Southern Environmental Law Center

Air Quality Modeling and Health Impacts Assessment for Southeastern North Carolina

Technical Memorandum

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1. Introduction and Overview of the Methodology

This report summarizes the application of air quality modeling tools to examine potential air quality impacts and related health effects associated with emissions from the proposed Carolinas Cement Company (CCC) facility near Castle Hayne, North Carolina.

This regional-scale photochemical air quality modeling and health risk assessment was conducted to examine and quantify the air quality and health-related benefits associated with the CCC facility. Key components of this assessment included:

- Emission inventory preparation
- Air quality model application
- Health impact/benefit assessment

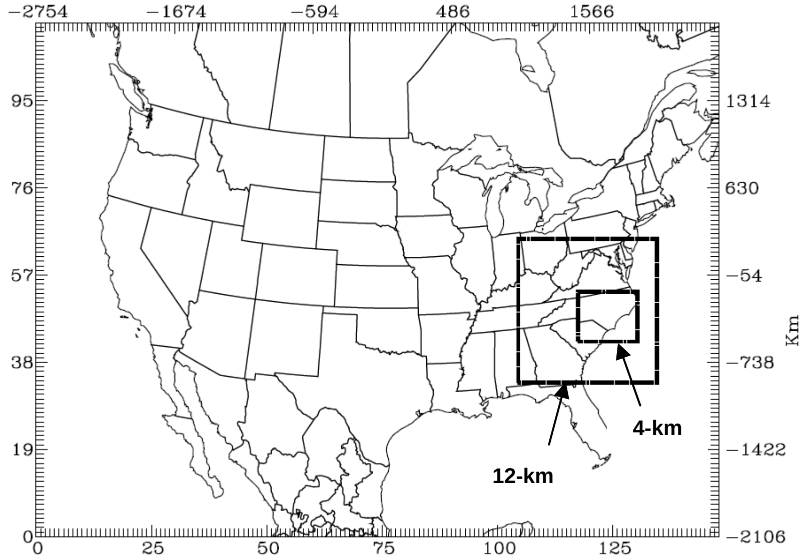
The primary tools that were used for this assessment include:

- Sparse-Matrix Operator Kernel Emissions (SMOKE) processing tool (version 2.5) for the preparation of model-ready emissions;
- Community Multiscale Air Quality (CMAQ) model (version 4.6) for quantifying the air quality changes associated with the CCC emissions; and
- Environmental Benefits Mapping and Analysis Program (BenMAP) tool (version 4.0.35) to assess the health-related impacts of the simulated changes in air quality.

These tools are widely used for conducting air quality and health effects analysis.

The CMAQ modeling domain is depicted in Figure 1-1. It consists of a regional-scale grid with 12-km horizontal resolution that covers North Carolina and all or portions of several surrounding states and a high-resolution (4-km) grid that is focused on southeastern North Carolina. Boundary conditions of pollutant concentrations for the 12-km domain were derived from a national-scale simulation run for a 36-km resolution continental U.S. (CONUS) modeling grid (also shown). Based on the CMAQ modeling results, air quality impacts and health effects were evaluated for a three-county area in southeastern North Carolina including New Hanover, Pender, and Brunswick Counties.

Figure 1-1. CMAQ Modeling Domain for the CCC Air Quality and Health Effects Modeling Analysis; Horizontal Grid Spacing is 36 km for the Outermost Grid, 12 km for the Intermediate Grid, and 4 km for the Inner Grid.



The CMAQ model was applied for a five-month simulation period (May through September), using meteorological inputs for a base year of 2001. The meteorological inputs were originally prepared by EPA and have been used for a number of other air quality modeling studies. This simulation period is characterized by typical meteorological conditions for the area of interest, with normal temperatures and precipitation amounts during the summer months (compared to 40 years of climatological data), but less than normal precipitation during the fall period. For these reasons, it was also selected for use in the Virginia Mercury Study (Douglas et al. 2008).

The modeling was conducted for the year 2014, since this would be consistent with a two-year construction period for the proposed facility. Emissions for all but the proposed CCC source were obtained from a 2014 national-scale emission inventory provided by EPA. The model-ready inventories contain emissions for all criteria pollutants for numerous source category sectors, including on-road mobile sources, non-road mobile sources (construction equipment, locomotives, ships, aircraft, etc.), electric generating unit (EGU) point sources, non-EGU point sources, area sources, biogenic sources, etc. Emissions and stack information for the CCC source were obtained from AERMOD input files and tabular emissions summaries prepared as part of the permit application (EQM, 2011). Two CMAQ simulations (with and without the CCC facility emissions) were conducted.

Following the application of CMAQ, the model outputs were processed for input to the BenMAP health effects analysis tool. BenMAP was used to estimate the health-related impacts and monetized health-related costs associated with the CCC emissions. BenMAP includes health impact functions, which relate a change in the concentration of a pollutant to a change in the incidence of a health endpoint. BenMAP also calculates the economic value of health impacts. For this study, the health effects analysis considered the effects of ozone and fine particulate matter ($PM_{2.5}$). Both of these are associated with respiratory and other health effects.

2. Emission Inventory Preparation

This section summarizes the data, methods, and procedures followed in preparing the emission inventories for use in the air quality modeling exercises.

2.1. Emissions Data and Methods

The CMAQ model requires as input hourly, gridded criteria pollutant emissions of both anthropogenic and biogenic sources that have been spatially allocated to the appropriate grid cells and chemically speciated for the applicable chemical mechanism used in the model. The modeling inventories were processed and prepared for CMAQ using EPA's Sparse-Matrix Operator Kernel Emissions (SMOKE) software (Version 2.5). The emissions inventories were derived, in part, from information developed by EPA for 2014 based on the 2002 modeling platform database.

The SMOKE input files for 2014 were obtained from the following EPA ftp site: ftp://ftp.epa.gov/EmisInventory/2002v3CAP. EPA routinely prepares these files for use in air quality modeling exercises. Input information was provided in these files for the 50 states and D.C. for a national-scale modeling domain. New biogenic emissions for the 12- and 4-km grids used in this analysis were generated using the BEIS3.14 model with BELD3 land use and 2001 meteorological data. Gridded surrogate data are required for the spatial allocation of emissions as part of the SMOKE processing. The gridded surrogate data for the 12-km grid were obtained from EPA, while the surrogates for the 4-km grid required for SMOKE processing were prepared using the Spatial Allocator in the Surrogate Tool and various shape file catalog files provided by EPA.

The modeling inventories include the following pollutants: volatile organic compounds (VOC), oxides of nitrogen (NO_x), carbon monoxide (CO), sulfur dioxide (SO_2), fine particulates ($PM_{2.5}$), coarse particulates (PM_{10}), mercury (Hg), and ammonia (NH_3).

The CCC emissions were obtained from AERMOD input files and tabular summaries of emissions for the CCC facility submitted as part of the permit application (EQM, 2011).

2.2. Emissions Processing Procedures

As noted above, SMOKE, version 2.5 was utilized to process the emissions and prepare CMAQ-ready inputs for the two scenarios. Emission files were prepared for the 12- and 4-km resolution grids used in the modeling analysis. Steps included a) processing the 2014 baseline emissions for all source sectors and, separately, the CCC facility-specific emissions using various SMOKE programs and inputs, b) merging the emissions from the various sectors to prepare the baseline and baseline plus CCC emission inventories, and c) review and quality assurance checks. As part of the processing step, the emissions were chemically speciated for use with the Carbon Bond 2005 (CB-05) chemical mechanism, temporally allocated to each hour of the simulation period, and spatially allocated to each grid cell (for both the 12- and 4-km grids).

