Ozone Environmental Assessment Plan: Scope and Methods for Exposure, Risk and Benefits Assessment

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DISCLAIMER

This draft scope and methods plan has been prepared by staff from the Health and Ecosystems Effects Group, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. Any opinions, findings, conclusions, or recommendations are those of the authors and do not necessarily reflect the views of the EPA. This document is being circulated to obtain review and comment from the Clean Air Scientific Advisory Committee (CASAC) and the general public. Comments on this document should be addressed to Vicki Sandiford, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, C539-01, Research Triangle Park, North Carolina 27709 (email: sandiford.vicki@epa.gov).

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1 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is presently conducting a review of the national ambient air quality standards (NAAQS) for ozone (O_3). Sections 108 and 109 of the Clean Air Act (Act) govern the establishment and periodic review of the NAAQS. These standards are established for pollutants that may reasonably be anticipated to endanger public health and welfare, and whose presence in the ambient air results from numerous or diverse mobile or stationary sources. The NAAQS are to be based on air quality criteria, which are to accurately reflect the latest scientific knowledge useful in indicating the kind and extent of identifiable effects on public health or welfare which may be expected from the presence of the pollutant in ambient air. The EPA Administrator is to promulgate and periodically review, at five-year intervals, primary (health-based) and secondary (welfare-based) NAAQS for such pollutants.[1] Based on periodic reviews of the air quality criteria and standards, the Administrator is to make revisions in the criteria and standards, and promulgate any new standards, as may be appropriate. The Act also requires that an independent scientific review committee advise the Administrator as part of this NAAQS review process, a function now performed by the Clean Air Scientific Advisory Committee (CASAC).

EPA's overall plan and schedule for this O_3 NAAQS review is presented in a Plan for Review of the National Ambient Air Quality Standards for Ozone (EPA, 2005a), which is available at: http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_cr_pd.html. That plan discusses the preparation of two key documents in the NAAQS review process: an Air Quality Criteria Document (AQCD) and a Staff Paper. The AQCD provides a critical assessment of the latest available scientific information upon which the NAAQS are to be based, and the Staff Paper evaluates the policy implications of the information contained in the AQCD and presents staff conclusions and recommendations for standard-setting options for the Administrator to consider. In conjunction with preparation of the Staff Paper, staff in EPA's Office of Air Quality Planning and Standards (OAQPS) conducts various policy-relevant assessments, including in this review vegetation exposure, risk and benefits analyses. This draft document describes the scope and methods that staff plans to use for these assessments. The final section of this scope and methods plan identifies the next steps in the planning, conduct, and documentation of these assessments. The parallel document developed for the human health assessment is available at: http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_cr_pd.html.

1.1 Purpose of Scope and Methods Plan

This plan is designed to outline the scope and approaches and highlight key issues in the estimation of vegetation exposures, risk and impacts to economic benefits posed by O_3 under existing air quality levels ("as is" exposures and vegetation risks), upon attainment of the current O_3 secondary NAAQS, and upon meeting various alternative standards in agricultural, rural

[1] Section 109(b)(2) [42 U.S.C. 7409] of the Act defines a secondary standard as one the attainment and maintenance of which in the judgment of the Administrator, based on such criteria, is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of such air pollutant in the ambient air.

and/or forested areas. These planned analyses will update and build upon the analyses conducted in the last review as discussed in some detail below. This plan is intended to facilitate consultation with the CASAC, as well as public review, and to obtain advice on the overall scope, approaches, and key issues in advance of the completion of such analyses and presentation of results in the draft O_3 Staff Paper.

The planned O_3 exposure, risk, and economic benefits analyses address seasonal exposures to O_3 and the associated risks to vegetation of crop yield and tree seedling biomass loss. These assessments only include vegetation effects for which there is adequate information to develop quantitative risk estimates. However, there are other welfare effects categories for which information is currently insufficient to develop quantitative risk estimates. Staff plans to discuss these additional welfare categories qualitatively in the O_3 Staff Paper. The environmental assessment is intended as a tool that, together with other information available on these endpoints and other welfare effects evaluated in the O_3 AQCD and O_3 Staff Paper, can aid the Administrator in judging whether the current secondary standard is requisite to protect the public welfare from any known or anticipated adverse effects associated with ambient O_3, or whether revisions to the standard are appropriate.

1.2 Background

During the last review of the O_3 NAAQS, as part of the development of the 1996 O_3 Staff Paper (EPA, 1996b), EPA conducted analyses that assessed national O_3 air quality, vegetation exposures and risk, impacts to economic benefits and the appropriateness of alternative exposure indices. These analyses were based upon the available science at that time, as evaluated in the 1996 O_3 AQCD (EPA, 1996a) and 1996 O_3 Staff Paper (EPA, 1996b).

1.2.1 Information Available in the Last Review

By far the most comprehensive and uniform vegetation effects database available was that on O_3 exposure-related crop growth and yield effects developed under the National Crop Loss Assessment Network (NCLAN) program. In total, 15 species (corn, soybean, wheat, hay [alfalfa, clover, and fescue], tobacco, sorghum, cotton, barley, peanuts, dry beans, potato, lettuce, and turnip) were studied. These species accounted for greater than 85% of U.S. agricultural acreage planted at that time. The NCLAN research program used the open-top chamber (OTC) methodology, which had the advantages of providing the least amount of environmental modification of any outdoor chamber available at that time and provided the researcher the means to build the most statistically robust designs possible, e.g., maximize the number of treatments and replicates. A similar research program evaluating O_3 exposure-related tree seedling biomass loss using OTCs was conducted by the National Health and Environmental Effects Research Laboratory-Western Ecology Division (NHEERL-WED) within EPA's Office of Research and Development. That program studied the effects of O_3 exposures on 11 tree species as seedlings, including aspen, red alder, black cherry, red maple, sugar maple, tulip poplar, Douglas fir, ponderosa pine, loblolly pine, eastern white pine, and Virginia pine. The exposure studies were conducted in 5 different regions of the country where the species were indigenous and used either modified ambient exposure or reconstructed exposures based on historical monitoring data.

