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ATMOSPHERIC NITROGEN DEPOSITION LOADINGS TO THE CHESAPEAKE BAY:

AN INITIAL ANALYSIS OF THE COST EFFECTIVENESS OF CONTROL OPTIONS

November 1996

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Prepared for:

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DISCLAIMER

FOREWORD

This report, the first in a series, examines the cost effectiveness of control options which reduce nitrate deposition to the Chesapeake watershed and to the tidal Bay. The report analyzes current estimates of the reductions expected to be brought about by implementation of the Clean Air Act Amendments of 1990 and additional reductions expected in the ozone transport region. Two regional models, the Regional Acid Deposition Model (RADM) of the airshed and the Chesapeake Bay Watershed Model (CBWM), track nitrate and its precursors from emission to deposition, and from deposition in the watershed to the tidal Bay.

The ultimate object of this analysis is to determine the sources of atmospheric nitrate deposited to the Bay, the loads from each major source, the load reduction amount brought about by controls, and the cost of these reductions. Seen in context, this initial analysis is set against a backdrop of rapidly improving monitoring, science, and modeling of the fate and transport of atmospheric nitrogen deposition. Nitrate monitoring over open tidal waters has improved over the past two years. Likewise, recent research in the area of cross-media nitrogen transfers has been particularly active. Refinements to the CBWM, to be completed in November, 1996, will further improve watershed modeling tools for the analysis of cross-media nitrogen transfer across the Chesapeake Bay's watershed and airshed.

The initial analysis of control option cost effectiveness reported here contributes to the establishment of a first-order estimate of control cost and is useful in distinguishing control options of relatively greater, or lesser, cost effectiveness. Methodologies of cost analysis applied in this report will be improved with the consideration of atmospheric deposition to other estuaries and by an expanded consideration of cross-media benefits in subsequent reports scheduled for publication in 1997.

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ACRONYMS AND ABBREVIATIONS

AFL	above fall line
AREAL	Atmospheric Research and Exposure Assessment Lab
ASCs	area source categories
BFL	below fall line
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CARB	California Air Resources Board
CBPO	Chesapeake Bay Program Office
CBWM	Chesapeake Bay Watershed Model
CMSA	consolidated metropolitan statistical area
EPA	U.S. Environmental Protection Agency
ERCAM	Emission Reduction and Cost Analysis Model
ETSD	Energy and Transportation Sectors Division
Evs	electric vehicles
GDP	gross domestic product
HDTs	heavy-duty trucks
I/M	inspection and maintenance
kg	kilograms
km	kilometers
lbs	pounds
LDGV	light-duty gasoline vehicle
LDTs	light-duty trucks
LDVs	light-duty vehicles
LEV	low-emission vehicle
MD	Maryland
MMBtu	million British thermal unit
MOU	memorandum of understanding
mph	miles per hour
MSA	metropolitan statistical area
NAPAP	National Acid Precipitation Assessment Program
NMOG	non-methane organic gases
NO_x	oxides of nitrogen
NSR	New Source Review
O&M	operating and maintenance
OAQPS	Office of Air Quality Planning and Standards
OPPE	Office of Policy, Planning and Evaluation
OTAG	Ozone Transport Assessment Group
OTC	Ozone Transport Commission
OTR	Ozone Transport Region
RACT	reasonably available control technology
RADM	Regional Acid Deposition Model
ROM	Regional Oxidant Model
SCCs	source classification codes
SCR	selective catalytic reduction

ACRONYMS AND ABBREVIATIONS (continued)

SIP	State Implementation Plan
TLEV	transitional low emission vehicle
tpy	tons per year
ULEV	ultra-low emission vehicle
VA	Virginia
VMT	vehicle miles traveled
ZEV	zero-emission vehicle

EXECUTIVE SUMMARY

To address the problems of excess nutrients in the Bay, the Chesapeake Bay Program jurisdictions have committed to reduce nitrogen and phosphorus pollution reaching the Bay by 40 percent from 1985 levels by the year 2000. Nutrients in the Chesapeake Bay originate from point sources (e.g., municipal and industrial wastewater), non-point sources (e.g., cropland, animal wastes, urban and suburban runoff), and airborne contaminants. Atmospheric nitrogen is largely produced from burning fossil fuels; its two largest sources are automobiles and fossil fuel electric generating plants. Atmospheric deposition accounts for 27 percent of the Bay's total nitrogen load. Thus, control of atmospheric sources could have significant potential to help the Bay watershed jurisdictions reach and maintain their 40 percent target reductions in a cost effective manner.

The nutrient reduction called for in the Bay Agreement is 40% of controllable loads. Controllable loads are defined as loads from point sources and nonpoint source loads from agriculture and urban land uses. Nonpoint source loads from forest and loads from air deposition are considered to be uncontrollable. As information from monitoring, research, and modeling analyses of atmospheric deposition loads increases, air deposition loads more become an important component of the Bay Agreement.

The purpose of this project was to examine whether programs to control regional airborne oxides of nitrogen (NO_x) are cost-effective ways to reduce nitrogen loads to the Bay compared with other management scenarios. Regional control programs considered in this analysis include: the Low Emission Vehicle (LEV) program of the Ozone Transport Commission (OTC), and a 0.15 pounds (lbs) per million British thermal unit (MMBtu) NO_x emission limit applied to large fuel combustors in the Northeast Ozone Transport Region (OTR) States. The effect of extending the OTR programs to wider areas of the country - whose emissions also influence the Bay - was also examined.

The above can be described as three primary scenarios, as listed below:

1. Clean Air Act (CAA) Scenario: The expected 2005 baseline under the CAA, with mandatory programs applied.
2. Scenario C2: The 2005 CAA Scenario with the OTC-LEV program, plus a 0.15 lbs/MMBtu NO_x emission limit applied to huge fuel combustors in the Northeast OTR (OTC Scenario).
3. Scenario E: Scenario C2 controls applied to the entire airshed. This airshed includes the NO_x source areas outside the Northeast OTR States that contribute the most to nitrogen deposition within the Bay watershed.

Information from three modeling efforts were used to perform this analysis. The Emission Reduction and Cost Analysis Model (ERCAM) for NO_x was used to project 2005 emission levels and control costs for the three scenarios listed above. The U.S. Environmental Protection Agency's (EPA) Atmospheric Research and Exposure Assessment Laboratory (AREAL) used the Regional Acid Deposition Model (RADM) to estimate airborne nitrogen deposition within the modeling domain for each of the three control scenarios. Lastly, the EPA Chesapeake Bay Program Office's (CBPO) Chesapeake Bay Watershed Model was used to estimate how differences in atmospheric nitrogen loadings to the Bay waters would affect; associated nitrogen loadings to the tidal waters of the Bay.

