PROTECTING AGRIGULTURAL CROPS FROM OZONE EXPOSURES KEY ISSUES AND FUTURE RESEARCH DIRECTIONS

HEALTH AND ENVIRONMENTAL AFFAIRS
API PUBLICATION NUMBER 305
AUGUST 1991

American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005

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ACKNOWLEDGEMENT

The authors (A.S. Lefohn and J.K. Foley) wish to acknowledge the assistance of Dr. E. Henry Lee, ManTech Environmental Technology, Inc., Corvallis, Oregon, for providing the SUM06 exposure-response equations used in the Lee *et al.* (1991) analyses; Ms. Susan Spruill, Department of Statistics, North Carolina State University, Raleigh, North Carolina, for providing the hourly ozone data for a subset of the NCLAN experiments; Mr. Douglas Shadwick, ManTech Environmental Technology, Inc., Research Triangle Park, North Carolina, for helpful suggestions, mathematical advice, and assistance; Ms. Phyllis E. Lefohn and James Spence of A.S.L. & Associates for assisting in the research, editing, and proofing of the work.

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EXECUTIVE SUMMARY

The ubiquity and toxicity of ambient air O_3 is well documented. Because O_3 is an omnipresent air pollutant that affects both human health and vegetation, the U.S. Environmental Protection Agency (EPA) has established both primary and secondary standards. There is no requirement that the primary and secondary standards be identical, nor is there any requirement that only a single expression of the standard be used (i.e., an average concentration for a single time period versus multiple exceedances or integrated exposures). Any effort to propose a secondary standard, whose form is different than the current form of the primary and secondary standard, implies that either (1) the current form is inappropriate for protecting the public welfare or (2) a more restrictive value of the current form of the standard is required.

There have been indications reported in the literature that the current form of the standard may not be appropriate for protecting vegetation from O_3 exposures. The purpose of this report is to identify and review some of the key issues related to assessing the effects of O_3 on vegetation. Our report has reviewed the available information on (1) components of O_3 exposure that elicit adverse effects on vegetation, (2) ways to describe these components in the form of O_3 exposure indices that may be useful in the standard-setting process for protecting vegetation, (3) the change in nonattainment status that may occur should the existing O_3 standard be modified, and (4) the need for future research efforts to explore the development of a multi-parameter index to protect vegetation from O_3 exposure.

Our results, using a select set of National Crop Loss Assessment Network (NCLAN) experimental data, tend to support the finding, suggested in the literature, that the repeated occurrence of hourly average O_3 concentrations of 0.10 ppm and higher result in adverse effects on vegetation. Although the hourly average concentrations below 0.10 ppm may be important in affecting crop yield, the NCLAN program was not developed to identify and quantify the specific exposure regimes that are responsible for the observed effects. In our analysis, we have presented exposure statistics to provide a variety of choices that allow investigators the opportunity to develop indices that are most relevant in predicting vegetation effects.

It has been assumed by some investigators that the O_3 exposures that occurred in the NCLAN chambers during the fumigation period were greater than those received during the remaining part of each day. For example, it has been assumed that the number of hourly average concentrations $\geq$ 0.06 ppm was much greater during the daylight hours than the late afternoon, evening, and early morning hours. For 22 sets of NCLAN experiments, over the entire exposure period, we have compared the SUM06 value calculated over the daily exposure period (e.g., 7 and 12 hours) with the SUM06 value calculated over a 24-h period. Assuming that the ambient hourly average concentrations reported for each experiment represented the exposure the crops received during those periods when fumigation did not occur, we combined these data with the fumigation-period information reported by the investigators for each chamber.

In most cases, the 24-h SUM06 values for the lower exposure chambers were more influenced by hourly average concentrations $\geq$ 0.06 ppm that occurred outside the daily fumigation period than the 24-h SUM06 values for the higher O_3 exposure treatments. The value calculated for the SUM06 index over the exposure period did not necessarily represent the 24-h SUM06 value. Thus, if one ignores the hourly average concentrations $\geq$ 0.06 ppm that occurred outside the fumigation period, exposure-response equations developed using only fumigation-period air quality data, would at times, appear to overestimate yield reductions. Thus, there is some degree of uncertainty associated with using the SUM06 exposure index and therefore, inferences based on the published exposure-response results should be used with caution.

The problems associated with using long-term seasonal average concentrations, such as 7-h seasonal values, as surrogates for dose are well documented. Any O_3 exposure index used to describe those regimes that cause vegetation effects must be able to characterize adequately the upper tail of the hourly average distribution curve. The cumulative exposure indices, SUM06 (i.e., the sum of all hourly average concentrations $\geq$ 0.06 ppm) and W126 (i.e., the sum of all hourly average concentrations where the higher concentrations receive greater weight than the lower values), have shown much promise in relating O_3 exposure with vegetation effects.

However, even if one is found to characterize the most important components of exposure (e.g., the upper tail of the hourly average distribution curve), a consistent relationship between an O_3 exposure index and vegetation effects may not always occur. We know, based on published results in the literature, that the occurrences of elevated O_3 hourly concentrations are important for eliciting adverse effects on agricultural crops. However, in addition to concentration, the (1) amount and chemical form of the pollutant that enters the target organism, (2) length of the exposure within each episodic event, (3) time between exposures (i.e., the respite or recovery time), and (4) sensitivity of the target organism are important factors that affect vegetation. When predicting vegetation effects, it is unclear how important these four factors are in an overall weighting scheme. However, at this time, given the current state of knowledge, concentration should be weighted more heavily than either sensitivity or actual dose.

For protecting vegetation from O_3 exposures, an important aspect that requires further attention is the use of experimental results obtained at low-elevation sites to predict O_3 vegetation effects that may occur at high-elevation locations. Ozone exposures that occur at high-elevation sites are often different from those that occur at lower elevation locations. Exposure regimes used in experiments performed at low-elevation locations should mimic those that occur at the high-elevation sites. In addition, the use of mole fraction (e.g., ppm) or absolute concentration (e.g., micrograms per cubic meter) to describe exposure is an important consideration. Exposure-response relationships developed using results obtained at low-elevation locations may require pressure adjustments when attempting to use air quality data obtained at high-elevation monitoring sites to predict vegetation effects. When concentrations of gases are defined in terms of mole fraction (i.e., units of ppm), the resulting term is invariant to temperature and pressure. However, if exposures measured at low-elevation sites are compared with those experienced at high-elevation sites, the variation of concentration (in units of micrograms per cubic meter) as a function of altitude may be significant. Given the same parts-per-million value experienced at both high- and low-elevation sites, the absolute concentrations (i.e., micrograms per cubic meter) at two elevations are different. Temperature decreases inversely relative to elevation and therefore, the change in absolute concentration would be less than estimated when only pressure changes are considered. However, temperature differences do not usually compensate for the pressure effect. The biological consequences of high-elevation exposures to the reduced absolute concentration of O_3 that are disguised by the use of mole fraction units of concentration need to be further investigated.

Because of the concern that the current form of the standard may not protect vegetation from O_3 effects, we have explored the effects on nonattainment status by lowering or modifying the current form. When exploring the effects on nonattainment status when the current form of the standard was changed from 0.12 ppm to either 0.10 or 0.08 ppm for the 1987-89 and 1986-88 periods, we found the greatest increase in nonattainment areas occurred when the standard was lowered to 0.10 ppm. The application of a revised standard for O_3 would mainly increase the number of nonattainment areas (i.e., CMSA, MSA, and non-MSA) that are not near the current existing areas. In other words, rather than growth occurring near existing nonattainment areas, it would occur at new locations removed from the current nonattainment areas.

Except for the Plains States, the major growth on a regional basis would be dramatic for all regions across the United States. The most dramatic differences would be in regions where states were completely in attainment with the current standard. For example, Oregon and Washington were in attainment for the 1987-89 period. However, if a standard of 0.10 ppm were applied, the Seattle/Tacoma, Portland, and Eugene areas would be classified as nonattainment. All Rocky Mountain states, other than the Salt Lake area of Utah, are currently in attainment. A revised standard would classify the Denver, Phoenix, and Las Cruces areas into nonattainment status.

As indicated, results reported in the literature indicate that the second highest daily maximum concentration appears to be an inappropriate index to use to protect vegetation from elevated O_3 exposures. As an alternative to the current form of the standard, it has been suggested that the SUM06 O_3 exposure index could be used as the form of a secondary standard to protect agricultural crops. It has been reported in the literature that a 3-month SUM06 value of 24.4 ppm-h was estimated to cause a 10% yield loss in some NCLAN experiments.

Accordingly, we identified those areas in the United States that experienced a SUM06 value of 24.4 ppm-h or higher over a 3-month period for the years 1987, 1988, and 1989. We explored whether there might exist a relationship between the current form of the standard, lowered to either 0.10 or 0.08 ppm, and the SUM06 3-month cumulative index. Based on our results, lowering the current form of the standard to either 0.10 or 0.08 ppm did not appear to guarantee that a specific monitoring site would achieve a SUM06 3-month cumulative value of 24.4 ppm-h or lower.

In addition, we found that the occurrence of 3-month SUM06 values of 24.4 ppm-h or higher was not correlated with elevated hourly average concentrations and concluded that the application of the SUM06 index as a secondary standard would result in inconsistent protection for vegetation. Using 1989 hourly averaged O_3 data, we found that no strong relationship appeared to exist between the number of occurrences of high hourly average O_3 and a maximum uncorrected 3-month SUM06 value $\geq$ 24.4 ppm-h. Several O_3 monitoring sites that violated the current standard experienced a 3-month SUM06 value < 24.4 ppm-h. Similarly, we found that several O_3 monitoring sites that did not violate the current standard experienced a maximum uncorrected 3-month SUM06 value $\geq$ 24.4 ppm-h.

As indicated, we found that a strong correlation between peak concentrations and the value of the SUM06 index did not necessarily occur under ambient conditions. However, as reported in the literature, the SUM06 index has performed well, using NCLAN data, in relating O_3 exposure and yield reduction. We found, at the 20% yield reduction level, that there were O_3 distributions (of hourly average concentrations) which contained a sufficient number of high hourly average concentrations. The NCLAN experimental protocol applied incremental and proportional additions that resulted in many of the treatments experiencing elevated O_3 exposures; many of the artificial regimes used by NCLAN contained the elevated hourly average concentrations that were reflected in the determination of the absolute values of the cumulative indices. Therefore, at many of the treatment levels, the magnitude of the SUM06 index, calculated using NCLAN protocols, appeared to be influenced by the peak exposures that correlated well with the observed growth reductions.

A major concern about the use of any exposure index (e.g., cumulative or seasonal average concentration) is whether the value of the index can be linked to a specific exposure regime. The absolute value of the index reflects only the mathematical calculation performed using hourly average O_3 concentrations. If we assume that the distribution of the highest hourly average concentrations (i.e., the upper tail of the distribution) is an important factor in affecting vegetation, then a single-parameter exposure index, such as the SUM06 or W126, in some instances, may not be specific enough to describe those important distributions that cause an O_3-related effect.

Although difficulties may exist for linking experimental exposure-response relationships with ambient air for predicting vegetation effects, single-parameter exposure indices have been used successfully for describing regional O_3 exposure in the United States. Yet, given the fact that we have shown that the magnitude of cumulative exposure indices, such as the W126 or SUM06 exposure index, is not necessarily strongly associated with the occurrence of high hourly average O_3 concentrations, why is it possible to successfully describe regional exposures using single-parameter cumulative indices?

The O_3 exposures experienced at each site are influenced by a multitude of factors. The elevation of a specific site, its ground cover (i.e., sorptive capacity), as well as its latitude, may influence O_3 production and destruction of the absolute O_3 exposure value experienced at a specific site. Many of the O_3 monitors used in the kriging analyses were situated near urban-oriented locations. Thus, the distribution of the hourly average concentrations may have been similar. For example, most of the urban-oriented monitoring sites may experience similar scavenging processes that result in 30% or more of the hourly average concentrations occurring below 0.015 ppm. In addition, the maximum hourly average concentrations experienced at many of these sites were similar. Thus, with similar hourly average distribution patterns, it would be assumed that the magnitude of a cumulative exposure index, such as the W126 or SUM06, would order itself properly, with the higher value corresponding to the higher exposure. This appears to be what occurred.

In addition to using cumulative exposure indices to describe regional O_3 exposures, a cumulative exposure index has been used in trends analysis. Trends for O_3 exposures over 5- and 10-year periods (i.e., 1984-1988 and 1979-1988) have been summarized for rural locations in the United States. The evidence for trends at each monitoring location was explored. Evidence for regional trends was based on studying the individual time trends observed for each of the sites in the region. The seasonal W126 cumulative exposure index was used to investigate trends. The results reported in the literature were consistent with the findings reported by the U.S. Environmental Protection Agency.

The explanation for the successful application of the cumulative index in the trends analysis was similar to the one given for the kriging analysis. For a specific monitoring site, the hourly average distribution pattern was similar over the years studied. The scavenging processes remained the same over time at a specific site. Thus, the difference in magnitude of the W126 index, at any one site over time, was reflected in changes in the distribution curve of the hourly average O_3 concentrations. Changes that occurred at the upper end of the distribution curve were reflected in the magnitude of the W126 index.

For some purposes, the single-parameter index appears to work appropriately. However, the predictive power involving exposure-response relationships that use single-parameter exposure indices may not be as strong as desired. A multiple-parameter index may be necessary to adequately describe distribution patterns of hourly average concentrations.
To improve the predictive capability that depends upon linking experimental exposure-response relationships with ambient air quality, it appears that indices, such as the SUM06 or W126, will have to be combined with other exposure parameters in order to mathematically define unique distribution patterns of hourly average concentrations.

Although moderate success has been achieved using the SUM06 and W126 exposure indices, consistency is important so that experimental exposure-response relationships can be strongly linked with ambient exposures. If this consistency is not present, then it will be difficult to use any exposure index in the development of a secondary standard.

For developing a secondary standard to protect vegetation, the combined exposure statistics should be selected based on the observation that high concentrations are expected to cause greater impact on vegetation than lower concentrations. It has been shown, when high hourly average concentrations are present in an exposure regime, that single-parameter cumulative indices can be used to relate O_3 exposures with vegetation growth reductions. However, when attempting to link experimental models with ambient air quality, it appears that the application of a single-parameter exposure index, in the form of a standard for protecting vegetation, will provide inconsistent results. **This does not imply that all currently used cumulative exposure indices are not appropriate for describing O_3 exposure. Rather, it appears that cumulative indices, such as the SUM06 and W126 indices, will have to be combined with other parameters to quantify accurately the occurrence of the high hourly average concentrations.**

The possible combination of exposure parameters, such as the (1) sigmoidally-weighted exposure index or (2) SUM06 index, with other indices should provide sufficient means to describe those unique distribution curves that have the potential for eliciting an adverse effect. Our reanalysis of the NCLAN data provided us with evidence that summaries of distribution patterns provide important information concerning the relationships between exposure and response. Future research efforts in this area point to the quantification of the distribution of the hourly average concentrations. The percentile distribution of the hourly average concentrations offers a way to characterize both high and low O_3 concentrations. With high confidence, from the percentile distribution of O_3, one can infer that the values in the tail of the distribution represent peaks in the time plots of hourly O_3 concentrations.

In addition, percentile distributions offer the opportunity to differentiate exposures experienced at remote or isolated sites from exposures experienced at sites influenced by urban sources. Monitoring sites under the influence of local urban sources experience approximately 50-70 percent of their hourly average O_3 concentrations above 0.015 ppm.

Although we have discussed the possible combinations of parameters to better link experimental exposure-response models with ambient air quality for predicting possible impacts on vegetation, at this time, information is not available to identify the specific parameters that should be combined. However, the results of the NCLAN experiments provide researchers with the opportunity to better understand the level of exposures that result in agricultural yield reduction. We have summarized the distribution of the hourly average concentrations that occurred in some of the NCLAN experiments. The characterized distributions reflected the importance of the upper end of the distribution curve in affecting crop yield reductions. We believe this additional information should assist researchers in identifying a multi-parameter exposure index that will properly relate ambient exposure to response.

A strong case has been made for selecting multi-parameter exposure indices for establishing a secondary standard to protect vegetation from high levels of O_3 exposure. However, caution is urged. Although we believe that an effort should be made to identify multi-parameter indices, it is important to note that a consistent relationship between multi-parameter exposure indices and vegetation effects may not always exist. Based on the analysis described in this report, at this time, we believe that further research is required before any single-parameter exposure index is used in the standard-setting process to protect vegetation from O_3 exposure.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The Clean Air Act requires the Administrator of the U.S. Environmental Protection Agency to establish national ambient air quality standards. These standards are designed to protect the public health and welfare from any known or anticipated adverse effects associated with the presence of criteria air pollutants. Primary air quality standards are promulgated to prevent adverse effects on human health, while secondary air quality standards are established to prevent adverse welfare effects (e.g., effects on vegetation, animals, deterioration of property materials, and visibility).

The ubiquity and toxicity of ambient air O_3 is well documented (EPA, 1986, 1988a). Because O_3 is an omnipresent air pollutant that affects both human health and vegetation, the U.S. Environmental Protection Agency (EPA) has established both primary and secondary standards.

On April 30, 1971, in the Federal Register (36 FR 8186), the Environmental Protection Agency promulgated National Ambient Air Quality Standards (NAAQS) for photochemical oxidants. The scientific, technical, and medical bases for these standards were contained in the air quality criteria documents for photochemical oxidants, published by the U.S. Department of Health, Education, and Welfare in March 1970. Both the primary and secondary standards were set at an hourly average level of 0.08 ppm, not to be exceeded more than once per year.

Based on a reassessment of the available data, in 1979, EPA revised both the primary and secondary standards for photochemical oxidants (i.e., O_3). The revised form of the standard (1) raised the primary standard to 0.12 ppm,

(2) raised the secondary standard to 0.12 ppm, and (3) changed the definition of the point at which the standard is attained to "when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is equal to or less than one." The phrase "expected number of days per calendar year" differed from the previous NAAQS for photochemical oxidants, which simply stated a particular concentration "not to be exceeded more than once per year." The federal standard for O_3 is based on the second daily occurrence of a maximum hourly average concentration above 0.12 ppm and is designed to protect both human health and welfare effects.

There is no requirement that the primary and secondary standards be identical, nor is there any requirement that only a single expression of the standard be used (i.e., an average concentration for a single time period versus multiple exceedances or integrated exposures). Any effort to propose a secondary standard, whose form is different than the current form of the primary and secondary standard, implies that either (1) the current form is inappropriate for protecting the public welfare or (2) a more restrictive value of the current form of the standard is required.

There have been indications reported in the literature (Lefohn *et al.*, 1989; Lee *et al.*, 1991) that the current form of the standard may not be appropriate for protecting vegetation from O_3 exposures. Lee *et al.* (1991) reported that, although no single exposure index was best in describing the exposure-response relationship for 49 case studies, the performance of the current form of the U.S. Federal standard was considerably worse than other exposure indices used in their analysis. The authors reported that the current form of the standard did not perform adequately because it (1) was poorly related to plant growth, (2) ignored exposure duration, and (3) placed too much emphasis on a single peak 1-h concentration.