The concentration-response (C-R) functions developed under both the NCLAN and NHEERL-WED programs formed the basis of the 1996 O_3 Staff Paper analyses. It was recognized in the last review that the exposure treatments used in the NCLAN experiments were modified ambient conditions (e.g., charcoal filtered, non-filtered/ambient, 1.5x, 2x and 3x). These treatments were built on the patterns of exposure typical of the region in which the crops were grown. The NCLAN C-R functions reflect crop response to O_3 air quality typical of many crop growing regions (e.g., containing episodic occurrences of peaks often typical of near-urban areas), and may not represent the relationship of crop response to O_3 under different exposure patterns (e.g., having fewer peaks and smaller peak-to-trough ratios characteristic of high elevation and/or more remote sites). An evaluation of whether the OTC itself might influence the O_3 exposure-plant response relationship found no results to suggest a difference in plant response to O_3 when grown in chambered and non-chambered plots (Heagle et al., 1988).

Information on other O_3-related effects of concern (e.g., mature tree O_3 response, both individually and under conditions of competition; vegetation response to O_3 in natural settings; and ecosystem level impacts) was extremely limited during the last review, and was insufficient to support either quantitative or qualitative assessments. Thus, the 1996 O_3 Staff Paper analyses were limited to evaluating crop and tree seedling exposures, risks, and agricultural economic benefits impacts.

Included within the vegetation effects literature reviewed in the 1996 O_3 AQCD was a subset of studies that examined the relative importance of different aspects of O_3 exposure in eliciting plant response. At that time, scientists recognized that O_3 uptake was theoretically most closely related to O_3 dose (e.g., the portion of O_3 exposure that is taken up by the plant and actually reaches the target tissue, integrated over time) and thus would be the best predictor of plant response. However, because uptake is species- and situation-specific, depends on the complex interactions of many variables, and is difficult to measure, researchers focused their studies on identifying suitable surrogate exposure indices for plant response. These studies indicated that "peaky" exposure regimes produced greater response than relatively "flat" regimes, and cumulative exposure seemed to be a better indicator than a single hourly value. Similar conclusions were reported in Lee et al. (1989). Using a regression analysis on crop yield data from the NCLAN studies to evaluate a total of 614 indices on the basis of statistical fit to the data, Lee et al. (1989) found that the top performing indices were multi-component forms which, similar to uptake, include multiple factors affecting plant response, are species-specific and highly complex. EPA staff concluded that these forms were not appropriate for standard-setting purposes at that time. However, within the same analysis, Lee et al. (1989) found that a group of indices that used a cut-off concentration level (e.g., SUMXX, AOTXX) and sigmoidally weighted cumulative indices were nearly as optimal as the multi-component forms in fitting the NCLAN data. Therefore, as a surrogate for uptake, EPA staff selected three cumulative, peak-weighted indices identified in Lee et al. (1989) or further evaluation: SUM06, W126, and AOT06.[2]

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[2] SUM06 is a "threshold" cumulative form with a selected threshold value of 0.06 ppm. Ozone concentrations below 0.06 ppm are assigned a weight of 0 and concentrations above are assigned a weight of 1. Concentrations which fall above 0.06 ppm are added together over a specified period of time (e.g., the maximum consecutive three month period within the O_3 season) to give a cumulative seasonal total exposure. AOT06 is similar to the SUM06, except that it is the <u>a</u>reas <u>o</u>ver the <u>t</u>hreshold (e.g., the difference between the concentration and the threshold levels),

Given that all three of these cumulative, peak-weighted forms were about equally good as measures to predict NCLAN C-R relationships, the staff recommended that the Administrator take into account additional policy considerations in comparing these indices for use as a basis for a national standard. These policy considerations included the degree to which each form would: 1) likely differentially target different concentration ranges across a variety of ambient O_3 distributions, 2) be least likely to be influenced by the O_3 levels considered at the time to fall within the range of background concentrations, and 3) have the likelihood of less overlap with alternative primary standard forms being considered. On the basis of these factors, staff concluded that the SUM06 index would likely provide a better complement to any of the alternative primary standards being considered, by better accounting for the vegetation effects associated with exposures within the mid-range concentrations, without being influenced by background O_3 concentrations. The outputs of subsequent analyses performed in support of the secondary NAAQS review were expressed mainly in terms of the SUM06, and in some cases, W126, for comparison.

1.2.2 Analyses Conducted in the Last Review

Exposure Characterization

The rural monitoring network in place at that time included approximately 80 monitors in Class I areas, as well as a number of other monitors classified as rural in EPA's AIRS database. However, many of those sites with a rural classification occurred within cities or Census Metropolitan Statistical Areas (CMSAs) and often demonstrated air quality patterns typical of urban areas. A map of the 1991 monitoring network for both urban and rural U.S. monitors indicated large sections of the country with little or no monitor coverage. These non-monitored areas included important growing regions for agricultural crops and forested ecosystems. Staff performed a number of air quality comparisons using available monitoring data. These evaluations indicated that there was considerable overlap between areas that would be expected not to meet the range of alternative 8-hr standards being considered for the primary NAAQS and those expected not to meet the range of values (expressed in terms of the SUM06 index) identified as being of concern for vegetation.

This result suggested that improvements in national air quality from attaining an 8-hr primary standard within the recommended range of levels would also reduce levels below those of concern for vegetation in those same areas. However, given that the greatest proportion of vegetation in the U.S. was found outside of urban centers where there were few or no monitors and where different environmental and elevational factors interact with O_3 precursors or O_3 transported into the site, there was considerable uncertainty as to the strength of the relationship between urban O_3 air quality and distributions that occur in rural or remote areas. Therefore, staff felt it was appropriate to go a step further and produce spatial estimations of national O_3 exposures in non-monitored agricultural, rural, and/or remote areas where vegetation and ecosystem effects of concern are most likely to occur.