Table ES-1 summarizes the study results for the primary air pollution control scenarios, sectors, and geographic divisions included in the study. Results are expressed in terms of the estimated reduction in nitrogen load and cost per pound of nitrogen reduced for applying controls in the Chesapeake Bay Program States (Pennsylvania, Maryland, Virginia, and the District of Columbia) as well as for the entire airshed affecting the Chesapeake Bay watershed Table ES-1 shows that by adopting and implementing the OTC-LEV and Stationary Source NO_x Initiatives, the Bay States can reduce nitrogen loads to the tidal waters of the Chesapeake Bay at a cost of $75 per pound of nitrogen load. This is cost competitive with the higher cost non-point source control measures such as forest and urban management practices, even without allocating any of the costs to other likely benefits of these programs, such as reducing ozone levels in the Northeast OTR, or reducing nitrogen deposition to the Great Lakes and other east coast estuaries besides the Chesapeake Bay.

NO_x control costs almost double as controls are extended from the Bay States to the entire Chesapeake Bay Airshed 2 States. Further controls of NO_x emissions from steam-electric utility plants are the most cost effective control measures, even when applied throughout the entire Bay airshed. Requiring cars and light trucks to meet LEV standards outside the OTR is expected to be more cost effective in reducing nitrogen loads than further industrial source controls in these States.

If OTC programs to reduce NO_x emissions are to be extended outside the Northeast OTR the State with the most cost effective emission reductions (cost per pound of nitrogen load reduced) is West Virginia. Controls in other non-OTC States are likely to be less cost effective than higher cost non-point source control management practices.

This analysis represents an important step in determining cost-effective strategies for reducing atmospheric nitrogen deposition to the Chesapeake Bay. Further refinement of the cost estimates would involve separating out those costs directly attributable to reducing nitrate loadings from those costs associated with other programs (reducing ambient ozone, nitrogen dioxide, and particulate concentrations) that, while intended for other environmental purposes, also reduce nitrate loadings.

In modeling a situation, like this one, where long-range transport of air pollutants is so important, it is difficult to make a fair comparison of costs and benefits. This difficulty occurs because the geographic area where the costs are incurred is frequently not the same area where the benefits are observed. In expressing the costs of the OTC-LEV petition and the Stationary Source NO_x Initiative, the costs observed in New England States outside the Bay Airshed 2 States have been omitted from the program costs presented in this report, because the benefits of NO_x controls applied in these States are not observed within the airshed. It should also be noted that benefits likely to be observed in watersheds other than the Chesapeake Bay (the Great Lakes, Long Island Sound, and Massachusetts Bay, for instance) have not been used to discount the costs presented here, either.

Table ES-1
Cost Comparison of Air Pollution Controls by Scenario:
Chesapeake Bay Assessment States versus Airshed 2 States[1]

	Bay States[2]		Airshed 2	
Scenario	Load Reduced (thousand lbs)	Cost per Pound ($/lb)	Load Reduced (thousand lbs)	Cost per Pound ($/lb)
CAA Scenario[3]	5,330	$75	11,570	$123
Scenario C2	6,480	$75	–	–
Scenario E	7,760	$77	17,010	S147
Sector				
Highway Vehicle (LEV)[4]	970	$132	1,700	$329
Utility (0.15 lbs/MMBtu)[4]	5,230	$54	14,610	$95
Non-Utility (0.15 lbs/MMBtu)[4]	180	$396	1,190	$466

NOTES: [1]The Chesapeake Bay Airshed 2 States include all or part of the following States: Delaware, the District of Columbia, Indiana, Kentucky, Maryland, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia.
[2]Bay States represent Pennsylvania, Maryland, Virginia, and the District of Columbia.
[3]Reductions and costs for the CAA Scenario are with respect to 1990 loads and, therefore, incorporate growth, as well as controls. Eliminating the effect of growth would result in higher load reductions and lower costs.
[4]Controls were applied only in the OTR for the Bay States analysis.

CHAPTER I
INTRODUCTION

In the Chesapeake Bay, two problems impair the growth of aquatic life. Low oxygen conditions and overgrowth of algae both contribute to the Bay's poor water quality and aquatic habitat loss. Land use changes and population growth have contributed to higher amounts of nutrients entering the Bay's tidal waters, which in turn lead to low oxygen levels and increased algae growth. Nitrogen and phosphorus are two nutrients that are contributing to poor water quality in the Bay. Excess nitrogen is responsible for eutrophication (low dissolved oxygen), which is the most significant water quality problem facing the Bay. Eutrophic conditions arise when excess nitrogen (a nutrient) feeds algal blooms which, in turn, consume oxygen as they decay. In order to address the problems of excess nutrients on the Bay, the Chesapeake Bay Program jurisdictions have committed to reduce nitrogen and phosphorus pollution reaching the Bay by 40 percent from 1985 levels by the year 2000.

Nutrients in the Chesapeake Bay originate from point sources (e.g., municipal and industrial wastewater), non-point sources (e.g., cropland, animal wastes, urban and suburban runoff), and airborne contaminants. Atmospheric nitrogen is largely produced from burning fossil fuels; its two hugest sources are automobiles and fossil fuel electric generating plants throughout the Chesapeake Bay airshed, which extends well beyond the watershed. Computer models indicate that about 10 percent of the Bay's nitrogen load is from airborne nitrogen deposited directly on the Bay surface and the tidal portion of its tributaries (EPA, 1994). Atmospheric nitrogen deposited throughout the 64,000 square mile watershed eventually runs into the tidal Bay. Air pollution accounts for 27 percent of the Bay's total nitrogen load.

To date, efforts to reduce nitrogen in the Bay have focused exclusively on point and non-point sources in the watershed. As the limit of nitrogen loading reductions from these sources is approached, the cost effectiveness of additional measures declines. Control of atmospheric sources has significant potential to help the Bay watershed jurisdictions reach and maintain their 40 percent target reduction in nitrogen loadings in a cost effective manner. For the above fall line basins, mobile sources contribute 30 to 40 percent of the inorganic nitrogen deposition from airborne sources. Utility and non-utility point sources contribute 30 to 50 percent of the inorganic airborne nitrogen deposition to the Bay (Dennis, in press).

