The Benefits of Air Pollutant Emissions Reductions in Maryland: Results from the Maryland Externalities Screening and Valuation Model

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Abstract

This paper reports the results of policy simulations of environmental and human health externalities arising from the production of electricity. The primary purpose of this paper is to illustrate the Maryland Externalities Screening and Valuation Model, developed for the State of Maryland's Department of Natural Resources. A secondary purpose is to estimate likely Maryland benefits from Title IV emissions reductions at electric power generation facilities. Sources and scope of benefits, and the potential of policy to achieve specific environmental and human health goals, are suggested by the results. We find that expected health benefits from reductions in power plant emissions dominate the estimated benefits of improved recreational visibility and residential visibility. The latter are the only environmental benefits the model is currently equipped to estimate, because of gaps in the science-to-economics literature. The model fully accounts for all significant environmental pathways, so future parameter estimates can be inserted as they are developed. We estimate that in 2010 Maryland health benefits will be about $0.7 billion, while recreational visibility benefits (in Shenandoah National Park) will be approximately $21 million (to residents of Virginia and Maryland), and residential visibility benefits, for inhabitants of a city of the size of Washington, DC and similarly affected by reduced urban visibility, will be about $1.2 million. This integrated-assessment model is designed to estimate and report also the tremendous uncertainties in measuring and valuing these effects.

Key Words: integrated assessment, health and environmental benefits, valuation, uncertainty

JEL Classification Numbers: I18, Q24, Q25, Q26, Q49

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THE BENEFITS OF AIR POLLUTANT EMISSIONS REDUCTIONS IN MARYLAND: RESULTS FROM THE MARYLAND EXTERNALITIES SCREENING AND VALUATION MODEL

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1. INTRODUCTION

This paper reports the results of policy simulations conducted using a probability model of environmental and human health externalities arising from the production of electricity. The primary purpose of the simulations is to illustrate the analytical capabilities of the Maryland Externalities Screening and Valuation Model, which has been developed for the State of Maryland's Department of Natural Resources by Resources for the Future. A secondary purpose of the simulations is to estimate likely benefits to Maryland from the emissions reductions called for by Title IV of the 1990 amendments to the Clean Air Act, for several baseline assumptions about what future emissions would look like, to 2030, in the absence of reductions. These estimates illustrate the sources and scope of benefits from reductions in emissions from electric power generation, and can reveal the potential of emissions reduction policy to achieve specific environmental and human health goals.

Our goal in developing the Maryland Model (MM) has been to account, as completely as possible, for all "damage pathways" mediating between the generation of electricity and ultimate effects on the environment and on human health. In this capacity, the model serves as a complex flow-chart, with the many linkages represented by what qualitative information was available to describe everything from impacts on land use and aesthetics, to changes in visibility, water quality, and health effects. Beyond this descriptive emphasis, we have combed the scientific literature to quantify as many of these linkages as are represented in this literature. Thus, parameter values, uncertainties, and functional forms available in the peer-reviewed academic literature are also represented in the model. As such, it serves as a library of the state-of-the-science research that has been conducted to date, and as a way of revealing significant gaps in this research, damage pathways along which not enough is known to estimate the value of improvements in outcomes on these pathways.

The model is based on a more general, less detailed decision-analysis integrated assessment model developed by RFF and teams of specialists in atmospheric science, soil and water chemistry, and other relevant scientific fields. The basis of MM is a rigorously peer-reviewed probabilistic model (the Tracking and Analysis Framework (TAF) model) used by

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the National Acid Precipitation Assessment Program (NAPAP) to estimate costs and benefits for the U.S. from reductions in acid precipitation. To specialize the model for Maryland, we have added many "modules" describing and quantifying important environmental pathways in Maryland. We have replaced TAF's broad-based source-receptor matrix with a much tighter grid, covering points throughout Maryland. Finally, we have replaced TAF's emphasis on freshwater resources in the Adirondacks region with an emphasis on the estuarine resources of the Chesapeake Bay.

The inputs to the model are emissions projections and source-receptor matrices that predict location-specific emissions and deposition as they will affect Maryland resources. We have further advanced our modeling of the health effects of power plant emissions. And, we have specialized the indexes of the model so that costs and benefits are assessed for Maryland households (and, in some cases, those of nearby states) and Maryland resources, rather than for the United States as a whole.

The model's outputs are monetized estimates of benefits of emissions reductions. Dollar estimates come from the research literature on human valuation of environmental and health outcomes, estimates which are drawn from a variety of careful economic studies.

The Maryland model, and its cousin, TAF, have been developed against the backdrop of the serious environmental consequences of emissions of SO_2 and NOx from electricity generation. Control of SO_2 emissions under the 1990 Clean Air Act Amendments instituted an important innovation in U.S. environmental policy: an average annual cap on aggregate emissions by electric utilities, which has been set at about one-half of the amount emitted in 1980. The emissions cap represents a guarantee that emissions will not increase with economic growth. Title IV also uses a more traditional approach in setting NOx emission rate limitations for coal-fired electric utility units, although this approach has been modified to allow emission rate averaging among commonly owned and operated facilities. Hence, there is no cap on NOx emissions, but Title IV is expected to result in a 27 percent reduction from 1990 levels.

Below, we briefly describe the model and its components, and then turn to the development and description of baseline assumptions and the default and sensitivity case scenarios.[1] The model estimates benefits of emissions reductions but does not include any machinery for estimating the costs of emissions control. While we shall describe the model in general terms, outlining its structure and contents, this paper is not intended as a detailed description of the pathways or the science represented in the model. For these descriptions, please refer to the *Report to Maryland Department of Natural Resources on the Development of the Maryland Externalities Screening and Valuation Model,* prepared by Resources for the Future and delivered to Maryland's DNR in Marcy, 1998.

[1] A detailed description of the Maryland model can be found in the report by Resources for the Future to the Maryland Department of Natural Resources, "Report to Maryland Department of Natural Resources on the development of the Maryland Externalities Screening and Valuation Model," March 1998.

Our policy simulations estimate benefits to human health, residential visibility, and "recreational" visibility (a significant amenity in a setting like Shenandoah National Park). Aquatic benefits are perhaps the most significant of omitted pathways in the Maryland Model.[2] Even so, our experience with TAF, and the results we have generated with MM, suggest that in both models, human health benefits dominate other effects.

In this report we estimate benefits of Title IV emissions reductions compared to an assumed, no-Title IV baseline, as a way of illustrating the capabilities of the Maryland model. Naturally, Title IV emissions reductions have a wider scope than would the emissions policies Maryland could enact unilaterally.) We also compare estimated benefits under several different possible sets of baseline assumptions. These concern the average age of plant retirement and the expected growth in demand for electric power. The model can also perform sensitivity analyses to indicate which of the many assumptions used in this model most influence the reported benefit levels, and an "importance" analysis, which reveals which of the model's inputs are most responsible for uncertainty in the benefit estimates.[3] Finally, in reporting the benefits estimates, we construct confidence intervals out of the statistical uncertainties associated with the health effects and other monetary values.

We find that expected health benefits from reductions in power plant emissions dominate the estimated benefits of improved recreational visibility and residential visibility, as they do on the national level in TAF. The benefits we estimate in our simulation are characterized ("health" and "visibility"), annual benefits. However, the model is currently designed to estimate values at five-year intervals. In 2010 mean estimates are that Maryland health benefits from Title IV-style abatement will be valued at about $0.7 billion, while recreational visibility benefits (for Shenandoah National Park) will be worth approximately $21 million (to residents of Virginia and Maryland), and residential visibility benefits, for inhabitants of a city of the size of Washington, D.C. and similarly affected by reduced urban visibility, will be about $1.2 million.

The actual size of our estimates will depend on what we assume about growth in electricity demand and on assumed plant retirement ages. However, in all of our simulations, health effects dominated visibility effects by an order of magnitude. We do not have a clear sense for the size of Maryland aquatic benefits.

2. DESCRIPTION OF THE MARYLAND EXTERNALITIES MODEL

The Maryland Model is an integrated assessment model of acid precipitation damages and the effects of Title IV of the 1990 Clean Air Act Amendments. It is based on the more

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[2] Chesapeake Bay aquatic benefits cannot be quantified because existing research results do not yet support it. Thus a prospective policy's benefits to recreational anglers, commercial fishermen, boaters, swimmers, and others interested in the fate of the Chesapeake Bay, cannot now be estimated. The research necessary to close the quantitative knowledge gap along this pathway is, however, proceeding apace outside of RFF.