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that are added together. The W126 is a sigmoidal weighting function that differentially weights each ozone concentration. The W126 function has an inflection point at 0.067 ppm and gives equal weight to values above 0.10 ppm. The weighted hourly values are then added over the specified time frame.

After considering various spatial estimation techniques and methods available, staff selected a method (described in the 1996 O_3 Staff Paper and in Hogsett et al., 1997) that had then been recently developed by NHEERL-WED scientists to generate national O_3 exposure surfaces for the contiguous U.S., using a geographical information system (GIS) as a tool. The GIS method was used to create what was referred to as a potential exposure surface (PES) using information about factors that influence O_3 formation and dispersal. The form of the PES was a 10 km grid superimposed across the country. Each 10 km cell of the PES was assigned a value representing the sum of all the O_3-relevant factors. Once the PES s values were assigned, the relationship between the PES values and the monitored O_3 values at each monitored site are used to calibrate the PES so that it could be used as an estimate of O_3 air quality in non-monitored areas. This method was thought to be an improvement over other methods available at the time because it tied the projected results to actual monitored data at monitored sites (1990 monitored data from EPA's AIRS database). However, it was also recognized that the uncertainties associated with the NHEERL-WED technique could not be quantified. National exposure maps were generated in terms of the SUM06 index for 1990 air quality and just meeting alternative primary standard options.

Assessment of Risks to Vegetation

Quantitative estimates of percent yield loss and biomass loss were generated for the geographic ranges of several crop (soybean, kidney bean, wheat, cotton, peanut, barley, corn, sorghum) and seedling tree species (black cherry, tulip poplar, white pine, aspen, sugar maple, ponderosa pine, red alder, Douglas fir, Virginia pine, red maple). These loss estimates were developed by overlaying the interpolated maps of "as is" 1990 air quality with the growing region for each vegetation species obtained from USDA crop and tree inventory databases, and applying existing NCLAN or NHEERL-WED C-R functions of predicted crop yield or tree seedling biomass loss, respectively, for a given O_3 concentration. Air quality scenarios were developed by analytically adjusting projected air quality distributions using the quadratic adjustment method to reflect just meeting the various alternative standard options (Horst, R. and M. Duff, 1995). Corresponding maps indicated areas that might continue to experience O_3 air quality levels associated with O_3-related impacts on crops and/or tree seedlings after just meeting the alternative standards under consideration.

In addition to the quantitative estimates of percent yield and/or biomass loss, staff identified a number of vegetation/ecosystem effects categories for which only qualitative assessments of risk could be described. These effects categories included shifts in relationships between vegetation and pests and pathogens, reduced plant vigor, reduced above and below-ground biodiversity, alterations in habitat quality, decreased reproductive success, alterations in nutrient and water flows, and aesthetic impairment due to visible foliar injury.

Economic Benefits Assessment

The quantitative economic benefits assessment evaluated the economic value associated with varying levels of yield loss for a number of nationally important commodity crops under different air quality scenarios associated with different combinations of alternative primary and secondary standards. Secondary standard options were expressed in terms of both the SUM06 and W126 forms, at the 10, 20 and 30 percent yield loss levels. Primary standard options ranged from the then current 0.12 ppm, 1-hr standard to the lowest alternative standard being considered, a 0.07 ppm, 8-hr standard. The Regional Model Farm (RMF), an agricultural benefits model, was used to generate the estimated benefits for commodity crops. The model incorporated the NCLAN C-R functions for 11 major field crops and the interpolated air quality maps described above. Benefits that accrued from just meeting alternative secondary standards were considered incremental to those that would be achieved by just meeting the alternative primary standards being considered. Except for the scenario of just attaining the then current 0.12 ppm, 1-hr primary standard and simultaneously meeting a secondary SUM06 standard at the lowest end of the recommended range (25 ppm-hrs.), the majority of the economic benefits achieved under each scenario were due to just meeting one of the alternative primary standard options.

The California Agricultural Resources Model (CARM), developed by the California Air Resources Board (Howitt, 1995a, 1995b) was used to analyze the benefits of reducing ambient O_3 on the O_3-sensitive, economically important fruits and vegetables endemic to California and other states with similar climate (Abt, 1995). These fruit and vegetable species included almond, apricots, avocados, cantaloupes, broccoli, citrus, grapes, plums, tomatoes, and dry beans. At that time, there were no national-level economic models that incorporated fruits and vegetables. Both NCLAN and non-NCLAN C-R functions were used, since a number of the fruits and vegetables were not part of the NCLAN study. The same air quality scenarios run with the RMF were also run using CARM. As with the commodity crop analysis described above, the majority of benefits accrued after just meeting the alternative 8-hr primary standard options, with small incremental benefits associated with just meeting an alternative secondary standard.

Though it was recognized that urban ornamentals and commercial forest species are additional vegetation categories that represent large economic sectors which are likely to experience some economic impacts associated with exposure to ambient levels of O_3, adequate C-R functions and economic damage functions for the potential range of effects relevant to these types of vegetation were not available at that time.

1.2.3 Summary of Conclusions and Decisions from the Last Review

Based on the economic benefits results for commodity crops and California fruit and vegetables described above, in combination with the quantitative risk estimates for tree seedlings, and consideration of the potential for occurrence of non-quantifiable risks to other vegetation categories and ecosystem services, staff concluded that consideration of a secondary standard, distinct from the primary, with a cumulative seasonal form was warranted, if the Administrator determined that additional protection was needed beyond that provided by the alternative primary standards under consideration.