The emission inventory processing quality assurance (QA) procedures included the preparation and examination of tabular emissions summaries and graphical display products.

2.3. Emissions Summary

The resulting baseline and CCC emissions are summarized in Table 2-1. This table summarizes total anthropogenic emissions for the 4-km grid, New Hanover and Pender Counties combined (without the addition of the CCC emissions), and the proposed CCC facility by source sector and species. The facility is located near the border of the two counties, so both counties were included in the county-level emissions total. Units are tons per day (tpd).

Table 2-1. Summary of Anthropogenic Emissions by Source Sector for the 2014 Baseline and the CCC Facility. Units are Tons per Day (tpd).

Sector	VOC (tpd)	NO_x (tpd)	CO (tpd)	SO_2 (tpd)	NH_3 (tpd)	$PM_{2.5}$ (tpd)	PMC (tpd)
4-km Modeling Grid							
Point	114.6	304.1	198.5	679.0	7.8	77.7	36.1
Nonpoint	445.0	45.5	386.5	50.6	619.5	133.6	196.5
Nonroad	153.0	160.2	1,614.4	2.8	0.2	19.7	3.7
Onroad	142.3	206.5	1,587.3	2.4	23.9	5.5	4.2
Total	**854.9**	**716.2**	**3,786.7**	**734.7**	**651.4**	**236.5**	**240.5**
New Hanover & Pender Counties, North Carolina (No CCC Emissions)							
Point	6.3	12.1	28.0	44.9	0.1	3.2	1.2
Nonpoint	15.2	1.3	28.4	1.3	9.7	3.0	4.0
Nonroad	5.2	9.6	61.1	1.0	0.0	0.7	0.1
Onroad	5.1	5.9	54.6	0.1	0.8	0.2	0.1
Total	**31.8**	**28.9**	**172.1**	**47.3**	**10.5**	**7.0**	**5.4**
Carolinas Cement Company LLC, Castle Hayne North Carolina Plant							
Total	**0.5**	**4.5**	**8.4**	**1.2**	**0.0**	**0.4**	**0.2**

Emissions from the proposed facility are equivalent to 1.5 percent of the estimated total VOC emissions, 15.6 percent of the NO_x emissions, 4.9 percent of the CO emissions, 2.5 percent of SO_2 emissions, 6.3 percent of the primary $PM_{2.5}$ emissions, and 4 percent of the primary PMcoarse (PMC) emissions estimated for 2014 for the two county area (without the CCC emissions). Note that PMC is defined as the difference between PM_{10} and $PM_{2.5}$.

3. Air Quality Modeling

The air quality modeling methods and results are presented in this section. Information about the emissions changes associated with the proposed CCC facility was incorporated into the model through the emission input files. The CMAQ modeling results provide the basis for the health effects and benefits modeling.

3.1. Overview of the CMAQ Modeling System

The CMAQ model is a state-of-the-science, regional air quality modeling system that can be used to simulate the physical and chemical processes that govern the formation, transport, and deposition of gaseous and particulate species in the atmosphere (Byun and Ching, 1999). The CMAQ tool was designed to improve the understanding of air quality issues (including the physical and chemical processes that influence air quality) and to support the development of effective emission control strategies on both the regional and local scale. The CMAQ model was designed as a "one-atmosphere" model. This concept refers to the ability of the model to dynamically simulate ozone, particulate matter, and other species (such as mercury) in a single simulation. In addition to addressing a variety of pollutants, CMAQ can be applied to a variety of regions (with varying geographical, land-use, and emissions characteristics) and for a range of space and time scales.

The CMAQ model numerically simulates the physical processes that determine the magnitude, temporal variation, and spatial distribution of the concentrations of gaseous and particulate species in the atmosphere and the amount, timing, and distribution of their deposition to the earth's surface. The simulation processes include advection, dispersion (or turbulent mixing), chemical transformation, cloud processes, and wet and dry deposition. The CMAQ science algorithms are described in detail by Byun and Ching (1999).

The CMAQ model requires several different types of input files. Gridded, hourly emission inventories characterize the release of anthropogenic, biogenic, and, in some cases, geogenic emissions from sources within the modeling domain. The emissions represent both low-level and elevated sources and a variety of source categories (including, for example, point, on-road mobile, non-road mobile, area, and biogenic). The amount and spatial and temporal distribution of each emitted pollutant or precursor species are key determinants to the resultant simulated air quality values.

The CMAQ model also requires hourly, gridded input fields of several meteorological parameters including wind, temperature, mixing ratio, pressure, solar radiation, fractional cloud cover, cloud depth, and precipitation. The meteorological input fields are typically prepared using a data-assimilating prognostic meteorological model, the output of which is processed for input to the CMAQ model using the Meteorology-Chemistry Interface Processor (MCIP). The prescribed meteorological conditions influence the transport, vertical mixing, and resulting distribution of the simulated pollutant concentrations. Certain meteorological parameters, such as mixing ratio, can also influence the simulated chemical reaction rates. Rainfall and near-surface meteorological characteristics govern the wet and dry deposition, respectively, of the simulated atmospheric constituents.

Initial and boundary condition (IC/BC) files provide information on pollutant concentrations throughout the domain for the first hour of the first day of the simulation and along the lateral boundaries of the domain for each hour of the simulation. Photolysis rates and other chemistry-related input files supply information needed by the gas-phase and particulate chemistry algorithms.

CMAQ version 4.6 was used for this study. This version of the model supports several options for the gas-phase chemical mechanism, particle treatment, aerosol deposition, and cloud treatment. All simulations conducted as part of this study used the CB-05 chemical mechanism. For particles, the AERO4 particle treatment, which includes sea salt, was applied.

3.2. CMAQ Application Procedures

The application of CMAQ, including the modeling domain, simulation period, input files (with the exception of the emission inventories), and post-processing and quality assurance procedures are discussed in this section. Preparation of the emission inventories for the application of CMAQ was discussed in detail in the previous section.

Modeling Domain and Simulation Period

The modeling domain used for this analysis was presented in Figure 1-1. It consists of a regional-scale grid with 12-km horizontal resolution that covers North Carolina and all or portions of several surrounding states and a high-resolution (4-km) grid that is focused on southeastern North Carolina.

The CMAQ model was applied for a five-month simulation period (May – September), using meteorological inputs for a base year of 2001. The simulation also included an additional five start-up simulation days, which were intended to reduce the influence of uncertainties in the initial conditions on the simulation results.

Meteorological Input Files

The 12-km resolution meteorological input files for the annual (2001) simulation period were originally prepared by EPA using the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Fifth Generation Mesoscale Model (MM5) (EPA, 2005). The MM5 outputs were postprocessed by EPA for input to CMAQ using the MCIP program. The meteorological fields for the 12-km study domain were extracted from a larger 12-km domain used by EPA for modeling the entire eastern U.S.

The 12-km meteorological inputs were also used as the basis for the 4-km meteorological fields. Interpolation and reanalysis methods were used to adapt the input files to the 4-km grid. The 12-km fields were interpolated to the 4-km grid. For most parameters, objective analysis (based on bi-linear interpolation) was used to combine the interpolated fields with available observations and thus adjust the 12-km fields to the 4-km grid. Certain parameters such as radiation, rainfall, and land-use-based quantities, which are not expected to exhibit smooth variations in space, were not interpolated and the values used for the 4-km sub-cells were the same as for the encompassing 12-km grid cell.