[3] Many of the model's parameters are entered as probability distributions rather than as point estimates. We do not report on sensitivity and importance analyses in this paper.

general, less comprehensive TAF model.[4] MM integrates TAF's models with Maryland-specific damage pathways and health effects and benefits modules developed by Resources for the Future. MM therefore includes modules for electric utility emissions; pollutant transport and deposition (including formation of secondary particulates, but excluding ozone); visibility effects; effects on recreational and commercial aquatic activities (particularly in the Bay) through direct and indirect nitrogen deposition; effects on freshwater resources through changes in soil and water chemistry; human health effects; and valuation of benefits.

The essential modules borrowed from the TAF model, including emissions, transport, and deposition, represent the state of the science in those respective modeling domains. Each of these modules was constructed and refined by a group of experts in the relevant field. In building TAF, modules were drawn primarily from the peer reviewed literature. Combined, the modules were the work of a team of more than 30 modelers and scientists, from institutions all over the country. As the framework integrating these literatures, TAF itself was itself subject to an extensive peer review in December 1995, which concluded that "TAF represent(s) a major advancement in our ability to perform integrated assessments" and that the model was ready for use by NAPAP.[5]

Considerable uncertainty in parameter and model form exists in each of the modeled domains, and in the underlying scientific and economic literature. We selected Analytica as the modeling platform for MM (and TAF) in part because of its capability to propagate model uncertainties through the model to the end results, and we have adopted a process designed to identify and characterize those uncertainties. The models' integrated assessment framework, as opposed to a suite of related but unlinked models, is the appropriate choice, because it meets the following needs:

- To provide comparable results across a variety of effects (visibility, recreational aquatic activities, human health), for a common region (the state of Maryland), and over a single time horizon (1995-2030);
- To provide an integrated analysis of benefits based on common assumptions, and to provide insight about model assumptions and components which contribute significantly to overall results;
- To suggest productive areas for future research and additional modeling based on an assessment of the current model's critical uncertainties and omissions.

MM characterizes emissions, emission transport, atmospheric concentrations of pollutants, and health effects, all at the state level. However, a much more disaggregated level of detail underlies these results. Where TAF has only a pair of emissions source-receptor points within

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[4] TAF is documented in Bloyd et al., 1996.

[5] ORNL, 1995. TAF is being used to provide supplementary analysis to NAPAP in drafting their 1996 Integrated Assessment, but it is not a centerpiece.

the state of Maryland, MM's source-receptor matrix covers the state in a reasonably dense grid of points. Similarly, human health benefits, while reported at the state level in MM, are actually estimated at the Maryland county level. Recreational visibility effects are characterized at Shenandoah National Park, for which a peer-reviewed visibility valuation study has been prepared--and used in TAF. Shenandoah NP is somewhat representative of the kinds of valuations that may occur in the Blue Ridge mountains within Maryland. Thus these estimates may help form expectations about likely benefits in Maryland, and the module is a useful placeholder for later replacement, if desired, by an in-state location. Because Shenandoah NP is used by many persons outside of Maryland, the model's values for recreational visibility are summed over the populations of both Virginia and Maryland. All of the results are reported on an absolute and on a per capita basis.

The Maryland Model's key modules are described in the following sections.

The Benefits Valuation Module

Welfare economics forms the basis for the valuation paradigm. Individual welfare is assumed to depend on the satisfaction of individual preferences, and monetary measures of welfare change are derived by observing how much individuals are willing to pay to obtain improvements or willing to give up to avoid damage. This approach is applied to nonmarket public goods like environmental quality or environmental risk reduction as well as to market goods and services. The estimates of willingness to pay (WTP) are based on revealed and stated preference studies in the economics literature. The revealed preference studies use widely accepted methods such as travel cost, hedonic property value, or observable market data. The stated preference studies use contingent valuation and conjoint analysis. Sometimes proxies for WTP, such as medical costs, must be used when the economic benefits literature is not sufficient.

Benefit valuation is essential for comparison of various physical effects with each other. Changes in miles of visibility and in the number of "reduced-activity" days cannot be directly compared in their importance as policy outcomes, except when expressed in terms of human valuation of these changes. From an economic perspective, values are measured by how much of one asset or service individuals in society will sacrifice in order to obtain or preserve another. Economics refers to this as an "opportunity cost approach" to valuation. Although values are expressed in monetary terms, in principle they can be expressed in other metrics. The value or opportunity cost of goods and services that are readily traded in markets is reflected in their prices. For goods that are not traded in markets, the economics literature on monetizing benefits and costs is more developed in certain areas than in others, and this is reflected in the characterization of uncertainty in the benefit models.

The Benefits Valuation Module provides an accounting of every damage pathway and benefit endpoint included in MM. While the list of damage pathways included in the model is extensive, gaps in the published research literature mean the valuation module currently can only value effects on visibility (recreational and residential, for sites in, or representative of, Maryland[6]) and human health. Valuation of pathways involving the Chesapeake Bay--sport and commercial fishing, boating, swimming, and non-use values--still contains no link between policy outcomes on the emissions side, and effects of emissions changes on fish populations and water quality on the benefits side. Links do exist between these latter effects and human willingness to pay for them. Other environmental effects, such as forest, stream, and material damages, land use, thermal effects, and aesthetics, are not currently monetized in the model, for the same reason as for aquatics, but are represented in MM in a qualitative manner.

Health Effects

The Health Effects Module is designed to estimate the health impacts of changes in air pollution concentrations. Impacts are expressed in terms of the number of days of acute morbidity effects of various types, the number of chronic disease cases, and the number of statistical lives lost to premature death. The change in the annual number of impacts of each health endpoint is the output of this module. Inputs consist of changes in ambient concentrations of SO_2 and NOx, demographic information on the population of interest, and miscellaneous additional information such as background PM_{10} levels for analysis of thresholds.

The module is based on concentration-response (C-R) functions found in the peer-reviewed literature. The C-R functions are taken, for the most part, from articles reviewed in the U.S. Environmental Protection Agency (EPA) Criteria Documents (see, for example, USEPA 1995). These documents are outcomes of a recurring comprehensive process initiated by the Clean Air Act and its Amendments for reviewing what is known about the health effects of the so-called "criteria" air pollutants.[7] Such information, and judgments about its quality, eventually help the Administrator of the EPA make decisions about National Ambient Air Quality Standards (NAAQS) that would "protect the public against adverse health effects with a margin of safety." These Criteria Documents contain thousands of pages evaluating toxicological, clinical, and epidemiological studies that relate particular criteria pollutants to a variety of health endpoints, including primarily acute cardiopulmonary and respiratory effects, chronic effects and prevalence of chronic illness, and premature mortality. The MM Health Effects Module contains complete C-R functions for PM_{10}, total suspended particulates (TSP), SO_2, sulfates (SO_4), NO_2, and nitrates (NO_3).[8]

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[6] A lack of valuation data for Maryland residential sites, as for recreational sites, means non-Maryland sites must for now be used as proxies. To represent residential visibility sites in Maryland, we include Atlantic City and Washington, DC.

[7] The Criteria Pollutants include ozone [O3], nitrogen dioxide [NO2], sulfur dioxide [SO2], particulate matter less than 10 microns in diameter [PM10], lead [Pb], and carbon monoxide [CO].

[8] Since nitrates are particulates, and no independent effect of nitrates on health has been established, they are treated as a component of PM10.

The Health Effects Module calculates morbidity impacts resulting from sulfates and nitrates, which are particulates created from emissions of SO_2 and NOx, respectively, and SO_2 and NOx as gases. Mortality impacts are only represented as resulting from the particulates. The C-R functions found in the literature for these endpoints are documented within the software model.

The top level of the Health Effects Module is structured according to an influence diagram that visually depicts the fact that, in a C-R function, concentration changes and demographic data determine the number of morbidity and mortality impacts experienced in a population. Within the morbidity and mortality submodules there is great flexibility to structure the model so as to test a range of assumptions about the relationship between pollutant concentrations and health effects.

For both the morbidity and mortality endpoints, the Health Effects Module contains a comprehensive library of C-R functions found in the peer reviewed literature, in total consisting of more than fifty studies linking air pollution to premature death, chronic disease, hospitalizations and other symptoms. The user may select from among any of the studies in the library available for a given health endpoint, or may decide to weight coefficients from a number of studies.