The States of Pennsylvania, Maryland, and Virginia; the District of Columbia; the Chesapeake Bay Commission; and the Federal Government represented by EPA, are partners in the Chesapeake Bay Program to reduce controllable phosphorus and nitrogen to the Bay by 40 percent by the year 2000 (Chesapeake Executive Council, 1987). The purpose of this analysis is to examine whether programs to control regional airborne NO_x are cost-effective ways to reduce nitrogen loads to the Bay compared with other management scenarios. Regional control programs considered in this analysis include: the LEV program of the OTC, and a 0.15 lbs per MMBtu NO_x emission limit applied to large fuel combustors in the Northeast OTR States. These two programs are referred to throughout this report as the OTC-LEV petition, and the OTC Stationary Source NO_x Control Initiative, respectively. The effect of extending the OTR control programs to wider areas of the country was also examined.

A major component of this analysis was the calculation of emissions reductions by source from control technologies and policies for which control efficiency and cost data were available. Sources affected by the airborne NO_x control strategies examined in the analysis included steam-electric utility plants, non-utility point sources, and motor vehicles.

The information flow in the analysis performed can be summarized as follows:

1. Emission data files were prepared for the 1990 base year and for 2005 to estimate ozone precursor emissions under different control strategies. These files were developed primarily as Regional Oxidant Model (ROM) inputs.

2. The Atmospheric Sciences Modeling Division at EPA's AREAL used the NO_x emission estimates from the ROM input files as input to the RADM. For some model runs, the scenarios were combined in different ways to apply outside the OTC State controls to the Chesapeake Bay airshed, as opposed to the entire ROM domain.

3. RADM outputs were provided to EPA's CBPO, where the Chesapeake Bay Watershed Model (CBWM) was used to quantify the impacts that airborne nitrogen deposited on the Bay watershed eventually has on nitrogen levels in the Bay tidal waters.

The NO_x emissions data files prepared as inputs to ROM included emission estimates for the following three scenarios:

- **Clean Air Act (CAA) Scenario:** CAA Baseline Case for year 2005 Baseline;
- **Scenario C2:** CAA Baseline controls plus the OTC-LEV petition and the Stationary Source NO_x Control initiative; and
- **Scenario E:** Scenario C2 controls applied to the entire airshed.

This report is organized in eight chapters, beginning with this introduction. Chapter II provides some summary information about the study region, and about the following three models that provided inputs to this analysis: ERCAM, RADM, and the CBWM. Chapter III describes the NO_x emission control scenarios that were examined in this analysis. Analysis methods for this study are detailed in Chapter IV. Airborne NO_x emissions and cost analyses are described in Chapter V. Results are presented in Chapter VI. Notable caveats and uncertainties are described in Chapter VII. Chapter VIII presents a summary of the conclusions of this analysis.

CHAPTER II
BACKGROUND

In addition to evaluating specific control programs in the OTR, this analysis also evaluated the effects of expanding the regions in which controls may be applied. This chapter identifies and describes the geographic areas important to this analysis. Background information on the models used in the overall approach to evaluate the impact of NO_x controls on nitrogen loadings to the Chesapeake Bay is also provided in this chapter.

A. AREA DEFINITIONS

There are several area definitions which are important to understanding the role of airborne nitrogen deposition within total nitrogen loads to the Chesapeake Bay. Nitrogen that is deposited within the watershed, or directly to tidal Bay water surfaces, both contribute to total nitrogen loads to the mainstream Bay and its tidal tributaries. The Chesapeake Bay watershed is shown in Figure II-1. Nitrogen deposited on laud and along stream edges may enter the water through run-off. Nitrogen entering through run-off, along with that deposited directly to the streams and rivers, is transported through the waters with losses resulting from biological, chemical, and physical processes (Linker et al.; 1993). A significant fraction of this nitrogen eventually enters the Bay and, along with the nitrogen deposited directly to Bay water surfaces, adds to Total nitrogen loads to the Chesapeake Bay.

The geographic range of influence of atmospheric pollution sources on nitrogen deposition to the watershed is referred to as the airshed. RADM was used to determine the range of influence leading to the definition of Airshed 1 and Airshed 2 (Dennis, in press). Airshed I was initially defined as the sphere of influence. Further modeling indicated that emissions from this region accounted for less than the anticipated 70 to 80 percent. The airshed was further expanded to reflect Airshed 2, which accounts for just over 70 percent of nitrogen deposition across the watershed. The geographic boundaries of Airshed 2 are shown in Figure II-2. Airshed 2 is still considered to be a conservative estimate of the actual airshed for the Chesapeake Bay.

Airshed 2 was used as the basis for determining which States should be included in the cost effectiveness modeling. The New England States, while affected by the OTC-LEV petition and the Stationary Source NO_x Initiative, are outside the range of influence on Chesapeake Bay nitrogen loadings defined by Airshed 2 and have therefore not been included in this cost effectiveness analysis. Figure II-3 shows the States examined in the cost analysis, both inside and outside of the OTR Because Airshed 2 includes a portion of Indiana, Kentucky, and Tennessee, decisions had to be made about whether to include or exclude these States from the cost analysis. Kentucky and Tennessee were included, and Indiana was excluded from the cost analysis based on source contribution information from RADM.