Based on a thorough review of the latest scientific information available in 1996, as described in the 1996 O_3 AQCD, on vegetation effects associated with exposure to ambient levels of O_3, as well as (1) staff assessments of the policy-relevant information in the 1996 O_3 AQCD and staff analyses of air quality, vegetation exposure and risk, and economic values presented in the 1996 O_3 Staff Paper; (2) consideration of the degree of protection to vegetation potentially afforded by the proposed 0.08 ppm, 8-hr primary standard; (3) CASAC advice and recommendations; and (4) public comments, the Administrator proposed to replace the existing

1-hr O_3 secondary NAAQS with one of two alternative new standards: a standard identical to the proposed 0.08 ppm, 8-hr primary standard, or alternatively, a new seasonal standard expressed as a sum of hourly concentrations greater than or equal to 0.06 ppm, cumulated over 12 hours per day during the maximum 3-month period during the O_3 monitoring season (SUM06), set at a level of 25 ppm-hr (61 FR 65716, December 13, 1996).

In her final decision, the Administrator determined that replacing the then current secondary standard with an 8-hr standard, set at a level of 0.08 ppm, identical in all respects to the new primary standard, would provide adequate protection to vegetation. The Administrator judged that this standard would provide substantially improved protection for vegetation from O_3-related adverse effects as compared to that provided by the then current secondary standard, while allowing time for additional research and the development of a more complete rural monitoring network and air quality database from which to evaluate the elements of an appropriate seasonal secondary standard. The decision not to set a cumulative seasonal secondary standard at that time was based in large part on the Administrator's recognition that the exposure, risk, and monetized valuation analyses presented in the proposal contain substantial uncertainties, resulting in only rough estimates of the increased public welfare protection likely to be afforded by each of the proposed alternative standards. In light of these uncertainties, the Administrator decided that it was not appropriate at that time to establish a new separate seasonal secondary standard given the potentially small incremental degree of public welfare protection that such a standard might afford.

The Administrator further concluded that continued research on the effects of O_3 on vegetation under field conditions and on better characterizing the relationship between O_3 exposure dynamics and plant response would be important in the next review because:

- The available biological database highlighted the importance of cumulative, seasonal exposures as a primary determinant of plant responses.

- The association between daily maximum 8-hr O_3 concentrations and plant responses had not been specifically examined in field tests.

- The impacts of attaining an 8-hr, 0.08 ppm primary standard in upwind urban areas on rural air quality distributions could not be characterized with confidence due to limited monitoring data and air quality modeling in rural and remote areas.

It was determined that setting the secondary standard equal to the primary standard would allow EPA the opportunity to evaluate more specifically the improvement in rural air quality and in O_3–related vegetation effects resulting from measures designed to attain the new primary standard. This information would allow for better evaluation of the incremental need for a distinct seasonal secondary standard in the next review of the O_3 criteria and standards (62 FR 38877-78, July 18, 1997).

2 OVERVIEW OF PLANNED ASSESSMENT

Ozone-related studies published since the last review have been evaluated in the first draft of the O_3 AQCD (EPA, 2005b). Though this new information has added to our knowledge, it has not fundamentally altered the conclusions of the 1996 O_3 AQCD (EPA, 1996a) with regard to the effects of O_3 on vegetation. On the other hand, new developments and/or refinements in available air quality models, spatial interpolation tools, field exposure methodologies, economic benefits models, and tree and stand growth simulation models have occurred, that may allow for improved exposure, risk and economic benefits assessments, including better characterization of and/or reduction in associated uncertainties. These developments are summarized below and discussed in the following sections.

- The Community Multiscale Air Quality (CMAQ) model, developed cooperatively by EPA and NOAA, incorporates up-to-date meteorology and emission inventories (Byun and Ching, 1999) as well as numerous other factors that influence O_3 formation and deposition. The CMAQ model represents the state of the science in developing predictions of O_3 air quality.

- A spatial interpolation tool embedded in EPA's Environmental Benefits Mapping and Analysis Program (BenMAP) can be used to interpolate between monitored sites using CMAQ model outputs to spatially scale the interpolation between monitors.

- Free Air CO_2 Enrichment (FACE) is an exposure methodology originally developed to expose vegetation without chambers to elevated levels of CO_2. It has been modified at some sites to include O_3 exposures (Dickson et al., 2000; Morgan et al., 2004).

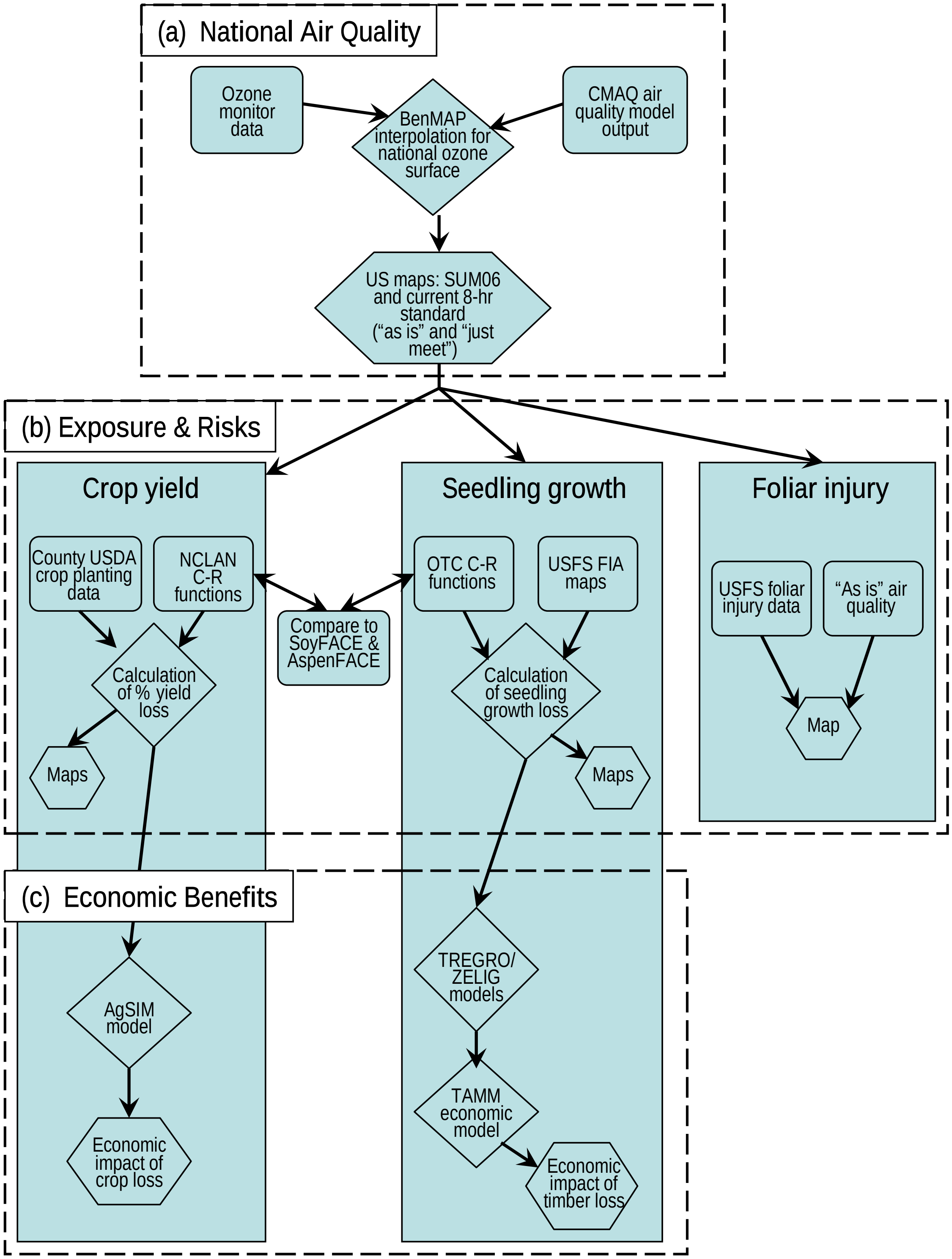
- The Agricultural Simulation Model (AGSIM©) is an econometric-simulation model used to calculate agricultural benefits of changes in O_3 exposure (Taylor et al., 1993). It has become the preferred model in a number of recent Agency analyses.