For the mortality endpoint, in addition to the choice of a C-R function, the various components of particulate matter can be treated separately. For example, some evidence suggests that the fine fraction of the mass may have more of an effect than the coarser components. To explore the effects of various assumptions that can be made concerning particulates, we have performed four simulations using plausible interpretations of the evidence on this subject, which we list in table 1, below. In contrast to our default assumptions, variant 1 assumes that particles 10 microns or less in diameter (PM_{10}) have no health effects below a threshold concentration of $30\mu g/m^3$ over 24 hours. Variants 2 and 4 assume that sulfates and nitrates have the equivalent potency in causing health effects as PM_{10}. Variant 4, though, also looks at the age-disaggregated effects of air pollution on mortality. These reflect the fact that the over-65 population is more likely to die as a result of high particulate levels than is the under-65 population. The default for our simulations treats sulfates as distinct and associates them with relatively greater potency than other constituents of PM_{10}. Finally, variant 3 combines the threshold and sulfates-as PM_{10} assumptions of the first two variants. The default was most plausible as a representation of the evidence at the time this work was completed.

The morbidity submodule allows the user a choice of either aggregating SO_2, PM_{10} and sulfate effects according to a scheme designed to avoid double-counting, such as symptom days and restricted activity days, or of using SO_4 effects as a proxy for particulate and SO_2 effects. NOx is included for eye irritation and phlegm days. As with the mortality submodule, default studies have been identified for each endpoint, but where other studies exist in the literature they may be substituted for the defaults.

Table 1. Options for Assessing Mortality Effects

Default	Nitrates treated as PM10, sulfates distinct and more potent
Variant 1	Threshold assumed for PM_{10} effects (30μg/m^3 over 24 hours)
Variant 2	Sulfates treated as PM10, nitrates have no effect on mortality rates
Variant 3	Variants 1, 2 combined
Variant 4	Sulfates and nitrates treated as PM10, disaggregated by age

The Health Valuation Submodule of the Benefits Valuation Module (described previously) assigns monetary values taken from the environmental economics literature (e.g., Lee et al., 1994) to the health effects estimates produced by the Health Effects Module. The benefits are totaled to obtain annual health benefits for each year modeled. The Health Valuation Submodule also contains a comprehensive library, based on the environmental economics literature, of values associated with morbidity and mortality endpoints. As with the Morbidity and Mortality Submodules, defaults have been selected, but the user may test the effects of assigning alternative values to the various health endpoints, consistent with the valuation literature.

Visibility

The Visibility Effects Module calculates visual impairment as expressed in visual range or deciviews of haze for a set of seven selected receptors. This module calculates changes in visual range for two cities representative of how effects might be distributed in Maryland (Atlantic City, NJ; Washington, DC), and one national park (Shenandoah). Seasonal distributions of mid-day visual range are based on estimated atmospheric sulfate and nitrate concentrations from the Atmospheric Pathways module (described below)--a reduced-form model of the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) model developed at Argonne National Laboratory (Shannon et al., 1997). Calculation of change in visual range is based on the peer-reviewed Visibility Assessment Scoping Model (VASM), which uses Monte Carlo techniques to estimate short-term variations of visual impairment based on seasonal lognormal distribution parameters of the six important particulate species (sulfate, nitrate, elemental carbon, organic carbon, fine-particle dust, and coarse-particle dust), relative humidity distribution statistics from climatology, and modeled changes in the seasonal means of the sulfate and nitrate concentrations.

The Visibility Valuation submodules examine both recreational and residential benefits. Chestnut and Rowe (1990) proposed a functional form to value both recreational and residential visibility that takes into account the nonlinearity of willingness to pay (WTP) for a given change in visual range (i.e., the diminishing marginal utility for visibility enhancement). WTP for improvements in recreational visibility were drawn from contingent valuation (CV) studies and involve both use and nonuse values for residents living in states close to Shenandoah National Park--Virginia and Maryland. To value residential visibility improvements we employ a range of WTP coefficients from the Brookshire et al. (1979) Los Angeles study, and the McClelland et al. (1991) study of Atlanta and Chicago. We assume residential WTP is positive only for local residents (e.g. only use values matter). In the results we present in this paper, there is no overlap between the populations for whom benefits are estimated on the residential and on the recreational sides. Were there to be--were Baltimore valuations available to replace Atlantic City valuations, for instance, we would have to adjust values for "in-state" recreational visibility to avoid double counting with improvements in residential visibility.

Aquatics

The aquatics modules are designed to map changes in nitrate deposition levels in the Chesapeake Bay to the valuations of users (swimmers, boaters, anglers) and non-users, and to predict changes in lake and stream chemistry and soil chemistry caused by acid deposition. The methodology for freshwater resources is appropriate for Maryland resources threatened by acid deposition, a particular concern for western Maryland. Because we suspect greater benefits--from higher valuations and larger user and non-user populations--exist for the reduction of eutrophication in the Bay, more effort has gone into developing MM's capacity to model these changes than in adapting the freshwater models. The models for acid deposition in fresh water have been ported over from the TAF model, but as now constituted are not entirely appropriate to Maryland resources. They were developed and calibrated for the granitic lakes of Adirondack Park. Comparable studies of resources similar to those found in western Maryland are not available. Here we briefly describe the freshwater models in a footnote.[9]

Less is known about the relationship between nitrogen deposition and recreational--and, in this case, commercial--fishing in the Chesapeake Bay than has been learned about acidification of Adirondack's high-elevation cold-water lakes. We have integrated what *is* known about Bay responses into MM's aquatic effects module. Deposition effects upon water chemistry in the Bay have been studied to a reasonable extent, and human valuations of *hypothetical*, and in some cases actual, changes in resource quality (including fish availability, boating, and "swimmability" of beaches) also exist in the peer-reviewed literature, and have been incorporated into the model. What is missing from the research base is an establishment

[9] Using a set of "acid stress indexes" (ASIs) that describe the responses of specific species of fish to varying levels of acidity (pH) in the water, the submodule estimates economic benefits resulting from improvements in recreational fishing due to decreased acidification. Future surface-water and soil chemistry conditions in the watersheds are projected by reduced-form models based on the Model of Acidification of Groundwater in Catchments (MAGIC). MAGIC is a lumped-parameter model that uses chemical equilibrium and mass balance equations to predict changes in lake and soil chemistry. The Recreational Lake Fishing submodule estimates changes in the catch rates (catch per unit effort, or CPUE) of specific species of fish. Benefits are calculated for the change in value of a single-day fishing trip (as opposed to an overnight or multi-day outing) as a result of changes in CPUE.

of the link between water chemistry and resource quality. Therefore MM models hypothetical aquatic effects.

The science behind the projections of nitrogen deposition into the Bay reflects the most current available modeling. In addition to our having specialized, for the Maryland model, the ASTRAP source-receptor matrix used in TAF to model air transport, we have also included EPA's Regional Atmospheric Deposition Model (RADM) source-receptor data (Dennis, 1994) to capture nitrogen deposition to the Chesapeake Bay from sources in the Bay airshed. This is a capability that is completely missing from TAF. For further information on both RADM and ASTRAP, please refer to the documentation contained in the Maryland model itself, and to RFF's March, 1998 report to Maryland DNR.[10]

Emissions Projections

The Emissions Projections Module forecasts annual emissions of SO_2 and nitrogen oxides (NOx) from the utility, industrial, residential, commercial, and transportation sectors in the continental United States through 2030. These data come from Energy Information Administration forms in which utilities self-report their emissions, and have been supplemented by a follow-up survey administered by persons working at Argonne National Laboratory (ANL). The emission projections reflect control policy options (e.g., emissions trading and banking) and assumptions regarding key uncertainties in areas that include retirement patterns, fuel costs, and demand growth. The model focuses on utility sector emissions and policies. Emissions in other sectors are included primarily to provide a context for the scale of utility emissions. Annual emissions are calculated for individual utility units on the basis of fuel use and emission factors. For SO_2, the emission factors are calculated from the fuel sulfur content and the effectiveness of boiler processes and controls in removing SO_2 from the flue gas stream. For NOx, the emission factors are based on empirical data and regulatory performance requirements.

A generating-unit inventory within the model stores the data required to estimate emissions from the utility sector. The unit inventory changes over time in response to (1) regulatory policy, (2) demand growth, (3) technical developments, and (4) economic factors. These influences are reflected in retirements of old unit, additions of new units, retrofit controls, fuel switching, and plant use adjustments. The Emissions Projections Module includes a set of algorithms that adjust the unit inventory corresponding to user-defined values for these four influences. The module has been designed to be simple yet to capture the effects of these most important determinants of emissions. The emission projections for each state in Maryland's airshed serve as input to the Atmospheric Pathways Module, described in the next sub-section.