FIGURE II-1
Chesapeake Bay Watershed
as Delineated by RADM
20 km x 20 km Grid

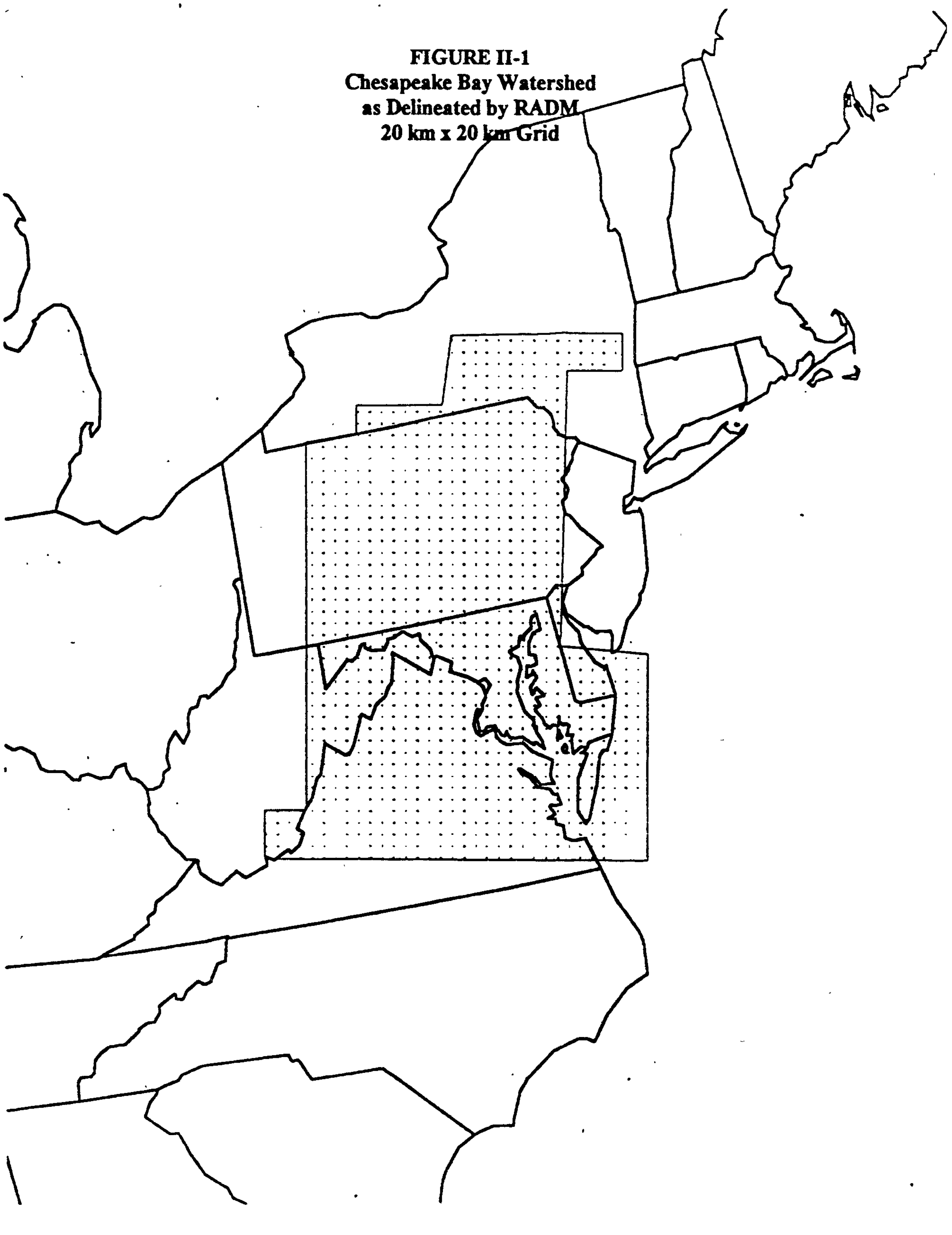


FIGURE II-2
Chesapeake Bay Airshed 2

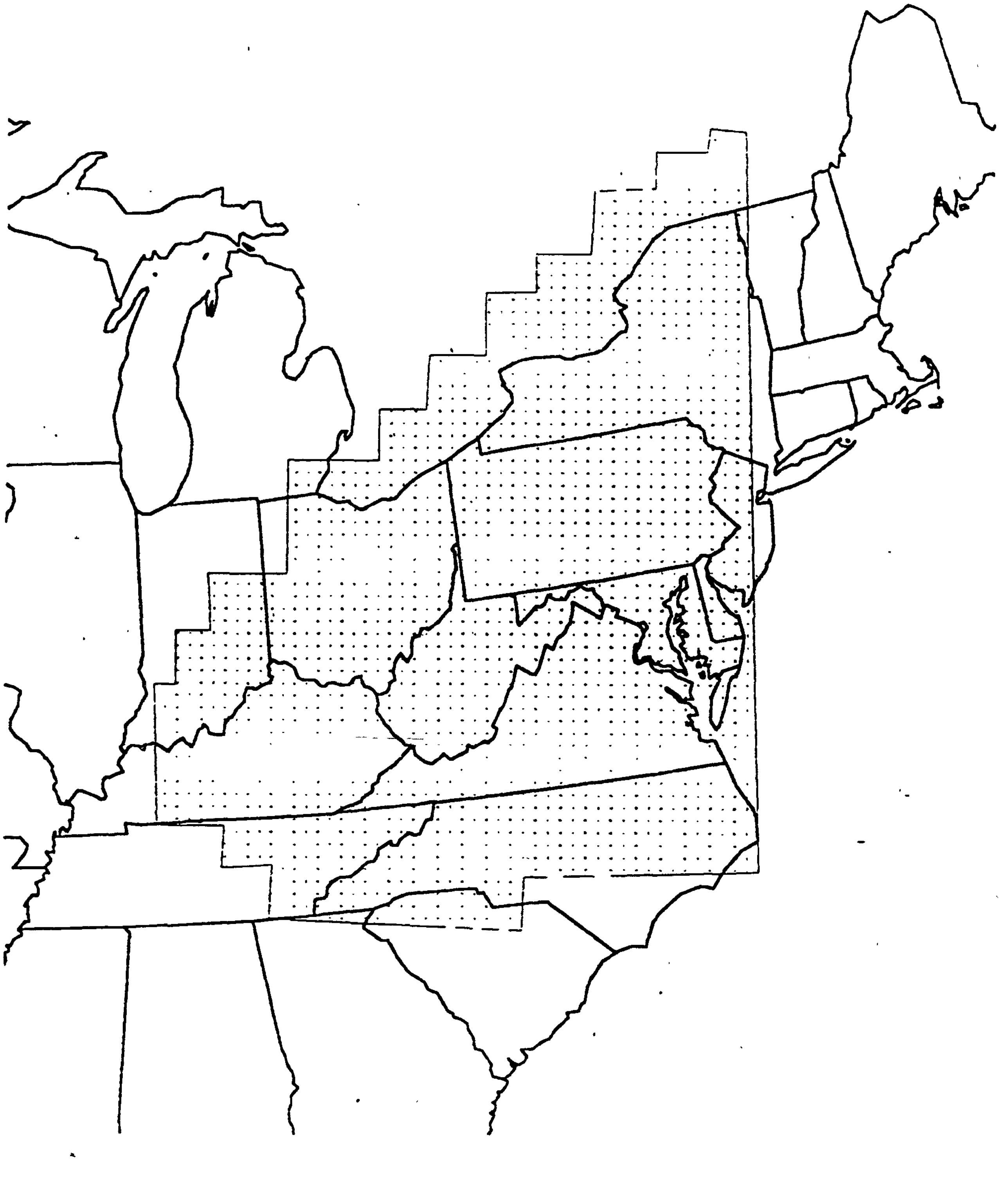
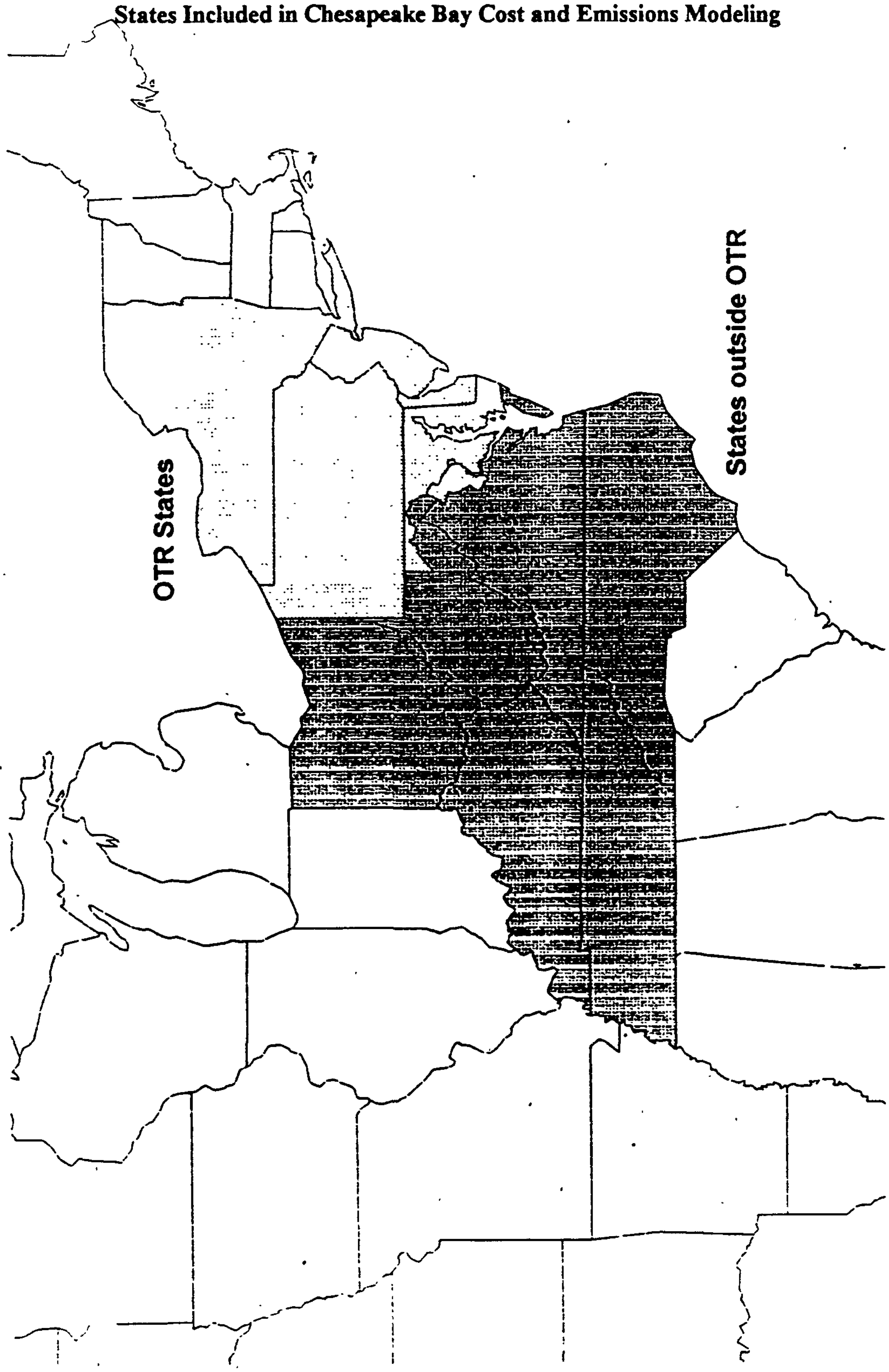