- The tree growth model, TREGRO, simulates a tree's utilization of resources to fix carbon in photosynthesis, allocation patterns used to maintain carbon fixation and nutrient and water uptake, and ability to repair pollution damage (Weinstein et al., 1991). TREGRO, linked with a stand-level model, ZELIG, has been used to make long-term estimates of stand growth under conditions of competition and different O_3 exposure scenarios. The Timber Assessment Market Model (TAMM) can be used with TREGRO/ZELIG to estimate economic impacts to commercial forests due to ambient O_3.

In the context of fulfilling the requirements of the Act for periodic review of the science and criteria upon which the secondary standard is based, staff plans to incorporate these recent developments in the analyses described below. Figure 1(a)-(c) depicts the components of the assessment planned for this review. Section 3 describes the planned approach for generating estimates of O_3 air quality to provide coverage in both monitored and non-monitored areas across the contiguous U.S., both for "as is" and selected alternative air quality scenarios. Section 4 focuses on crops and describes the planned approach to characterize exposures, risk of yield loss, and economic benefit impacts. Section 5 focuses on trees and describes the planned approach for estimating tree seedling exposures and risk of biomass loss. In addition, staff's consideration of a case study with ponderosa pine to explore using the TREGRO, ZELIG and TAMM models to estimate O_3 effects on mature trees, forest stands, and potentially economic impacts on a commercial tree species is discussed. Section 5 further describes staff's planned approach for evaluating the potential risks to natural vegetation from O_3 exposures by generating spatial maps that combine USDA Forest Service Forest Inventory and Analysis (FIA) visible foliar injury data with national air quality to observe the degree of co-occurrence. A planned comparison of selected C-R functions generated for crops (soybean) and tree seedlings (aspen) using the OTC methodology with more recent exposure-response data generated using the FACE methodology is described in sections 4 and 5, respectively.

Staff recognizes that in recent years there has been a growing interest in the development of new flux measurement methods, general and species-specific flux models, and policy tools for practical application of O_3 flux. However, unlike the extensive amount of data available on the relationships between O_3 exposures and plant response, which form the scientific basis supporting the current secondary NAAQS, comparable data linking measured or modeled O_3 flux with plant effects is extremely limited, and in the judgment of the staff, insufficient to support the type of quantitative analyses described in this Plan. Staff plans instead to discuss the emerging body of flux literature in the Staff Paper, based on the more detailed description in the O_3 AQCD (EPA, 2005b), with consideration given as to how this type of information might be taken into account in the future in evaluating/modifying traditional vegetation risk estimation approaches.

Figure 1. Major Components of Planned Environmental Assessment



3 NATIONAL AIR QUALITY ANALYSIS

3.1 Overview

To accomplish an assessment of the effects of ambient O_3 exposures on vegetation and ecosystems, it is important to characterize O_3 air quality for broad geographical areas of concern. This presents a great challenge since vast rural areas of the U.S. where important crops and natural vegetation occur do not have O_3 monitors. There is evidence that the risk of O_3 exposure to vegetation is actually greater in rural areas downwind from urban areas, where anthropogenic and natural O_3 precursors combine to create relatively high concentrations of O_3 (Gregg et al., 2003). Thus, sophisticated models of air quality and data from surrounding monitors must be used to fill in the gaps in the non-monitored areas. This section describes how staff plans to combine monitored observations and modeled O_3 predictions from CMAQ to estimate O_3 exposures in areas without monitors.

3.2 Ozone Monitor Data and CMAQ Model Outputs

Staff plans to use O_3 outputs from the EPA/NOAA CMAQ model system (http://www.epa.gov/asmdnerl/CMAQ, Byun and Ching, 1999) to spatially scale an interpolation of O_3 monitoring data for the contiguous U.S. CMAQ is a multi-pollutant, multiscale air quality model that contains state-of-science techniques for simulating all atmospheric and land processes that affect the transport, transformation, and deposition of atmospheric pollutants and/or their precursors on both regional and urban scales. It is designed as a science-based modeling tool for handling many major pollutants (including photochemical oxidants/O_3, PM, and nutrient deposition) holistically. CMAQ incorporates output fields from emissions and meteorological modeling systems and several other data sources through special interface processors into the CMAQ Chemical Transport Model (CCTM). Currently, the Sparse Matrix Operator Kernel Emissions (SMOKE) System produces the emissions factors and the Fifth Generation Penn State University/ National Center for Atmospheric Research Mesoscale Model (MM5) provides the meteorological fields. CCTM then performs chemical transport modeling for multiple pollutants on multiple scales.