Should one want to develop an O_3 standard that provides an adequate measure of protection to vegetation, it would be necessary to define, in as precise terms as possible, the relationship between O_3 exposures and the potential for adverse effects on vegetation. Although the form of the standard should be made as simple as possible, it is essential that the standard be related directly or indirectly to identifiable adverse effects. The U.S. EPA (1988b) has made a distinction between the relative importance of foliar injury to vegetation and reduced crop yield. Greater emphasis has been placed on damage or yield loss than on injury, where injury encompasses all measurable plant reactions, such as reversible changes in metabolism, reduced photosynthesis, leaf necrosis, leaf drop, altered quality, or reduced growth, that do not influence agronomic yield or reproduction and damage includes all effects that reduce the intended human use or value of the plant or ecosystem (Tingey *et al.*, 1990).

The purpose of this report is to identify and review some of the key issues related to assessing the effects of O_3 on vegetation. Our report has reviewed the available information on (1) components of O_3 exposure that elicit adverse effects on vegetation, (2) ways to describe these components in the form of O_3 exposure indices that may be useful in the standard-setting process for protecting vegetation, (3) the change in nonattainment status that may occur should the existing O_3 standard be modified, and (4) the need for future research efforts to explore the development of a multi-parameter index to protect vegetation from O_3 exposure.

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CHAPTER 2

EXPOSURES THAT RESULT IN VEGETATION GROWTH REDUCTION

2.1 INTRODUCTION

For assessing the efficacy of a standard to protect vegetation from O_3, the actual pollutant levels below which plants will be protected must be identified. Guderian *et al*. (1985) have pointed out that during chronic exposures, injury increases with increasing concentration and that plant growth is influenced more by concentration than exposure duration, when similar products of concentration and time are used. Similar results have been published relating O_3 exposure to vegetation growth reduction.

The importance of high hourly average O_3 concentrations affecting vegetation growth has been documented (U.S. EPA, 1986). Short-term, high concentrations have been identified as being more important than long-term, low concentrations (Heck *et al*., 1966; Heck and Tingey, 1971; Bicak, 1978; Henderson and Reinert, 1979; Nouchi and Aoki, 1979; Reinert and Nelson, 1979; Bennett, 1979; Stan *et al*., 1981; Musselman *et al*., 1983, 1986; Ashmore, 1984; Amiro *et al*., 1984; Tonneijck, 1984; Hogsett *et al*., 1985a). Similarly, for trees, high concentrations appear to be an important factor (Hayes and Skelly, 1977; Mann *et al*., 1980; Hogsett *et al*., 1985b).

Although all plants are capable of being adversely affected by exposure to phytotoxic gases and particulates in polluted air, the nature of the response can be extremely variable. Runeckles and Wright (1988) have indicated the following features play important roles in determining target sensitivity:

- the species of plant;
- the stage of development of the plant;

- the nature of the pollutant or mix of pollutants;
- the pattern of exposure to the pollutant(s), which involves consideration of the concentration and durations of exposure;
- environmental conditions in the soil, such as water availability and nutrition;
- environmental conditions in the ambient air, such as light intensity, temperature, humidity, and air movement; and
- biological factors, such as the occurrence of pests and diseases, and competitive stresses exerted by individual plants on their neighbors.

For estimating levels that are required to protect vegetation from O_3 exposures, it is necessary to take into consideration the large variability in response. This chapter discusses the ranges of O_3 exposures that result in injury and damage to vegetation, as well as exposure indices that warrant further consideration as possible surrogates for dose in the standard-setting process.

2.2 OZONE EXPOSURES THAT AFFECT YIELD REDUCTION

Guderian *et al.* (1985) have proposed maximum acceptable O_3 concentrations for the protection of vegetation. The authors' numerical values are based on the limiting values proposed by Jacobson (1977) and the exposure-response values for definite injury levels developed by Heck and Brandt (1977). In general, the recommendations made by Guderian *et al.* (1985) appear to reinforce the belief that hourly average concentrations of 0.10 ppm and higher are required to elicit adverse effects on vegetation.

The one exception to the recommendations made by Guderian *et al.* (1985) was for the protection of sensitive species. The authors recommended that sensitive vegetation should not be exposed for more than 4 hours to hourly average concentrations of 0.05 ppm. Ozone hourly average concentrations of

0.05 ppm routinely occur at many "clean" site locations in the world (Lefohn *et al.*, 1990a). The occurrence of hourly average concentrations of 0.05 ppm are not necessarily associated with anthropogenic sources and thus, using a threshold of 0.05 ppm may not be realistic for protecting sensitive species. Table 2-1 summarizes the recommendations made by the authors for hourly average concentrations for durations of exposures of 0.5, 1, 2, and 4 hours. The information in the table provides an indication that long-term exposures consisting only of lower hourly average O_3 concentrations will not necessarily produce adverse effects on vegetation.

The National Crop Loss Assessment Network (NCLAN) program represents one of the most extensive data bases in existence for identifying O_3 exposure regimes that may elicit an adverse effect on crops. NCLAN was initiated and sponsored by the U.S. Environmental Protection Agency to evaluate the effects of O_3 on the productivity of major regional crops under field conditions. Open-top chambers were used to introduce artificial O_3 exposures. For the period 1980 through 1986, NCLAN investigators exposed several different crops to O_3 exposures to identify levels at which crop reduction occurred. Table 2-2 summarizes the different crops and periods of exposure.

The limitations of the NCLAN methodologies have been described elsewhere (Lefohn and Runeckles, 1987; Krupa and Kickert, 1987; Lefohn *et al.*, 1988; Lee *et al.*, 1988; Heuss, 1982; Krupa, 1985; Brennan *et al.*, 1987; Smith *et al.*, 1987; Ashmore, 1988; Runeckles and Wright, 1988). Some of the more important limitations summarized by Lefohn *et al.* (1989) are

- Even though high ambient hourly O_3 concentrations are observed during 1200-2000h at agricultural sites in much of the U.S. during the crop growth season, the NCLAN experiments were designed with exposures to added O_3 in the open-top chambers between <u>0900-1559h</u> or, in the final years of the program, 0900-2059h. When the 0900-1559h, 7-h period was used, frequent high O_3 ambient exposures beyond 1559h were excluded from calculations of exposure indices, although the crops received these ambient exposures;

- The relative differences between the O_3 exposure treatments were always constant. In most cases, O_3 was added to the chambers when the hourly average concentration exceeded 0.03 ppm. Thus, the plants in the higher O_3 treatments were given little opportunity to recover from stress. Under actual ambient conditions, O_3 concentrations vary in time and space and periods occur when exposures are both high and low (Runeckles and Wright, 1988);

- In the exposure treatments with highest O_3, in the cases examined, the frequency distribution of hourly O_3 within the chambers showed a bimodal distribution (Lefohn *et al.*, 1988) or even a polymodal distribution (Heagle *et al.*, 1986). Ambient O_3 follows a unimodal distribution;

- In some cases, infrequent sampling of O_3 within a given hour has resulted in uncertainty and controversy regarding the accuracy of the published hourly average O_3 values;

- In analyzing NCLAN data and establishing cause-and-effect relationships, a number of exposure parameters and models were tested (refer to Heck *et al.*, 1988). In the end, the Weibull function was selected as providing the most suitable empirical exposure-response model. Since experimental results were obtained first and the model fitted afterwards, concern may be raised as to whether the best-fit model is a product of the specific NCLAN experimental design. The Weibull model performed differently at different NCLAN sites. Furthermore, it was unable to explain one set of independent results (Brennan *et al.*, 1987; Smith *et al.*, 1987);

The 7-h (0900-1559h) average, calculated over an experimental period, was used to summarize O_3 exposures by the NCLAN program (Heck *et al.*, 1982). The 7-h daily daylight period was selected by NCLAN because the parameter was believed to correspond to the period of greatest plant susceptibility to O_3 pollution. In addition, the 7-h period of each day (0900-1559h) was assumed to correspond to the time that the highest hourly O_3 concentrations would occur. In later years, the 12-h average, calculated over an experimental period, was used to describe O_3 exposures. In the published literature, the majority of NCLAN's experiments were summarized using the 7-h experimental-period average and other long-term average concentration statistics.

In retrospective studies using NCLAN data, attempts were made to explore the efficacy of alternative O_3 exposure statistics in describing the relationship between exposure and response (Lefohn *et al.*, 1988; Lee *et al.*, 1988, 1989, 1991). Because the retrospective studies mainly focused on the adequacy of mathematical parameters to relate exposure with growth reduction, no attempt was made to describe the specific O_3 exposure regimes that elicited an adverse effect on vegetation. It was assumed that the mathematical parameters adequately correlated with the important components of exposure that elicit an adverse effect. As will be discussed in a later chapter, the absolute value associated with an exposure index does not necessarily correlate with the important components of exposure. Therefore, we investigated the O_3 exposures that occurred in the NCLAN experiments for which a specific level of growth reduction was observed.

Lee *et al.* (1991), using vegetation effects data obtained from 31 field experiments (involving 12 crops), mostly operated by the NCLAN program, evaluated the efficacy of four O_3 exposure indices. Based on a review of the efficacy of the four O_3 exposure indices evaluated by Lee *et al.* (1991), Tingey *et al.* (1991) recommended that the SUM06 O_3 exposure index could be applied as the form of a secondary standard to protect agricultural crops. The authors reported that a 3-month SUM06 value of 24.4 ppm-h was estimated to cause a 10% yield loss in half the cases they investigated.

As a part of their analysis, the investigators developed, using the SUM06 index (the sum of all hourly average concentrations $\geq$0.06 ppm over the exposure period), exposure-response models that predicted yield reduction. In most cases, Lee *et al.* (1991) used only the artificial fumigation period (e.g., 7- and 12-h periods) to determine the SUM06 value. The investigators assumed that the period outside the fumigation window (i.e., the 17 and 12 hours, respectively) did not contribute greatly to the SUM06 value. Based on the Lee *et al.* (1991) equations, Table 2-3 summarizes the predicted yield loss, using the SUM06 value of 24.4 ppm-h.

Lee *et al.* (1991) assumed a SUM06 value of 0.00 ppm-h at 100% yield. We explored the validity of using a 3-month cumulative SUM06 value of 0.00 ppm-h. Lefohn and Foley (1991) have characterized O_3 hourly average concentration data collected at several national park locations and have compared these data with several "clean" O_3 monitoring sites (Lefohn *et al.*, 1990a). Using hourly average O_3 data from six national park sites (Glacier, Great Sand Dunes, Yellowstone, Badlands, Theodore Roosevelt, and Arches) and two national forest locations (Custer and Ochoco), the SUM06 3-month cumulative value was determined over a 24-h window period (Table 2-4). The average 3-month cumulative SUM06 value over the 16 site-years was 3.07 ppm-h. This value was used in the equations developed by Lee *et al.* (1991) and the results compared with the predicted yield loss that resulted when an assumed SUM06 value of 0.00 ppm-h was used at the 100 yield point. As indicated in Table 2-3, the "correction factor" is small and therefore, an assumed SUM06 value of 0.00 ppm-h for "clean" site locations does not result in large discrepancies when compared with the predicted yield losses when a SUM06 value of 3.07 ppm-h is used.

As indicated above, Lee *et al.* (1991) assumed that the SUM06 value was not greatly influenced by the O_3 exposures that occurred outside the 7- and 12-h daylight period when fumigation occurred. The investigators assumed that the number of hourly average concentrations ≥ 0.06 ppm was much greater during the daylight hours than the late afternoon, evening, and early morning hours. For 22 sets of NCLAN experiments, over the entire exposure period, we have compared the SUM06 value calculated over the daily exposure period (e.g., 7 and 12 hours) with the SUM06 value calculated over a 24-h period. Assuming that the ambient hourly average concentrations reported for each experiment represented the exposure the crops received during those periods when fumigation did not occur, we combined these data with the fumigation-period information reported by the investigators for each chamber.

As anticipated, in most cases, the 24-h SUM06 values for the lower-exposure chambers were more influenced by hourly average concentrations ≥ 0.06 ppm that occurred outside the daily fumigation period than the 24-h SUM06 values for the higher O_3 exposure treatments (Table 2-5). The value calculated for the SUM06 index over the exposure period did not necessarily represent the 24-h SUM06 value. Thus, if one ignores the hourly average concentrations ≥ 0.06 ppm that occurred outside the fumigation period, the exposure-response equations developed by Lee *et al*. (1991), at times, appear to overestimate yield reductions. Because, in most cases, the form of the model used by Lee *et al*. (1991) is dependent on several variables, it is unclear if the overestimation would affect the entire range of O_3 exposures or only the lower exposures.

We have summarized the O_3 exposures, by treatment level, that occurred in 22 NCLAN experiments (Table 2-6). Because the exposures within each chamber, at a specific treatment, were similar within an experiment, we have presented one chamber per treatment per experiment in order to summarize the exposure statistics. No attempt was made to combine similar treatments within an experiment and pool the results. The exposure statistics were determined over a 24-h time frame during the exposure period.

Although there were inaccuracies associated with using the exposure-response models developed by Lee *et al.* (1991), we applied the models to obtain rough estimates of yield reduction. The exposure-response models were used to calculate SUM06 cumulative exposures that produced 10%, 20%, and 30% yield reductions for a subset of the NCLAN experiments (Table 2-7). The values of the SUM06 cumulative exposures that produced a specific yield reduction (i.e., 10%, 20% and 30%) were compared with the treatment levels that occurred within each experiment to identify those exposure regimes that may have been responsible for the crop reduction (see Tables 2-6 and 2-7). Because of the uncertainty associated with the yield predictions, we summarized the exposure statistics for those treatments that predicted approximately 20% yield reduction (Table 2-8), recognizing that the yield reduction would more than likely be less than the 20% predicted. In most cases, the SUM06 value listed in Table 2-7 in the 20% reduction column could not be matched with the SUM06 value experienced in a specific treatment. Therefore, the summary statistics from the treatment that experienced the SUM06 value closest to the value listed in Table 2-7 were used in Table 2-8. Most of the identified exposure regimes were associated with treatments where O_3 had been incrementally or proportionally added into the chamber. In approximately 85% of the cases, the SUM06 cumulative exposure value used, which was determined over the fumigation period, represented more than 85% of the actual value experienced over the 24-h period.

In general, repeated exposures of hourly average concentrations $\geq$ 0.10 ppm occurred in most of the treatments identified in Table 2-8. Similar to the results reported by Lee *et al.* (1991), soybean data predominated the analysis. Reviewing the results for soybean, we found, in most cases, that at least 5% of the hourly concentrations in the identified exposure regimes were ≥ 0.10 ppm in the NCLAN open-top chambers. The frequency of occurrence ≥ 0.10 ppm ranged from 5 to 517 and the maximum hourly average concentrations in the experiments ranged from 0.123 ppm to 0.292 ppm.

For wheat, an inconsistent result occurred. Because Vona wheat is extremely sensitive to O_3 exposures (EPA, 1986), ambient O_3 exposures were predicted to cause a 20% yield reduction. However, as noted in Table 2-5, 54% and 40% of the SUM06 values experienced in the NF treatments in 1982 and 1983, respectively, occurred outside the 7-h exposure period window. Thus, the application of the SUM06 model determined by Lee *et al.* (1991) would result in an overestimate of yield reduction. For Abe and Arthur, we found that NCLAN experimental exposures with large numbers of hourly average concentrations ≥ 0.10 ppm (i.e., 186) resulted in a predicted 20% yield reduction.

Tobacco and peanut appeared to be more sensitive to O_3 exposure than cotton (Table 2-8). In addition, corn and sorghum appeared to be highly resistant to O_3 exposure.

Our results, using a select set of NCLAN experimental data, tend to support the finding suggested by Guderian *et al.* (1985) that the repeated occurrence of hourly average O_3 concentrations of 0.10 ppm and higher result in adverse effects on vegetation. In our analysis, we subjectively used a 20% yield reduction threshold. We believe that using a lower yield reduction threshold would not be appropriate at this time because of all the uncertainties mentioned previously. Although the hourly average concentrations below 0.10 ppm may have been important in affecting crop yield in the experiments, the NCLAN program was not developed to identify and quantify the specific exposure regimes that are responsible for the observed effects. Thus, at this time, we believe that the approach we have used makes it possible for those who are interested to establish secondary standards that will protect vegetation from O_3 exposures. The exposure statistics presented in Table 2-8 provide a variety of choices that allow investigators the opportunity to develop indices that are most relevant in predicting vegetation effects.

2.3 SELECTING APPROPRIATE EXPOSURE INDICES

In the previous section, the discussion focused on the components of O_3 exposure that elicit adverse effects on vegetation. In this section, the focus turns toward ways to accurately describe these components in the form of exposure indices that may be useful in the standard-setting process for protecting vegetation.

As discussed in the previous section, there are a number of ways in which hourly O_3 concentrations can be summarized. The selection of suitable measures for defining the "dose" term in exposure/dose-response relationships is an important aspect that has received considerable discussion (U.S. EPA, 1986; Hogsett *et al.*, 1988; Lefohn *et al.*, 1989; Lefohn *et al.*, 1990b). Any index that is selected as a surrogate for "dose" should (1) describe the most important exposure characteristics that elicit an adverse effect and (2) order itself properly when comparing the absolute value experienced in an experiment, with the value calculated under actual ambient conditions.

Exposure indices are important because they form the linkage between air quality standards that are promulgated to protect specific targets and the actual dose that is responsible for eliciting an effect. Results have been reported in the literature relating O_3 exposure with vegetation effects. Although the perfect exposure index that can serve as a surrogate for dose does not exist, there are some O_3 exposure indices that do relate fairly well with vegetation effects (Lefohn *et al.*, 1988; Lefohn *et al.*, 1990b; Lee *et al.*, 1988, 1989, 1991).

For almost seventy years, air pollution specialists have explored alternative mathematical approaches for summarizing ambient air quality information in a form that can serve as a surrogate for dose. For assessing the possible effects of O_3 on agricultural crop and forest, researchers have focused on characterizing 1-h average values in "biologically meaningful" forms. Obtaining a definition of "biologically meaningful" from several different effects researchers is a difficult task. However, based on biological evidence, it is clear that any parameter used as a dose surrogate for predicting vegetation effects should focus on the upper tail (i.e., the highest hourly average concentrations) of the distribution curve.

For vegetation, there has been considerable effort to identify ways to describe O_3 exposures that elicit adverse effects (EPA, 1986; Lefohn and Runeckles, 1987; Krupa and Kickert, 1987; Hogsett *et al.*, 1988; EPA, 1988a; Lefohn *et al.*, 1989; Lefohn *et al.*, 1990b). Since the early 1980s, there has been much discussion concerning the importance of the higher hourly average concentrations in relationship to the lower concentrations (EPA, 1986; Lefohn and Runeckles, 1987; Lefohn *et al.*, 1989; Lefohn *et al.*, 1990b). Several different types of exposure indices have been proposed.