FIGURE II-3

States Included in Chesapeake Bay Cost and Emissions Modeling



The final important term for this analysis is source-region. A source-region is defined according to both emission sources and geographic boundaries. The impact of NO_x emissions on atmospheric deposition were examined for several source-regions using RADM (Dennis, 1996). Examples of source-regions include: all sources in Airshed 2; mobile sources in Maryland; utilities in Pennsylvania; and all sources in the Bay States. Source-regions are defined to examine the importance and cost-effectiveness of controls in any combination of regions and source types.

B. ERCAM

ERCAM-NO_x is a national model designed to examine the emission reductions and costs associated with a variety of NO_x control measures (Pechan, 1994c). This model projects costs and emissions associated with NO_x control measures, using the Interim 1990 Inventory as input data (EPA, 1993). ERCAM-NO_x is divided into separate modules to address the unique growth and control strategy applications of each of the following four emission sectors: steam-electric utilities, non-utility point sources, motor vehicles, and non-road engines/vehicles.

In the ERCAM-NO_x development process, the modeling objectives established for model design were to:

- provide quick turnaround analyses to EPA;
- model all sectors of NO_x emitters, and to incorporate control measures covering as large a percentage of the inventory as possible;
- use the Interim 1990 Inventory as input data and design the model so that State Implementation Plan (SIP) inventories for 1990 can be easily incorporated as they become available;
- examine costs and emission results at the State or regional level;
- provide accurate results at the nonattainment area level, as well as at the national level;
- provide results in a spreadsheet format for EPA use; and
- incorporate multiple control measures for each source category to allow for easy examination of the costs and benefits of different levels of control.

Control and cost information for the model is organized by cost pod in the control strategy data bases. A pod is a group of source types, as defined by source classification codes (SCCs) or area source categories (ASCs), which have similar process and emission characteristics, control techniques, and control costs. A cost pod may have one or several control options (which consist of the control technique, efficiency, and cost parameters). The basic structure of the control strategy data bases is shown in Table II-1.

Table II-1
Basic Elements of Control Strategy Data Base

Pod	Source category or grouping of SCCs for control purposes
Pod Name	Descriptive name of pod
CS	Control strategy code
CS Name	Control strategy name (e.g., selective catalytic reduction [SCR])
Reduction	Percentage reduction associated with the control
Cost Parameters	Size-specific cost equation parameters for capital and operating and maintenance (O&M) costs; cost per ton estimate for sources where size-specific equations are not applicable

A unique **ERCAM-NO_x** simulation is defined by:

- Projection year (1996, 1999, 2002, 2005, 2007, 2010);
- Scenario file name;
- Whether Title IV (Acid Rain) controls are included,
- Point source reasonably available control technology (RACT) size cutoffs; and
- Motor vehicle scenario name.

The *scenario file* designates which control strategies will be applied to each ozone nonattainment classification, as well as to attainment areas within the Northeast Transport Region. The *control strategy code* specifies which control measure will be applied to that combination of ozone nonattainment category and pod. The complete set of attainment category/pod/control strategy combinations is referred to by a unique three- character string, such as "CAA" or "MAX." The emission reduction and cost parameters associated with the control strategy are stored in the control strategy file.

Title IV controls represent the emission limits for utility boilers mandated under the CAA. Each existing unit has been identified as a phase 1 or phase 2 unit, and control strategies have been selected to bring units into compliance with the expected Title IV **NO_x** standards.