Initial and Boundary Conditions and Geophysical Input Files

Existing CMAQ results for the 36-km CONUS domain (refer to Figure 1-1) were used to generate boundary conditions for the 12-km domain. This prior run used the 2001 meteorological fields and 2010 emissions. For both CMAQ scenarios, the output from the 12-km grid was used to generate boundary conditions for the 4-km grid (one-way nesting). Gridded land-use and photolysis rate input files were prepared for the 12- and 4-km grids and the simulation period using standard CMAQ utility programs (CMAS, 2008).

Post-processing and Quality Assurance Procedures

Quality assurance of the CMAQ runs included the following steps:

- Scripts were routinely checked to ensure that the correct input files and output file names were used. Any messages generated by CMAQ were checked and reconciled.
- For each simulation, plots of daily maximum 8-hour average ozone and 24-hour average $PM_{2.5}$ for the 15th day of each month were prepared. Plots of monthly average $PM_{2.5}$ were also prepared. These were examined and compared with the results for other runs and the concentration patterns and values were checked for reasonableness. These metrics were chosen for consistency with those used in current National Ambient Air Quality Standards (NAAQS). It is expected that shorter averaging periods would show higher concentrations.
- Difference plots comparing $PM_{2.5}$ and ozone concentrations for the “with” and “without” scenarios were also prepared.

Following the quality assurance of the modeling results, the CMAQ results were post-processed for input to the health impacts and benefits modeling, as discussed in Section 4 of this memo.

3.3. CMAQ Modeling Results

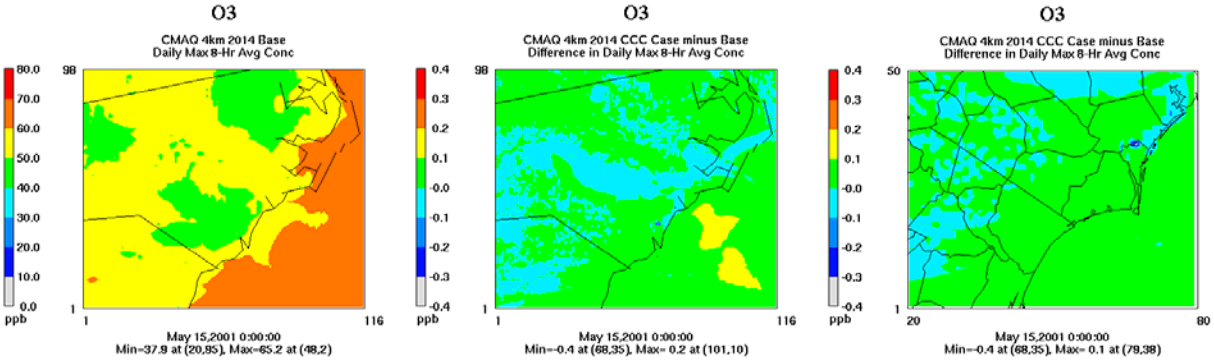
The CMAQ modeling results are presented in this section. The plots show the simulated ground-level ozone and $PM_{2.5}$ concentrations and differences for the 4-km grid and a subset of the 4-km grid (to better distinguish county level impacts).

Ozone

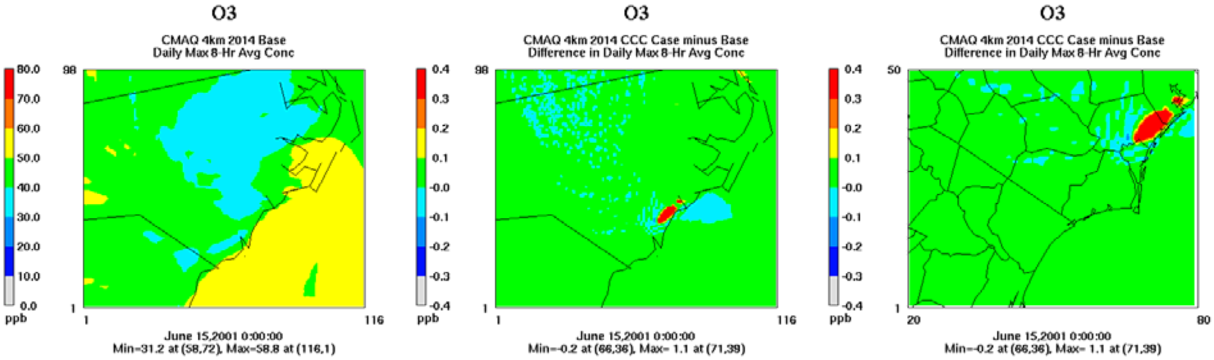
Figure 3-1 displays simulated daily maximum 8-hour ozone concentration (ppb) and differences in simulated daily maximum 8-hour ozone concentration (ppb) between the CCC and baseline scenarios for the 15th of each month. The scales are different for the absolute value and difference plots.

Figure 3-1. CMAQ-Derived Daily Maximum 8-Hour Ozone Concentration (ppb) for the 4-km Grid (Left), Difference in Daily Maximum 8-Hour Ozone Concentration (ppb) for the 4-km Grid (Center), and Difference in Daily Maximum 8-Hour Ozone Concentration (ppb) for a Subset of the 4-km Grid (Right). Differences are With-CCC Minus 2014 Baseline.