A 6-h long-term seasonal average O_3 exposure parameter was used by Heagle *et al.* (1974). Also, Heagle *et al.* (1979) reported the use of a 7-h experimental-period average. As indicated earlier in this chapter, the 7-h (0900-1559h) average, calculated over an experimental period, was adopted as the statistic of choice by the U.S. EPA's National Crop Loss Assessment Network (NCLAN) program (Heck *et al.*, 1982). Toward the end of the program, NCLAN redesigned its experimental protocol and applied proportional additions of O_3 to its crops for 12-h periods. The expanded 12-h window reflected NCLAN's desire to capture more of the daily O_3 exposure.

In the 1980s, concerns about the use of a long-term average to summarize exposures of O_3 appeared in the literature (Lefohn and Benedict, 1982; Tingey, 1984; Lefohn, 1984; Lefohn and Tingey, 1985). Long-term seasonal average concentrations (e.g., 7-or 12-h average concentrations) did not correlate strongly at most O_3 monitoring sites with the components of exposure regimes that were most important in affecting vegetation. EPA (1986) noted that the weight of evidence appeared to suggest that long-term averages, such as the 7-h seasonal average, were not adequate indicators for relating O_3 exposure and plant response. EPA (1988b) pointed out that repeated peak concentrations appeared to be the most critical element in determining plant response, and the Agency indicated that exposure indicators which emphasize peak concentrations and accumulate concentrations over time, probably provide the best biological basis for standard setting.

Searching for an alternative to the long-term average concentration parameter, Lefohn and Benedict (1982) introduced an exposure parameter based on the hypothesis that if the higher O_3 concentrations were more important in eliciting adverse effects on agricultural crops than the lower values, then the higher hourly mean concentrations should be given more weight than the lower values. This integrated exposure parameter summed all hourly concentrations equal to and above a threshold level (i.e., 0.10 ppm). The exposure parameter was similar to that used by Oshima (1975), where the difference between the value above 0.10 ppm and 0.10 was summed.

In the late 1980s, the focus turned from the use of long-term seasonal averages to cumulative indices (e.g., exposure parameters that sum the products of concentrations multiplied by time over an exposure period). Besides the cumulative indices proposed by Oshima *et al.* (1976) and Lefohn and Benedict (1982), other cumulative indices, such as (1) the number of occurrences of daily maximum hourly averaged concentrations greater than a threshold level (Ashmore, 1984) and (2) the use of exponential functions (Nouchi and Aoki, 1979; Larsen and Heck, 1984) to assign unequal weighting to O_3 concentrations were suggested.

The use of the integrated exposure index, as defined by Oshima (1975) and Lefohn and Benedict (1982), had limitations. The parameter ignored the lower hourly mean concentrations. Early evidence for testing cumulative indices came from results reported by Oshima *et al.* (1976). Similarly, Lefohn and Benedict (1982), applying their cumulative integrated exposure index, reported fairly good agreement between exposures of O_3 and predicted agricultural yield loss in California. The two exposure indices apparently performed well because of the frequent occurrence of high hourly mean O_3 concentrations (e.g., $\geq$ 0.10 ppm) and possibly, the short period between episodes. The high frequency of such concentrations was responsible for the magnitude of the cumulative index, as well as the impacts on agricultural crops, and thus, a favorable correlation existed between the index and the agricultural effect.

NCLAN data offered the opportunity to test the hypothesis that cumulative indices that describe O_3 exposures may adequately serve as a dose surrogate for describing exposure/dose-response relationships for agricultural crops. Retrospective studies were performed using NCLAN data (Lefohn *et al.*, 1988; Lee *et al.*, 1988, 1989, 1991).

Lefohn *et al.* (1988), using wheat and soybean data sets summarized by Kohut *et al.* (1986, 1987), compared the use of several exposure indices in describing the relationship between O_3 and reduction in agricultural crop yield. Two of the indices used by Lefohn *et al.* (1988) were determined using a sigmoidally-weighted function, as proposed by Lefohn and Runeckles (1987). The sigmoidally-weighted function focused on the higher hourly average concentrations, while retaining the lower and less biologically-effective concentrations. The sigmoidal weighting function was of the form:

$$w_i = 1/[1+M \times \exp(-A \times c_i)]$$

where: M and A are arbitrary positive constants

w_i = weighting factor for concentration i

c_i = concentration i (in ppm)

The arbitrary positive constants M and A were 4403 and 126 ppm^{-1}, respectively. Their values were subjectively determined to develop a weighting function that (1) focused on hourly average concentrations as low as 0.04 ppm, (2) had an inflection point near 0.065 ppm, and (3) had an equal weighting of 1 for hourly average concentrations at approximately 0.10 ppm and above.

Unlike the seasonal average index, the cumulative indices performed well when data were combined over a two-year period. Lefohn *et al.* (1988) reported that while none of the exposure indices consistently provided a best fit with the models tested, their analysis indicated that exposure indices that weight peak concentrations of O_3 differently than lower concentrations of an exposure regime could be used in the development of exposure-response functions.

In a more extensive analysis of NCLAN data, Lee *et al*. (1988) fitted more than 600 exposure indices to response data from seven crop studies. For most of the NCLAN experiments used in their analyses, they characterized the daily hourly mean O_3 concentrations that were recorded over the 7-h period (0900-1559h) by the original experimenters. The alfalfa experiments described by Hogsett *et al*. (1985a) collected exposure data over a 24-h period and these data were included in the analysis of Lee *et al*. (1988). Using mostly the 7-h windowed data provided by the NCLAN investigators, the "best" exposure indices were those that applied a general phenologically weighted, cumulative-impact (GPWCI) index with a sigmoid weighting on concentration and a gamma weighting function as a surrogate for changes in plant sensitivity over time. Cumulative indices with various threshold values performed as well as the GPWCIs. Lee *et al*. (1988) reported that mean indices (e.g., 7-h exposure-period means) did not perform well. The authors concluded that the top-performing indices were those whose form (1) accumulated the hourly O_3 concentrations over time, (2) used a sigmoid weighting scheme, which emphasized concentrations of 0.06 ppm and higher, and (3) phenologically weighted the exposure. The authors suggested that lower concentrations should be included, but given lesser weight, in the calculation of the exposure index. In a subsequent analysis using NCLAN data, Lee *et al*. (1989) reported that the phenologically weighted cumulative impact indices, as well as the sigmoidally-weighted integrated index, centered at 0.062 ppm, and the cumulative censored indices that integrated hourly average concentrations of

0.06 and 0.07 ppm or higher, performed at near optimal levels. The results reported by Lefohn *et al*. (1988) and Lee *et al*. (1988, 1989) demonstrated that some cumulative indices could be used in relating O_3 exposure to vegetation effects.

Research results reported by the U.S. EPA and other investigators have illustrated that cumulative exposure indices appear to provide more promise than long-term average concentration exposure indices in relating exposures with vegetation effects (U.S. EPA, 1988b; Lefohn *et al*., 1990b). Although cumulative indices offer the advantage of focusing on the higher hourly average concentrations, not all cumulative indices achieve this goal. For example, Lefohn *et al*. (1989) pointed out that the cumulative exposure index that sums all hourly average concentrations (SUMO) weights the lower concentrations more than the higher ones. As indicated above, biological results reported in the literature indicate that an appropriate exposure index should emphasize the higher hourly average concentrations.

In Section 2.2, we found that the NCLAN results support the observation that the occurrence of high hourly average concentrations results in measurable yield reduction. In Section 2.3, we found that the use of long-term average concentrations as dose surrogates does not provide sufficient focus on the high hourly average concentrations and that cumulative exposure indices appear to perform well in the development of exposure-response relationships. Based on evidence published in the literature, as well as special analytical studies sponsored by EPA (1988a, b), the use of cumulative indices to describe exposures of O_3 for predicting agricultural crop effects appears to be a more rational approach than the use of long-term seasonal averages.

Although the appeal of a single number, such as a single exposure index, to describe ambient O_3 pollutant exposure is undeniable, there are problems associated with condensing data to such a point that the identification of the important components of exposure are eliminated. The problems associated with using long-term seasonal average concentrations as surrogates for dose were mentioned above. In addition, it is important to point out that a consistent relationship between an O_3 exposure index and vegetation effects may not occur, even if one is found to characterize the most important components of exposure (e.g., the upper tail of the hourly average distribution curve). We know, based on published results in the literature, that the occurrences of elevated O_3 hourly concentrations are important for eliciting adverse effects on agricultural crops. However, in addition to concentration, the (1) amount and chemical form of the pollutant that enters the target organism, (2) length of the exposure within each episodic event, (3) time between exposures (i.e., the respite or recovery time), and (4) sensitivity of the target organism are important factors that affect vegetation. When predicting vegetation effects, it is unclear how important these four factors are in an overall weighting scheme. If both sensitivity and the actual dose that enters the organism are as important as ambient concentration in the weighting scheme, then a given pollutant exposure will elicit varying biological responses at different times for the same crop, as conjectured by Krupa and Teng (1982). However, at this time, given the current state of knowledge, concentration should be weighted more heavily than either sensitivity or actual dose.

2.4 LINKING EXPERIMENTAL RESULTS WITH HIGH-ELEVATION OZONE EXPOSURES

For protecting vegetation from O_3 exposures, an important aspect that requires further attention is the use of experimental results obtained at low-elevation sites to predict O_3 vegetation effects that may occur at high-elevation locations. It is important to note that O_3 exposures at high-elevation sites are often different from those that occur at lower elevation locations. At some high-elevation sites, the highest O_3 exposures occur in the late evening or early morning hours (Berry, 1964; Lefohn and Mohnen, 1986), which produce a diurnal pattern that is distinctly different from that observed at lower elevation sites (Berry, 1964; Stasiuk and Coffey, 1974; Mohnen *et al.*, 1977; Miller *et al.*, 1986; Lefohn and Jones, 1986; Lefohn and Mohnen, 1986). A flat diurnal pattern, which is observed at some high-elevation sites, is usually interpreted as indicating a lack of efficient scavenging of O_3 and/or a lack of photochemical precursors.

It is important to pay specific attention to the types of exposure indices used to describe high-elevation O_3 exposures. Many times the high-elevation diurnal patterns are different from those at the lower elevation sites, because the lowest O_3 hourly average concentrations at many high-elevation sites are near 0.04 ppm (Lefohn and Jones, 1986). The calculated value determined for exposure indices that focus on the lower hourly average concentrations (e.g., SUMO index) tends to overstate the potential effects of O_3 on vegetation (Lefohn *et al.*, 1992). The absolute value of the SUMO exposure index is influenced by the large number of values in the mid-concentration range. The mid-concentration range appears not to be as biologically significant as the infrequent occurrence of the higher concentrations.

In addition to the selection of specific exposure indices that are useful for describing O_3 exposures that occur at high-elevation locations, the use of mole fraction (e.g., ppm) or absolute concentration (e.g., micrograms per cubic meter) to describe exposure is an important issue. Lefohn *et al.* (1990c) have pointed out that exposure-response relationships developed using results obtained at low-elevation locations may require pressure adjustments when attempting to use air quality data obtained at high-elevation monitoring sites to predict vegetation effects. When concentrations of gases are defined in terms of mole fraction (i.e., units of ppm), the resulting term is invariant to temperature and pressure. However, if exposures measured at low-elevation sites are compared with those experienced at high-elevation sites, the variation of concentration (in units of micrograms per cubic meter) as a function of altitude may be significant. Given the same parts-per-million value experienced at both high- and low-elevation sites, the absolute concentrations (i.e., micrograms per cubic meter) at two elevations are different. Temperature decreases inversely relative to elevation and therefore, the change in absolute concentration would be less than estimated when only pressure changes are considered. However, temperature differences do not usually compensate for the pressure effect (Lefohn *et al.*, 1990c).

In considering the effect of pressure changes on concentration, EPA (1978) indicated that moles of gaseous pollutant per liter of air was the most useful parameter when considering health effects caused by exposure to air pollution. The same should be true when considering effects of air pollution on vegetation. There are numerous environmental factors that affect the relationship between exposure and response. For example, the amount of O_3 entering the stomata, as well as temperature, relative humidity, cloud cover, and moisture status may influence the actual dose the plant experiences (Runeckles, 1987). However, assuming that the sensitivity of the biological target is nearly identical at both low and high elevations, some adjustment should be necessary when attempting to link experimental data obtained at low-elevation sites with air quality data monitored at high-elevation stations. Lefohn *et al.* (1990c), using Boyle's Law as a first approximation, found that the value of cumulative exposure indices that use a threshold concentration can vary substantially as a function of pressure. The authors pointed out that although the magnitude of adjustment to each hourly average concentration was less than 20%, the cumulative effect of applying a number of small corrections, that were <u>biased</u> in the same direction, to an exposure index with a threshold, resulted in potentially large adjustments.

Responding to Lefohn *et al.* (1990c), Larson and Vong (1990) discussed the limitations of the use of O_3 concentration as mass per unit volume and derived a correction for temperature and pressure changes. The authors' approach was based upon a theoretical evaluation of the O_3 flux relative to its value at standard conditions. Temperature and pressure were allowed to vary but wind speed and tree dimensions were held constant. The relative change in the flux to the intercellular air space of the foliage at the top of the forest canopy was estimated as a function of temperature and pressure. Larson and Vong (1990) subdivided the overall resistance to mass transfer into three components: the stomatal resistance, the needle/branch boundary layer resistance, and the turbulent air resistance at the top of the canopy. Based on their theoretical calculation, the authors concluded that if identical O_3 mass concentrations were measured at two sites separated by 2000 m elevation, the O_3 flux at the lower site would exceed the flux at the higher site by 4-

8%, due to temperature and pressure effects on both air volume and O_3 deposition velocity.

Larson and Vong (1990) considered deposition instead of concentration in their analysis. Although, at this time, there is no parameter that links deposition with direct vegetation effects, if an index were developed and exhibited cumulative properties with a threshold deposition value, an adjustment, perhaps similar to the magnitude described by Lefohn *et al.* (1990c), still appears to be required. Using the range of adjustments suggested by Larson and Vong (1990), we explored the effect on cumulative indices by applying adjustment in the range of 1-10% to each of the hourly average concentrations. We compared the values of the cumulative indices, SUM06, SUM07, and W126, after the hourly concentrations were adjusted, with the values of the cumulative indices that were based on unadjusted hourly average concentrations.

The results of the comparison are provided in Tables 2-9 through 2-11. The tables summarize the percentage differences between adjusted and unadjusted integrated exposures as a function of the percent changes made to each of the hourly average concentrations. ***A review of the tables shows, depending upon the adjustment factor selected, that substantial differences occur between the unadjusted and adjusted cumulative index.*** For example, in 1987, for the high-elevation Whiteface Mountain 1 site, if the effect of temperature and pressure resulted in an adjustment factor of 10%, a 47.9% reduction in the SUM07 cumulative value would have been experienced (Table 2-10). Therefore, assuming that the exposure-response models were developed using hourly average data reported in parts per million at a low-elevation location, the concentration information would have to be changed to absolute concentration units (e.g., micrograms per cubic meter) and adjustments made to reflect the lower exposures experienced at the high-elevation site.

Additional experimental research is required to clarify this important issue (Lefohn *et al.*, 1990c; Lefohn and Lucier, 1991). Neither target sensitivity nor temperature considerations were integrated into the adjusted cumulative exposure values described above. As indicated above, temperature is not considered an important ameliorating factor when actual ambient temperatures are used. However, the sensitivity of the target organism may be an important consideration. Unfortunately, the relationship of target organism sensitivity to O_3 and to elevation and temperature has not been evaluated. In the absence of such information, the biological consequences of high-elevation exposures to the reduced absolute concentration of O_3, that are disguised by the use of mole fraction units of concentration, need to be further investigated. For biological purposes, concentration should be converted to micrograms per cubic meter units, based upon ambient pressures and temperatures. Only then will it be possible to compare the results of biological investigations conducted at low- and high-elevation sites, particularly if these involve the generation of exposure-response relationships based upon cumulative threshold-sensitive indices.

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Table 2-1. Proposed maximum acceptable ozone concentrations for protection of vegetation (adapted from Guderian *et al.*, 1985).

Exposure duration (h)	Resistance Level (ppm)		
	Sensitive	Intermediate	Less Sensitive
0.5	0.150	0.25	0.50
1.0	0.075	0.18	0.25
2.0	0.060	0.13	0.20
4.0	0.050	0.10	0.18

Table 2-2. Summary of experiments in the NCLAN program.

Research Group	Year	Alfalfa	Barley	Corn	Cotton	Fescue/ Clover	Sorghum	Kidney Bean	Head Lettuce	Peanut	Soybean	Tomato	Tobacco	Turnip	Wheat
		Number of Days Exposed to Ozone													
Argonne National Lab (CSRCLAP)	80										56				
Argonne National Lab (CSRCLAP)	81			82											
Argonne National Lab (CSRCLAP)	82						84								56
Argonne National Lab (CSRCLAP)	83										83				53
Argonne National Lab (CSRCLAP)	84	53													
Argonne National Lab (CSRCLAP)	85			82							87				
Argonne National Lab (CSRCLAP)	86										94				
Boyce Thompson Institute (NERCLAP)	80							21							
Boyce Thompson Institute (NERCLAP)	81										70				
Boyce Thompson Institute (NERCLAP)	82							43			55				71
Boyce Thomspon Institute (NERCLAP)	83														36
Boyce Thomspon Institute (NERCLAP)	84					93									
Boyce Thompson Institute (NERCLAP)	85					118									
North Carolina State Univ. (SERCLAP)	80									112				38	
North Carolina State Univ. (SERCLAP)	81										110				
North Carolina State Univ. (SERCLAP)	82				119						89				
North Carolina State Univ. (SERCLAP)	83										110		96		
North Carolina State Univ. (SERCLAP)	84					176					106				
North Carolina State Univ. (SERCLAP)	85				126	193									
North Carolina State Univ. (SERCLAP)	86										107				
Beltsville (SERCLAP)	81										55				
Beltsville (SERCLAP)	82										81				
Beltsville (SERCLAP)	83										63				
Univ. of California (SWRCLAP)	81				71							62			
Univ. of California (SWRCLAP)	82		46		99							62			
Univ. of California (SWRCLAP)	83		94						52						
Univ. of California (SWRCLAP)	84	*													
Univ. of California (SWRCLAP)	85	200			73										

* The alfalfa experiment was started in 1984 and completed in 1985.

Table 2-3. The predicted yield loss using a SUM06 value of 24.4 ppm-h, using the SUM06 Lee *et al.* (1991) equations (assuming SUM06=0 ppm-h and SUM06=3.07 ppm-h for "clean" sites).