CMAQ can generate estimates of hourly O_3 concentrations for a grid of the contiguous U.S., making it possible to express model outputs in terms of a variety of exposure indices (e.g., SUM06, 8-hr average). Due to the significant resources required to run CMAQ, however, model outputs are currently only available for limited years and intra-annual time periods. Currently, outputs from CMAQ version 4.4 are available for the year 2001. This is the most recent year available that utilizes the more refined 12 km x 12 km grid for the eastern U.S., while using the 36 km x 36 km grid for the western U.S. Emissions inventories used in this model run were prepared for the year 2001 and are consistent with inventories used for the analysis of the Clean Air Interstate Rule (CAIR) rule (EPA, 2005c). The staff recognizes that O_3 exposures vary between years depending on meteorology and other factors. Therefore, staff will consider adding additional years for comparison as more CMAQ outputs become available.

Monitored hourly O_3 data from EPA's Air Quality System (AQS; http://www.epa.gov/ttn/airs/airsaqs) and Clean Air Status and Trends Network (CASTNet; http://www.epa.gov/castnet/) databases will be obtained for 2001.

3.3 Generation of National Ozone Exposure Surface

To generate a National Ozone Exposure Surface (NOES), staff plans to primarily use the interpolation module in BenMAP, which uses the enhanced Voronoi Neighbor Averaging (eVNA) interpolation method to combine monitored data with spatial scaling from CMAQ model outputs (see appendix C.3.2 of http://www.epa.gov/ttn/ecas/models/modeldoc.pdf). It is expected that this eVNA approach will be an improvement over a simple interpolation between monitors that does not use spatial scaling. It also retains the true monitored values at monitored sites. However, in areas of the country with little or no monitor coverage, staff recognizes that the interpolation would depend on data from distant monitors that may have very little correlation with the true O_3 exposure at the unmonitored cell. Thus, staff is evaluating the benefit of identifying criteria that could be used to define the appropriate spatial "window" within which monitored sites can be used to interpolate values for the non-monitored area. In addition, the staff is also considering whether it might be more suitable in these cases to use CMAQ modeled O_3 exposures instead of relying on interpolated O_3 values.

In order to generate a NOES in terms of a particular index, the monitored data and CMAQ model outputs that form the basis for the interpolation need to be characterized in terms of that index. At a minimum, staff plans to generate the NOES in terms of both the 12-hr (8 am to 8 pm), 3-month SUM06 index and the 8-hr average index that reflects the form of the current secondary standard. Therefore, prior to the interpolation, hourly monitored data and CMAQ model outputs will be characterized in terms of these indices. Staff recognizes that additional indices may be selected for further evaluation upon review of the information contained in the revised O_3 AQCD and results of any additional air quality analyses performed. Any expanded evaluation of additional indices would be contained and discussed in the Staff Paper.

The following air quality scenarios will be generated:

- "As is" air quality (using base year 2001)
- Meeting the current standard: 4th highest daily maximum 8-hr average of 0.084 ppm
- Meeting alternative O_3 standards

In conjunction with the health risk assessors, staff is currently considering various approaches to simulate just meeting the current and alternative standards, including the quadratic air quality adjustment that was used in the last review (Johnson, 1997) and variations of the proportional adjustment method. In addition, staff is currently investigating methods for generating adjusted air quality in non-monitored areas.

The NOES, depicted as a GIS layer, will provide the exposures needed as input to the crop and tree seedling risk and economic benefits assessments described in sections 4 and 5 below.

4 CROP EXPOSURE, RISKS AND ECONOMIC BENEFITS ANALYSES

4.1 Overview

In light of a number of changes since the last review, including an updated air quality model, a new spatial interpolation tool to better characterize O_3 exposures in crop growing regions, current monitoring data, recent crop planting information, and an alternative agricultural economic model that reflects the most up-to-date market forces, staff plans to update the previous review's crop assessment and economic benefits analysis in order to better assess the adequacy of the level of protection afforded by the current standard. One element of the analysis that has not changed since the last review is the source of the crop yield loss C-R functions. The crop assessment was built upon the NCLAN O_3 C-R functions. Since very few new studies have published C-R functions that would be useful in an updated assessment, C-R functions from NCLAN remain the best data available for a national assessment of crop loss under various O_3 air quality scenarios. However, at the time of the last review, C-R functions were not expressed specifically in terms of an 8-hr average index. Staff plans to re-analyze the NCLAN C-R functions in terms of the current 8-hr standard form to assess the strength of the current standard form as a predictor of NCLAN crop response. Limited data on soybean yield loss is available from the SoyFACE experimental site in Illinois. Given staff's necessary reliance on NCLAN C-R functions for the foreseeable future to conduct national exposure assessments, staff plans to conduct a limited evaluation of the appropriateness of using NCLAN soybean C-R functions to predict the soybean yield losses observed in SoyFACE.

4.2 NCLAN Concentration-Response Functions

In the last review, C-R functions were developed in terms of the SUM06 and W126 indices for most NCLAN crops (Lee and Hogsett, 1996). Currently, work is underway to re-analyze the NCLAN database to recalculate the C-R functions in terms of an 8-hr average index. Specifically, staff plans to plot relative crop yield loss against an 8-hr average index calculated from the 1-hr averages contained in the NCLAN database. The benefits of this re-analysis are two-fold: 1) permits evaluation of the appropriateness of the 8-hr average index for predicting growth effects of the NCLAN studies as compared to a SUM06 index and 2) permits direct evaluation of estimated yield effects expected to occur under air quality scenarios expressed in terms of the current 8-hr, 0.08 ppm standard level.