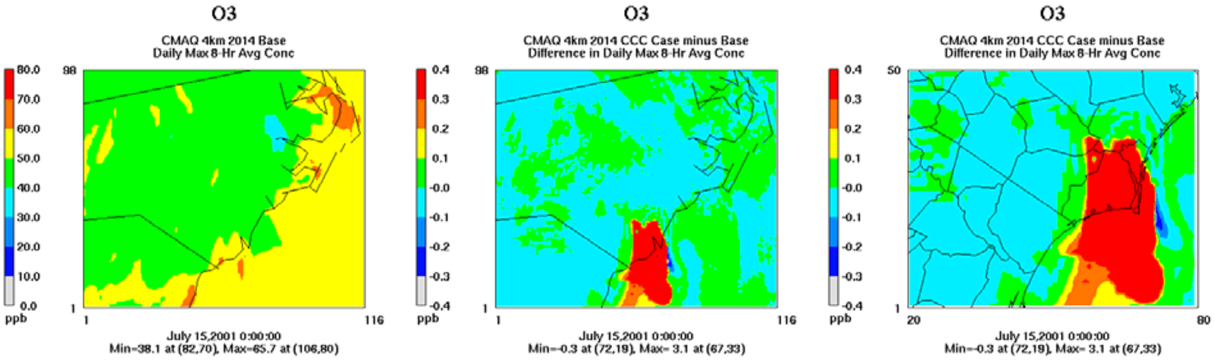
15 May



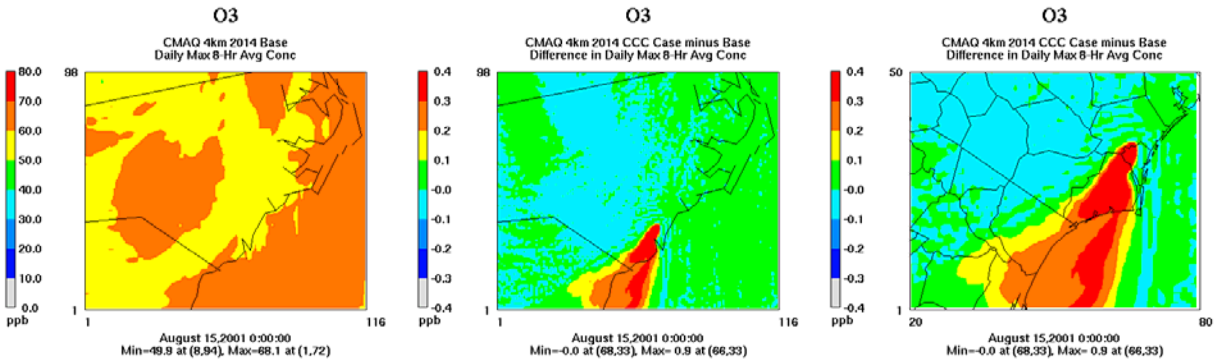
15 June



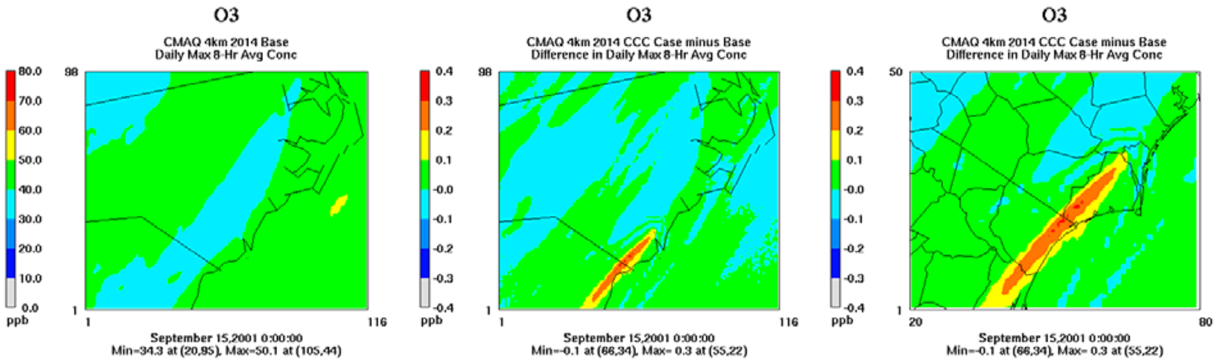
15 July



15 August



15 September



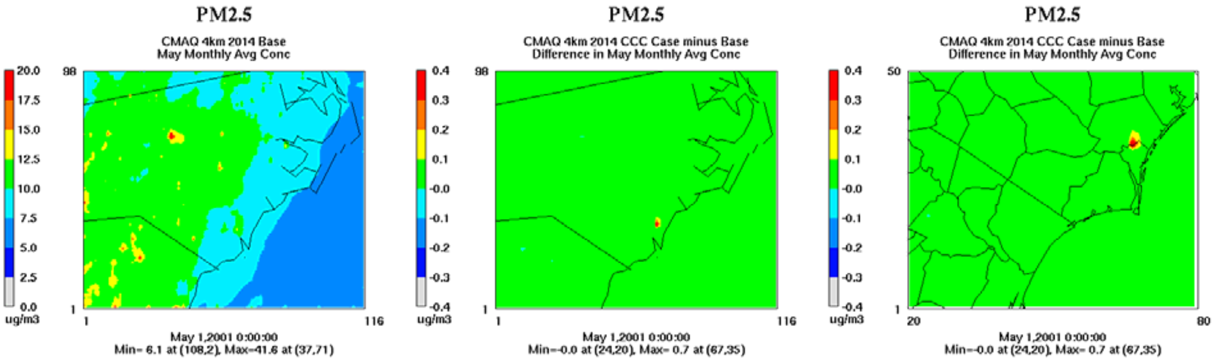
The 2014 baseline ozone concentrations within the area of interest are in the range of 40 to 70 ppb on the selected days. The increase in ozone due to the CCC emissions ranges from less than one to greater than 3 ppb for these days. The difference patterns depict the orientation of the impact plume and highlight the differences in prevailing wind directions on the selected days. Ozone is a secondary pollutant that is formed in the atmosphere by a series of reactions involving ultra-violet radiation and precursor emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs). The increases in ozone concentration are primarily due to the increase in NO_x emissions associated with the CCC facility. Since ozone can take some time to form, the maximum impact frequently occurs downwind of the source. There are also some decreases in ozone apparent in the difference plots. These are a result of complexities and resulting nonlinearities in the ozone chemistry. Under certain conditions (usually characterized by a high VOC to NO_x ratio), increases in NO_x emissions can lead to decreases in ozone. The decreases range from -0.1 to -0.2 ppb for the selected days and are smaller in absolute magnitude than the increases. Overall, the increases in ozone concentration are potentially meaningful relative to the absolute simulated concentrations and the current U.S. EPA 8-hour average ozone standard (75 ppb).

PM$_{2.5}$

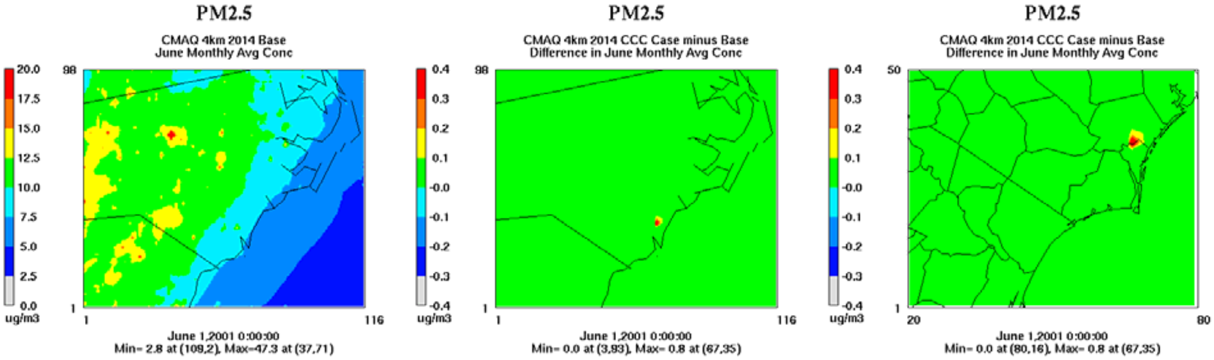
Figure 3-2 displays the difference in simulated monthly average PM$_{2.5}$ concentration (μgm^{-3}) and difference in monthly average PM$_{2.5}$ concentration (μgm^{-3}) between the CCC and baseline scenarios for each simulation month.

Figure 3-2. CMAQ-Derived Monthly Average PM$_{2.5}$ Concentration (μgm^{-3}) for the 4-km Grid (Left), and Difference in Monthly Average PM$_{2.5}$ Concentration (μgm^{-3}) for the 4-km Grid (Center), and Difference in Monthly Average PM$_{2.5}$ Concentration (μgm^{-3}) for a Subset of the 4-km Grid (Right). Differences are With-CCC Minus 2014 Baseline.