Crop	Predicted Yield Loss	
	Assuming SUM06=0	Assuming SUM06=3.07
Soybean		
A80SO Corsoy	24.7	23.8
A83CV Amsoy_71	6.5	6.5
A83CV Corsoy_79	1.2	1.2
A85SO Corsoy_79 Dry	0.2	0.2
A85SO Corsoy_79 Wet	0.4	0.4
A86SO Corsoy_79 Dry	0.0	0.0
A86SO Corsoy_79 Wet	0.4	0.4
B83SO Corsoy_79 Dry	27.2	21.7
B83SO Corsoy_79 Wet	26.8	24.9
B83SO Williams Dry	12.3	11.7
B83SO Williams Wet	21.6	20.2
I81SO Hodgson	23.0	20.4
R81SO Davis	12.2	11.3
R82SO Davis	14.4	13.8
R83SO Davis Dry	9.2	8.0
R83SO Davis Wet	10.0	9.2
R84SO Davis Dry	6.3	6.2
R84SO Davis Wet	6.3	6.2
R86SO Young Dry	6.7	6.3
R86SO Young Wet	6.7	6.3

Table 2-3. (Continued).

Crop	Predicted Yield Loss	
	Assuming SUM06=0	Assuming SUM06=3.07
Sorghum		
A82SG Dekalb	1.1	1.1
Wheat		
A82WH Abe	14.4	14.3
A83WH Abe	1.8	1.8
A82WH Arthur_71	13.6	13.5
A83WH Arthur_71	9.8	9.7
I82WH Vona	59.3	54.4
I83WH Vona	54.0	51.6
Corn		
A81MA PAG 397	0.4	0.4
A81MA Pioneer 3780	2.6	2.6
Kidney Bean		
I80KB Cal Lt. Red	56.4	56.4
I82KB Cal Lt. Red	23.5	23.3
Potato		
P85PO Norchip	24.7	22.0
P86PO Norchip	16.0	15.0

Table 2-3. (Continued).

Crop	Predicted Yield Loss	
	Assuming SUM06=0	Assuming SUM06=3.07
Cotton		
C81CO Acala SJ-2 Dry	4.8	4.8
C81CO Acala SJ-2 Wet	12.6	12.3
C82CO Acala SJ-2 Dry	13.2	12.8
C82CO Acala SJ-2 Wet	24.7	22.6
C85CO Acala SJ-2 Dry	2.7	2.3
C85CO Acala SJ-2 Wet	4.2	3.7
R82CO Stoneville	10.5	10.3
R85CO McNair Dry	0.4	0.4
R85CO McNair Wet	8.7	8.4
Lettuce		
C83LE Empire	1.7	1.7
Peanut		
R80PN NC-6	4.8	4.7
Turnup		
R80TN Just Right	59.5	57.1
R80TN Purp. Top Wh Globe	54.3	52.7
R80TN Shogoin	54.3	50.6
R80TN Tokyo Cross	54.5	54.0

Table 2-3. (Continued).

Crop	Predicted Yield Loss	
	Assuming SUM06=0	Assuming SUM06=3.07
Tobacco		
R83TO McNair 944	10.0	9.1
Barley		
C83BA CM-72 Dry	1.5	1.2
C83BA CM-72 Wet	-	-

Table 2-4. June-August percentile distribution of **hourly** O_3 concentrations and values for the SUM06 values calculated for a 24-h window for "clean" sites in the United States with data capture ≥ 75% for the 3-month period. Concentrations are in ppm units.

Site/AIRS ID	Year	Min.	Percentiles 10	30	50	70	90	95	99	Max	No. of Obs.	SUM06 (ppm-h)
Glacier NP, MT 300298001	1989	.000	.005	.015	.026	.036	.046	.050	.056	.065	2125	.86
Great Sand Dunes NM, CO 080030002	1989	.011	.030	.036	.040	.043	.048	.050	.055	.060	1924	0.24
Yellowstone NP, WY 560391010	1989	.003	.029	.030	.038	.044	.051	.055	.060	.069	2016	1.90
Badlands NP, SD 460711001	1989	.009	.025	.033	.040	.046	.054	.056	.065	.071	2093	3.07
Theodore Roosevelt NP,ND 380530002	1984	.000	.019	.029	.036	.042	.050	.055	.063	.068	2017	2.71
	1986	.004	.019	.028	.034	.039	.046	.049	.053	.059	2180	0.00
	1989	.005	.024	.033	.041	.047	.056	.062	.067	.073	2193	9.88
	1990	.005	.019	.028	.034	.040	.049	.054	.063	.070	2190	2.92
Arches NP, UT 490190101	1989	.000	.034	.041	.046	.051	.058	.060	.066	.080	1836	6.74
Custer NF, MT 300870101	1978	.000	.015	.030	.035	.040	.050	.055	.055	.065	2106	0.85
	1979	.010	.030	.035	.040	.045	.050	.055	.060	.065	2109	1.76
	1980	.015	.030	.040	.045	.050	.055	.060	.065	.070	1839	10.52
	1981	.010	.025	.035	.040	.045	.045	.045	.050	.070	1828	0.61
	1983	.010	.030	.035	.040	.045	.050	.055	.060	.065	2181	4.18
Ochoco NF, OR 410130111	1982	.010	.025	.035	.040	.045	.050	.055	.060	.065	1994	1.87
	1983	.010	.025	.030	.035	.040	.050	.050	.055	.060	2107	0.96

Table 2-5. Comparison of SUM06 (exposure window) cumulative exposure values with the SUM06 (24-h window) values and percentage of 24-h cumulative value that occurred during the exposure window. Cumulative values are in units of ppm-h.

Site/ Treatment	SUM06 (Exposure Period)	SUM06 (24-h)	%	Length of Exposure (Hours)
SOYBEAN				
ARGONNE 1980 (CORSOY)				
CF	0.3	2.7	11	7
AA	5.2	7.6	68	7
NF	5.4	7.7	70	7
NF + 0.03	18.8	21.1	89	7
NF + 0.06	32.5	34.8	93	7
NF + 0.09	43.0	45.3	95	7
ARGONNE 1983 (CORSOY/AMSOY)				
CF	0.3	5.2	6	7
AA	12.9	17.9	72	7
NF	12.4	17.4	71	7
NF + 0.03	34.5	39.2	88	7
NF + 0.06	52.5	57.4	92	7
ARGONNE 1983 (PELLA/WILLIAMS)				
CF	0.3	5.3	6	7
AA	13.0	17.9	72	7
NF	11.7	16.6	70	7
NF + 0.03	33.4	37.9	88	7
NF + 0.06	52.3	57.2	91	7
ARGONNE 1985 (CORSOY_79)				
CF - D	0.5	2.1	26	12
CF - W	0.3	1.8	14	12
AA - W	16.5	18.0	91	12
NF - D	13.6	15.2	90	12
NF - W	13.5	15.1	90	12
NF x 1.33 - D	32.1	33.7	95	12
NF x 1.33 - W	34.4	36.0	96	12
NF x 1.67 - D	50.0	51.6	97	12
NF x 1.67 - W	52.7	54.3	97	12
NF x 2.00 - D	68.0	69.6	98	12
NF x 2.00 - W	71.6	73.2	98	12

Table 2-5. (Continued).

Site/ Treatment	SUM06 (Exposure Period)	SUM06 (24-h)	%	Length of Exposure (Hours)
ARGONNE 1986 (CORSOY_79)				
CF - D	0.0	0.9	0	12
CF - W	0.0	0.9	0	12
AA - D	9.8	10.6	92	12
AA - W	11.4	12.2	93	12
NF - D	8.9	9.9	90	12
NF - W	10.0	10.9	92	12
NF x 1.5 - D	44.5	45.4	98	12
NF x 1.5 - W	46.3	47.2	98	12
NF x 2.0 - D	67.1	68.0	99	12
NF x 2.0 - W	68.4	69.3	99	12
NF x 2.5 - D	91.5	92.4	99	12
NF x 2.5 - W	93.2	94.1	99	12
BELTSVILLE 1983 (CORSOY_79/Williams_79)				
CF - D	0.1	3.7	3	7
CF - W	0.0	3.6	0	7
AA - D	12.2	15.7	78	7
AA - W	12.3	15.8	78	7
NF - D	11.6	15.1	77	7
NF - W	9.5	13.1	75	7
NF + 0.03 - D	27.8	31.3	89	7
NF + 0.03 - W	27.2	30.7	89	7
NF + 0.06 - D	42.7	46.2	92	7
NF + 0.06 - W	42.6	46.2	92	7
NF + 0.09 - D	51.6	55.2	94	7
NF + 0.09 - W	51.6	55.2	94	7
BTI 1981 (HODGSON)				
CF	0.1	0.6	11	7
AA	0.2	0.7	29	7
NF	0.5	1.1	45	7
NF + 0.03	9.4	10.0	94	7
NF + 0.06	26.7	27.2	98	7
NF + 0.09	41.3	41.8	99	7
RALEIGH 1981 (DAVIS)				
CF	0.6	7.1	8	7
AA	21.0	27.5	76	7
NF	24.8	31.3	79	7
NF + 0.02	44.6	51.1	87	7
NF + 0.03	62.8	69.3	91	7
NF + 0.05	79.2	85.7	92	7

Table 2-5. (Continued).

Site/ Treatment	SUM06 (Exposure Period)	SUM06 (24-h)	%	Length of Exposure (Hours)
NF + 0.07	94.2	100.7	94	7
RALEIGH 1982 (DAVIS)				
CF	0.4	5.7	7	7
AA	14.0	19.2	73	7
NF	11.4	16.7	68	7
NF + 0.02	32.4	37.7	86	7
NF + 0.04	51.6	56.8	91	7
NF + 0.06	67.2	72.5	93	7
NF x 1.3	32.4	37.7	86	7
NF x 1.6	45.2	50.5	90	7
NF x 1.9	52.6	57.9	91	7
RALEIGH 1983 (DAVIS)				
CF - D	1.4	13.0	11	7
CF - W	1.0	12.6	8	7
AA - D	25.1	36.8	68	7
AA - W	24.9	36.6	68	7
NF - D	19.5	31.2	62	7
NF - W	18.0	29.7	61	7
NF + 0.02 - D	47.6	59.3	80	7
NF + 0.02 - W	47.6	59.3	80	7
NF + 0.04 - D	68.5	80.2	85	7
NF + 0.04 - W	71.5	83.2	86	7
RALEIGH 1984 (DAVIS)				
CF - D	0.4	5.0	8	7
CF - W	0.4	5.0	8	7
AA	14.6	19.2	76	7
NF - D	12.3	16.9	73	7
NF - W	10.1	14.7	69	7
NF + 0.015 - D	35.0	39.6	88	7
NF + 0.015 - W	36.1	40.7	89	7
NF + 0.030 - D	49.9	54.5	92	7
NF + 0.030 - W	52.8	57.4	92	7
NF + 0.045 - D	61.4	66.0	93	7
NF + 0.045 - W	59.1	63.7	93	7
NF + 0.060 - D	71.6	76.2	94	7
NF + 0.060 - W	72.9	77.5	94	7

Table 2-5. (Continued).

Site/ Treatment	SUM06 (Exposure Period)	SUM06 (24-h)	%	Length of Exposure (Hours)
RALEIGH 1986 (YOUNG)				
CF - D	1.1	1.2	95	12
CF - W	0.3	0.4	85	12
AA - W	16.3	16.4	99	12
NF - D	16.3	16.3	100	12
NF - W	12.7	12.7	100	12
NF x 1.3 - D	54.3	54.4	100	12
NF x 1.3 - W	51.5	51.5	100	12
NF x 1.6 - D	75.3	75.4	100	12
NF x 1.6 - W	72.9	72.9	100	12
NF x 1.9 - D	94.3	94.4	100	12
NF x 1.9 - W	91.9	91.9	100	12
NF x 1.3*	57.4	57.4	100	12
NF x 1.6*	72.6	72.6	100	12
NF x 1.9*	98.1	98.2	100	12

*Rain Exclusion Cap

SORGHUM

ARGONNE 1982 (DEKALB)				
CF	0.0	2.6	1	7
AA	5.6	8.2	69	7
NF	6.1	8.7	70	7
NF + 0.02	21.7	24.3	89	7
NF + 0.04	40.9	43.4	94	7
NF + 0.07	59.9	62.5	96	7
NF + 0.10	76.1	78.7	97	7

WHEAT

ARGONNE 1982 (ABE/ARTHUR_71)				
CF	0.1	1.9	7	7
AA	3.8	5.4	70	7
NF	4.0	5.7	70	7
NF + 0.03	21.8	23.5	93	7
NF + 0.06	36.1	37.9	95	7
NF + 0.09	47.3	49.0	96	7

Table 2-5. (Continued).

Site/ Treatment	SUM06 (Exposure Period)	SUM06 (24-h)	%	Length of Exposure (Hours)
ARGONNE 1983 (ABE/ARTHUR_71)				
CF	0.2	3.6	5	7
AA	6.2	9.5	65	7
NF	5.4	8.8	62	7
NF + 0.02	15.7	19.0	82	7
NF + 0.04	25.8	29.1	88	7
NF + 0.06	33.8	37.2	91	7
BTI 1982 (VONA)				
CF	0.1	0.9	11	7
AA	4.4	8.3	53	7
NF	3.2	7.0	46	7
NF + 0.03	17.5	21.4	82	7
NF + 0.06	29.4	33.6	88	7
NF + 0.09	40.8	44.6	92	7
BTI 1983 (VONA)				
CF	1.0	2.2	46	7
AA	8.4	13.3	63	7
NF	7.6	12.6	60	7
NF X 1.5	16.2	21.1	77	7
NF X 2.0	22.4	27.3	82	7
CORN				
ARGONNE 1981 (PAG 397/PIONEER 3780)				
CF	0.2	2.0	10	7
AA	9.0	10.9	83	7
NF	8.0	9.9	81	7
NF + 0.03	35.7	37.6	95	7
NF + 0.06	56.6	56.8	100	7
NF + 0.09	74.3	76.1	98	7
NF + 0.12	90.1	91.9	98	7
COTTON				
RALEIGH 1982 (STONEVILLE)				
CF	0.6	9.3	6	6
CF*	0.1	8.8	2	6
AA	17.2	25.9	66	6
NF	21.6	30.3	71	6

Table 2-5. (Continued).

Site/ Treatment	SUM06 (Exposure Period)	SUM06 (24-h)	%	Length of Exposure (Hours)
NF*	24.2	32.9	74	6
NF + 0.02	42.7	51.4	83	6
NF + 0.04	56.8	65.5	87	6
NF + 0.06	71.6	80.3	89	6
NF + 0.02*	36.6	45.3	81	6
NF + 0.04*	58.8	67.5	87	6
NF + 0.06*	65.0	73.7	88	6
* Frustum Doses				
RALEIGH 1985 (McNAIR)				
CF - D	0.3	0.7	44	12
CF - W	0.3	0.7	44	12
CF*	0.9	1.3	70	12
AA	29.6	30.0	99	12
AA - D	21.6	22.0	98	12
AA - W	25.5	25.9	98	12
NF - D	19.1	19.5	98	12
NF - W	19.3	19.7	98	12
NF x 1.33 - D	43.2	43.6	99	12
NF x 1.33 - W	41.0	41.4	99	12
NF x 1.33*	42.4	42.8	99	12
NF x 1.66 - D	67.1	68.0	99	12
NF x 1.66 - W	63.4	63.8	99	12
NF x 1.99 - D	89.5	89.9	100	12
NF x 1.99 - W	83.6	84.0	100	12
NF x 1.99*	87.4	87.8	100	12
*Rain Exclusion Cap				
PEANUT				
RALEIGH 1980 (NC-6)				
CF	0.5	3.2	16	8
AA	25.8	28.4	91	8
NF + 0.015	26.1	28.8	91	8
NF + 0.045	57.5	60.2	94	8
NF + 0.075	84.7	87.4	97	8
NF + 0.105	108.1	110.8	98	8

Table 2-5. (Continued).

Site/ Treatment	SUM06 (Exposure Period)	SUM06 (24-h)	%	Length of Exposure (Hours)
TOBACCO				
RALEIGH 1983 (McNAIR 944)				
CF	1.1	3.1	36	12
AA	43.2	45.2	96	12
NF	28.5	30.5	94	12
NF + 0.02	49.2	51.2	96	12
NF + 0.04	58.2	60.2	97	12
NF + 0.06	67.8	69.8	97	12
NF x 1.3	38.8	53.1	73	6
NF x 1.3	71.4	73.4	97	12
NF x 1.6	48.7	62.9	77	6
NF x 1.6	86.6	88.6	98	12
NF x 1.9	71.8	73.8	81	6
NF x 1.9	105.5	107.5	98	12

Table 2-6. Summary of ozone exposures that occurred in selected NCLAN experiments and chambers. Concentrations are in units of ppm.

Site/Treatment	Min.	Percentiles 10	30	50	70	90	95	99	Max	No. of Obs.	No. Occurrences ≥0.06	≥0.08	≥0.10	SUM (ppm-h) 06	08	W126
SOYBEAN																
A80SO - Corsoy																
CF-1	0.000	0.000	0.009	0.017	0.027	0.042	0.052	0.075	0.109	1344	36	10	2	2.7	0.9	2.6
AA-1	0.000	0.000	0.011	0.023	0.036	0.055	0.068	0.088	0.109	1344	103	23	4	7.6	2.1	6.7
NF-1	0.000	0.000	0.011	0.022	0.036	0.056	0.068	0.087	0.109	1344	105	30	3	7.8	2.6	6.8
NF + 0.03-1	0.000	0.000	0.011	0.026	0.045	0.077	0.090	0.111	0.123	1344	263	113	35	21.1	10.7	17.7
NF + 0.06-1	0.000	0.000	0.011	0.026	0.047	0.103	0.122	0.143	0.176	1344	344	290	156	34.6	30.8	33.2
NF + 0.09-1	0.000	0.000	0.011	0.026	0.048	0.139	0.156	0.184	0.200	1344	351	319	289	45.3	43.1	44.9
A83SO - Corsoy/Amsoy																
CF-1	0.000	0.001	0.011	0.019	0.029	0.046	0.056	0.076	0.128	1992	74	17	3	5.3	1.5	4.8
AA-1	0.000	0.001	0.014	0.025	0.038	0.063	0.077	0.099	0.147	1992	240	83	19	18.6	7.8	15.6
NF-1	0.000	0.001	0.014	0.025	0.038	0.062	0.075	0.091	0.128	1992	232	74	8	17.3	6.6	14.1
NF + 0.03-1	0.000	0.001	0.014	0.028	0.049	0.083	0.098	0.123	0.168	1992	467	223	90	39.1	22.1	33.2
NF + 0.06-1	0.000	0.001	0.014	0.029	0.057	0.111	0.128	0.158	0.198	1992	576	459	291	59.1	51.0	56.0
A83SO - Pella/Williams																
CF-1	0.000	0.001	0.011	0.020	0.030	0.046	0.057	0.076	0.128	1992	76	17	3	5.5	1.5	5.0
NF-1	0.000	0.001	0.014	0.025	0.037	0.061	0.072	0.090	0.128	1992	213	57	10	15.8	5.1	12.8
NF + 0.03-1	0.000	0.001	0.014	0.028	0.049	0.083	0.099	0.125	0.173	1992	464	235	95	39.2	23.3	33.7
NF + 0.06-1	0.000	0.001	0.014	0.029	0.057	0.110	0.128	0.157	0.204	1992	575	435	285	58.5	48.8	55.0
A85SO - Corsoy 79																
CF-1D	0.000	0.000	0.004	0.013	0.024	0.039	0.046	0.061	0.085	2352	28	1	0	1.8	0.1	2.0
CF-1W	0.000	0.001	0.006	0.013	0.022	0.037	0.044	0.060	0.085	2352	26	1	0	1.7	0.1	1.7
AA-1W	0.000	0.000	0.012	0.026	0.039	0.061	0.071	0.085	0.103	2352	252	45	2	18.0	3.9	14.5
NF-1D	0.000	0.000	0.009	0.023	0.038	0.058	0.067	0.082	0.098	2352	210	32	0	14.8	2.8	11.7
NF-1W	0.000	0.000	0.011	0.024	0.038	0.057	0.065	0.077	0.109	2352	189	19	1	13.1	1.6	10.6
NF x 1.33-1D	0.000	0.000	0.009	0.024	0.044	0.074	0.087	0.105	0.126	2352	447	179	45	35.1	16.6	28.7
NF x 1.33-1W	0.000	0.000	0.011	0.026	0.045	0.075	0.087	0.109	0.129	2352	477	184	46	37.5	17.2	30.4
NF x 1.67-1D	0.000	0.000	0.009	0.024	0.050	0.091	0.107	0.131	0.154	2352	588	348	160	52.2	35.4	46.3
NF x 1.67-1W	0.000	0.000	0.011	0.026	0.051	0.092	0.109	0.131	0.153	2352	609	367	171	54.3	37.4	48.3
NF x 2.00-1D	0.000	0.000	0.008	0.023	0.051	0.110	0.129	0.160	0.194	2352	657	495	319	67.5	56.2	63.0

able 2-6. (Continued).