The CAA major source size definitions are chosen as the default RACT source size cutoffs. Other cutoffs may be specified, with separate cutoffs for each nonattainment classification Default RACT source sizes are according to major stationary source definitions, which are 100 tons per year (tpy) in moderate ozone nonattainment areas and the OTC States, 50 tpy in serious ozone nonattainment areas, 25 tpy in severe areas, and 10 tpy in extreme areas.

Similar to the stationary source scenario, a motor vehicle scenario is also chosen for a model simulation. The motor vehicle scenario file specifies which set of MOBILE5a emission factors to apply to each county. Flags included are: type of inspection and maintenance (I/M) program, reformulated gasoline, oxygenated fuels, CAA tailpipe standards, and California LEV program. This file also drives which cost parameters to apply to estimate the cost of motor vehicle controls. The motor vehicle cost file contains costs for each of these options in dollars per registered vehicle, dollars per mile traveled or dollars per new vehicle.

The control cost equations have been updated several times since the latest **ERCAM-NO_x** documentation was prepared. Such updates have been included in the cost calculations performed for this analysis. The most significant of these updates is to the cost equations for advanced technologies (such as SCR) being applied to steam-electric utility boilers (Acurex, 1995). Updating these cost equations served to lower the cost per ton of **NO_x** reduced for the stationary source control measures that might be needed to comply with the Stationary Source **NO_x** Initiative.

The results of applying the OTC-LEV program and the Stationary Source **NO_x** Initiative are measured from a projection of **NO_x** emissions in 2005 under a CAA baseline. The CAA baseline was developed by applying growth and control factors to the Interim 1990 Inventory (the base year inventory) (EPA, 1993). For **NO_x**, the most significant control measures included in the CAA baseline are as follows:

1. *RACT-level controls in major stationary sources* are applied according to the major stationary source definition, which varies by ozone nonattainment area classification. Affected areas are the entire Northeast OTR and ozone nonattainment areas outside the OTR.

2. *Title IV (Acid Rain) NO_x emission limits* affect certain steam-electric utility units (Phase I and Phase II boilers).

3. Areas with planned *enhanced I/M programs* achieve NO_x benefits. Highway vehicle emissions are also affected by new *Federal emission standards (Tier 1).*

4. Certain categories of nonroad engines/vehicles are assumed to be affected by new *Federal emissions standards.*

5. New sources in ozone nonattainment areas and the OTR are subject to more stringent *New Source Review (NSR)* requirements. Projections assume that SCR is representative of NSR requirements.

C. RADM

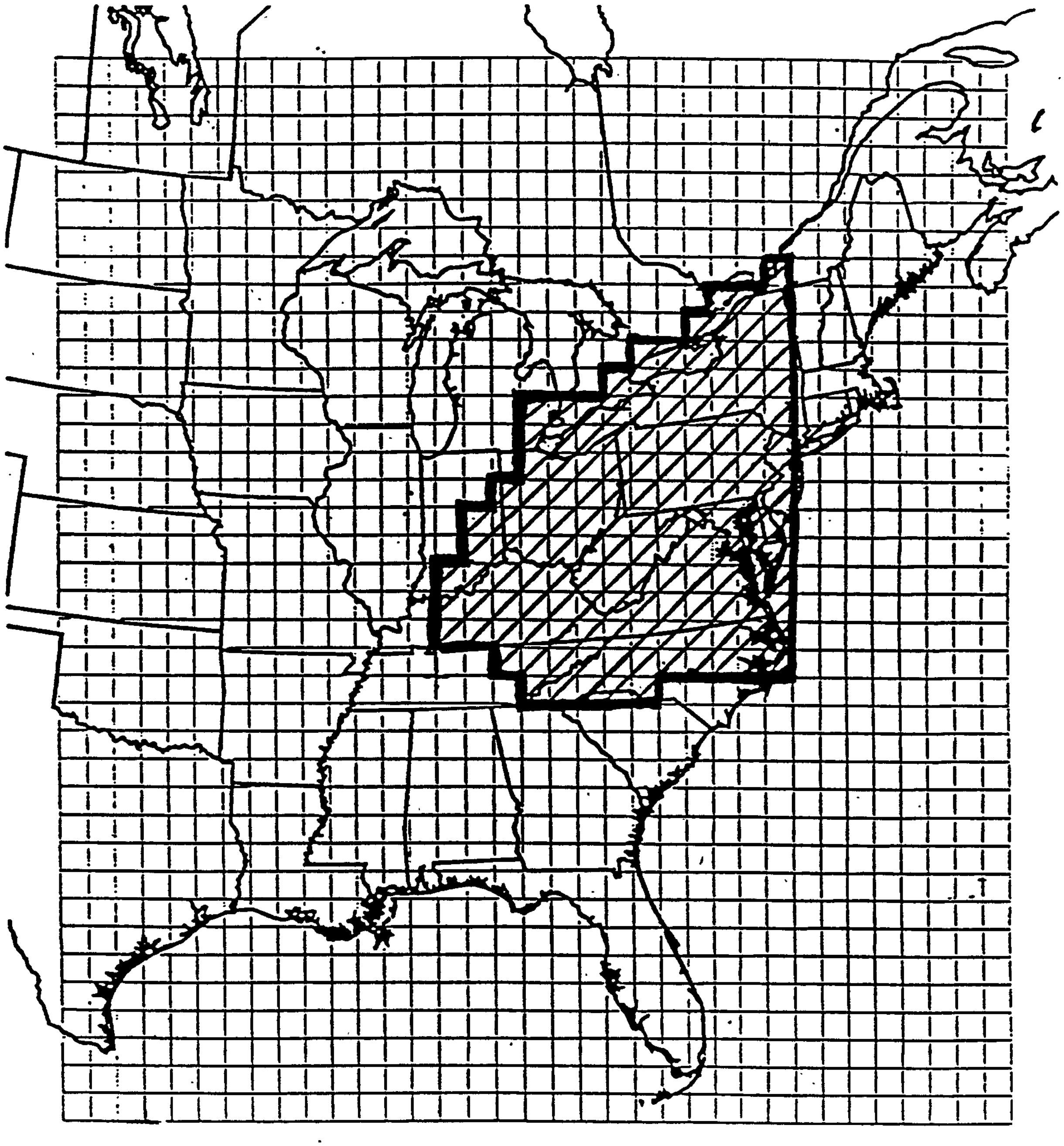
EPA's RADM supplied the airborne nitrogen deposition estimates for the different control scenarios evaluated in this study (Dennis, in press). RADM has been developed over the past ten years under the auspices of the National Acid Precipitation Assessment Program (NAPAP) to address policy and technical issues associated with acidic deposition. The model is designed to do the following: to provide a scientific basis for predicting changes in deposition occurring as a result of changes in precursor emissions; to predict the influence of sources in one region on acidic deposition in other sensitive receptor regions; and to predict the levels of acidic deposition in certain sensitive receptor regions.

