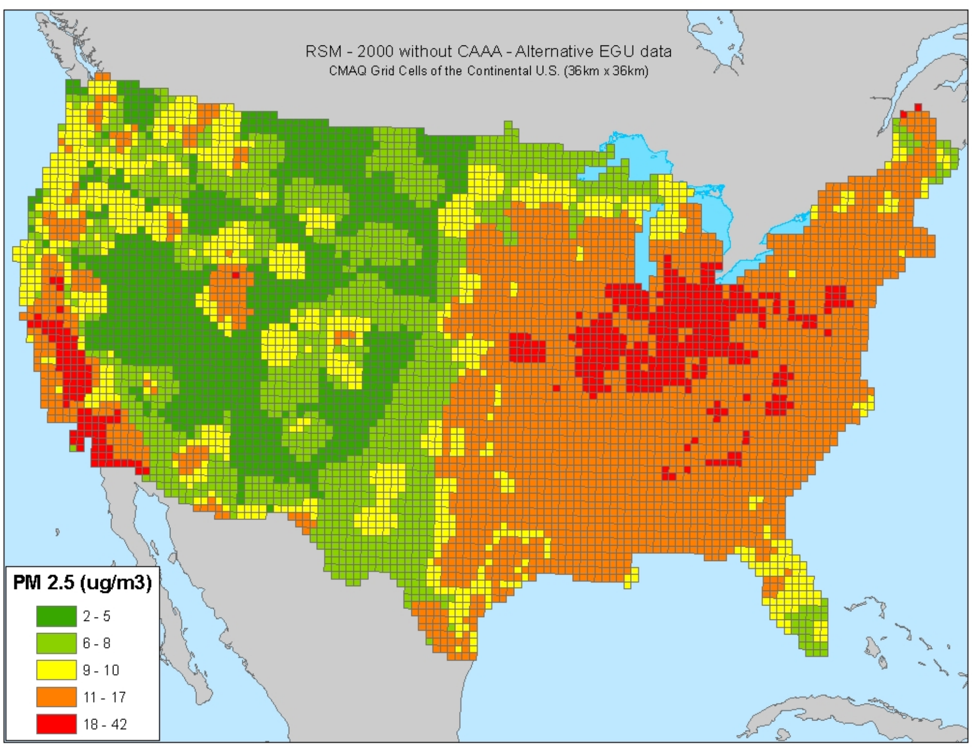
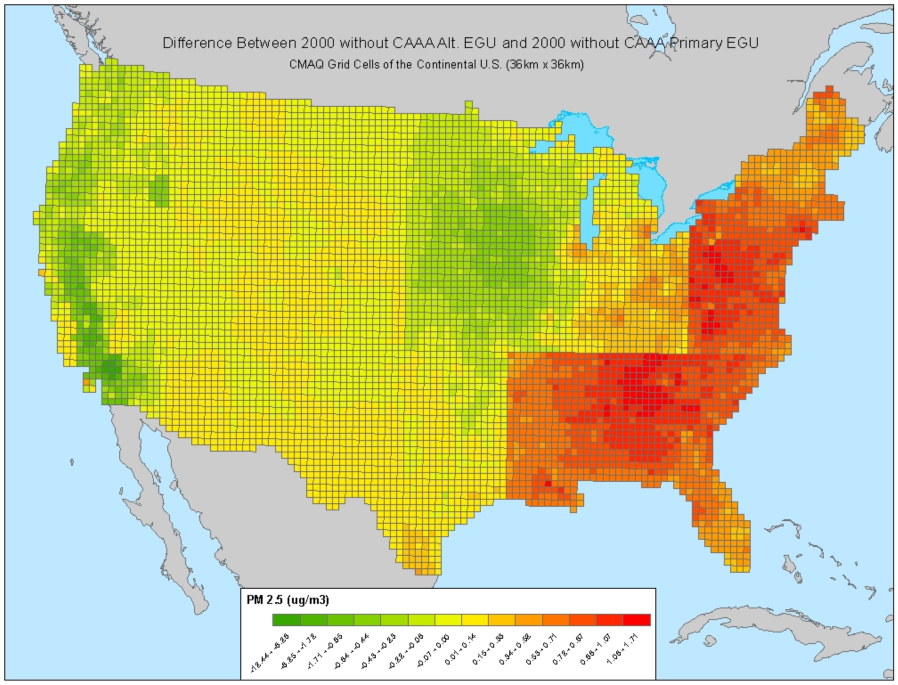