Site/Treatment	Min.	Percentiles 10	30	50	70	90	95	99	Max	No. of Obs.	No. Occurrences ≥0.06	≥0.08	≥0.10	SUM (ppm-h) 06	08	W126
NF x 2.00-1W	0.000	0.000	0.011	0.026	0.063	0.114	0.134	0.162	0.199	2352	729	547	358	75.1	62.5	70.0
A86SO - Corsoy 79																
CF-1D	0.000	0.001	0.007	0.012	0.021	0.034	0.042	0.056	0.072	2040	14	0	0	0.9	0.0	1.0
CF-1W	0.000	0.001	0.005	0.010	0.020	0.034	0.041	0.056	0.072	2040	14	0	0	0.9	0.0	1.1
AA-1D	0.000	0.002	0.014	0.026	0.039	0.055	0.064	0.083	0.117	2040	151	31	5	10.7	2.8	9.0
AA-1W	0.000	0.002	0.014	0.026	0.040	0.058	0.065	0.085	0.119	2040	194	42	10	13.8	3.8	11.4
NF-1D	0.000	0.002	0.014	0.025	0.038	0.055	0.062	0.076	0.103	2040	129	15	1	8.8	1.3	7.3
NF-1W	0.000	0.002	0.013	0.025	0.039	0.055	0.063	0.083	0.115	2040	159	30	9	11.4	2.8	10.0
NF x 1.5-1D	0.000	0.003	0.016	0.031	0.053	0.081	0.096	0.124	0.173	2040	534	232	79	43.4	22.7	35.6
NF x 1.5-1W	0.000	0.002	0.014	0.030	0.053	0.082	0.096	0.128	0.179	2040	564	251	95	46.4	24.8	38.4
NF x 2.0-1D	0.000	0.002	0.016	0.033	0.065	0.105	0.125	0.165	0.229	2040	697	492	262	67.7	53.4	62.3
NF x 2.0-1W	0.000	0.002	0.015	0.033	0.065	0.105	0.124	0.161	0.242	2040	719	510	271	69.6	55.1	63.7
NF x 2.5-1D	0.000	0.002	0.016	0.035	0.085	0.137	0.161	0.207	0.279	2040	784	654	515	92.1	83.2	88.6
NF x 2.5-1W	0.000	0.002	0.016	0.035	0.085	0.137	0.161	0.210	0.292	2040	777	652	517	92.1	83.4	89.0
B83SO - Corsoy 79/Williams 79																
CF-1D	0.000	0.001	0.004	0.011	0.022	0.044	0.054	0.080	0.108	1512	51	15	1	3.7	1.3	3.3
CF-1W	0.000	0.002	0.005	0.011	0.020	0.042	0.052	0.080	0.108	1512	50	15	1	3.6	1.3	3.1
AA-1D	0.000	0.002	0.005	0.018	0.038	0.065	0.077	0.090	0.126	1512	200	60	10	15.0	5.3	12.1
AA-1W	0.000	0.002	0.005	0.017	0.038	0.068	0.080	0.096	0.136	1512	217	86	13	16.7	7.7	13.7
NF-1D	0.000	0.002	0.006	0.018	0.037	0.063	0.074	0.087	0.111	1512	184	51	5	13.5	4.4	10.6
NF-1W	0.000	0.002	0.005	0.017	0.034	0.060	0.070	0.083	0.108	1512	151	37	2	10.8	3.1	8.2
NF + 0.03-1D	0.000	0.002	0.006	0.019	0.049	0.084	0.098	0.118	0.137	1512	364	204	66	30.5	19.5	26.0
NF + 0.03-1W	0.000	0.002	0.006	0.019	0.049	0.084	0.097	0.118	0.135	1512	359	198	70	30.1	18.9	25.8
NF + 0.06-1D	0.000	0.002	0.006	0.019	0.055	0.114	0.130	0.149	0.176	1512	440	357	244	45.6	39.9	43.1
NF + 0.06-1W	0.000	0.002	0.006	0.019	0.055	0.117	0.130	0.151	0.183	1512	433	350	249	45.3	39.5	43.0
NF + 0.09-1D	0.000	0.002	0.006	0.019	0.055	0.146	0.160	0.187	0.204	1512	439	392	345	56.4	53.2	55.2
NF + 0.09-1W	0.000	0.002	0.006	0.019	0.055	0.140	0.156	0.178	0.194	1512	440	391	343	54.8	51.4	53.5
I81SO - Hodgson																
CF-1	0.000	0.004	0.007	0.011	0.016	0.029	0.038	0.051	0.072	1680	8	0	0	0.5	0.0	0.6
AA-1	0.000	0.004	0.007	0.015	0.025	0.040	0.046	0.058	0.072	1680	10	0	0	0.7	0.0	1.2
NF-1	0.000	0.004	0.007	0.015	0.025	0.040	0.046	0.056	0.072	1680	8	0	0	0.5	0.0	1.2
NF + 0.03-1	0.000	0.004	0.007	0.015	0.031	0.056	0.063	0.074	0.085	1680	115	4	0	7.8	0.3	6.2

Table 2-6. (Continued).

Site/Treatment	Min.	Percentiles 10	30	50	70	90	95	99	Max	No. of Obs.	No. Occurrences ≥0.06	≥0.08	≥0.10	SUM (ppm-h) 06	08	W126
NF + 0.06-1	0.000	0.004	0.007	0.015	0.031	0.083	0.090	0.105	0.132	1680	323	191	29	26.7	17.4	22.9
NF + 0.09-1	0.000	0.004	0.007	0.015	0.031	0.122	0.135	0.153	0.171	1680	350	326	290	41.5	39.8	41.1
<u>R81SO - Davis</u>																
CF-1	0.000	0.002	0.013	0.021	0.030	0.046	0.055	0.072	0.145	2664	101	11	1	7.0	1.0	5.7
AA-1	0.000	0.003	0.015	0.027	0.042	0.065	0.072	0.086	0.145	2664	364	54	3	25.9	4.8	19.5
NF-1	0.000	0.003	0.015	0.026	0.043	0.066	0.075	0.088	0.145	2664	421	79	6	30.2	7.0	22.6
NF + 0.02-1	0.000	0.003	0.014	0.026	0.048	0.082	0.092	0.109	0.145	2664	629	288	72	50.6	26.9	41.8
NF + 0.03-1	0.000	0.003	0.015	0.026	0.052	0.097	0.110	0.128	0.163	2664	736	507	240	67.2	51.2	60.7
NF + 0.05-1	0.000	0.003	0.015	0.026	0.054	0.123	0.138	0.159	0.193	2664	763	647	527	85.6	77.7	82.6
NF + 0.07-1	0.000	0.003	0.015	0.026	0.054	0.149	0.167	0.187	0.203	2664	766	672	623	101.4	95.1	99.2
<u>R82SO - Davis</u>																
CF-1	0.000	0.001	0.009	0.015	0.023	0.040	0.052	0.081	0.132	2160	72	21	3	5.4	1.9	4.7
AA-1	0.000	0.001	0.013	0.025	0.041	0.063	0.069	0.089	0.132	2160	261	38	6	18.5	3.5	14.0
NF-1	0.000	0.001	0.013	0.025	0.040	0.061	0.070	0.089	0.132	2160	230	40	6	16.5	3.6	13.4
NF + 0.02-1	0.000	0.001	0.013	0.026	0.047	0.080	0.091	0.123	0.203	2160	471	218	56	39.0	21.4	33.1
NF + 0.04-1	0.000	0.001	0.013	0.026	0.053	0.103	0.117	0.140	0.171	2160	589	429	240	56.5	45.4	52.4
NF + 0.06-1	0.000	0.001	0.013	0.026	0.056	0.134	0.148	0.178	0.221	2160	631	535	455	75.4	68.7	73.4
NF x 1.3-1	0.000	0.001	0.013	0.025	0.043	0.080	0.098	0.123	0.145	2160	418	218	90	35.8	21.8	31.5
NF x 1.6-1	0.000	0.001	0.013	0.025	0.044	0.105	0.124	0.160	0.205	2160	486	341	241	49.4	39.4	46.3
NF x 1.9-1	0.000	0.001	0.013	0.025	0.047	0.122	0.150	0.189	0.225	2160	512	390	298	59.0	50.6	56.5
<u>R83SO - Davis</u>																
CF-1D	0.000	0.002	0.013	0.023	0.036	0.054	0.066	0.082	0.105	2640	188	37	3	13.5	3.2	11.6
CF-1W	0.000	0.002	0.013	0.022	0.033	0.053	0.065	0.083	0.105	2640	178	39	3	12.9	3.4	11.0
AA-1D	0.000	0.002	0.015	0.028	0.047	0.073	0.083	0.100	0.128	2640	481	172	25	36.8	15.4	30.2
AA-1W	0.000	0.002	0.015	0.028	0.047	0.073	0.083	0.100	0.133	2640	475	170	26	36.4	15.3	30.1
NF-1D	0.000	0.002	0.015	0.027	0.044	0.070	0.079	0.092	0.122	2640	415	120	9	31.1	10.6	25.2
NF-1W	0.000	0.002	0.015	0.027	0.045	0.070	0.079	0.092	0.113	2640	416	121	10	31.1	10.7	25.4
NF + 0.02-1D	0.000	0.002	0.015	0.030	0.055	0.089	0.104	0.126	0.155	2640	721	378	163	61.6	37.7	53.1
NF + 0.02-1W	0.000	0.002	0.015	0.030	0.054	0.087	0.101	0.119	0.138	2640	698	359	140	58.7	35.0	50.7
NF + 0.04-1D	0.000	0.002	0.015	0.031	0.061	0.112	0.127	0.146	0.166	2640	812	587	373	80.6	64.8	75.4
NF + 0.04-1W	0.000	0.002	0.015	0.031	0.062	0.111	0.127	0.144	0.160	2640	816	602	386	81.0	65.9	75.8

able 2-6. (Continued).

Site/Treatment	Min.	Percentiles 10	30	50	70	90	95	99	Max	No. of Obs.	No. Occurrences ≥0.06	≥0.08	≥0.10	SUM (ppm-h) 06	08	W126
R84SO - Davis																
CF-1D	0.000	0.005	0.014	0.021	0.030	0.044	0.053	0.074	0.113	2496	71	10	1	5.0	0.9	4.9
CF-1W	0.000	0.005	0.014	0.021	0.030	0.045	0.053	0.074	0.113	2496	71	9	1	5.0	0.8	4.9
AA-1	0.000	0.006	0.017	0.028	0.040	0.060	0.071	0.089	0.115	2496	255	57	10	18.7	5.2	15.8
NF-1D	0.000	0.005	0.016	0.027	0.038	0.058	0.067	0.082	0.113	2496	218	35	4	15.5	3.1	12.5
NF-1W	0.000	0.005	0.016	0.027	0.037	0.056	0.065	0.080	0.113	2496	188	27	1	13.3	2.4	11.2
NF + 0.015-1D	0.000	0.006	0.018	0.030	0.047	0.077	0.089	0.113	0.140	2496	512	208	59	41.2	19.9	34.8
NF + 0.015-1W	0.000	0.006	0.018	0.029	0.046	0.075	0.089	0.110	0.159	2496	486	193	62	38.9	18.6	32.6
NF + 0.030-1D	0.000	0.006	0.018	0.030	0.050	0.088	0.104	0.131	0.161	2496	615	365	160	54.1	36.5	48.2
NF + 0.030-1W	0.000	0.006	0.018	0.030	0.052	0.093	0.109	0.133	0.162	2496	653	419	177	58.7	42.3	52.9
NF + 0.045-1D	0.000	0.006	0.018	0.030	0.054	0.110	0.125	0.152	0.193	2496	687	536	341	69.9	59.4	66.5
NF + 0.045-1W	0.000	0.006	0.018	0.030	0.051	0.099	0.119	0.144	0.181	2496	647	463	240	62.2	49.3	58.0
NF + 0.060-1D	0.000	0.006	0.018	0.030	0.054	0.126	0.144	0.179	0.215	2496	699	569	433	79.2	70.2	76.5
NF + 0.060-1W	0.000	0.006	0.018	0.030	0.053	0.123	0.141	0.171	0.211	2496	685	563	448	77.2	68.8	74.9
R86SO - Young																
CF-1D	0.000	0.002	0.009	0.015	0.022	0.037	0.043	0.057	0.099	2568	17	1	0	1.2	0.1	1.6
CF-1W	0.000	0.002	0.007	0.012	0.019	0.033	0.039	0.051	0.074	2568	6	0	0	0.4	0.0	0.9
AA	0.000	0.003	0.015	0.026	0.043	0.066	0.079	0.098	0.139	2568	350	115	21	26.7	10.6	22.5
AA-1W	0.000	0.003	0.013	0.023	0.036	0.059	0.070	0.096	0.146	2568	237	74	19	18.1	7.0	15.6
NF-1D	0.000	0.003	0.012	0.021	0.034	0.056	0.069	0.093	0.133	2568	216	68	11	16.3	6.3	13.7
NF-1W	0.000	0.003	0.012	0.021	0.033	0.053	0.065	0.084	0.117	2568	176	35	3	12.7	3.1	10.5
NF x 1.3-1D	0.000	0.003	0.013	0.024	0.047	0.089	0.107	0.137	0.206	2568	597	345	175	53.7	36.2	47.7
NF x 1.3-1W	0.000	0.003	0.013	0.023	0.046	0.087	0.101	0.129	0.198	2568	573	323	136	50.2	32.8	44.1
NF x 1.6-1D	0.000	0.003	0.013	0.025	0.055	0.111	0.134	0.170	0.252	2568	721	527	339	74.8	61.1	70.1
NF x 1.6-1W	0.000	0.003	0.013	0.025	0.057	0.113	0.135	0.173	0.264	2568	730	533	340	76.0	62.3	70.7
NF x 1.9-1D	0.000	0.003	0.013	0.025	0.065	0.135	0.162	0.207	0.312	2568	794	633	465	94.5	82.9	90.7
NF x 1.9-1W	0.000	0.003	0.013	0.025	0.061	0.135	0.166	0.205	0.310	2568	778	621	461	92.9	81.9	88.8
NF x 1.3-1*	0.000	0.003	0.013	0.024	0.049	0.090	0.108	0.138	0.198	2568	607	372	176	55.3	38.8	49.9
NF x 1.6-1*	0.000	0.003	0.013	0.024	0.054	0.115	0.140	0.173	0.247	2568	706	522	355	75.3	62.3	71.0
NF x 1.9-1*	0.000	0.003	0.013	0.025	0.062	0.140	0.171	0.216	0.339	2568	787	652	495	97.5	88.0	94.1

*Rain Exclusion Cap

'able 2-6. (Continued).

Site/Treatment	Min.	Percentiles 10	30	50	70	90	95	99	Max	No. of Obs.	No. Occurrences ≥0.06	≥0.08	≥0.10	SUM (ppm-h) 06	08	W126
SORGHUM																
A82SG - Dekalb																
CF-1	0.000	0.001	0.007	0.013	0.023	0.039	0.047	0.065	0.102	2040	38	4	1	2.6	0.4	2.3
AA-1	0.000	0.001	0.010	0.020	0.034	0.052	0.063	0.078	0.124	2040	124	15	6	8.8	1.4	7.2
NF-1	0.000	0.001	0.010	0.020	0.034	0.052	0.062	0.076	0.114	2040	121	13	5	8.4	1.2	6.9
NF + 0.02-1	0.000	0.001	0.010	0.023	0.041	0.068	0.082	0.100	0.140	2040	323	121	21	24.9	11.2	20.2
NF + 0.04-1	0.000	0.001	0.010	0.023	0.048	0.091	0.105	0.129	0.175	2040	501	309	136	44.3	31.0	39.0
NF + 0.07-1	0.000	0.001	0.010	0.023	0.054	0.116	0.130	0.154	0.192	2040	588	514	360	63.0	57.9	60.8
NF + 0.10-1	0.000	0.001	0.010	0.023	0.055	0.145	0.160	0.185	0.223	2040	599	557	516	79.1	76.3	78.2
WHEAT																
A82WH - Abe/Arthur 71																
CF-1	0.000	0.002	0.013	0.020	0.029	0.042	0.049	0.067	0.082	1344	28	2	0	1.9	0.2	1.8
AA-1	0.000	0.002	0.014	0.024	0.038	0.055	0.063	0.074	0.113	1344	88	6	1	6.0	0.6	5.0
NF-1	0.000	0.002	0.015	0.025	0.037	0.054	0.063	0.077	0.120	1344	87	9	2	6.0	0.8	5.0
NF + 0.03-1	0.000	0.002	0.015	0.027	0.047	0.079	0.094	0.113	0.149	1344	300	130	43	24.1	12.5	19.8
NF + 0.06-1	0.000	0.002	0.015	0.027	0.053	0.109	0.121	0.144	0.170	1344	373	293	186	37.4	31.8	35.3
NF + 0.09-1	0.000	0.002	0.015	0.027	0.054	0.143	0.155	0.178	0.200	1344	383	347	312	49.0	46.5	48.4
A83WH - Abe/Arthur 71																
CF-1	0.000	0.004	0.012	0.021	0.030	0.044	0.054	0.076	0.142	1296	45	11	3	3.4	1.1	3.1
AA-1	0.000	0.004	0.019	0.028	0.040	0.059	0.071	0.097	0.142	1296	127	31	11	9.5	3.0	8.0
NF-1	0.000	0.004	0.019	0.029	0.040	0.057	0.069	0.097	0.142	1296	118	28	8	8.8	2.7	7.4
NF + 0.02-1	0.000	0.004	0.019	0.032	0.046	0.072	0.085	0.121	0.142	1296	239	84	28	18.8	8.2	15.4
NF + 0.04-1	0.000	0.004	0.019	0.032	0.052	0.088	0.107	0.137	0.163	1296	343	202	86	30.1	20.3	26.4
NF + 0.06-1	0.000	0.004	0.019	0.032	0.054	0.108	0.123	0.159	0.186	1296	365	295	186	37.4	32.5	35.6

'able 2-6. (Continued).