The RADM is a Eulerian model in which concentrations of gaseous and particulate species are calculated for specific fixed positions in space (grid cells) as a function of time. The concentration of a specific pollutant in a grid cell at a specified time is determined by the following variables: the emissions input rate; the transport of that species by wind into and out of the grid in three dimensions; movement by turbulent motion of the atmosphere; chemical reactions that either produce or deplete the chemical specie; the change in concentration due to vertical transport by clouds; aqueous chemical transformation and scavenging; and removal by dry deposition.

The version of RADM used for these analyses is referred to as RADM2.61, and covers a geographic domain of 2,800 by 3,040 kilometers (km) that stretches from east of central Texas and south of James Bay, Canada, to the southern tip of Florida. RADM2.61 uses grid cells of 80 by 80 km and has 15 logarithmically-spaced vertical layers, covering the distance from ground level to 16 km in altitude, the top of the free troposphere, and the beginning of the stratosphere. The RADM horizontal domain consists of 36 by 38 km horizontal grid cells, which, together with 15 vertical layers, results in a total of 19,950 cells. The geographic boundaries of RADM domain are illustrated in Figure II-4, with the periphery of the Airshed 2 region also highlighted.

The meteorological fields used to drive the RADM were from the Pennsylvania State University Center for Atmospheric Research Mesoscale Model (MM4). The MM4 is a weather model; it is used to recreate historical meteorology in detail. Because RADM predicts hourly chemistry on a synoptic time scale of several days (chemical meteorology), an aggregation technique developed during NAPAP is used to develop annual estimates of acidic deposition (Dennis et al., 1990).

Figure II-4
RADM Domain and Chesapeake Airshed 2 Boundaries



Eulerian, or fixed-grid models, are suitable for representing the full, complex non-linearity of the photochemistry involved in the oxidation of primarily-emitted species to acidic substances. However, Eulerian models have not been used to study source-receptor relationships.

The range of influence of point source NO_x emissions on nitrogen deposition predicted by the RADM is about 700 to 800 km. This range is consistent with a residence time of 1 to 1.5 days. For all practical purposes, the range of influence of area sources is the same as for point sources, according to the RADM. The model rapidly mixes the primary emissions and the secondary oxidation products vertically throughout the mixed layer during daylight hours. The vertical mixing in the model is evidently thorough enough to mask any distinction of emissions source height.

D. CHESAPEAKE BAY WATERSHED MODEL

The Chesapeake Bay Program has developed models for the Bay drainage basin and the tidal waters of the Bay. The CBWM, which covers the entire 64,000 square miles of the drainage basin, was initially developed during the research phase of the program and has been updated periodically (Linker et al., 1993; Donigian et al., 1991). In 1992, the CBWM helped establish the Chesapeake Bay Agreement nutrient reduction goals for all the major Chesapeake Bay tributary basins*. Since then, the CBWM has gone through two major refinements (Phase III and Phase IV) aimed at providing a better tool for tracking progress toward achieving the year 2000 basinwide 40 percent nutrient reduction goal. Completion of these refinements is scheduled for November, 1996**. The cost effectiveness analysis results reported here are based on the initial phase of CBWM refinements, which incorporates finer spatial detail in land use and model segmentation***. A more comprehensive analysis of the cost effectiveness of air controls, to be completed in 1997, will be based on the Phase IV CBWM which includes daily inputs of wet deposition, a refined spatial accounting of dry deposition, and improved simulation of atmospheric nutrient inputs on forest, pasture, and urban lands. Figure II-5 illustrates the segmentation of the Phase III Chesapeake Bay Watershed Model coverage by basin. The Phase III Watershed Model was calibrated for the four-year period from 1984 to 1987 based on monitoring data from the tributaries.

The CBWM simulates nonpoint source nutrient loads from eight land uses, point source nutrient loads, and atmospheric deposition nutrient loads. Table II-2 lists the distribution of 1985 CBWM land uses for the basin. The CBWM processes these loads through the river systems and delivers the loads to the Bay for use in the model. The Watershed Model has been used to evaluate the load reductions for a range of different management scenarios, to establish the controllable non-point source loads, to forecast the loads from a projected 2000 land use and population growth scenario, and to define a limit of technology scenario for non-point source control measures. The output from the CBWM is used to develop the input loads for the Chesapeake Bay Water Quality Model.

* Phase II Chesapeake Bay Watershed Model
** Phase IV Chesapeake Bay Watershed Model
*** Phase III Chesapeake Bay Watershed Model