4.3 Estimation of Yield Loss for NCLAN Crops

County-level crop planting data will be obtained from USDA-NASS (National Agricultural Statistics Service; http://www.usda.gov/nass) for 2001 for each NCLAN crop as available. This information will be used to create GIS maps containing the planting data for each species/cultivar of commodity crop. Staff plans to overlay the NOES (as discussed in section 3.3) with GIS maps of the crop growing regions and then calculate yield loss using the relevant C-R functions. This combination of data will result in an estimate of county-level percent yield loss for each NCLAN crop. Staff plans to create GIS maps of percent yield loss of each crop for the counties in which they were planted in 2001. This analysis will also be performed for just meeting the current standard and other alternative standards. The change in crop county-level percent yield loss estimates between 'as is' 2001 air quality and meeting various standards will serve as inputs to the AGSIM© agricultural economic benefits model.

4.4 Economic Benefits Analysis Associated with Crop Yield Loss

The peer-reviewed AGSIM© model (Taylor et al., 1993) has been utilized recently in many major policy evaluations.[3] AGSIM© is an econometric-simulation model used to calculate agricultural benefits of changes in O_3 exposure and is based on a large set of statistically estimated demand and supply equations for agricultural commodities produced in the United States. Initially, AGSIM© will be used to calculate the economic benefits of yield changes between the 'as is' and 'just meet' scenarios for base year 2001. This approach will also be used to calculate benefits from any alternative standards under consideration. If data are available, the same analysis will be performed using air quality data from other years.

4.5 Comparison of NCLAN and FACE for Soybean

Since the last review, the majority of the O_3 exposure vegetation effects research published in the scientific literature and discussed in the draft O_3 AQCD (EPA, 2005b) have continued to use the OTC exposure method. A few studies, however, have employed the FACE technology. This latter method releases gas (e.g., CO_2, O_3) from a series of orifices placed along the length of the vertical pipes surrounding a circular field plot and uses the prevailing wind to distribute it. This exposure method may more closely replicate conditions in the field and, more importantly for tree/forest research, has the benefit of being able to expand vertically with the growth of the trees, allowing for exposure experiments to span numerous years. On the other hand, the FACE methodology is expensive to operate, likely limiting the number of new sites that will employ these systems, and cannot be used to build statistically robust C-R functions like those produced with OTCs since it is not possible to produce O_3 concentrations below ambient. Given these limitations of FACE, staff recognizes that the C-R functions developed with OTCs will likely continue to be the most useful for supporting a broad-scale impact analysis.

In the U.S., only the SoyFACE experiment in Illinois uses FACE technology to study O_3 effects on crops. Data are now available for a commonly used Pioneer soybean cultivar (Morgan et al., 2004). The data were generated using a step exposure regime (ambient and 1.2 x ambient). FACE data, however, could potentially be used to evaluate how well NCLAN C-R functions predict observed response to O_3 exposures in a more realistic non-chambered field setting. Staff plans to directly compare published yield loss values observed at SoyFACE with those predicted at the same levels of O_3 exposure in terms of the SUM06 and/or 8-hr average indices using the composite C-R functions developed from NCLAN. Results from this comparison would provide some estimate of the appropriate level of confidence to afford estimates of soybean yield loss at ambient exposures in the field using NCLAN C-R function. The completion of this comparison is conditional on the availability of the data from the SoyFACE experiment.

5 TREE EXPOSURE, RISK AND ECONOMIC BENEFITS ANALYSES

5.1 Overview

In the last review, analyses of the effects of O_3 on trees were limited to 11 tree species for which C-R functions for the seedling growth stage had been developed from OTC studies

[3] For example, AGSIM© has been used in EPA's prospective study of the benefits deriving from the Clean Air Act Amendments of 1990 required by section 812-B of the Clean Air Act, non-road land-based diesel engine rule, and proposed Clear Skies legislation.

conducted by NHEERL-WED. Since the last review, only a few studies have developed C-R functions for additional tree seedling species (EPA, 2005b). Section 5.2 outlines how staff plans to re-analyze the OTC C-R functions in terms of an 8-hr average index. Section 5.3 describes how staff plans to update the tree seedling risk analysis performed in the last review. Section 5.4 discusses staff's planned approach for modeling O_3 impacts on mature trees. Section 5.5 describes how staff plans to evaluate whether OTC C-R functions can predict the growth effects observed in tree seedlings in experiments using the FACE exposure methodology. In section 5.6, staff presents its planned approach for assessing O_3 effects on vegetation in natural settings using visible foliar injury data. These tree and/or forest analyses being considered would enable staff to begin to assess important long-term effects of various secondary standard levels on forest ecosystem health and services.

5.2 Tree Seedling Concentration-Response Functions

Similar to crops (section 4.2), C-R functions for tree seedling biomass loss due to O_3 exposures have not been reported in terms of an 8-hr average index. Staff plans to re-analyze the 11 OTC tree seedling C-R functions described in the 1996 O_3 Staff Paper in terms of the current 8-hr exposure metric. This re-analysis will enable staff to evaluate the appropriateness of using an 8-hr average index as a predictor of tree seedling growth/biomass losses and to directly evaluate estimated seedling biomass loss values expected to occur under air quality exposure scenarios expressed in terms of the current 8-hr, 0.08 ppm secondary standard.

5.3 Estimation of Biomass Loss for Tree Seedlings

In the 1996 O_3 Staff Paper, information on tree species growing regions was derived from the USDA Atlas of United States Trees (Little, 1971). Staff plans to use more recent information from the USDA Forest Service FIA database in order to update tree growing ranges for the 11 tree species studied by NHEERL-WED. In a process similar to that used for crops (see section 4.3), staff plans to combine the NOES (from section 3.3) with the C-R function for each of the tree seedling species and information on each tree species growing region to produce estimates of biomass loss for each of the 11 tree seedling species. From this information, staff plans to generate GIS maps depicting these results for each NOES scenario.