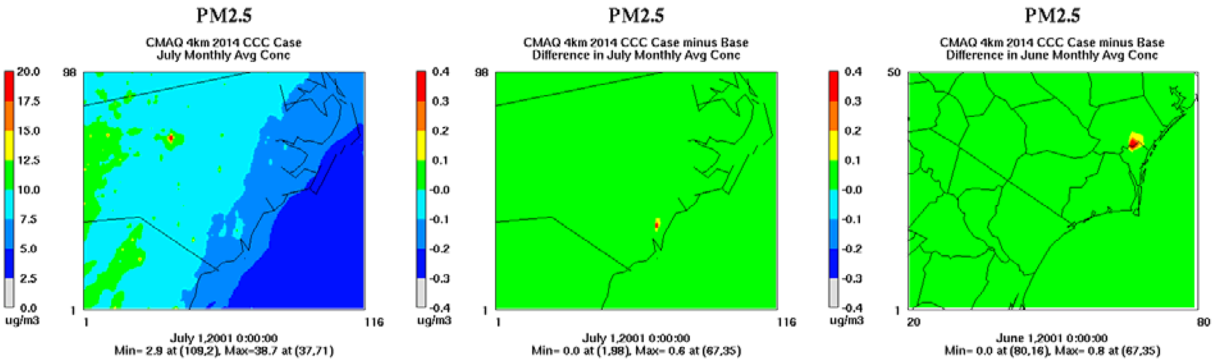
May



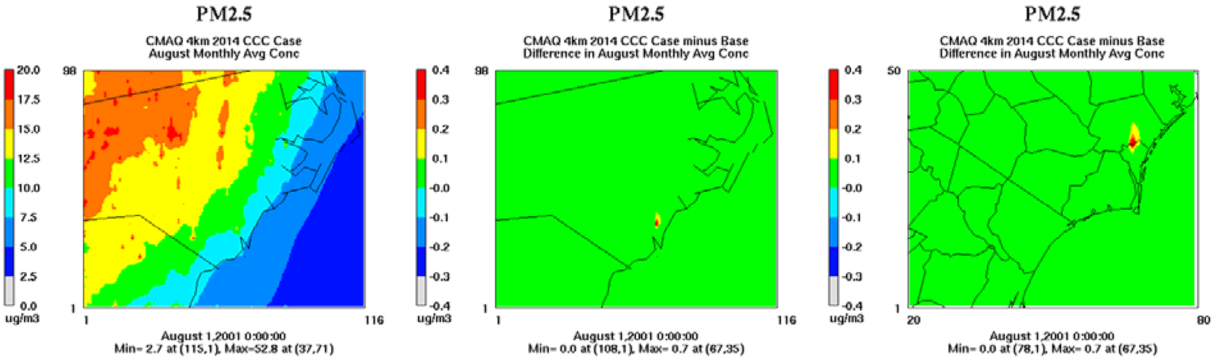
June



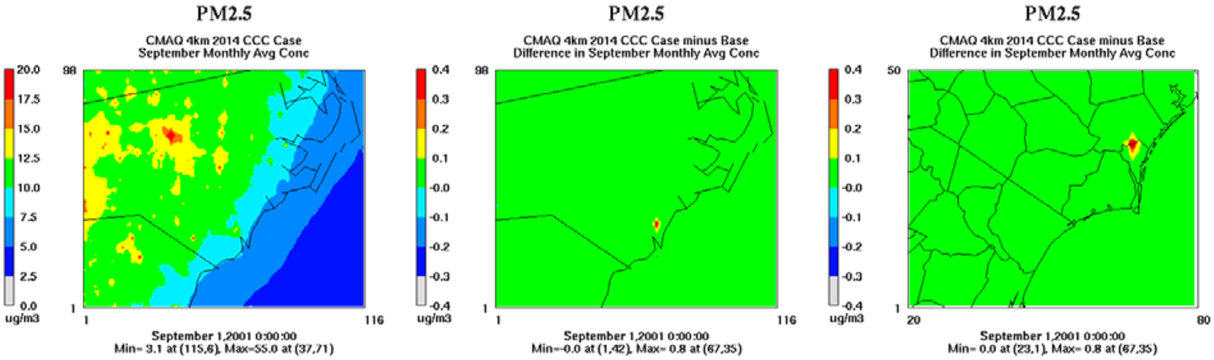
July



August



September



The monthly average baseline $PM_{2.5}$ concentrations estimated for 2014 within the area of interest are in the range of 5 to 15 μgm^{-3}. The increase in monthly average $PM_{2.5}$ due to the CCC emissions ranges from 0.6 to 0.8 μgm^{-3}, and the impacts occur near the location of the proposed facility. This suggests that most of the impacts are from the primary $PM_{2.5}$ emissions.

Secondary $PM_{2.5}$ formed from precursors such as SO_2 and NO_x would likely appear over a broader area (primarily near the source and downwind), and the difference patterns would be similar to those for ozone. Overall, the localized increases in $PM_{2.5}$ concentration are potentially meaningful relative to the absolute simulated concentrations and the current annual $PM_{2.5}$ standard (15 μgm^{-3}).

4. Health Effects and Benefits Assessment

The methods and results of the health effects and benefits modeling related to ozone and fine particulate matter ($PM_{2.5}$), are presented in this section.

Following the application of CMAQ, the CMAQ-derived air quality estimates were processed for input to the BenMAP health effects analysis tool, and BenMAP was used to estimate the health impacts and monetized health-related benefits associated with the changes in air pollution from the CCC emissions as simulated by CMAQ. The BenMAP tool includes health impact functions, which relate a change in the concentration of a pollutant to a change in the incidence of a health endpoint. BenMAP also calculates the economic value of health impacts. Because ozone and $PM_{2.5}$ are secondary pollutants, this assessment of the health effects for ozone and $PM_{2.5}$ addresses the effects of changes in the precursor emissions including VOC, NO_x and SO_2 emissions.

4.1. Overview of the BenMAP Modeling System

BenMAP is a computer program developed by EPA that uses interpolation functions, population projections, health impact functions, and valuation functions to translate simulated changes in air pollution concentration into changes in health-related incidences and monetized health-related benefits. BenMAP is primarily intended as a tool for estimating the human health effects and economic benefits associated with changes in ambient air pollution. EPA originally developed this tool to analyze national-scale air quality regulations. The health benefits and monetary values derived using BenMAP are intended to inform policy makers by enabling the comparison of the benefits and costs of various regulatory measures (Abt Associates, 2010).

BenMAP relies on the input of air quality information that can be used to calculate the change in ambient air pollution associated with a change in emissions. Typically, the results from two air quality modeling simulations (with different emission inputs) are used. In some cases, measured ambient air quality data can also be used.

BenMAP calculates health effects based on expected relationships between the change in concentration and certain health effects (also known as health endpoints), using concentration-response (C-R) functions from epidemiology studies (Abt Associates, 2010). The response functions are used together with population data to estimate health effects. For a model-based application, health effects are calculated on a grid cell-by-grid cell basis and then summed to obtain regional and national-scale estimates. In its most basic form, the health effect for a given health endpoint is a function of the change in air concentration, concentration-response estimates, and population. Primary health endpoints include premature mortality, heart attacks, and chronic respiratory illnesses.

After estimating the change in adverse health effects associated with a given change in air quality, BenMAP calculates the monetary benefits associated with those changes (Abt Associates, 2010). Simply, the economic value is based on the change in the incidence of a certain adverse health effect multiplied by the value of the health effect (on a per-incident or per-case basis). For example, the value associated with avoided premature mortality is typically calculated using the Value of Statistical Life (VSL), which is the monetary amount that people are willing to pay to slightly reduce the risk of premature death. For other health effects, the medical costs of the illness are typically used to estimate value. The BenMAP database includes several different valuation functions for VSL and other health endpoints.