EXHIBIT 3-10 DIFFERENCE BETWEEN ALTERNATIVE EGU AND PRIMARY EGU RSM REULTS



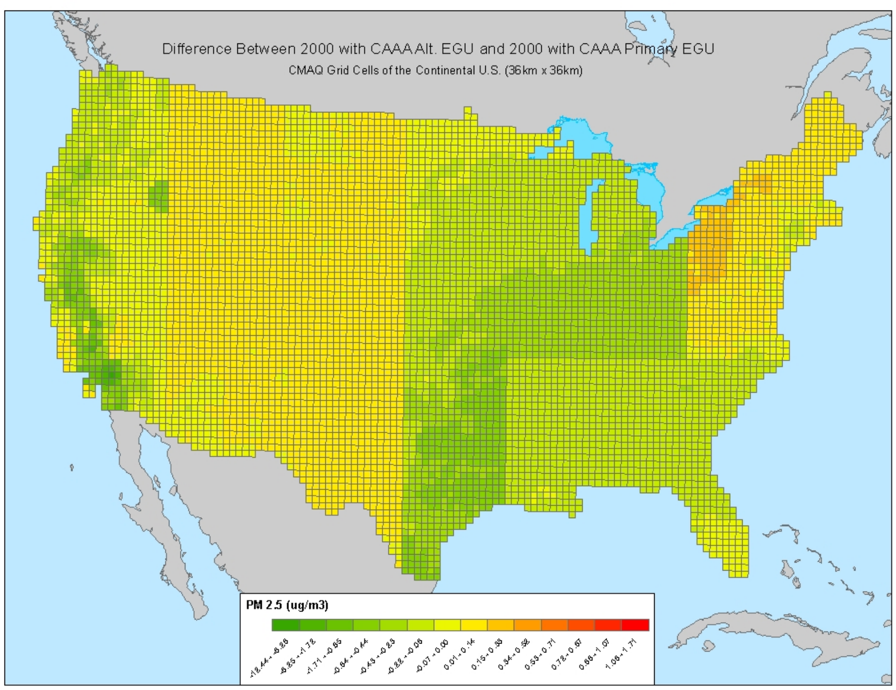


EXHIBIT 3-11 COMPARISON OF MEAN VALUES FOR 2000 CORE AND ALTERNATIVE EGU SCENARIOS

ENDPOINT GROUP	2000 CORE SCENARIO		2000 ALTERNATIVE EGU SCENARIO		PERCENT DIFFERENCE
	INCIDENCE	VALUATION (MIL 2006$)	INCIDENCE	VALUATION (MIL 2006$)	VALUATION
Mortality – Pope et al., 2002	12,300	$83,100	18,600	$125,000	50.4%
Infant Mortality – Woodruff et al, 1997	33	$252	48	$368	46.0%
Chronic Bronchitis	7,250	$2,990	10,700	$4,410	47.5%
Nonfatal Myocardial Infarction	17,400	$1,780	25,900	$2,650	48.9%
Hospital Admissions, Respiratory	2,770	$38.6	4,210	$58.7	52.1%
Hospital Admissions, Cardiovascular	5,340	$153	8,200	$238	55.6%
Emergency Room Visits, Respiratory	13,000	$4.79	19,300	$7.12	48.6%
Acute Bronchitis	21,200	$9.23	30,200	$13.1	41.9%
Lower Respiratory Symptoms	255,000	$4.69	365,000	$6.70	42.9%
Upper Respiratory Symptoms	196,000	$6.01	282,000	$8.63	43.6%
Asthma Exacerbation	230,000	$11.8	330,000	$16.9	43.2%
Minor Restricted Activity Days	9,420,000	$557	13,900,000	$820	47.2%
Work Loss Days	1,620,000	$244	2,380,000	$359	47.1%
TOTAL		**$89,200**		**$134,000**	**50.2%**

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3.5 DISCUSSION

The sector scenario results suggest the following broad conclusions:

- The marginal benefits of additional reductions are greatest in the EGU, non-EGU point source, and area source emitting sectors, largely because the pollutant mix in those sectors yields a high benefit per ton of pollutant reduced.
- The spatial pattern of emissions, and therefore of proportional emissions reductions, across major emitting sectors show some differences, but they are not dramatic. The maps in Exhibit 3-6 indicate that, in 2020, most of the remaining emissions remain concentrated in the Northeast and in California, with non-EGU emissions concentrating more in the Southeast, and nonroad emissions concentrated in the agriculturally oriented North Central and California areas of the country.
- Benefits per ton of emissions across all sectors are higher in 2020 than 2010. The reason appears to be that, for all sectors, the with-CAAA emissions mix in 2020 includes a higher percentage of direct particulate emissions (POC and PEC) than in 2010. Other EPA analyses conducted with PM RSM have suggested that reductions of directly emitted particulates have a higher benefit per ton than other reductions of other pollutants. For policy purposes, this suggests that that . percentage of POC and PEC are higher.
- The shape of the marginal benefits curves across sectors are generally flat for the EGU and non-EGU sectors, somewhat positive for the non-road and onroad sectors, and much more positive for the area source sector. The shape of marginal pollutant response curves in PM RSM can differ dramatically across pollutants, across space, and across levels of pollutant emissions. The reason marginal benefits of pollutant reduction exceed marginal damages of pollutant increases for the area source sector may therefore be a complex combination of factors. Further analysis of the reasons underlying these marginal benefits results could yield further policy-relevant insights that could be used to target future emissions strategies beyond the "on the books" CAAA regulations that are the subject of the second prospective.

For the alternative EGU emissions scenarios, the substantial, 50 percent difference in air quality outcomes and benefits results is the result of our construction of a substantially different without-CAAA scenario. The original motivation of the analysis was concern that the spatial pattern of emissions for the with-CAAA scenario for 2000 predicted by an IPM run for a historical year differed from the spatial pattern observed in the emissions monitor data for the same year. Exhibits 3-9 through 3-11 above illustrate that the difference in benefits results is instead due primarily to differences in the without-CAAA scenario among the two alternative scenario specifications. The result probably suggests that IPM performs reasonably well in estimating the 2000 with-CAAA scenario, but it appears uncertainty in estimating a counterfactual scenario is much larger than uncertainty in estimating the factual case. While we can clearly conclude that the alternative counterfactuals assumptions have a large effect on results, we are left without a clear answer to the question of which method of estimating emissions without the CAAA regulations in place is superior.

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