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5.4 Modeling of Tree Growth and Economics

In the 1996 O_3 Staff Paper, analyses on trees were limited to the seedling growth stage. Because it is difficult and costly to construct OTCs to expose mature trees, few OTC data were available at that time on the growth/biomass response of mature trees to O_3. Recent experiments using the FACE methodology have been able to expose 3 tree species to O_3 beyond the seedling growth stage. However, this methodology has not yielded C-R functions at this time. Therefore, in order to go beyond the seedling stage, staff is investigating the appropriateness of using tree growth, stand dynamics and timber economic models to evaluate the effect of changing O_3 air quality scenarios from just meeting alternative O_3 standards on the long-term growth of forests and potential economic consequences to the timber industry.

A tree growth simulation model, TREGRO (Weinstein et al, 1991) has been used to evaluate the effects of a variety of O_3 scenarios on several species of trees in different regions of the U.S. However, in order to examine tree growth rates over long time periods, competition among tree species must also be taken into account. Some researchers have linked TREGRO to the stand growth model, ZELIG (Urban et al., 1991), to simulate succession in mixed stands (Laurence et al., 2000; Weinstein et al., 2005). The linked TREGRO and ZELIG modeling system can be modified to predict the effects of O_3 on basal area and other growth parameters of some species. Those model growth outputs that are relevant to timber production could be input into the TAMM (http://www.treesearch.fs.fed.us/pubs/7589) commercial timber model. TAMM is a spatial model of the solid wood and timber elements of the U.S. forest products sector developed by the USDA Forest Service (Adams and Haynes, 1996) and can be used to predict the effect of meeting the current and alternative standards on the U.S. timber market by changing the annual growth rates of commercial forest growing-stock inventories.

Staff is considering collaborating with the EPA NHEERL-WED lab to use the TREGRO and ZELIG modeling system to assess long-term ponderosa pine growth in the context of the mixed conifer forest of the San Bernardino Mountains of California associated with 'as is' air quality, and air quality adjusted to just meet alternative O_3 standards. Staff plans to use outputs from the linked TREGRO and ZELIG modeling system in conjunction with the TAMM timber economic model to characterize the economic impact of changes ponderosa pine growth rates under different O_3 scenarios Given the time available, staff is planning to limit this portion of the assessment to evaluating only ponderosa pine.

There are many uncertainties and limitations in the modeling framework outlined above. For example, the TREGRO model is currently only parameterized for a subset of the 11 tree species for which seedling biomass C-R functions were available at the time of the last review. This subset includes: ponderosa pine, loblolly pine, tulip poplar, red oak, sugar maple, and red spruce. Though TREGRO could potentially be parameterized for other tree species for which C-R functions exist, this has not yet been done. Second, there is evidence that seedlings and mature trees may respond differently to O_3 exposure (Hanson et al, 1994). Third, when modeling growth of trees into the future, many simplifying assumptions must be used with respect to environmental factors that may be changing along with O_3 such as carbon dioxide concentrations, temperatures, and rainfall patterns. Consequently, these models provide only a framework for scientists and policy-makers to investigate questions about how factors such as O_3 may affect forest growth.

5.5 Comparison of OTC and FACE for Aspen

Similar to the case study described for soybean (section 4.5), the majority of O_3 exposure studies on trees have continued to use OTCs. Only one site in the U.S. is using FACE technology to study the effect of O_3 on trees. Specifically, the Aspen FACE experiment, located in Rhinelander, Wisconsin, is studying O_3 effects on aspen clones with a range of O_3 tolerance (Karnosky et al., 1999; http://aspenface.mtu.edu/). Concentration-response data for these same aspen clones generated using OTCs have been published (Karnosky et al., 1996). Staff plans to compare stem diameter and height responses predicted from the OTC studies to results observed in the FACE experiments.[4]

[4] For this analysis, the OTC study data will be obtained from the NHEERL-WED database and Dr. David Karnosky, director of Aspen FACE, has agreed to send the raw FACE data underlying published studies to EPA.

5.6 Visible Foliar Injury Concurrence with Ozone Exposures

A large database exists for the occurrence of visible foliar injury symptoms indicative of exposures to phytotoxic O_3 concentrations in many regions of the country. The USDA Forest Service FIA program collects information about O_3 injury to plants on a network of bio-monitoring plots (bio-sites) using O_3 sensitive bio-indicator plants (trees, woody shrubs, and non-woody herb species; http://www.fiaozone.net). Field protocols are documented by the USDA Forest Service (1999). The O_3 bio-monitoring network provides information about visible O_3 injury to plants in forested landscapes on regional and national scales. Results from the bio-monitoring network have recently been published (Coulston et al., 2003, 2004; Smith et al., 2003). The bio-monitoring database, with over 1000 sites sampled across the country, will be mapped in GIS for 2001 and overlaid with the NOES. These maps will allow staff to characterize the extent to which visible foliar injury occurred in areas of relatively high estimated O_3 exposures.

6 NEXT STEPS

A consultation with the CASAC O_3 Panel is expected to take place within a few weeks after the release of this document to obtain input on this draft assessment plan. Staff will then proceed to develop exposure, risk and economic benefits estimates associated with the various air quality scenarios to be included in this assessment. The methodology and tools being used to develop these estimates will be discussed further in the first draft O_3 Staff Paper and in a separate draft environmental assessment report that will include limited initial assessment results. After the release of the first draft Staff Paper for CASAC and public review, staff anticipates also releasing the initial draft assessment report for review. Staff will take into account comments received on these draft documents in preparing revised drafts of the O_3 Staff Paper and the environmental assessment report. The second drafts of these documents will include and discuss the completed assessment results. The revised draft environmental assessment report is planned for release in April 2006 in conjunction with a second draft O_3 Staff Paper for review by CASAC and the public at a meeting to be held in July 2006. Staff will consider these review comments and prepare a final environmental assessment report by September 2006.

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