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[10] *Report to Maryland Department of Natural Resources on the Development of the Maryland Externalities Screening and Valuation Model* (Austin et al., 1998).

Embedded in the emissions projection module is an algorithm, developed by Argonne National Laboratory and based on their so-called GECOT unit inventory, for determining compliance activities at different power generation facilities. The module includes a comprehensive listing of these plants in Maryland. Modeled compliance options for SO_2 reductions include scrubbing, fuel switching (including plant modifications), retirement, and replacement of plants. Decisions by certain utilities to install retrofit desulfurization equipment (scrubbers) for compliance in Phase I of the SO_2 trading program are taken as given. The module ranks further compliance options on a unit cost ($/ton reduction) basis, with the most cost-effective units being implemented first, until the emission reduction requirements are satisfied.

Emission allowance trading is modeled implicitly by allocating compliance in a cost-effective way. NOx compliance is modeled to achieve emission rate reductions sufficient to meet the emission reduction goals of the program. Emission rates are equivalent to low NOx burners absent the further flexibility for compliance that characterizes the SO_2 program. This description differs somewhat from actual implementation, which has allowed firms to average emission rates among commonly owned and operated facilities.

For SO_2 reductions, the module predicts the industry will rely on fuel switching and blending as the primary means of compliance, and that much of this switching will be implemented at low cost or cost savings for the affected firms. Scrubbing is also implemented, to a limited degree. This scenario appears robust to recent developments in the coal industry, although we explore the robustness of the module through scenario analysis about plant lifetimes.

Atmospheric Pathways

The Atmospheric Pathways Module is based on the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) model. ASTRAP is a Lagrangian (trajectory), linear, long-term, regional model that is designed for assessment applications such as the Maryland Model. ASTRAP is highly parameterized, with parameterizations based on field studies of the relevant processes. ASTRAP was simulated prior to inclusion in TAF (and MM), using highly detailed emission inventories, in order to produce the source-receptor matrices that are contained in the Atmospheric Pathways Module. ASTRAP's outputs compare favorably with long-term averages of observations as well as more complex diagnostic Eulerian models--such as RADM (Regional Atmospheric Deposition Model). ASTRAP is particularly efficient in examining the effects of year-to-year climatological variability in seasonal average concentrations and deposition accumulations through exercise with meteorological data for different years.

The Atmospheric Pathways Module predicts the seasonal and annual average atmospheric concentrations and cumulative wet and dry deposition of sulfur and nitrogen species resulting from anthropogenic emissions of oxides of sulfur and nitrogen as projected by the Emissions Projections Module. Four atmospheric species concentrations are calculated for a set of North American receptor locations (two of which, as mentioned earlier, are relevant to the Maryland Model), for emission inventories aggregated to U.S. state totals in the Emissions Projections Module. MM adopts ASTRAP and those of its receptors that are local to the state of Maryland.[11] The output of the Atmospheric Pathways Module are passed to the various effects modules described earlier. The Atmospheric Pathways Module uses its own output as well, in estimating precipitation acidity from calculated wet deposition of sulfate and nitrate, through regressions based on observed relationships.

Other Effects Not Modeled

Aside from aquatics and several other pathways specifically mentioned previously, there are numerous other effects of Title IV that MM does not model quantitatively. The reason is, as before, because of a lack of proper scientific and/or economic data and models. These effects include material and cultural resources damages, nonuse values for ecosystem health, recreational forests, agriculture, commercial forestry, and radiative forcing. Material and cultural resource valuation lacks a complete inventory of affected assets, data about the economic lives of affected assets, and information on behavioral responses. While nonuse values of ecosystem health are expected to be large, there is no characterization of ecosystem changes associated with Title IV or of a valuation framework for assessing benefits from improvements in ecological indicators, especially given the temporal aspects of ecological dynamics. Similarly, the link between primary pollutants and forest recreation effects that people care most about is not established. Exposure to ambient ozone is likely to be the most significant air pollutant causing significant effects on crops, but the studies examining these effects fail to account for behavioral responses in an adequate way, and the data on changes in ozone as a result of Title IV are not currently available. Lastly, atmospheric models predict changes in particulates and their effect on radiative forcing, but the economic methods for modeling damages of climate change are very uncertain, and data for valuation of local effects are not available.

3. BASELINES AND SCENARIOS

The analysis requires an estimate of the time path of emissions of SO_2 and NOx (plus associated abatement costs) from 1995 to 2030, in the absence of Title IV--termed the baseline--and estimates of the emissions associated with Title IV. Subtracting policy scenario emissions from baseline emissions provides the estimated changes--which are fed into the atmospheric transport module--for which benefits are estimated in this model. Benefits estimates are compared under a consistent set of assumptions across all valued pathways.

For the illustrative analysis presented here, which is designed to reveal capabilities of the model, we have developed several candidate baseline emissions scenarios. The scenarios differ according to their assumptions about plant lifetimes (60 versus 70 years), growth in

[11] Western Maryland is represented by an ASTRAP receptor cite in eastern West Virginia.

electricity demand to 2030 (3 percent, termed "high growth," and 1 percent, termed "low growth"), and whether or not Title IV controls are in place.

We have chosen a 70-year, low-growth, no Title IV scenario as a default baseline against which to compare the various scenarios. We believe this scenario is the most likely to occur among several candidate scenarios. It also matches the TAF baseline. However, we also explore the effects of changing the baseline to a 60-year plant retirement age, and to a high growth assumption for electricity demand. These baselines correspond to what might have happened in the absence of the 1990 Clean Air Act amendments. The purpose of any of these baseline choices is to illustrate the capabilities of the model as currently constituted. These simulations will reveal, according to the assumptions in the model, the likely effects of changes in average plant retirement age, differences in actual demand growth, and the likely benefits to Maryland (in terms of visibility and health) of Title IV emissions reductions.

Against these baselines we contrast corresponding scenarios under which Title IV provisions have been adopted--all of which implicitly involve SO_2 trading and NOx reductions mandates. The first phase of SO_2 reductions, implemented in 1995, require average emission rates of about 2.5 lb. sulfur per million Btu heat input. This rate applied to 431 actual generating units nationwide, including the so-called "substitution and compensation" units that were voluntarily brought into Phase I to ease the cost of compliance on average.[12] The second phase, to take effect in 2000, will lower average emission rates to about 1.2, and will affect over 2,000 units nationwide. The first phase of NOx controls took effect in 1996 and reduced emission rates to 0.45 or 0.50 lb. per million Btu, affecting 239 units nationally. All but 16 of these were also affected by Phase I SO_2 rules. The second phase of NOx controls expands the set of affected facilities and, while not yet finalized as of this writing, are expected to take effect in 2000.

The scenarios we specifically compare, where in the baseline we assume no adoption of Title IV provisions, are: (1) low growth, 60-year retirement; (2) high growth, 60-year retirement; and (3) low growth, 70-year retirement age. For good measure, we also compare (4) low growth, 50-year retirement.[13] Sensitivities for each of the three components of a scenario (Title IV; demand growth; plant retirement age) can therefore all be assessed.

Since health effects proved to be so important in NAPAP's TAF analyses, we subject them to especially detailed simulations here as well. Under our default baseline for power plant life expectancy and growth in electricity demand, we explore four health-effects scenarios involving different assumptions involved in estimating health benefits. We compare outputs with those of our default assumptions for the health benefits case.

The default-case health benefits estimates result from our best judgment about the epidemiological and valuation literature at the time the work was completed. Our most

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[12] MM contains a complete inventory of plant characteristics--including phase I and II reductions--for all plants in Maryland, just as TAF contains characteristics for all plants nationally.

[13] MM baseline options, which are user-selectable, have deliberately been streamlined relative to TAF, both because of the demonstration nature of the model, and because it consumes a great deal of memory.

important choice concerns the C-R functions for the effects of reductions in sulfates and nitrates on mortality. For sulfates we use a weighted mean of the coefficient estimates from two benefit studies, and we give both studies equal weight. This predicts the change in the number of incidents of mortality annually resulting from changes in total PM_{10} (sulfate and nitrate) concentrations. The low estimate (0.1 percent), based on Plagiannakos and Parker (1988), assumes that sulfates are equally as potent as any PM_{10} particle class, and estimates only daily mortality. The high estimate (0.7 percent), based on Pope et al. (1995), addresses the effects of cumulative exposure to fine particles, and probably captures much of the daily mortality risk. The high estimate implies that sulfates, which fall into the fine fraction of the particulate mass, are a relatively potent constituent of PM_{10}.