Site/Treatment	Min.	Percentiles 10	30	50	70	90	95	99	Max	No. of Obs.	No. Occurrences ≥0.06	≥0.08	≥0.10	SUM (ppm-h) 06	08	W126
BTI82WH - VONA																
CF-1	0.000	0.006	0.012	0.017	0.025	0.040	0.047	0.063	0.074	1464	8	0	0	0.5	0.0	1.4
AA-1	0.000	0.011	0.025	0.035	0.043	0.058	0.066	0.075	0.091	1464	142	4	0	9.5	0.3	7.2
NF-1	0.000	0.011	0.025	0.034	0.042	0.057	0.064	0.072	0.098	1464	114	2	0	7.6	0.2	6.2
NF + 0.03-1	0.000	0.011	0.026	0.037	0.049	0.074	0.087	0.104	0.126	1464	292	113	19	22.6	10.3	18.6
NF + 0.06-1	0.000	0.011	0.026	0.037	0.052	0.100	0.114	0.134	0.150	1464	379	255	153	35.2	26.8	32.3
NF + 0.09-1	0.000	0.011	0.026	0.037	0.053	0.127	0.147	0.172	0.207	1464	386	307	261	44.5	39.3	43.2
BTI83WH - VONA																
CF-1	0.000	0.002	0.010	0.015	0.025	0.044	0.056	0.070	0.084	864	33	3	0	2.2	0.2	1.7
AA-1	0.000	0.006	0.022	0.037	0.052	0.074	0.092	0.110	0.123	864	180	67	22	14.1	6.4	11.9
NF-1	0.000	0.006	0.021	0.036	0.049	0.071	0.083	0.097	0.116	864	165	51	4	12.4	4.7	9.8
NF x 1.5-1	0.000	0.006	0.022	0.038	0.057	0.098	0.115	0.144	0.160	864	247	129	82	22.0	14.0	19.2
NF x 2.0-1	0.000	0.006	0.022	0.039	0.060	0.121	0.137	0.169	0.194	864	265	177	130	27.2	21.3	25.1
CORN																
A81MA - PAG 397/Pioneer 3780																
CF-1	0.000	0.000	0.005	0.011	0.019	0.036	0.047	0.065	0.108	1968	30	4	1	2.1	0.4	2.0
AA	0.000	0.000	0.008	0.018	0.032	0.054	0.068	0.086	0.117	1968	146	36	7	10.9	3.3	9.2
NF-1	0.000	0.000	0.008	0.019	0.033	0.054	0.066	0.086	0.116	1968	134	28	7	10.0	2.6	8.8
NF + 0.03-1	0.000	0.000	0.008	0.020	0.047	0.082	0.094	0.113	0.156	1968	463	213	73	38.1	20.6	31.7
NF + 0.06-2	0.000	0.000	0.008	0.020	0.052	0.111	0.126	0.150	0.187	1968	552	461	306	57.5	51.0	55.1
NF + 0.09-1	0.000	0.000	0.008	0.020	0.054	0.147	0.160	0.186	0.223	1968	571	535	500	77.1	74.6	76.6
NF + 0.12-1	0.000	0.000	0.008	0.020	0.054	0.177	0.191	0.219	0.252	1968	573	549	532	92.9	91.3	92.7
COTTON																
R82CO - Stoneville																
CF-1	0.000	0.003	0.016	0.024	0.032	0.048	0.058	0.081	0.152	2856	127	31	7	9.4	2.9	8.6
CF-1*	0.000	0.002	0.011	0.017	0.026	0.046	0.057	0.079	0.152	2856	120	27	5	8.8	2.6	7.6
AA-2	0.000	0.003	0.018	0.029	0.043	0.064	0.072	0.086	0.152	2856	381	51	7	27.1	4.6	20.7

Table 2-6. (Continued).

Site/Treatment	Min.	Percentiles 10	30	50	70	90	95	99	Max	No. of Obs.	No. Occurrences ≥0.06	≥0.08	≥0.10	SUM (ppm-h) 06	08	W126
NF-1	0.000	0.003	0.018	0.029	0.044	0.065	0.074	0.087	0.152	2856	390	64	7	28.2	5.8	22.7
NF-1*	0.000	0.003	0.017	0.029	0.045	0.066	0.076	0.089	0.152	2856	454	101	7	32.9	8.9	25.3
NF + 0.02-1	0.000	0.003	0.018	0.029	0.050	0.077	0.086	0.099	0.152	2856	646	230	26	49.9	20.9	40.3
NF + 0.04-1	0.000	0.003	0.017	0.029	0.051	0.093	0.105	0.120	0.152	2856	734	447	192	64.4	44.2	57.6
NF + 0.06-1	0.000	0.003	0.017	0.029	0.052	0.111	0.123	0.138	0.152	2856	759	615	426	77.6	67.6	74.5
NF + 0.02-1*	0.000	0.003	0.017	0.029	0.048	0.077	0.085	0.097	0.152	2856	586	222	18	45.3	19.8	37.4
NF + 0.04-1*	0.000	0.003	0.018	0.029	0.052	0.095	0.106	0.123	0.153	2856	753	505	213	67.5	50.0	61.3
NF + 0.06-1*	0.000	0.003	0.018	0.029	0.052	0.106	0.117	0.131	0.152	2856	750	600	372	73.7	63.3	70.4
*Frustum Doses																
R85CO (McNair)																
CF-1D	0.000	0.002	0.010	0.017	0.024	0.035	0.042	0.053	0.077	3000	11	0	0	0.7	0.0	1.4
CF-1W	0.000	0.002	0.009	0.015	0.022	0.032	0.038	0.051	0.077	3000	11	0	0	0.7	0.0	1.0
CF*	0.000	0.002	0.008	0.014	0.021	0.031	0.040	0.056	0.080	3000	20	1	0	1.3	0.1	1.5
AA-2	0.000	0.003	0.013	0.026	0.042	0.066	0.079	0.100	0.125	3000	401	145	27	30.9	13.3	26.2
AA-1D	0.000	0.002	0.012	0.024	0.038	0.060	0.070	0.090	0.110	3000	298	77	7	22.0	6.9	18.4
AA-2W	0.000	0.002	0.012	0.024	0.039	0.063	0.076	0.090	0.122	3000	347	100	5	25.9	8.8	21.6
NF-1D	0.000	0.002	0.012	0.023	0.036	0.058	0.069	0.085	0.109	3000	269	55	4	19.5	4.8	15.8
NF-1W	0.000	0.003	0.012	0.023	0.037	0.058	0.069	0.092	0.123	3000	263	78	11	19.7	7.1	17.0
NF x 1.33-1D	0.000	0.003	0.012	0.024	0.042	0.077	0.097	0.136	0.179	3000	545	266	135	47.2	28.1	40.9
NF x 1.33-1W	0.000	0.003	0.012	0.024	0.041	0.073	0.091	0.129	0.166	3000	487	226	118	41.4	23.5	35.9
NF x 1.33-1*	0.000	0.002	0.012	0.023	0.040	0.073	0.094	0.120	0.173	3000	492	230	115	41.8	23.7	36.3
NF x 1.66-1D	0.000	0.003	0.012	0.024	0.046	0.091	0.121	0.169	0.218	3000	678	392	241	65.8	45.8	59.2
NF x 1.66-1W	0.000	0.003	0.012	0.024	0.045	0.090	0.119	0.176	0.231	3000	657	391	227	64.3	45.8	58.3
NF x 1.99-1D	0.000	0.003	0.012	0.024	0.052	0.117	0.154	0.221	0.291	3000	810	609	407	92.9	78.9	88.2
NF x 1.99-1W	0.000	0.002	0.012	0.024	0.047	0.105	0.143	0.213	0.314	3000	740	510	340	81.4	65.2	76.3
NF x 1.99-1*	0.000	0.002	0.012	0.024	0.049	0.110	0.147	0.199	0.258	3000	759	534	362	83.3	67.6	78.1
* Rain Exclusion Cap																
PEANUT																
R80PN - NC-6																
CF-1	0.000	0.004	0.014	0.021	0.029	0.042	0.050	0.066	0.091	2688	46	3	0	3.1	0.3	3.5

able 2-6. (Continued).

Site/Treatment	Min.	Percentiles 10	30	50	70	90	95	99	Max	No. of Obs.	No. Occurrences ≥0.06	≥0.08	≥0.10	SUM (ppm-h) 06	08	W126
AA-1	0.000	0.004	0.017	0.029	0.044	0.067	0.074	0.090	0.116	2688	375	78	7	27.2	6.9	21.7
NF + 0.015-1	0.000	0.004	0.017	0.029	0.043	0.066	0.076	0.091	0.112	2688	369	101	5	27.2	8.8	22.0
NF + 0.045-1	0.000	0.004	0.017	0.030	0.051	0.089	0.102	0.121	0.138	2688	663	382	150	57.0	37.5	50.2
NF + 0.075-1	0.000	0.004	0.017	0.031	0.062	0.117	0.135	0.157	0.184	2688	824	679	468	87.6	77.4	84.2
NF + 0.105-1	0.000	0.004	0.017	0.031	0.071	0.149	0.166	0.190	0.208	2688	851	775	677	111.0	105.8	109.7
TOBACCO																
R83TO - McNair 944																
CF-1	0.000	0.002	0.013	0.021	0.030	0.044	0.052	0.069	0.091	1968	41	7	0	2.9	0.6	3.2
NF-1	0.000	0.002	0.018	0.033	0.052	0.073	0.082	0.093	0.122	1968	428	122	8	31.6	10.6	24.6
AA-1	0.000	0.003	0.020	0.040	0.059	0.82	0.092	0.108	0.137	1968	576	245	41	45.4	22.4	37.5
NF + 0.020-1	0.000	0.003	0.018	0.037	0.061	0.089	0.104	0.121	0.155	1968	611	288	117	50.7	28.4	42.6
NF + 0.040-1	0.000	0.003	0.018	0.037	0.065	0.104	0.120	0.140	0.174	1968	652	423	231	60.5	44.6	54.9
NF + 0.060-1	0.000	0.003	0.018	0.037	0.068	0.121	0.137	0.155	0.185	1968	672	489	370	69.8	57.2	65.5
NF x 1.3-1	0.000	0.003	0.019	0.041	0.072	0.113	0.125	0.147	0.188	1968	725	514	319	70.4	55.6	65.2
NF x 1.6-1	0.000	0.003	0.019	0.042	0.084	0.136	0.151	0.171	0.204	1968	795	622	460	87.3	75.3	82.9
NF x 1.9-1	0.000	0.003	0.019	0.043	0.096	0.160	0.177	0.204	0.249	1968	838	700	571	104.7	95.1	101.4
NF x 1.3-1*	0.000	0.003	0.018	0.035	0.059	0.096	0.119	0.141	0.181	1968	581	324	171	52.4	34.6	46.4
NF x 1.6-1*	0.000	0.003	0.018	0.035	0.061	0.110	0.137	0.167	0.217	1968	611	384	244	60.5	44.8	55.3
NF x 1.9-1*	0.000	0.003	0.018	0.036	0.064	0.139	0.170	0.212	0.229	1968	638	445	332	73.3	59.9	68.9

*7 Hour Exposure Period

Table 2-7. SUM06 cumulative exposures, using the SUM06 Lee *et al.* (1991) equations (assuming SUM06=0 for "clean" sites) that predict 10%, 20%, and 30% yield losses.

Crop	Percent Yield Loss		
	10%	20%	30%
Soybean			
A80SO Corsoy	12.7	20.8	28.4
A83CV Amsoy_71	29.3	39.5	47.7
A83CV Corsoy_79	38.1	44.4	48.9
A85SO Corsoy_79 Dry	65.4	79.6	89.9
A85SO Corsoy_79 Wet	65.9	82.0	94.0
A86SO Corsoy_79 Dry	93.9	99.2	102.6
A86SO Corsoy_79 Wet	63.0	78.8	90.7
B83SO Corsoy_79 Dry	5.2	14.9	28.7
B83SO Corsoy_79 Wet	10.0	18.6	27.3
B83SO Williams Dry	21.2	34.9	47.8
B83SO Williams Wet	12.6	22.8	33.1
I81SO Hodgson	9.9	20.9	33.4
R81SO Davis	20.5	38.2	56.2
R82SO Davis	18.9	31.0	42.3
R83SO Davis Dry	26.8	56.8	90.7
R83SO Davis Wet	24.4	46.5	69.6
R84SO Davis Dry	31.2	45.9	58.5
R84SO Davis Wet	31.2	45.9	58.5
R86SO Young Dry	33.3	58.4	83.0
R86SO Young Wet	33.3	58.4	83.0
Sorghum			
A82SG Dekalb	65.7	91.3	112.2

Table 2-7. (Continued).

Crop	Percent Yield Loss 10%	20%	30%
Wheat			
A82WH Abe	20.3	28.9	36.0
A83WH Abe	31.1	34.6	36.8
A82WH Arthur_71	21.0	29.7	37.0
A83WH Arthur_71	24.6	35.4	44.4
I82WH Vona	2.9	6.1	9.7
I83WH Vona	5.5	9.6	13.7
Corn			
A81MA PAG 397	54.3	64.9	72.5
A81MA Pioneer 3780	40.1	52.7	62.5
Cotton			
R82CO Stoneville	23.7	36.7	48.2
R85CO McNair Dry	74.2	96.4	113.6
R85CO McNair Wet	26.9	44.0	59.8
Peanut			
R80PN NC-6	34.7	49.0	60.9
Tobacco			
R83TO McNair 944	24.5	46.9	70.5

Table 2-8. Summary of ozone exposures that are closest to those predicted for 20% yield reduction per SUM06 exposure-response models used by Lee et al. (1991) in selected NCLAN experiments. Concentrations are in units of ppm.

Experiment	Chamber	Min.	Percentiles 10	30	50	70	90	95	99	Max	No. of Obs.	No. Occurrences ≥0.06	≥0.08	≥0.10	SUM (ppm-h) 06	08	W126
SOYBEAN																	
A80SO - Corsoy	NF+0.03-1	0.000	0.000	0.011	0.026	0.045	0.077	0.090	0.111	0.123	1344	263	113	35	21.1	10.7	17.7
A83SO - Amsoy	NF+0.03-1	0.000	0.001	0.014	0.028	0.049	0.083	0.098	0.123	0.168	1992	467	223	90	39.1	22.1	33.2
A83SO - Corsoy	NF+0.06-1	0.000	0.001	0.014	0.029	0.057	0.110	0.128	0.157	0.204	1992	575	435	285	58.5	48.8	55.0
A85SO - Corsoy_79 Dry	NFx2.00-1D	0.000	0.000	0.008	0.023	0.051	0.110	0.129	0.160	0.194	2352	657	495	319	67.5	56.2	63.0
A85SO - Corsoy_79 Wet	NFx2.00-1W	0.000	0.000	0.011	0.026	0.063	0.114	0.134	0.162	0.199	2352	729	547	358	75.1	62.5	70.0
A86SO - Corsoy_79 Dry	NFx2.5-1D	0.000	0.002	0.016	0.035	0.085	0.137	0.161	0.207	0.279	2040	784	654	515	92.1	83.2	88.6
A86SO - Corsoy_79 Wet	NFx2.0-1W	0.000	0.002	0.015	0.033	0.065	0.105	0.124	0.161	0.242	2040	719	510	271	69.6	55.1	63.7
B83SO - Corsoy_79 Dry	NF-1D	0.000	0.002	0.006	0.018	0.037	0.063	0.074	0.087	0.111	1512	184	51	5	13.5	4.4	10.6
B83SO - Corsoy_79 Wet	NF+0.03-1W	0.000	0.002	0.006	0.019	0.049	0.084	0.097	0.118	0.135	1512	359	198	70	30.1	18.9	25.8
B83SO - Williams Dry	NF+0.03-1D	0.000	0.002	0.006	0.019	0.049	0.084	0.098	0.118	0.137	1512	364	204	66	30.5	19.5	26.0
B83SO - Williams Wet	NF+0.03-1W	0.000	0.002	0.006	0.019	0.049	0.084	0.097	0.118	0.135	1512	359	198	70	30.1	18.9	25.8
I81SO - Hodgson	NF+0.06-1	0.000	0.004	0.007	0.015	0.031	0.083	0.090	0.105	0.132	1680	323	191	29	26.7	17.4	22.9
R81SO - Davis	NF-1	0.000	0.003	0.015	0.026	0.043	0.066	0.075	0.088	0.145	2664	421	79	6	30.2	7.0	22.6
R82SO - Davis	NF+0.02-1	0.000	0.001	0.013	0.026	0.047	0.080	0.091	0.123	0.203	2160	471	218	56	39.0	21.4	33.1
R83SO - Davis Dry	NF+0.02-1D	0.000	0.002	0.015	0.030	0.055	0.089	0.104	0.126	0.155	2640	721	378	163	61.6	37.7	53.1
R83SO - Davis Wet	NF+0.02-1W	0.000	0.002	0.015	0.030	0.054	0.087	0.101	0.119	0.138	2640	698	359	140	58.7	35.0	50.7
R84SO - Davis Dry	NF+0.015-1D	0.000	0.006	0.018	0.030	0.047	0.077	0.089	0.113	0.140	2496	512	208	59	41.2	19.9	34.8
R84SO - Davis Wet	NF+0.015-1W	0.000	0.006	0.018	0.029	0.046	0.075	0.089	0.110	0.159	2496	486	193	62	38.9	18.6	32.6
R86SO - Young Dry	NFx1.3-1D	0.000	0.003	0.013	0.024	0.047	0.089	0.107	0.137	0.206	2568	597	345	175	53.7	36.2	47.7
R86SO - Young Wet	NFx1.3-1W	0.000	0.003	0.013	0.023	0.046	0.087	0.101	0.129	0.198	2568	573	323	136	50.2	32.8	44.1
SORGHUM																	
A82SG - Dekalb	NF+0.10-1	0.000	0.001	0.010	0.023	0.055	0.145	0.160	0.185	0.223	2040	599	557	516	79.1	76.3	78.2
WHEAT																	
A82WH - Abe	NF+0.03-1	0.000	0.002	0.015	0.027	0.047	0.079	0.094	0.113	0.149	1344	300	130	43	24.1	12.5	19.8
A82WH - Arthur_71	NF+0.06-1	0.000	0.002	0.015	0.027	0.053	0.109	0.121	0.144	0.170	1344	373	293	186	37.4	31.8	35.3
A83WH - Abe	NF+0.06-1	0.000	0.004	0.019	0.032	0.054	0.108	0.123	0.159	0.186	1296	365	295	186	37.4	32.5	35.6
A83WH - Arthur_71	NF+0.06-1	0.000	0.004	0.019	0.032	0.054	0.108	0.123	0.159	0.186	1296	365	295	186	37.4	32.5	35.6
BTI82WH - VONA	NF-1	0.000	0.011	0.025	0.034	0.042	0.057	0.064	0.072	0.098	1464	114	2	0	7.6	0.2	6.2
BTI83WH - VONA	NF-1	0.000	0.006	0.021	0.036	0.049	0.071	0.083	0.097	0.116	864	165	51	4	12.4	4.7	9.8

able 2-8. (Continued).