4.2. BenMAP Application Procedures

For this application, BenMAP was applied for May through September, a total of 153 days. The input files for ozone contain 153 days of hourly average ozone concentrations for each grid cell in the CMAQ modeling domain. The input files for $PM_{2.5}$ contain 153 days of 24-hour average $PM_{2.5}$ concentration for each grid cell. BenMAP was applied for the area covering New Hanover, Pender, and Brunswick Counties. BenMAP includes population data at the census-tract level and algorithms for characterizing demographic changes (age distribution) over time. For this analysis, population estimates for 2014 were used. This is consistent with the CMAQ simulation year of 2014. Note that the population values do not account for the increase in population due to tourism in the coastal communities during the summer months. BenMAP was applied separately for ozone and $PM_{2.5}$.

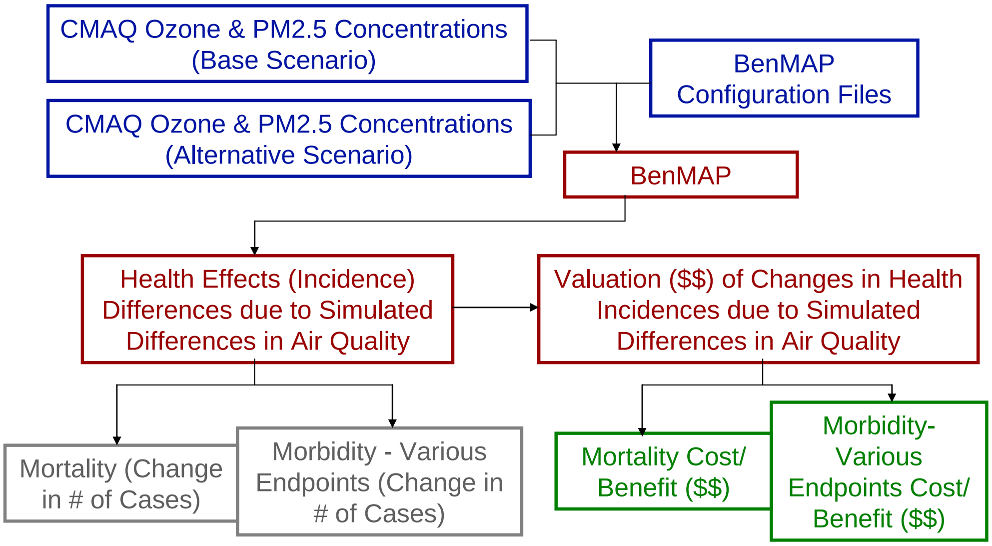
For each pollutant and simulation couple, the application of BenMAP included four steps:

- Incorporation of the CMAQ modeling results into the air quality grid files required by BenMAP (air quality grid creation);
- Calculation of the change in the incidence of adverse health effects based on the differences in the CMAQ-derived ozone and $PM_{2.5}$ concentrations between the two simulations;
- Aggregation of the incidence results and calculation of the economic value of the aggregated incidences; and
- Preparation of tabular and graphical summaries; quality assurance and analysis of the results.

In the air quality grid creation step, the CMAQ model results were used directly.

Figure 4-1 illustrates the steps and components of the BenMAP application procedure.

Figure 4-1. Schematic Diagram of the BenMAP Health Effects and Benefits Analysis



Health Impact Functions

BenMAP was used to calculate reductions in both mortality and a range of non-fatal health effects (morbidity), based on epidemiological studies of a number of U.S. and non-U.S. (Canadian) populations.

BenMAP can estimate changes in a wide range of health impact “endpoints” associated with changes in ozone and $PM_{2.5}$ exposure. The endpoints are grouped broadly as “mortality” and “morbidity.” Mortality endpoints include changes in “all-cause” mortality, as well as mortality due to specific causes, such as cardiopulmonary disease. Morbidity endpoints include specific illnesses and symptoms (e.g. “asthma exacerbations”); events requiring medical care (e.g. emergency room visits and hospital admissions); and adverse effects that involve lost work or restricted activity days. Acute respiratory symptoms are defined as any of 19 symptoms (Krupnick et al., 1990) including chest discomfort, shortness of breath, coughing, and wheezing.

EPA has evaluated the literature related to the adverse effects of ozone and particulate exposures and identified a set of endpoints for which the associations are considered to be well established, and for which reliable exposure-response relationships have been developed (Abt Associates, 2010). For this analysis, the EPA-recommended set of health endpoints for use with the latest version of BenMAP was used.

Valuation Metrics

BenMAP was also used to estimate reductions in monetized health-related benefits (based on value of statistical life studies, lost wages, and health care expenses) associated with the health impacts. These estimates are derived using a set of monetary surrogates for the various health effects developed by EPA and public health researchers. BenMAP also tracks changes over time in willingness-to-pay for reductions in health risks, and includes adjustment factors that incorporate the effect of inflation on health-related costs.

The assessment of monetized health-related benefits involves assigning monetary values to each health endpoint, and totaling the overall benefits associated with changes in pollutant exposures. Different valuation methods are used for the various health endpoints. The monetary surrogate value for mortality is derived using a Value of Statistical Life (VSL) approach, that is, the monetary cost of a single “statistical” death (Abt Associates, 2010).

Valuation methods for morbidity endpoints (non-fatal health effects) include approaches referred to as cost-of-illness (COI), willingness-to-pay (WTP), and lost wages or productivity (Abt Associates, 2010). COI estimates comprise a range of approaches, which account for the costs of medical care, and in some cases lost wages. WTP approaches refer to methods where voluntary payments to avoid disease are directly or indirectly estimated and used to estimate monetized health-related benefits. Finally, lost productivity methods value the time lost to illness using wage rates or the estimated value of leisure or school time (Abt Associates, 2010). For all endpoints, the total monetized health-related benefit for a given endpoint is estimated by multiplying the monetary values for that endpoint by the estimated change in the number of “cases” of the endpoint. For most studies, morbidity values are small compared to the mortality values. Thus, the specific valuation methods used for morbidity have only a small effect on the overall monetized health-related benefits estimates.

For this analysis, the EPA-recommended set of valuation methods for the latest version of BenMAP was used. The endpoints include monetized health-related benefits associated with changes in mortality, as well as a range of morbidity endpoints. All monetized health-related benefits results for this analysis are presented in year 2009 equivalent dollars. The VSL used by BenMAP is $6.3 million (in 2000-equivalent dollars). This value is converted to the currency year used for the analysis within the modeling tool.

4.3. BenMAP Results

The health incidence results presented in this section are the BenMAP-derived mean values. The valuation estimates reflect both an income growth adjustment and a time lag between exposure and $PM_{2.5}$ mortality.

The income growth adjustment accounts for expected growth in real income over time. Economic theory suggests that WTP for most goods and services (such as environmental protection) will increase if income increases. To account for growth in income through 2020, BenMAP applied the following factors to the valuation results: 1.20 for long-term mortality, 1.23 for chronic health impacts, and 1.07 for minor health impacts.

The valuation results for $PM_{2.5}$ assume that there is a time lag between changes in $PM_{2.5}$ concentration and changes in $PM_{2.5}$ mortality. To account for this, monetized health-related impacts and/or benefits occurring in the future are discounted. For this analysis, the BenMAP-derived reductions were multiplied by 0.91 to achieve a 3% "discount rate" and by 0.82 to achieve a 7% "discount rate." Similar adjustments do not exist for ozone.

All of the incidence and valuation results are rounded to two significant figures (and include at most up to one decimal place). Incidence results are given as whole numbers.