We depart from some of the benefit literature (Hagler Bailly, 1995) by ignoring the higher estimates of the particulate mortality coefficient (1.4 percent) found in the Dockery et al. (1993) study--because this study only examines mortality effects in 6 cities and a small sample of 8,111 people, as opposed to the 151 cities and 552,000 people represented in the Pope et al. (1995) sample.[14]

We further assume, based on Schwartz and Dockery (1992), that nitrates are no different in potency than any constituent of PM_{10}. Taken together, these choices imply that nitrates are, overall, less potent than sulfates, an assumption that reasonably reflects the state of knowledge about these pollutants. For both functions we assume that there are no thresholds with respect to human health effects, meaning health benefits from emissions reductions will occur regardless of what the baseline concentration is for particulates. We examine the implications of this choice, however, by assuming in one simulation that threshold effects are present.

Our other key choice is which estimate to use to value reductions in mortality risk. In the base case, we use a lognormal distribution with mean of $3.1 million per statistical life (in 1990 dollars), and a 90 percent confidence interval from $1.6 to $6 million. This distribution generally agrees with the valuation literature, but is somewhat on the low side because we give less weight to labor market studies, relative to contingent valuation studies. The CV studies are marginally more appropriate for valuing mortality risks in the environmental health context, and also capture age effects, based on Jones-Lee et al. (1985). The Jones-Lee study finds that the value of a statistical life for persons 65 years and older is about three-quarters that of the average (40 year old) participant in their study.

For health effects, we explore three options to this base case, and compare them each individually to the default assumptions. We also explore a combined case.

- Impose threshold for PM_{10}. In this case we assume that there is a threshold in effects at a 24-hour average concentration of 30 $\mu g/m^3$ PM_{10} (Lee et al., 1995).

[14] A fourth study, Evans et al. (1984), with a mid-range particulate mortality coefficient (0.3 percent) was also considered by Hagler Bailly (1995). We implicitly endorse use of this study as it falls within the range of low and high estimates we use in the Maryland default case.

Days in which the baseline concentration of PM_{10} in a county is below this amount will not register benefits of sulfate or nitrate reductions.

- Treat sulfates as PM_{10}. In this case we assume that nitrates have *no* effect on mortality rates, in line with the lack of any direct epidemiological evidence linking nitrates with such effects. We assume that sulfates are no more potent than any other PM_{10} constituent and use the daily mortality studies only (equivalent to applying the base case mortality assumptions for nitrates to sulfates).

- Mortality Risk Valuation. Even using the Jones-Lee et al. study to adjust the estimated value of a statistical life (VSL) for age probably overestimates benefits of mortality risk reductions from PM_{10} because this study (and the rest of the VSL literature) provides estimates for reducing risks of *accidental and immediate* death, such as in a car accident. Particulate matter exposure, on the other hand, may lead to higher probabilities of death for individuals only when they are already quite old. For most of the population, then, the mortality benefits of *today's* PM_{10} reduction may be zero or very small. These reductions may contribute to a higher probability of developing chronic respiratory disease which, in turn, may reduce life expectancy. Said another way, the WTP for a risk reduction realized in the future is likely to be much lower if one has to pay today versus in the future. Unfortunately, we cannot take this effect into account directly in the sensitivity analysis. Instead we use an approach to adjust the VSL downwards, based on life-years remaining, that probably provides a lower bound to the VSL.[15]

  For this estimate, different C-R functions were used than in the default, to allow us to distinguish between the two age groups as well as to aggregate sulfate and nitrate reductions into a total PM_{10} reduction (Hagler Bailly, 1995). The new C-R functions make this case not comparable to the default, so we have created a new comparison case using the Hagler Bailly C-R functions and the default VSL.

- Combined Case. In this case we assume that there is a 30 $\mu g/m^3$ PM_{10} threshold *and* that sulfates only have the potency of the average PM_{10} particle.

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[15] This age-disaggregated estimate, which is based on a procedure that assumes each year of life is worth the default VSL divided by the life expectancy of a 40 year old, and that those over 65 are willing only to pay by the year for the number of years they can be expected to live, results in the assignment of a VSL to the over-65 population of $0.9 million, about 1/3 that of the under 65 population, for which the VSL is assumed to take the default value.

It is worth noting that there are additional reasons why WTP estimates in the "auto-death"-type context may over- or underestimate PM-mortality risks. Overestimates might result if the older people at risk from PM have compromised health. WTP estimates might be too low if air pollution is thought to be an involuntary risk (whereas auto-death risk is arguably voluntary).

4. RESULTS

Table 2 summarizes the mean expected benefits in per capita terms for the included benefit pathways, for our main run of 50 realizations of the Monte Carlo simulation model.[16] These exact results are not repeatable, because they are the outcome of a random process. Our choice of sampling procedure can be varied, as well. The virtue of this approach is that it avoids a false sense of precision in the estimates, and allows us to focus on the likely distribution of outcomes and to identify qualitative results.

Table 2. Per Capita Benefits in 2010 for Affected Population

Effect	Benefits per capita (1990$)
Human Morbidity	5.6
Human Mortality	116.8
Recreation. Visibility	1.6
Resid. Visibility	2.0

Estimates in Table 2 are projected for the year 2010, when the second phase of the national SO_2 and NOx programs are expected to be in full effect. The dominant source of benefits is reduced human mortality risks. Mortality effects clearly are the dominant benefit category, exceeding recreational and residential visibility estimates by several orders of magnitude, and morbidity by an order of magnitude in these estimates.

Benefits are presented as the average per capita level over all Maryland residents. A virtue of a per capita comparison is that we can include benefit pathways that have not actually been modeled for sites in Maryland. Certain sites modeled in TAF are useful as placeholders for the Maryland analysis, and may be reasonable estimates of these values for Maryland. For instance, basing residential visibility benefit estimates on Washington, D.C. and Atlantic City, two cities that arguably have visibility conditions similar to those of certain of Maryland's residential areas (Montgomery and Prince Georges counties; Baltimore), provides useful estimates of what the per capita valuations of visibility might be in those parts of Maryland. By contrast, aquatic benefits, when they eventually are estimated, will be those that would actually obtain for the appropriate Maryland user (and non-user) populations and, if desired, in other nearby states.

Recreational visibility represents an estimate of average willingness-to-pay for modeled visibility improvements at Shenandoah NP, for residents of "nearby" states (we use Virginia and Maryland only). The figure reported for residential visibility is the Maryland per capita figure for benefits measured in Atlantic City and Washington, D.C. This should be treated as a place-holder value, not only because neither site is in Maryland, but also because these urban locations may differ significantly from the Maryland suburbs and smaller cities

[16] MM can handle any reasonable number of iterations. However, it is such a comprehensive model that memory constraints begin to bind for large requests, and time can be an issue even for smaller requests.

where many of its residents live. Thus, $2.0 may be an over-estimate. However, the per capita value for D.C. residents of improvements in residential visibility in Washington is larger, $2.3 per person.

We express benefits in per capita terms for each affected population in order to obtain a measure of the potential magnitude of such benefits at a regional level. In extrapolating, allowance must be made that not all parts of Maryland or surrounding states are equally positioned to allow residents to enjoy Maryland's aquatic benefits, nor are they equally affected by attenuated visibility[17]

A potential point of confusion is the measure of the number of tons of emissions reduced under Title IV. This measure depends crucially on the assumed baseline emissions path--on what one assumes would have happened in the absence of the program. To avoid confusion over this issue, we also express benefits on a per ton of emission reductions basis. Measured in this way, health still plays a dominant role in the assessment of benefits. Median mortality benefits for Maryland per ton of SO_2 reduction, under MM's default scenario, are approximately $50,000. The median value of human *morbidity* effects for MM are about $2,200 per ton of SO_2 reduction. The median estimate of benefits resulting from changes in NOx emissions in 2010 are roughly $40,000 per ton for mortality (through the change in nitrate concentrations) and about $2,000 for morbidity. These figures do not include the effects from changes in ozone concentrations. By contrast, likely *costs*, on a national average annualized basis for 2010, were estimated in the TAF model to be $271 per ton of SO_2 emission reduction, and $382 per ton for NOx.[18]

Figure 1 displays health benefits only, under alternative baseline assumptions about plant lifetimes and growth in electricity demand. In 2020, the year for which the benefit-cost ratio was greatest in the TAF analysis, annual Maryland health benefits (1990$) here would be $0.7 billion in the default case (low growth-70 year retirements). Benefits drop to $0.6 billion in the low growth-60 year retirements case. It is also interesting that benefits in the low growth-60 year retirement case are less than or equal to those of the default case in every year. When less efficient plants are retired earlier, there are fewer emissions to reduce under the policy. Similarly, relative to high growth in electricity demand, a lower growth path implies that there is a lower opportunity cost to retiring older plants. Emissions in the baseline are lower than in the default case, and hence emission reductions and program benefits would be lower. At present, the model cannot forecast benefits beyond 2020 because we do not have county-level population projections for Maryland beyond that year.