Experiment	Chamber	Min.	10	30	50	70	90	95	99	Max	No. of Obs.	No. Occurrences ≥0.06	≥0.08	≥0.10	SUM (ppm-h) 06	08	W126
CORN																	
A81MA - PAG 397	NF+0.06-2	0.000	0.000	0.008	0.020	0.052	0.111	0.126	0.150	0.187	1968	552	461	306	57.5	51.0	55.1
A81MA - Pioneer	NF+0.06-2	0.000	0.000	0.008	0.020	0.052	0.111	0.126	0.150	0.187	1968	552	461	306	57.5	51.0	55.1
COTTON																	
R82CO - Stoneville	NF-1	0.000	0.003	0.018	0.029	0.044	0.065	0.074	0.087	0.152	2856	390	64	7	28.2	5.8	22.7
R85CO (McNair) Dry	NFx1.99-1D	0.000	0.003	0.012	0.024	0.052	0.117	0.154	0.221	0.291	3000	810	609	407	92.9	78.9	88.2
R85CO (McNair) Wet	NFx1.33-1W	0.000	0.003	0.012	0.024	0.041	0.073	0.091	0.129	0.166	3000	487	226	118	41.4	23.5	35.9
PEANUT																	
R80PN - NC-6	NF+0.015-1	0.000	0.004	0.017	0.029	0.043	0.066	0.076	0.091	0.112	2688	369	101	5	27.2	8.8	22.0
TOBACCO																	
R83TO - McNair 944	NF+0.020-1	0.000	0.003	0.018	0.037	0.061	0.089	0.104	0.121	0.155	1968	611	288	117	50.7	28.4	42.6

Table 2-9. The effect of pressure and temperature changes on the SUM06 cumulative exposure index.

Site		Year	Index	Value	Percent Reduction 1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
HF 1	HOWLAND FOREST 1	87	S06	9024	-1.0	-12.9	-13.8	-25.6	-37.3	-37.9	-49.5	-56.3	-56.7	-63.4
MM 1	MOUNT MITCHELL 1	86	S06	69969	-1.0	-6.6	-7.6	-13.1	-18.7	-19.5	-25.0	-29.0	-29.8	-33.8
MM 1	MOUNT MITCHELL 1	87	S06	98550	-1.0	-10.8	-11.7	-21.4	-31.0	-31.8	-41.3	-46.0	-46.5	-51.1
MM 2	MOUNT MITCHELL 2	86	S06	7242	-1.0	-18.5	-19.4	-36.6	-53.9	-54.3	-71.3	-77.1	-77.4	-83.1
MM 2	MOUNT MITCHELL 2	87	S06	85324	-1.0	-9.5	-10.4	-18.8	-27.2	-28.0	-36.2	-42.1	-42.7	-48.5
MS 1	MOOSELAUKE 1	86	S06	1590	-1.0	-3.5	-4.5	-6.9	-9.4	-10.3	-12.7	-18.1	-19.0	-24.3
MS 1	MOOSELAUKE 1	87	S06	72743	-1.0	-8.0	-9.0	-15.9	-22.8	-23.6	-30.5	-34.6	-35.3	-39.5
SH 1	SHENANDOAH 1	87	S06	96988	-1.0	-7.8	-8.7	-15.5	-22.2	-23.0	-29.6	-34.2	-35.0	-39.5
SH 2	SHENANDOAH 2	87	S06	102486	-1.0	-8.3	-9.2	-16.4	-23.6	-24.4	-31.5	-36.6	-37.3	-42.4
SH 3	SHENANDOAH 3	87	S06	40351	-1.0	-9.2	-10.1	-18.1	-26.1	-26.9	-34.8	-40.4	-41.0	-46.4
WF 1	WHITEFACE MOUNTAIN 1	86	S06	35560	-1.0	-11.8	-12.7	-23.4	-34.1	-34.8	-45.2	-50.7	-51.3	-56.6
WF 1	WHITEFACE MOUNTAIN 1	87	S06	91360	-1.0	-8.4	-9.3	-16.6	-23.9	-24.7	-31.9	-35.5	-36.2	-39.7
WF 3	WHITEFACE MOUNTAIN 3	87	S06	80948	-1.0	-6.3	-7.2	-12.4	-17.6	-18.5	-23.6	-27.8	-28.6	-32.8
WF 4	WHITEFACE MOUNTAIN 4	87	S06	40112	-1.0	-8.4	-9.3	-16.6	-23.9	-24.7	-31.8	-35.9	-36.6	-40.7
WT 1	WHITETOP 1	87	S06	218032	-1.0	-7.6	-8.5	-15.0	-21.4	-22.2	-28.6	-32.4	-33.2	-36.9
230090003	ACADIA NP	87	S06	30574	-1.0	-9.1	-10.0	-17.9	-25.9	-26.7	-34.5	-37.1	-37.8	-40.4
2300900031	ACADIA NP	86	S06	22857	-1.0	-9.4	-10.3	-18.6	-26.9	-27.6	-35.8	-39.6	-40.3	-44.1
360310002	ESSEX CO(WFM)	87	S06	94232	-1.0	-8.4	-9.3	-16.6	-23.9	-24.7	-31.9	-35.5	-36.2	-39.7
3603100022	ESSEX CO(WFM)	86	S06	44146	-1.0	-12.4	-13.3	-24.5	-35.6	-36.3	-47.3	-51.9	-52.5	-57.0
360310005	ESSEX CO(HUNT)	87	S06	36528	-1.0	-8.7	-9.7	-17.3	-24.9	-25.7	-33.2	-37.2	-37.9	-41.7
3603100051	ESSEX CO(HUNT)	86	S06	23739	-1.0	-9.4	-10.3	-18.6	-26.9	-27.7	-35.8	-39.7	-40.3	-44.1
482890002N05	SHEN, DICKEY RIDGE	83	S06	236002	-1.0	-2.0	-21.9	-22.7	-23.5	-24.3	-25.1	-26.0	-26.8	-61.6
482890002N05	SHEN, DICKEY RIDGE	84	S06	146030	-1.0	-2.0	-42.4	-43.0	-43.6	-44.2	-44.7	-45.3	-45.9	-46.5
482890002N05	SHEN, DICKEY RIDGE	85	S06	121139	-1.0	-2.0	-48.1	-48.6	-49.1	-49.7	-50.2	-50.7	-51.3	-51.8
482890003N05	SHEN, BIG MEADOWS	83	S06	178618	-1.0	-2.0	-23.5	-24.3	-25.1	-25.9	-26.7	-27.4	-28.2	-69.6
482890003N05	SHEN, BIG MEADOWS	84	S06	161555	-1.0	-2.0	-52.5	-52.9	-53.4	-53.9	-54.4	-54.9	-55.4	-55.9
482890003N05	SHEN, BIG MEADOWS	85	S06	68256	-1.0	-2.0	-65.5	-65.9	-66.2	-66.6	-67.0	-67.3	-67.7	-68.0
482890004N05	SHEN, SAWMILL RUN	83	S06	129124	-1.0	-2.0	-23.1	-23.9	-24.7	-25.5	-26.3	-27.1	-27.9	-57.8
482890004N05	SHEN, SAWMILL RUN	84	S06	110343	-1.0	-2.0	-47.1	-47.6	-48.2	-48.7	-49.3	-49.8	-50.3	-50.9
482890004N05	SHEN, SAWMILL RUN	85	S06	64274	-1.0	-2.0	-57.6	-58.1	-58.5	-58.9	-59.4	-59.8	-60.2	-60.7
510150004	SHEN, SAWMILL RUN	86	S06	93186	-1.0	-2.0	-56.2	-56.6	-57.1	-57.5	-58.0	-58.4	-58.9	-59.4
510150004	SHEN, SAWMILL RUN	87	S06	116714	-1.0	-8.1	-9.0	-16.0	-23.0	-23.8	-30.7	-34.6	-35.3	-39.2
511130003	SHEN, BIG MEADOWS	86	S06	95743	-1.0	-2.0	-62.7	-63.1	-63.5	-63.8	-64.2	-64.6	-65.0	-65.4
511130003	SHEN, BIG MEADOWS	87	S06	187009	-1.0	-7.9	-8.9	-15.7	-22.5	-23.4	-30.1	-34.1	-34.8	-38.8
511870002	SHEN, DICKEY RIDGE	86	S06	77973	-1.0	-2.0	-65.1	-65.4	-65.8	-66.2	-66.5	-66.9	-67.2	-67.6
511870002	SHEN, DICKEY RIDGE	87	S06	180598	-1.0	-6.5	-7.5	-12.9	-18.4	-19.2	-24.6	-28.2	-29.0	-32.6

Table 2-10. The effect of pressure and temperature changes on the SUM07 cumulative exposure index.

	Site	Year	Index	Value	Percent Reduction 1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
HF 1	HOWLAND FOREST 1	87	S07	1553	-1.0	-14.3	-27.6	-28.3	-41.3	-54.2	-63.6	-72.8	-73.1	-82.1
MM 1	MOUNT MITCHELL 1	86	S07	41353	-1.0	-7.9	-14.7	-15.6	-22.3	-29.0	-34.9	-40.7	-41.3	-47.1
MM 1	MOUNT MITCHELL 1	87	S07	36798	-1.0	-10.3	-19.6	-20.4	-29.5	-38.6	-43.5	-48.5	-49.0	-53.9
MM 2	MOUNT MITCHELL 2	87	S07	30835	-1.0	-11.6	-22.1	-22.9	-33.2	-43.5	-49.1	-54.8	-55.3	-60.8
MS 1	MOOSELAUKE 1	86	S07	1070	-1.0	-4.6	-8.1	-9.0	-12.5	-16.0	-22.0	-28.0	-28.8	-34.6
MS 1	MOOSELAUKE 1	87	S07	38524	-1.0	-7.0	-12.9	-13.8	-19.6	-25.4	-31.9	-38.2	-38.9	-45.1
SH 1	SHENANDOAH 1	87	S07	48107	-1.0	-10.6	-20.1	-20.9	-30.3	-39.6	-45.6	-51.5	-52.1	-57.9
SH 2	SHENANDOAH 2	87	S07	46093	-1.0	-10.9	-20.8	-21.7	-31.4	-41.1	-47.0	-53.0	-53.5	-59.3
SH 3	SHENANDOAH 3	87	S07	15934	-1.0	-10.9	-20.8	-21.6	-31.3	-40.9	-47.2	-53.5	-54.0	-60.1
WF 1	WHITEFACE MOUNTAIN 1	86	S07	10131	-1.0	-12.5	-24.0	-24.7	-36.0	-47.2	-55.3	-63.4	-63.8	-71.7
WF 1	WHITEFACE MOUNTAIN 1	87	S07	49161	-1.0	-8.4	-15.7	-16.6	-23.8	-31.0	-36.5	-41.9	-42.6	-47.9
WF 3	WHITEFACE MOUNTAIN 3	87	S07	48616	-1.0	-6.6	-12.2	-13.1	-18.6	-24.1	-29.0	-34.0	-34.7	-39.5
WF 4	WHITEFACE MOUNTAIN 4	87	S07	20411	-1.0	-8.7	-16.3	-17.2	-24.7	-32.2	-37.4	-42.5	-43.1	-48.1
WT 1	WHITETOP 1	87	S07	121735	-1.0	-8.8	-16.5	-17.4	-25.0	-32.6	-38.0	-43.4	-44.1	-49.4
230090003	ACADIA NP	87	S07	17157	-1.0	-8.4	-15.7	-16.6	-23.8	-31.0	-34.6	-38.1	-38.8	-42.3
2300900031	ACADIA NP	86	S07	11109	-1.0	-7.4	-13.8	-14.7	-21.0	-27.2	-30.2	-33.2	-33.9	-36.8
360310002	ESSEX CO(WFM)	87	S07	50640	-1.0	-8.4	-15.7	-16.6	-23.8	-30.9	-36.4	-41.8	-42.4	-47.7
3603100022	ESSEX CO(WFM)	86	S07	13362	-1.0	-14.3	-27.5	-28.2	-41.2	-54.1	-59.9	-65.6	-66.0	-71.7
360310005	ESSEX CO(HUNT)	87	S07	18052	-1.0	-10.8	-20.5	-21.3	-30.9	-40.4	-46.5	-52.5	-53.0	-59.0
3603100051	ESSEX CO(HUNT)	86	S07	11454	-1.0	-8.2	-15.4	-16.2	-23.3	-30.3	-34.4	-38.4	-39.1	-43.1
482890002N05	SHEN, DICKEY RIDGE	83	S07	100739	-1.0	-33.0	-33.7	-34.4	-35.1	-35.8	-36.4	-37.1	-37.8	-38.5
482890002N05	SHEN, DICKEY RIDGE	84	S07	86755	-1.0	-31.2	-31.9	-32.6	-33.3	-34.0	-34.7	-35.4	-60.2	-60.6
482890002N05	SHEN, DICKEY RIDGE	85	S07	64870	-1.0	-28.8	-29.6	-30.3	-31.0	-31.7	-32.5	-33.2	-56.0	-56.4
482890003N05	SHEN, BIG MEADOWS	83	S07	60365	-1.0	-42.6	-43.2	-43.8	-44.4	-45.0	-45.6	-46.2	-46.7	-47.3
482890003N05	SHEN, BIG MEADOWS	84	S07	79195	-1.0	-38.7	-39.3	-39.9	-40.6	-41.2	-41.8	-42.4	-69.0	-69.4
482890003N05	SHEN, BIG MEADOWS	85	S07	24250	-1.0	-52.3	-52.8	-53.3	-53.8	-54.3	-54.7	-55.2	-72.0	-72.3
482890004N05	SHEN, SAWMILL RUN	83	S07	60566	-1.0	-28.7	-29.4	-30.2	-30.9	-31.6	-32.3	-33.1	-33.8	-34.5
482890004N05	SHEN, SAWMILL RUN	84	S07	60205	-1.0	-33.0	-33.6	-34.3	-35.0	-35.7	-36.4	-37.1	-65.8	-66.2
482890004N05	SHEN, SAWMILL RUN	85	S07	28083	-1.0	-40.6	-41.2	-41.8	-42.4	-43.0	-43.6	-44.2	-67.1	-67.5
510150004	SHEN, SAWMILL RUN	86	S07	42087	-1.0	-43.7	-44.3	-44.8	-45.4	-46.0	-46.6	-47.1	-76.8	-77.1
510150004	SHEN, SAWMILL RUN	87	S07	61605	-1.0	-9.4	-17.8	-18.6	-26.8	-35.0	-40.7	-46.4	-47.0	-52.6
511130003	SHEN, BIG MEADOWS	86	S07	36828	-1.0	-47.8	-48.3	-48.8	-49.4	-49.9	-50.4	-51.0	-75.9	-76.2
511130003	SHEN, BIG MEADOWS	87	S07	99216	-1.0	-9.2	-17.3	-18.2	-26.2	-34.2	-39.6	-45.0	-45.6	-50.9
511870002	SHEN, DICKEY RIDGE	86	S07	28076	-1.0	-52.8	-53.3	-53.7	-54.2	-54.7	-55.2	-55.7	-82.3	-82.5
511870002	SHEN, DICKEY RIDGE	87	S07	111669	-1.0	-7.4	-13.8	-14.7	-21.0	-27.3	-32.4	-37.6	-38.2	-43.3

Table 2-11. The effect of pressure and temperature changes on the W126 cumulative exposure index.