Ozone

BenMAP results for ozone mortality are presented in Table 4-1. The mortality estimates are based on epidemiology literature. Six studies are included in the BenMAP output for ozone mortality, as listed below. Descriptions and detailed references for these studies can be found in the BenMAP users guide (Abt Associates, 2010).

Table 4-1. BenMAP Results for Ozone-Related Mortality Based on a Five-Month Analysis Period: Increase in the Incidence of Premature Mortality Associated with the Emissions from the CCC Facility.

Epidemiology Literature	No. of Cases (3-County Area)
Mortality, Non-Accidental (Ito et al.)	<1
Mortality, Non-Accidental (Schwartz)	<1
Mortality, Non-Accidental (Bell et al.)	<1
Mortality, All Cause (Levy et al.)	<1
Mortality, All Cause (Bell et al.)	<1
Mortality, Cardiopulmonary (Huang et al.)	<1

The values range from 0.1 to 0.4.

BenMAP results for other ozone-related health effects and associated endpoints (morbidity) are presented in Table 4-2.

Table 4-2. BenMAP Results for Ozone-Related Morbidity Based on a Five-Month Analysis Period: Increase in the Incidence of Various Morbidity Endpoints Associated with Emissions from the CCC Facility.

Epidemiology Literature	No. of Cases (3-County Area)
Emergency room visits, respiratory (all ages)	0
Hospital admissions, respiratory (all ages)	1
Acute ozone-related respiratory symptoms (& minor restricted-activity days) (age 18-65)	530
School or activity loss days (age 5-17)	160
Reduced worker productivity days (age 18-65)	320

Among the direct health effects, acute respiratory symptoms are most common. Based on these results, there are 530 cases of acute respiratory symptoms (such as shortness of breath, coughing, and wheezing) during the five-month modeling period due to the higher ozone concentrations within the 3-county area.

BenMAP valuation results for ozone related mortality are presented in Table 4-3. The monetized health-related costs represent regional costs, in U.S. 2009-equivalent dollars.

Table 4-3. BenMAP-Derived Monetized Health-Related Costs for Ozone-Related Mortality (Millions U.S. Dollars) Associated with the Emissions from the CCC Facility (Based on a Five-Month Analysis Period).

Epidemiology Literature	3-County Area Monetized Health Related Costs (Millions U.S. $2009)
Non-accidental (Ito et al.)	3.7
Non-accidental (Bell et al. (U.S. cities))	0.8
Non-accidental (Schwartz et al.)	1.3
All causes (Levy et al.)	3.8
All causes (Bell et al.)	2.7
Cardiopulmonary	1.2

BenMAP valuation results for other ozone-related health effects and associated endpoints (morbidity) are presented in Table 4-4.

Table 4-4. BenMAP-Derived Monetized Health-Related Costs for Ozone-Related Morbidity (Thousands U.S. Dollars) Associated with the Emissions from the CCC Facility (Based on a Five-Month Analysis Period).

Epidemiology Literature	3-County Area Monetized Health Related Costs (Thousands U.S. $2009)
Emergency room visits, respiratory (all ages)	0
Hospital admissions, respiratory (all ages)	13
Acute ozone-related respiratory symptoms (& minor restricted-activity days) (age 18-65)	16
School or activity loss days (age 5-17)	10
Reduced worker productivity (age 18-65)	37

The total monetized health effects due to the changes in ozone associate with the CCC facility range from 0.9 to 3.9 million for the three-county area, depending upon the mortality study selected.

$PM_{2.5}$

BenMAP results for $PM_{2.5}$ mortality are presented in Table 4-5. The mortality estimates are based on both epidemiology literature and expert elicitation. Descriptions and detailed references for these studies can be found in the BenMAP users guide (Abt Associates, 2010). The studies as well as the aggregation and pooling assumptions are different for $PM_{2.5}$, compared to ozone, such that there are different endpoints, and the results for individual endpoints, even those with with similar names, cannot be directly compared but represent the best available information from relevant $PM_{2.5}$ studies.

Table 4-5. BenMAP Results for $PM_{2.5}$-Related Mortality Based on a Five-Month Analysis Period: Increase in the Incidence of Premature Mortality Associated with the Emissions from the CCC Facility.

Epidemiology Literature	No. of Cases (3-County Area)
Harvard six-city study (Laden et al.)	1
ACS study (Pope et al.)	<1
Infant mortality study (Woodruff et al.)	0
Expert Elicitation	
Expert A	1
Expert B	<1
Expert C	1
Expert D	1
Expert E	1
Expert F	<1
Expert G	<1
Expert H	1
Expert I	1
Expert J	1
Expert K	<1
Expert L	<1

The values listed as less than one range from 0.1 to 0.4. BenMAP results for other $PM_{2.5}$-related health effects and associated endpoints (morbidity) are presented in Table 4-6.

Table 4-6. BenMAP Results for $PM_{2.5}$-Related Morbidity Based on a Five-Month Analysis Period: Increase in the Incidence of Various Morbidity Endpoints Associated with Emissions from the CCC Facility.

Epidemiology Literature	No. of Cases (3-County Area)
Chronic bronchitis (age >=25)	<1
Emergency room visits for asthma (age <17)	<1
Acute bronchitis (age <17)	1
Asthma exacerbation (age <17)	13
Lower respiratory symptoms (age <17)	8
Upper respiratory symptoms (age <17)	6
Acute PM-related respiratory symptoms (& minor restricted-activity days) (age 18-65)	320
Work loss days (age 18-65)	54
Nonfatal myocardial infarction (age >17)	<1
Hospital admissions - respiratory (all ages)	<1
Hospital admissions - cardiovascular (age >17)	<1

The values listed as less than one range from 0.1 to 0.4. The number of cases of acute respiratory symptoms is the most common among the direct health endpoints. Based on these results, there are 320 cases of acute respiratory symptoms during the modeling period due to the higher $PM_{2.5}$ concentrations within the 3-county area.

BenMAP valuation results for $PM_{2.5}$ related mortality are presented in Table 4-7. The monetized health-related costs represent regional costs, in millions of U.S. 2009-equivalent dollars.

Table 4-7. BenMAP-Derived Monetized Health-Related Costs for $PM_{2.5}$-Related Mortality (Millions U.S. Dollars) Associated with the Emissions from the CCC Facility (Based on a Five-Month Analysis Period).

Epidemiology Literature	3-County Area Monetized Health Related Costs (Millions U.S. $2009)	
	3% Discount Rate	7% Discount Rate
Harvard six-city study (Laden et al.)	9.4	8.4
ACS study (Pope et al.)	3.6	3.3
Infant mortality study (Woodruff et al.)	0	0
Expert Elicitation		
Expert A	9.9	8.4
Expert B	1.0	0.9
Expert C	8.2	7.4
Expert D	5.4	4.9
Expert E	13	11
Expert F	0.6	0.5
Expert G	4.4	3.9
Expert H	5.4	4.8
Expert I	7.7	6.9
Expert J	6.8	6.1
Expert K	0.1	0.1
Expert L	0.6	0.6

For the 3% discount rate, the calculated monetized health-related costs for the three-county region range from 3.6 to 9.4 million dollars for premature mortality based on the epidemiological studies. The range among the expert estimates is somewhat larger.

For the 7% discount rate and using the same studies, the calculated monetized health-related costs range from 3.3 to 8.4 million dollars for the three-county area.

BenMAP valuation results for other $PM_{2.5}$-related health effects and associated endpoints (morbidity) are presented in Table 4-8.