Because of the dominant role of health effects, we devote a considerable part of our sensitivity analysis to whether the mortality and morbidity benefit estimates are robust. Below, Figure 2 displays the annual health benefits for the default scenario, with associated

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[17] Recall that the issue of which sites have been modeled exists because MM and TAF are based on previously-conducted studies. Thus the models are completely dependent for their site choices on what has been produced in the research literature.

[18] Recall that control costs are not estimated in MM.

90% uncertainty bars. Median Maryland health benefits in the default scenario rise from just under $200 million in 1995 to nearly $600 million in 2020.[19] The ramp up of benefits after 1995 is attributable to meeting Title IV goals for 2000 as well as to population and income growth. In TAF, which has state-level population projections to 2030, benefits drop after 2020 anyway, due to plant retirements that occur in the baseline.

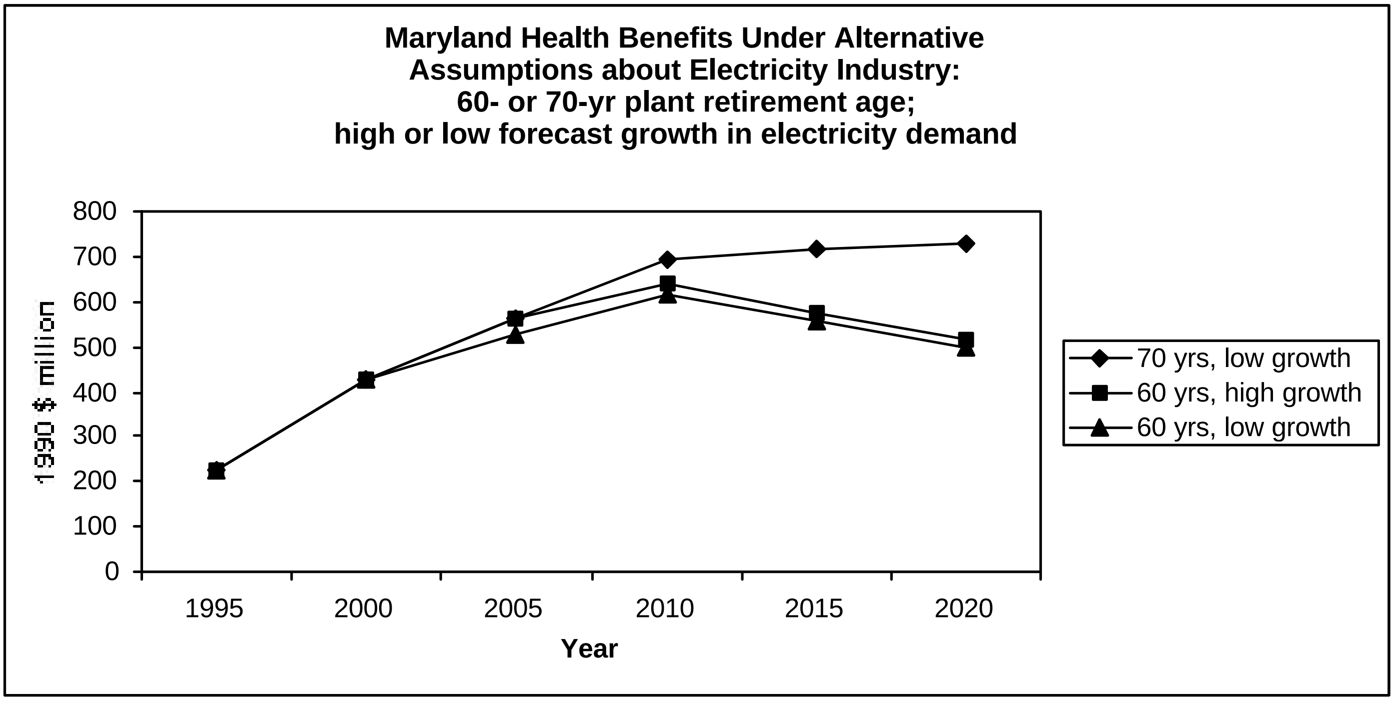

Figure 1

Our main observation in Figure 2 is that the uncertainty bounds around the benefit estimates show that there is no year in which benefits (at the 5 percent confidence level) are less than a reasonable expectation of what the control costs might be.[20] For 2010, about 95 percent of total health benefits result from mortality benefits. Also, in TAF, only about 11 percent of total benefits were attributed to NOx reductions (the rest were attributed to sulfate reductions). In that model, NOx reductions also accounted for closer to 27 percent of

[19] In Table 1, we reported *mean* levels, which are somewhat greater than medians in the skewed health distribution.

[20] This assertion is based on our work on costs and benefits in the TAF model. See Burtraw et al.

morbidity benefits. (We have not attempted to attribute benefits separately to NOx and SO_2 for this report of the MM results.)