Figure II-5
Chesapeake Bay Watershed Model Segmentation

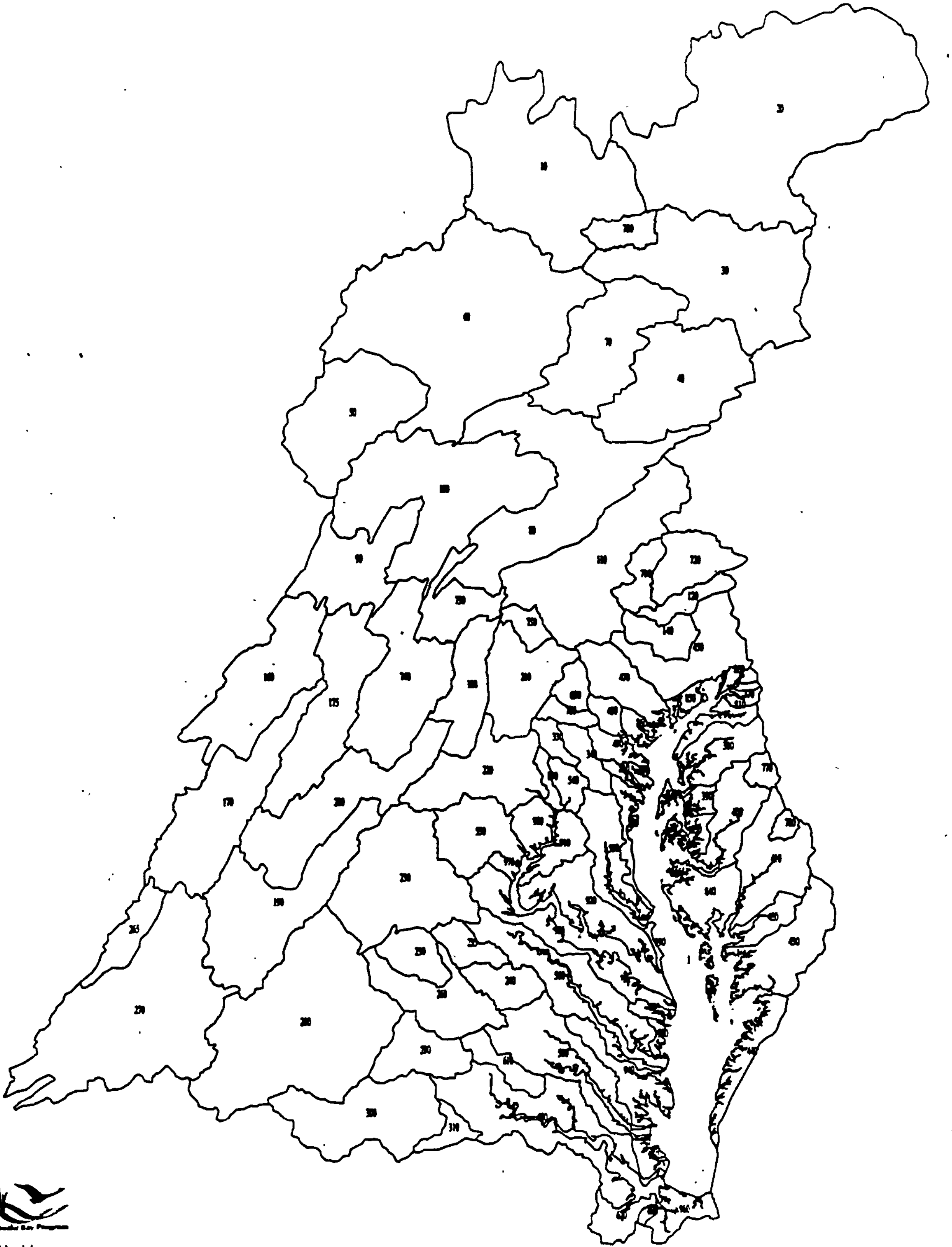


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Table II-2
Distribution of Land Uses in the Chesapeake Basin Watershed Model

Land Use	Total Acreage	Percentage of Total Basin
Cropland	8,237,125	20%
Pasture	3,740,981	9%
Forest	24,457,144	60%
Urban	4,032,669	10%
Water	526,115	1%
Animal Waste	12,650	<1%

SOURCE: EPA 1995.

CHAPTER III
NO_x CONTROL PROGRAMS EVALUATED

Two regional NO_x control programs were modeled in this analysis. The OTC-LEV petition is designed to reduce mobile source emissions, and the Stationary Source NO_x Initiative is targeted to reduce emissions from large fuel combustors. Background information on each of the NO_x control programs being evaluated in Scenario C2 and Scenario E is provided in this chapter.

A. OTC LOW EMISSION VEHICLE PROGRAM

In September 1990, the California Air Resources Board (CARB) approved its LEV and Clean Fuels regulations (CARB, 1990). These regulations establish four new classes of light- and medium-duty vehicles with increasingly stringent emission levels: transitional low emission vehicle (TLEV), LEV, ultra-low emission vehicle (ULEV), and zero-emission vehicle (ZEV). The regulations also established a decreasing fleet average standard for emissions of non-methane organic gases (NMOG). Auto manufacturers can meet the fleet average NMOG standard using any combination of TLEVs, LEVs, ULEVs, and ZEVs they choose. However, CARB also included a ZEV requirement as part of the LEV regulations. Starting in 1998, 2 percent of the vehicles produced for sale in the State must be ZEVs. This percentage increases to 5 percent in 200 1 and to 10 percent in 2003. ZEVs are defined as vehicles with no direct exhaust or evaporative emissions; only battery-powered electric vehicles (EVs) are expected to meet this standard in the near term.

Since the LEV program was adopted in California, many States in other areas of the country have considered exercising their authority under Section 177 of the CAA to adopt the California emission standards. Interest in this program began in the Northeast States. Since then, States in the mid-Atlantic region have evaluated program adoption. Other States that have considered LEV adoption have included Texas, Illinois, and Wisconsin. In October 1991, OTC States signed a memorandum of understanding (MOU) on the California LEV program (OTC, 1991). In signing this MOU, each of the member States agreed to propose regulations and/or legislation as necessary to adopt light-duty motor vehicle standards identical to those in the California LEV program, effective in the OTR as soon as possible and in accordance with Section 177 of the CAA.

On February 1,1994, the OTC voted to recommend that EPA mandate the California LEV program in the Northeast, and shortly thereafter presented a petition to EPA (OTC, 1994). The analyses presented in this report for the costs and benefits of the OTC-LEV program are from analyses performed by an EPA contractor in September 1994 (Pechan, 1994a; Pechan, 1994b). Since the time that these analyses were completed, the Northeast States and the auto manufacturers have discussed the option of a 49-State LEV program. If a 49-State LEV program is adopted, then the emissions and costs for the modeling region will change somewhat from the results of the September/December 1994 analyses.

B. STATIONARY SOURCE NO_x INITIATIVE

In September 1994, the OTR States signed an MOU on development of a regional strategy for the control of NO_x emissions from stationary sources (OTC, 1994). Through this MOU, the member States agreed to propose regulations ant/or legislation for the control of NO_x emissions from boilers and other indirect heat exchangers with a maximum gross heat input rate of at least 250 MMBtu per hour. Requirements are proposed to be somewhat different for each of the three zones within the Northeast OTR These three zones are: (1) the OTR's Northern Zone, consisting of the northern portion of the OTR (2) the OTR's Inner Zone, consisting of the central eastern portion of the OTR, and (3) the OTR's Outer Zone consisting of the remainder of the OTR Figure III-1 illustrates the boundaries of the Inner, Outer, and Northern Zones of the OTR

The States agreed to require sources in the Inner and Outer Zone to either reduce their rate of NO_x emissions by 75 percent from base year levels by May 1,2003, or to emit NO_x at a rate no greater than 0.15 lbs per MMBtu. In the Northern Zone, States agreed to require subject sources to reduce their rate of NO_x emissions by 55 percent from base year levels by May 1,2003, and to emit NO_x at a rate no greater than 0.2 lbs per MMBtu. Note that this represents phase 3 requirements which may be adjusted based on modeling and other information on the amount of NO_x reductions needed to achieve air quality standards.

As part of this study, the effects of the OTR stationary source NO_x initiative were simulated by applying control measures necessary to reduce each unit's emission to 0.15 lbs of NO_x per MMBtu or less. While this may overstate the costs and benefits of the initiative in the Northern Zone, the sources in this zone do not affect the Chesapeake Bay watershed.

Figure III-1
Northern, Inner, and Outer Zone Boundaries of the OTR