Table 4-8. BenMAP-Derived Monetized Health-Related Costs for $PM_{2.5}$-Related Morbidity (Thousands U.S. Dollars) Associated with the Emissions from the CCC Facility (Based on a Five-Month Analysis Period).

Epidemiology Literature	3-County Area Monetized Health Related Costs (Thousands U.S. $2009)
Chronic bronchitis (age>=25)	150
Emergency room visits for asthma (age <17)	0
Acute bronchitis (age <17)	0
Asthma exacerbation (age <17)	1
Lower respiratory symptoms (age <17)	0
Upper respiratory symptoms (age <17)	0
Acute PM-related respiratory symptoms (& minor restricted-activity days) (age 18-65)	23
Work loss days (age 18-65)	9
Nonfatal myocardial infarction (age >17)	51
Hospital admissions - respiratory (all ages)	1
Hospital admissions - cardiovascular (age >17)	2

Morbidity costs are estimated to be approximately $240,000 for the three-county area. The total costs due to the changes in $PM_{2.5}$ associate with the CCC ranges from 3.5 to 9.6 million dollars for the 3-county area, depending upon the mortality study and discount selected.

5. Summary

The objective of this analysis was to examine and quantify the air quality impacts and health effects associated with emissions from the proposed CCC facility. The CMAQ air quality model was used to quantify the air quality impacts and BenMAP was used to assess the health-related impacts of the simulated changes in air quality. The analysis focused on southeastern North Carolina (see Figure 1-1).

Two CMAQ simulations (with and without the CCC facility emissions) were run. Plots of daily maximum 8-hour ozone and difference in daily maximum 8-hour ozone (with and without the CCC emissions) were generated for the 15th of each month simulated. Results for these days indicate an increase in daily maximum 8-hour ozone that ranges from less than one to greater than 3 ppb. The area of maximum impact depends upon the meteorological conditions and especially the prevailing wind directions. Decreases in ozone, due to the complexities in ozone chemistry, also occur and range from -0.1 to -0.2 ppb for the selected days.

Plots of monthly average $PM_{2.5}$ concentration and difference in monthly average $PM_{2.5}$ concentrations (with and without the CCC emissions) were generated for each month. The impacts occur near the location of the proposed facility, with impacts of greater than 0.2 μgm^{-3} as far as 10 km (6 miles) away. The maximum increase in monthly average $PM_{2.5}$ due to the CCC emissions ranges from 0.6 to 0.8 μgm^{-3}.

The BenMAP results indicate that there are health effects associated with the increases in ozone and $PM_{2.5}$ concentration. Among the direct health effects, acute respiratory symptoms (minor restricted activity days) are most common. The BenMAP results indicate 530 cases of acute respiratory symptoms (such as shortness of breath, coughing, and wheezing) during the five-month modeling period due to the higher ozone concentrations within the 3-county area. In addition, the results indicate 320 cases of acute respiratory symptoms during the modeling period due to the higher $PM_{2.5}$ concentrations within the 3-county area. Since the modeling period includes the months in which the highest ozone concentrations are typically recorded, the health effects estimates for ozone are likely representative of the entire year. However, for $PM_{2.5}$, high concentrations can occur year round and some of the highest values typically occur during the winter months. Thus the health effects estimates for $PM_{2.5}$ represent only a portion of those expected for an entire year.

The mortality estimates are higher for $PM_{2.5}$, compared to ozone.

A summary of the combined monetized health effects for both ozone and $PM_{2.5}$ using two of the most widely referenced mortality studies (Bell et al. (2005) for ozone mortality (all causes) and Pope et al. (2002), for $PM_{2.5}$ mortality) is presented in Table 5-1. The range for $PM_{2.5}$ mortality reflects the different assumptions regarding cessation lag (discount rate). The monetized health-related benefits are given in 2009-equivalent U.S. dollars. Note that these values were calculated for a five-month simulation period and would likely be greater if CMAQ and BenMAP were applied for an annual simulation period. This is especially true for $PM_{2.5}$, since this is a year-round pollutant.

Table 5-1. Total BenMAP-Derived Valuation Results for Ozone and $PM_{2.5}$ Associated with Emissions from the Proposed CCC Facility, Based on Ozone Mortality from Bell et al., and $PM_{2.5}$ Mortality from Pope et al. with 3 and 7% Discounts.

	New Hanover, Pender & Brunswick Counties Monetized Health Related Costs (Millions U.S. $2009)	
	High End	Low End
Ozone-Mortality (Bell et al.)	2.7	2.7
Ozone-Morbidity	0.076	0.076
PM-Mortality (Pope et al., 3 & 7% discount rate)	3.6	3.3
PM-Morbidity	0.24	0.24
Total	*6.62*	*6.32*
Total (2 significant figures)	6.6	6.3

Using these studies, the estimated total cost associated with emissions from the CCC facility is 6.3 to 6.6 million dollars, based on ozone, $PM_{2.5}$, and the modeling results for the five-month period. Please note that both higher and lower estimates can be obtained by combining the results of the different studies and assumptions, as presented earlier in this report. These values are simply based on two of the more frequently referenced studies.

6. References

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About ICF

ICF International (www.icfi.com) partners with government and commercial clients to deliver consulting services and technology solutions in environment, energy, transportation, economics, social programs, and homeland security. For more than 35 years, ICF's Air Quality Modeling (AQM) group has been a leader in the development and use of advanced analysis and modeling tools to support air quality assessments of primary and secondary pollutants, including ozone, carbon monoxide, toxics, mercury, $PM_{2.5}$, and regional haze and visibility.

The ICF AQM group includes senior scientists with specialization in the following areas: meteorological and air quality data analysis; emission inventory preparation and quality assurance; meteorological modeling (and, in particular, the use of dynamic meteorological models to prepare inputs for photochemical modeling); development and application of photochemical models for regulatory and research purposes and both regional- and urban-scale analysis; evaluation of model performance for meteorological and air quality/deposition models; and preparation of EPA-approved technical support documents that have been submitted by states as part of their attainment and maintenance plans.

ICF scientists developed the Urban Airshed Model (UAM) modeling system, the variable-grid version of that modeling system (UAM-V), and the REgional Modeling System for Aerosols and Deposition (REMSAD). The ICF scientists who participated in the present study for SELC are currently or have recently been involved in a number of air quality modeling studies using EPA's CMAQ and BenMAP modeling systems. For example, ICF recently applied the CMAQ to simulate the contributions to mercury deposition to Virginia water bodies as part of the Virginia Mercury Study. In addition, the ICF modeling team used the CMAQ model to conduct a national and regional-scale assessment of the costs and benefits of the Clean Air Act Amendments (CAAA) on ozone, $PM_{2.5}$, and regional haze throughout the U.S. This study included high-resolution CMAQ modeling of both the western and eastern U.S., preparation of detailed retrospective and prospective modeling emission inventories for four years (1990, 2000, 2010 and 2020), both with and without the CAAA measures, and the conduct and detailed analysis of multiple annual CMAQ simulations. BenMAP was then used to estimate the health effects and monetized health effects. For two recent studies for the National Highway Traffic Safety Administration (NHTSA), ICF applied the CMAQ and BenMAP tools for a national domain to assess the future air quality/health benefits of 1) various Corporate Average Fuel Economy (CAFE) standards proposed for cars and trucks and 2) the Medium- and Heavy-Duty Fuel Efficiency Improvement Program. ICF is also represented on EPA's Community Modeling Analysis System (CMAS) advisory group that provides advice to EPA regarding the development and use of CMAQ, BenMAP, and other air quality assessment tools.

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