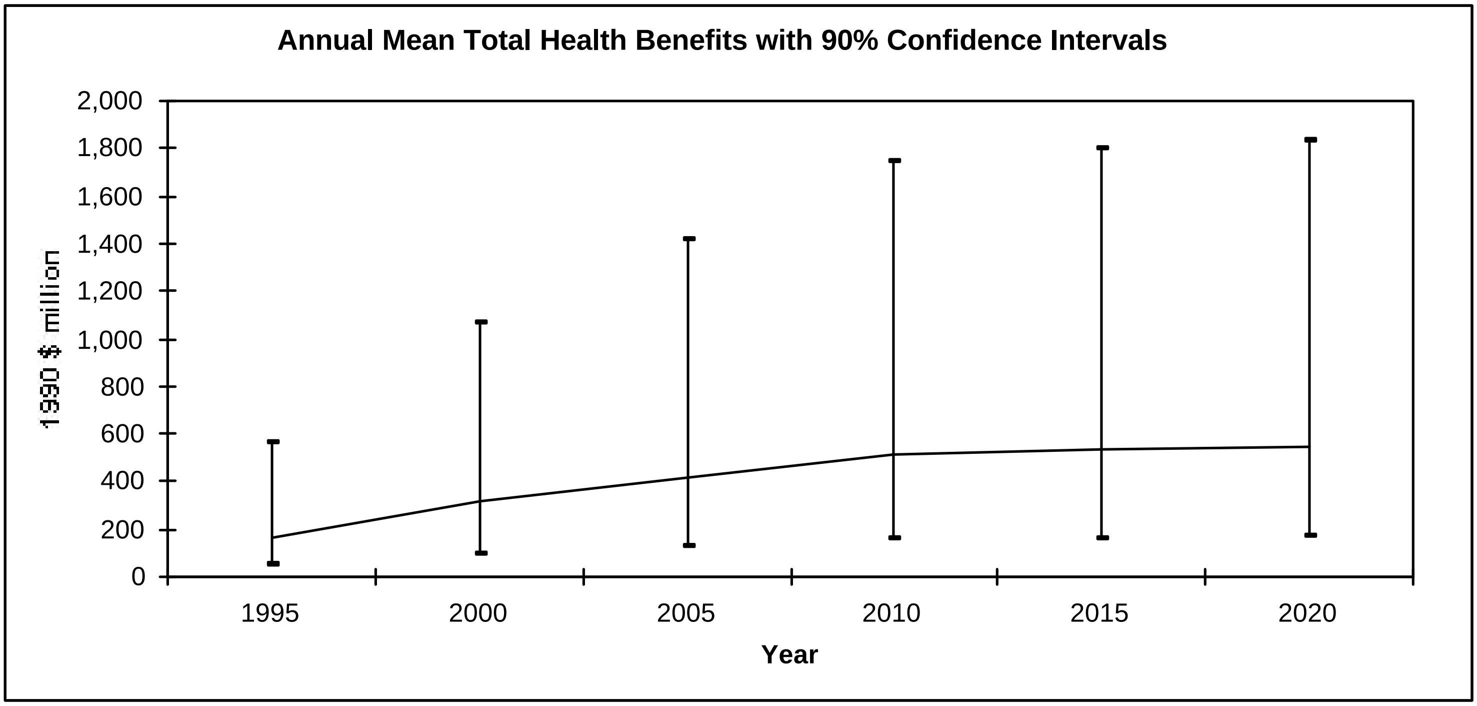

Figure 2

Next, Figure 3 reports the annual mean total health benefits for the default case, along with cases for which there is a PM_{10} threshold; sulfates are treated as PM10; a combined case; mortality risk valuation is disaggregated by age; and an age-disaggregated comparison. Each of the different statistical scenarios is *designed* to reduce benefits, and therefore to provide a more conservative estimation. Aside from the combined case, the most dramatic reduction in benefits occurs when we use very conservative assumptions to value statistical life. For instance, in 2010, expected total health benefits are $700 million in the default scenario, but less than $200 million in this sensitivity case. The TAF analysis revealed that while estimated 5th percentile benefits were less than annualized control costs up to 2000 or 2005, depending on the case, total costs never exceeded total estimated health benefits under any individual scenario. Only when a *combined* sensitivity analysis was performed, where sulfates were assumed to affect mortality with same the potency as the average component of PM_{10}, and that there was an effects threshold of 30 $\mu g/m^3$ PM_{10}, was it found that total expected benefits were even close to what control costs were expected to be. They were still, however, greater than TAF's expected costs even in that extreme case.

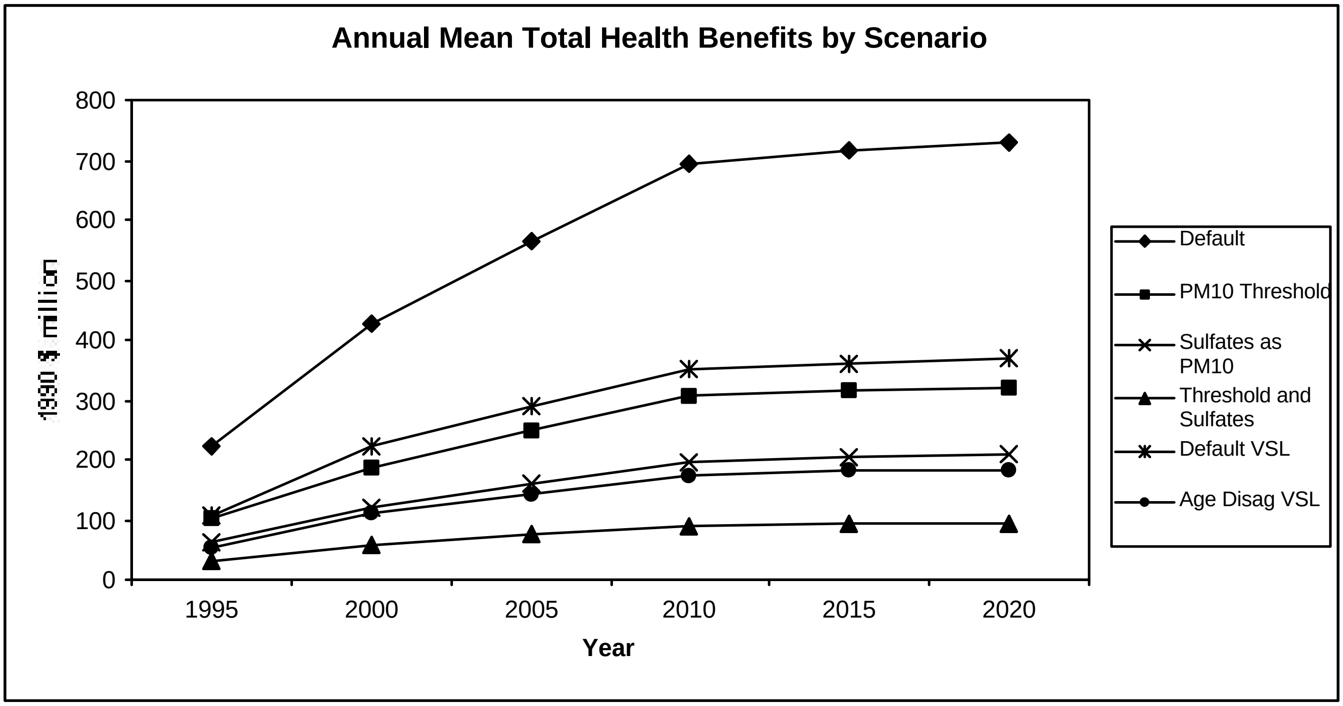

Figure 3

Legislative debates about acid rain in the 1980s had a sharp regional character. Since acid deposition typically occurs far from the source of emissions, which were largely concentrated in the Ohio Valley, many observers claimed that emissions from these power plants were contributing to environmental degradation in the Northeast. The TAF analysis showed that the regional decomposition of health benefits from reduced emissions has less of this regional differentiation, because atmospheric concentrations are affected closer to the source of emissions. The import of this, for Maryland, is that DNR can expect meaningful in-state benefits to result from meaningful in-state changes in emissions levels. Table 3, which is drawn from the TAF analysis, illustrates that, on a state-wide level and expressed in per capita terms, the greatest health benefits are expected to accrue to the regions with the greatest changes in emissions.

Unmodeled Pathways and Research Priorities

To varying degrees, members of the team of scientists and economists that contributed to construction of TAF (and therefore, by extension, of important parts of MM) initiated review and modeling of environmental pathways that were not part of TAF's quantitative analysis. The Maryland Model, of course, contains a very rich variety of pathways that have not yet been quantified and which were not included in TAF. Table 4 lists unquantified pathways missing from TAF, some of which are also missing in the Maryland Model. None of these pathways has been quantified yet. The table includes a relative ranking of the expected magnitudes of these pathways, along with a prioritization for further research. This is according to our assessment of the value of additional information for each of the pathways.

Table 3. Expected Total Health Benefits for 2010 and Percent of National SO_2 Emission Reductions by State, from TAF

State	Per Capita Health Benefits (1990$)	Percent of National Health Benefits	Percent of National SO_2 Emission Reductions
WV	$171.38	1.8%	12.0%
OH	$159.85	10.2%	23.3%
DC	$158.81	0.5%	0.0%
PA	$157.84	11.0%	9.8%
VA	$135.41	5.5%	0.4%
MD	**$131.77**	**4.1%**	**0.4%**
DE	$131.21	0.6%	0.0%

Table 4. Qualitative Evaluation of Expected Benefits and Value of Additional Information for Modeled and Nonmodeled Pathways

Categories ● high ◉ high-mid ◒ mid ⊙ low-mid ○ low	<u>Expected Benefit:</u> Are expected benefits large?	<u>Value of Additional Information:</u> With the goal of improving benefit estimates, what is the relative short-term return on investment?
Health: Mortality	●	●
Health: Morbidity	◉	◉
Visibility	◉	◉
Materials and Cultural Resources	◉	◉
Nonuse Values: Ecosystem Health	●	◒
Aquatics: Recreation	⊙	◒
Forests: Recreation	⊙	◒
Agriculture and Commercial Forestry	◒	⊙
Radiative Forcing	⊙	○

Short run and long run research needs vary among the modeled and unmodeled pathways. Estimates of health and visibility benefits remain uncertain; however, a separate "importance analysis," not reported in this paper, suggests that the cost of reducing uncertainty for those two types of benefit appears to be relatively less than many other areas.[21] The TAF experience suggests these are the two dominant benefits areas nationwide. This may also be true in Maryland, but it is likely that aquatic resources will prove to be much more important (in terms of expected benefits) for Maryland than they are nationally. The Chesapeake Bay is not only larger relative to Maryland than are total U.S. aquatic resources relative to total U.S. area, but the Bay is also a unique natural resource valued even by many persons who live far away from it. While MM currently is unable to estimate aquatic benefits, the research necessary to close the gap in the damage pathway from emissions to "angler catch per unit effort," and so to permit the estimation of aquatics benefits, is currently being conducted (independent of RFF). If the results of this research are as hoped, they may permit the linkage of extant research on benefits of (i.e., willingness to pay for) hypothetical changes in Bay water quality or fish availability to effects of emissions reductions on Bay water quality.

While there remain many research issues facing health scientists and epidemiologists, in terms of increasing understanding of emission effects, economists should work to improve the basis for the valuation of small changes in mortality health risks from environmental changes. Economists also need to develop estimates of WTP to avoid these risks, estimates that depend on the age and health status of the affected individual. Visibility valuation needs to be more precise with respect to endpoints that are relevant to assessment of benefits, and particular attention should be paid to the *nature* of preferences for changes in visibility. These can include trade-offs between changes in mean and extreme values of visual range. Benefits may also be sizable in the areas of materials and cultural resources. Rapid progress in monetizing these benefits could be made through further work on the valuation of cultural resources, which should concentrate on the identification of the most important of these resources, and of those of their attributes that represent endpoints meaningful to individuals. Assessment of commercial materials benefits, such as reduced corrosion of galvanized fencing, would require an improved inventory of affected materials, and improved estimates of their economically useful lives.

The steps needed to monetize some of the great many of the damage pathways not included in TAF, and unquantified in MM, are considerable as well, if not necessarily difficult. For instance, consider MM's pathways for commercial fishing effects. Baseline data, both biological and economic, can be found without too much difficulty. More problematic, of course, is the estimation of fish counts, and the price effects of changes in Bay water quality--especially as prices will respond not only to quantity and quality, but also to

[21] The software platform in which MM is implemented includes the facility to estimate the contribution to final uncertainty of uncertainties in each of the input parameters. This is referred to as "importance" analysis, and indicates where reductions in model uncertainty can most easily be achieved.

entry and exit by fishing operations as market conditions change. This level of modeling has greater economic content, and requires greater modeling effort, than, for instance, estimating WTP for reduced damages to cultural materials.

Over a longer time frame, the assessment of nonuse values for ecosystem health should be afforded high priority. A significant fraction of valuation for improvements in Chesapeake Bay water quality, for instance, will probably come from nonuse values. A research emphasis in this area would require sustained levels of funding over several years to yield reliable results, however. Agriculture and commercial forestry would be somewhat more promising were a sustained level of funding to be committed to further research along those pathways. One reason sustained funding over time would be necessary is that agriculture is undergoing structural change due to reforms passed by Congress in 1996 that may not be fully attained until the next decade. In addition, estimating rural ozone effects may be costly and time consuming, though such modeling would also contribute to an understanding of human health benefits and forest recreation.

The most important of the uncertainties and omissions in the TAF analysis, and which affect the Maryland Model, are summarized in Table 5, which appears as an appendix to this paper. In this table we indicate our qualitative assessment of the direction of the bias for each of these shortcomings. A plus sign (+) indicates the uncertainty or omission imposes an upward bias in our benefit or cost estimate; a negative sign (-) indicates otherwise. Additional information about the uncertainties and limitations at each step in the TAF model is provided in the documentation for TAF (Bloyd et al., 1996).

5. CONCLUSIONS

This paper has reported on estimated benefits of a particular emissions policy for Maryland--to wit, the implementation of Federal Title IV requirements from the 1990 Clean Air Act Amendments. This policy has been chosen for simulations of the Maryland Model, developed by Resources for the Future for Maryland's Department of Natural Resources, to illustrate the capabilities of the model. The estimates represent the most current available science and economics models, but may not, themselves, be of primary interest in this paper, because the policy chosen for the analysis is a federal policy already being implemented, rather than a prospective state policy. The analysis has also not included information on the costs of implementing this policy. The purpose of this paper is to demonstrate some of the analytical capabilities of the Maryland Externalities Screening and Valuation Model.

The exercise has consisted of selecting sample baseline emissions scenarios, and contrasting these against a proposed control scenario. This has permitted us to estimate annual Maryland benefits, with uncertainties, for several significant damage pathways, health and visibility. In the analysis we have also attempted to reveal some of the many capabilities of the health module for representing research results produced in the relevant scientific literature.

Table 5: Major Uncertainties and Omissions and Direction of Bias in MM

Uncertainties and Omissions	Bias	Description
BENEFITS		
AGGREGATION TO STATE LEVEL	**?**	Emissions and atmospheric transport are modeled at state level. Effects are modeled at Maryland county level. Probability distributions are used to represent variability in parameter assumptions.
ATMOSPHERIC MODEL DOES NOT CAPTURE ROLE OF AMMONIA	**+**	Ammonia may be a limiting factor in formation of secondary particulates. Reductions in one (e.g. sulfates) may allow increases in the other (e.g. nitrates).
AQUATIC EFFECTS NOT DIRECTLY MEASURED	**+/?**	Valuation studies are represented in the model, but the scientific link from atmospheric, terrestrial, and aquatic effects to changes in water quality and fish availability has not yet been completed.
RECREATIONAL VISIBILITY	**+/?**	Only one park included, and it is not in Maryland. However, this may capture the majority of benefits: it is somewhat representative of Maryland resources, and the state-level resolution of the model means Shenandoah NP effects are similar to MD effects. Contingent valuation methods uncertain. Valuation is not precise with respect to the distribution of visibility improvements over time.
RESIDENTIAL VISIBILITY	**?**	Only two cities evaluated, one somewhat remote from Maryland; benefits represented on "affected per capita" basis.
MORBIDITY MEASURES	**-**	Reduced workplace productivity for small effects not captured.
MORTALITY COEFFICIENT	**+**	Use of mortality coefficients treats all mortality effects equally. A preferable approach would be life-years lost.
VALUE OF STATISTICAL LIFE	**+/?**	The VOSL approach does not value appropriately small changes in life expectancy realized late in life (+). Health status is not included (+). However, VOSL ignores involuntary nature of exposure (-).
NON-MONETIZED ENVIRONMENTAL ENDPOINTS AND NONUSE VALUES LISTED IN TABLE 6	**-**	Magnitude of use values for unvalued pathways may be small, as indicated by included aquatic endpoints. However, nonuse measures are not explored and may be significant.

The Maryland Model represents peer-reviewed, "state-of-the-science" research results on emissions, transport, environmental and health effects, and human valuation of meaningful outcomes. These research findings, culled from a careful review of the literature (Austin et al., 1997) and from the rigorously peer-reviewed TAF model--the non-economic modules of which were created by leading scientists (and which are contained in MM)--are embedded in a flow-chart "influence diagram" that portrays the physical links from emissions to environmental effects. The end result is a model that (1) serves as a library of relevant scientific and economic research (each module is extensively documented within the model, so the model can be used both for analytical purposes and as a reference); (2) familiarizes Maryland's Department of Natural Resources with NAPAP's approach to assessing effects of emissions policy; (3) reveals environmental pathways along which insufficient research has been performed to date, and where state resources can be directed to advantage in reducing uncertainty or in permiting benefits estimation; and (4) is a policy analysis tool, in that the (monetized) benefits of potential policies can be evaluated along whichever pathways are currently monetized. In its present form, the model estimates benefits for human health and visibility.

As expected given the TAF results, the dominant category of benefits for a Maryland implementation of Title IV-style reductions from the 1990 Clean Air Act Amendments--this is the policy scenario we have analyzed--is reductions in human mortality. If the TAF analysis can be a guide, we expect these benefits alone to be several times greater than the costs to implement the emissions reduction program. Benefits of reductions in morbidity (e.g. discomfort and reduced-activity-days) and improvements in visibility also appear to be significant on a per capita basis. We find mortality values that are less than previous estimates made for the EPA (Hagler Bailly, 1995). Still, in our analysis there is no year in which health benefits alone at the 5 percent confidence level are less than the levelized expected costs one might expect from evidence in the TAF study.

We emphasize that there are tremendous uncertainties in measuring and valuing reductions in human mortality. Recent economic critiques have argued that the use of the "value of a statistical life," instead of a more appropriate measure of quality-adjusted life years lost, as the basis for valuing health risks from air pollution could grossly overestimate mortality benefits. In addition, economists have questioned the appropriateness of using labor studies of prime age men to value changes in life expectancy that occur among an older population. In the future we expect these critiques to gain in credibility as more is learned about how to measure benefits. On the other hand, we note that because environmental exposures are involuntary, studies of labor market behavior may *underestimate* willingness to pay to avoid environmental exposures.

Morbidity, recreational visibility, and residential visibility benefits each separately appear to lie within an order of magnitude of one another. We do not model the contribution of NOx to ozone, which is known to have significant morbidity effects. This is intended as an area of future enhancement of the Maryland model. The visibility estimates illustrate the potential magnitude of this benefit category, but we note that the literature is narrow and should be subjected to closer scrutiny.

The strength of this kind of analysis is that it offers a great deal of flexibility in exploring uncertainties in the measurement of benefits and costs, while employing a consistent set of assumptions in the comparison of benefits across categories. The important remaining gaps and uncertainties in this analysis can serve as a reminder of all that is yet to be learned in this field of research.

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