	Site	Year	Index	Value	Percent Reduction 1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
HF 1	HOWLAND FOREST 1	87	W126	11913	-5.6	-11.0	-16.2	-21.1	-25.8	-30.3	-34.5	-38.6	-42.5	-46.1
MM 1	MOUNT MITCHELL 1	86	W126	58319	-3.9	-7.8	-11.6	-15.4	-19.0	-22.7	-26.2	-29.7	-33.1	-36.4
MM 1	MOUNT MITCHELL 1	87	W126	82432	-4.8	-9.4	-13.9	-18.3	-22.6	-26.7	-30.7	-34.5	-38.2	-41.8
MM 2	MOUNT MITCHELL 2	86	W126	10014	-6.0	-11.8	-17.2	-22.4	-27.4	-32.0	-36.5	-40.7	-44.6	-48.3
MM 2	MOUNT MITCHELL 2	87	W126	71150	-4.8	-9.6	-14.1	-18.6	-22.9	-27.1	-31.1	-35.0	-38.7	-42.3
MS 1	MOOSELAUKE 1	86	W126	2161	-4.4	-8.7	-12.9	-16.9	-20.9	-24.7	-28.4	-32.0	-35.5	-38.8
MS 1	MOOSELAUKE 1	87	W126	66671	-4.3	-8.6	-12.7	-16.7	-20.7	-24.5	-28.2	-31.8	-35.4	-38.8
SH 1	SHENANDOAH 1	86	W126	183	-4.7	-9.3	-13.6	-17.7	-21.6	-25.4	-28.9	-32.3	-35.6	-38.7
SH 1	SHENANDOAH 1	87	W126	76878	-4.3	-8.5	-12.7	-16.7	-20.7	-24.6	-28.4	-32.0	-35.6	-39.1
SH 2	SHENANDOAH 2	87	W126	79978	-4.4	-8.8	-13.0	-17.2	-21.2	-25.2	-29.0	-32.7	-36.3	-39.8
SH 3	SHENANDOAH 3	86	W126	48	-5.1	-9.9	-14.5	-18.9	-23.1	-27.0	-30.8	-34.3	-37.7	-40.9
SH 3	SHENANDOAH 3	87	W126	34788	-4.8	-9.4	-13.9	-18.3	-22.5	-26.6	-30.6	-34.4	-38.1	-41.7
WF 1	WHITEFACE MOUNTAIN 1	86	W126	31224	-5.2	-10.3	-15.1	-19.8	-24.4	-28.7	-32.9	-37.0	-40.8	-44.5
WF 1	WHITEFACE MOUNTAIN 1	87	W126	78491	-4.2	-8.3	-12.3	-16.3	-20.1	-23.9	-27.5	-31.1	-34.6	-38.0
WF 3	WHITEFACE MOUNTAIN 3	87	W126	70254	-3.8	-7.5	-11.1	-14.7	-18.2	-21.6	-25.0	-28.3	-31.6	-34.7
WF 4	WHITEFACE MOUNTAIN 4	87	W126	35242	-4.3	-8.4	-12.5	-16.5	-20.3	-24.1	-27.7	-31.3	-34.8	-38.1
WT 1	WHITETOP 1	87	W126	163524	-3.8	-7.6	-11.3	-14.9	-18.6	-22.1	-25.6	-29.0	-32.4	-35.7
230090003	ACADIA NP	87	W126	32320	-4.2	-8.3	-12.3	-16.1	-19.8	-23.4	-26.9	-30.2	-33.5	-36.6
2300900031	ACADIA NP	86	W126	26301	-4.5	-8.9	-13.1	-17.2	-21.1	-24.9	-28.5	-32.1	-35.4	-38.7
360310002	ESSEX CO(WFM)	87	W126	80429	-4.2	-8.3	-12.3	-16.2	-20.1	-23.8	-27.5	-31.0	-34.5	-37.9
3603100022	ESSEX CO(WFM)	86	W126	41256	-5.2	-10.3	-15.2	-19.9	-24.4	-28.8	-32.9	-37.0	-40.8	-44.4
360310005	ESSEX CO(HUNT)	87	W126	32339	-4.5	-8.9	-13.2	-17.3	-21.4	-25.3	-29.2	-32.9	-36.5	-39.9
3603100051	ESSEX CO(HUNT)	86	W126	25114	-4.6	-9.1	-13.4	-17.5	-21.6	-25.5	-29.2	-32.9	-36.4	-39.8
482890002N05	SHEN, DICKEY RIDGE	83	W126	156856	-3.9	-7.8	-11.6	-15.4	-19.1	-22.7	-26.2	-29.7	-33.1	-36.4
482890002N05	SHEN, DICKEY RIDGE	84	W126	103905	-4.0	-7.8	-11.7	-15.4	-19.1	-22.8	-26.3	-29.8	-33.2	-36.5
482890002N05	SHEN, DICKEY RIDGE	85	W126	83067	-4.0	-7.9	-11.7	-15.5	-19.2	-22.8	-26.4	-29.8	-33.2	-36.5
482890003N05	SHEN, BIG MEADOWS	83	W126	110120	-4.3	-8.5	-12.7	-16.8	-20.7	-24.6	-28.4	-32.1	-35.6	-39.1
482890003N05	SHEN, BIG MEADOWS	84	W126	107591	-4.4	-8.8	-13.0	-17.2	-21.2	-25.2	-29.0	-32.7	-36.4	-39.9
482890003N05	SHEN, BIG MEADOWS	85	W126	48696	-5.1	-10.0	-14.7	-19.3	-23.7	-27.9	-32.0	-35.9	-39.7	-43.3
482890004N05	SHEN, SAWMILL RUN	83	W126	90847	-3.7	-7.4	-11.0	-14.6	-18.1	-21.5	-24.8	-28.1	-31.3	-34.4
482890004N05	SHEN, SAWMILL RUN	84	W126	76420	-4.2	-8.3	-12.3	-16.3	-20.1	-23.9	-27.6	-31.2	-34.8	-38.2
482890004N05	SHEN, SAWMILL RUN	85	W126	44179	-4.6	-9.1	-13.5	-17.7	-21.8	-25.8	-29.7	-33.4	-37.0	-40.5
510150004	SHEN, SAWMILL RUN	86	W126	64309	-4.7	-9.4	-13.9	-18.2	-22.5	-26.6	-30.6	-34.4	-38.2	-41.8
510150004	SHEN, SAWMILL RUN	87	W126	90748	-4.1	-8.0	-12.0	-15.8	-19.6	-23.3	-26.9	-30.4	-33.9	-37.3
511130003	SHEN, BIG MEADOWS	86	W126	65046	-5.0	-9.8	-14.4	-19.0	-23.3	-27.6	-31.6	-35.5	-39.3	-42.9
511130003	SHEN, BIG MEADOWS	87	W126	144365	-4.1	-8.1	-12.0	-15.9	-19.7	-23.4	-27.0	-30.6	-34.1	-37.5
511870002	SHEN, DICKEY RIDGE	86	W126	56349	-5.1	-10.1	-14.9	-19.5	-23.9	-28.2	-32.3	-36.3	-40.1	-43.7
511870002	SHEN, DICKEY RIDGE	87	W126	145031	-3.6	-7.2	-10.8	-14.3	-17.8	-21.2	-24.6	-27.9	-31.1	-34.3

CHAPTER 3

THE EFFECTS ON NONATTAINMENT STATUS IF THE CURRENT STANDARD WERE CHANGED

3.1 INTRODUCTION

Given the concern that the current form of the O_3 standard may not be appropriate for protecting vegetation (Lee *et al.*, 1991; Tingey *et al.*, 1991), we have explored the effects on nonattainment status by lowering or modifying the current form.

The interpretation of the current form of the O_3 standard is relatively straightforward. In general, the average number of days per year above the level of the standard must be less than or equal to 1. In its simplest form, the number of exceedances each year would be recorded and then averaged over the past 3 years to determine if this average is less than or equal to 1. Most of the complications that arise are associated with accounting for incomplete sampling or changes in emissions.

The key terms used in this discussion are defined as follows:

- Hour is interpreted as clock hour.
- Day (i.e., daily) is interpreted as calendar day.
- Air quality data are examined on a site-by-site basis and each individual site must meet the standard. Data from several different sites are not normally combined or averaged when assessing compliance.
- "A daily maximum value" refers to the maximum hourly O_3 value for a day.
- "A valid daily" maximum means that at least 75% of the hourly values from 9:01 A.M. to 9:00 P.M. (Local Standard Time) were measured or at least one hourly value exceeded the level of the standard.
- The word "exceedance" is used to describe a daily maximum O_3 measurement that is above the level of the standard. The phrase "expected number of exceedances" is equivalent to "the expected number of daily maximum O_3 values above the level of the standard."

3.2 LOWERING THE CURRENT FORM OF THE SECONDARY OZONE STANDARD FROM 0.12 PPM TO 0.10 AND 0.08 PPM

For the current form of the standard, EPA uses the following two methods to determine the average number of exceedances of O_3 in a year:

- The **Design Value** method; and
- The **Estimated Exceedance** method.

In general, a complete year of data is a year in which at least 75 percent of the required monitoring days in the O_3 season have recorded daily maximum values. In some cases, compliance can be determined with less than 75 percent data capture. Using the data from such cases, however, is always approached with caution and efforts are made to look more closely at the data to obtain a better picture of air quality.

3.2.1 DESIGN VALUE

Using the design value is the easiest way of evaluating nonattainment. The design value is the daily maximum value over a set of complete monitoring years that will deliver an average number of exceedances greater or less than 1.0. For example, if the fourth highest value in 3 complete years of data is greater than the standard, then there will be four exceedances in three years and the site will be in nonattainment because the average number of exceedances is greater than 1.0. Likewise, if the fourth highest value does not exceed the standard, then the site has no more than three exceedances in 3 years and is in compliance with the standard. It follows that if only 2 complete years of data are available, the third highest value in the period will determine the compliance with the standard, and with only 1 complete year of data available, the second highest value in that year, if it exceeds the standard, will place the site in nonattainment.

In conjunction with the design value determination, then, it is possible to have 3 monitoring years of data but only 2 years with 75 percent or more of the daily maximums recorded. In this instance, according to the procedure, the third highest value would be used to determine nonattainment. In order to ensure, however, that valid daily maximums in an incomplete year are not ignored, the daily maximums for all 3 years are considered when determining the design value.

In some cases, no complete years of data are available (i.e., no years have 75 percent of daily maximums recorded). Accordingly, if there are fewer than 90 days of data for the monitoring period, then compliance will be determined on a case-by-case basis. However, if there are at least 90 days of data in the 3-year period, the design value can be determined as follows: Divide the number of valid daily maximums during the 3-year period by the required number of monitoring days per year, and add 1.0 to the above total, then use the integer portion of the result as the rank of the design value.

The first part of this formula delivers a number that reflects the number of complete years of data that would result if all the valid daily maximums were recorded in one monitoring season. Since the rank of the design value is determined by the number of complete years of data, 1.0 must be added to this total to deliver the rank of the design value that, if greater than the standard, would cause the average number of exceedances in a year to be greater than 1.0. The integer portion is taken for the obvious reason that a rank must be a whole number.

Although the design value can be used in most cases, it is important to carefully evaluate the effects of missing data. Some sites actually in nonattainment might appear to be in attainment if the design value determination is used alone. For example, if monitoring were to occur for 200 days at a specific site which appeared to be in attainment, it is impossible to ascertain unequivocally the nonattainment status, using the design value method, if the O_3 season for that site was defined as 214 days. It is possible that the maximum values that were experienced during the 14 days, when monitoring did not occur, might have exceeded the standard and therefore, placed the site in nonattainment by increasing the average exceedances to more than one per year. This consideration is especially important when only one more exceedance for the year would place the site in nonattainment.

3.2.2 ESTIMATED EXCEEDANCE

When the validity of using the design value is in question due to missing data, the number of exceedances in a year is estimated by mathematically compensating for the missing days through the use of the estimated exceedance formula.

The following formula is used to estimate the number of exceedances per year:

$$e = v + (v / n) * (N - n - z)$$

Where v = the number of daily values above the level of the standard.

n = the number of valid daily maximums.

N = the number of required monitoring days in a season.

z = the number of days assumed to be less than the standard level.

e = the estimated number of exceedances for the year.

The estimated number of exceedances, e, is rounded to one decimal place, with fractions containing 0.05 rounded up.

The 75 percent data criterion is desirable when using the estimated exceedance formula. It is possible to use years that do not meet this criterion. However, caution is exercised when using data from years with less than 75 percent data capture. In particular, a monitor with 50 percent or less data capture is looked at very closely.

The estimated exceedances over all monitoring years are averaged to determine if the site has more or less than an average of one exceedance per year. With this in mind, the following guidelines were used in our analysis:

- If a year had at least 75% data capture and at least one exceedance ($v \geq 1$), then the data from that year were used with complete validity;
- If a year had at least 75% data capture but no exceedances ($v = 0$), then $e = 0$. The data from that year were used in the final averaging;
- If a year had less than 75% data capture and no exceedances ($v = 0$), then $e = 0$. The data from that year were **not** used in the final averaging;
- If a year had less than 75% data capture and at least one exceedance ($v \geq 1$) then $e \geq 1$. The data from that year were used in the final averaging. However, sites with extremely poor data capture were closely examined.

3.2.3 LOWERING THE STANDARD TO 0.10 AND 0.08 PPM

Use of the two methods described above usually determined compliance with the O_3 standard. However, there are some exceptions. For example, sites with inadequate data capture or sites without monitors but in the vicinity of a nonattainment area, require a subjective determination of nonattainment status by proper authorities (i.e., the states or the EPA).

Ozone hourly average concentrations from each site for 1986, 1987, 1988, and 1989 in the EPA's AIRS database were reviewed, using the guidelines provided by the U.S. Environmental Protection Agency (EPA, 1979; EPA, 1990).

Those sites found to be in nonattainment were organized into either (1) Metropolitan Statistical Areas (MSA), (2) Consolidated Metropolitan Statistical Areas (CMSA), or (3) non-MSA subdivisions (Bureau of the Census, 1988). The results of the analysis, using the current form of the standard (i.e., 0.12 ppm), were compared with EPA's list of nonattainment areas for the periods 1986-1988 and 1987-1989.

In a few instances, EPA identified counties as being in nonattainment even though (1) the monitoring data showed no exceedances or (2) there were no O_3 monitoring sites in the county. Two counties in Maine (Lincoln and Waldo) are two examples where O_3 was not monitored but the counties were included in the nonattainment list for both 1986-1988 and 1987-1989. Upon further discussion with EPA, we learned that either the state or EPA has the option to place a county in nonattainment, if areas around the county have been designated as being in nonattainment. Thus, in our analysis using the 0.12 ppm form of the standard, we have included those areas that have been subjectively determined by either the state or EPA as being in nonattainment, even though monitoring data did not justify such a designation. However, for the 0.10 and 0.08 ppm analyses, areas are designated as being in nonattainment only when monitoring data support the designation. Therefore, a small number of areas designated as being in nonattainment for the 0.12 ppm analysis are not identified as being in nonattainment when the 0.10 and 0.08 ppm thresholds are applied.

Tables 3-1 to 3-3 summarize the nonattainment areas for the years 1986-1988, using threshold values of 0.12, 0.10, and 0.08 ppm, respectively. Figures 3-1 to 3-3 show the nonattainment areas for the period. The gray-shaded areas identify counties not located in any specific MSA or CMSA. For the period 1986-1988, there were 101 areas that did not meet the NAAQS for O_3 (Table 3-1). When a threshold of 0.10 ppm was applied, there were 180 areas in nonattainment for the same period (Table 3-2). When a threshold of 0.08 ppm was used, there were 220 areas in nonattainment (Table 3-3). As indicated previously, those areas designated as nonattainment, using the 0.10 and 0.08 ppm thresholds, are based solely on monitoring data. The states and the EPA might identify additional sites in nonattainment, based on subjectively determined criteria.

Tables 3-4 to 3-6 summarize the nonattainment areas for the years 1987-1989, using threshold values of 0.12, 0.10, and 0.08 ppm, respectively. Figures 3-4 to 3-6 show the areas in nonattainment. For this period, there were 96 areas that did not meet the NAAQS for O_3 (Table 3-4). EPA had previously announced that there were 96 areas in nonattainment; however, Fayette County, Tennessee, is also in nonattainment, although apparently not identified by the EPA. However, EPA has decided recently to include this county in the Memphis MSA. Table 3-7 summarizes the compliance schedules set by the Clean Air Act for the 96 areas now violating federal health standards for O_3. When a threshold of 0.10 ppm was applied, there were 181 areas in nonattainment for the same period (Table 3-5). When a threshold of 0.08 ppm was used, there were 231 areas in nonattainment (Table 3-6). As indicated previously, those areas designated as nonattainment, using the 0.10 and 0.08 ppm thresholds, are based solely on monitoring data.

For both the 1986-1988 and 1987-1989 periods, O_3 data collected by the State of Nevada were not included. EPA believes that some of the data are questionable and therefore, the Agency decided not to use the information.

Because O_3 exposures in 1989 were lower in many areas of the United States when compared with exposures in 1988, there were fewer areas in nonattainment, using the current form of the standard (i.e., 0.12 ppm), for the period 1987-1989 when compared with the period 1986-1988 (96 versus 101 areas). The following areas designated as being in nonattainment for 1986-1988 were in attainment for the period 1987-1989:

ANDERSON, SC
COLUMBIA, SC
HUNTSVILLE, AL
JACKSONVILLE, FL
LAFAYETTE-WEST LAFAYETTE, IN
PHOENIX, AZ
PORTLAND-VANCOUVER, OR-WA
TULSA, OK

Evansville (IN-KY), Johnson City-Kingsport-Bristol (TN-VA), and Smyth Co (VA) were in nonattainment for 1987-1989, but not for the period 1986-1988.

As indicated in the results section, using a threshold of 0.10 ppm, there were 180 nonattainment areas in 1986-1988, compared with 181 nonattainment areas in 1987-1989. Using the 0.10 ppm threshold, the following areas that were in nonattainment for 1986-1988 were in attainment for the period 1987-1989:

BLOOMINGTON-NORMAL, IL
GADSDEN, AL
GREELEY, CO
JEFFERSON CO, KS
MEDFORD, OR
ODESSA, TX
SALEM, OR
WICHITA, KS
WICOMICO CO, MD

The following areas were in nonattainment in 1987-1989, but in attainment in 1986-1988:

DAVENPORT-ROCK ISLAND-MOLINE, IA-IL
DODGE CO, WI
DOOR CO, WI

GILES CO, TN
HOUMA-THIBODAUX, LA
SAN LUIS OBISPO CO, CA
ST. MARY PAR (CO.), LA
TYLER CO, TX
VICTORIA, TX
WAUSAU, WI

When the 0.08 ppm threshold was applied, there were 220 nonattainment areas in 1986-1988, compared with 231 nonattainment areas in 1987-1989. Using the 0.08 ppm threshold, the following areas that were in nonattainment for 1986-1988 were in attainment for the period 1987-1989:

GADSDEN, AL
MESA CO, CO
ODESSA, TX
SPOKANE, WA
WILLIAMSON CO, IL

The following areas were in nonattainment in 1987-1989, but in attainment in 1986-1988:

ALEXANDRIA, LA
ANDERSON, IN
APACHE CO, AZ
CHITTENDEN CO, VT
DOOR CO, WI
FORT MYERS-CAPE CORAL, FL
HOUMA-THIBODAUX, LA
MARIPOSA CO, CA
OCONEE CO, SC
PITTSFIELD, MA
ST MARY PAR (CO.), LA
TUOLUMNE CO, CA
TYLER CO, TX
VICTORIA, TX
WASHINGTON CO, ME
YUKON-KOYUKUK CO, AK

Several of the areas listed in the nonattainment tables for 1986-1988 were in attainment for 1987-1989 because these areas did not violate the standard in 1989. In some cases, areas listed in nonattainment for the 1987-1989 period were in attainment in 1986-1988 because insufficient monitoring data existed during the earlier period. Other areas, having monitored during 1986, did not monitor during the 1987-1989 period. In other cases, the loss or gain of monitoring years changed either the design value or expected exceedances, with the result that sites would either be added or deleted from the nonattainment list.

As indicated previously, when the validity of using the design value is in question due to missing data, the number of exceedances in a year was estimated by mathematically compensating for the missing days through the use of an estimated exceedance formula. EPA has calculated, for the current form of the standard, the value for "z" (the number of days assumed to be less than the standard level over the number of missing days). For estimating nonattainment using the 0.10 and 0.08 ppm thresholds, we assumed $z = 0$. The result of assuming $z = 0$ is that for the cases where nonattainment status for a specific site is based on the "estimated exceedance method," we may have overestimated the number of exceedances.

To estimate the overall effect of setting $z = 0$, we reviewed the O_3 data for those sites in nonattainment, using the 0.10 and 0.08 ppm thresholds. We then evaluated which of the two methods (i.e., design value or estimated exceedance) was used to determine the nonattainment status. For the period 1987-1989, 97.4% of the nonattainment classifications, using the 0.10 ppm threshold, were based on the "design value" method. For the 0.08 ppm threshold, 99.8% of the nonattainment classifications were based on the "design value" method. Therefore, the effect of assuming $z = 0$ for the 1987-1989 data, for classifying nonattainment, did not have a major impact on the final results. We assume that a similar conclusion would result if the 1986-1988 data were re-evaluated.

In summary, when exploring the effects on nonattainment status when the current form of the standard was changed from 0.12 ppm to either 0.10 or 0.08 ppm for the 1987-89 and 1986-88 periods, we found the greatest increase in nonattainment areas occurred when the standard was lowered to 0.10 ppm. The major growth in nonattainment areas consisted of an increase in the number of areas versus an expansion of existing nonattainment areas. The application of a revised standard for O_3 would mainly increase the number of nonattainment areas (i.e., CMSA, MSA, and non-MSA) that are not near the current existing areas. In other words, rather than growth occurring near existing nonattainment areas, it would occur at new locations removed from the current nonattainment areas.

Except for the Plains States, the major growth on a regional basis would be dramatic for all regions across the United States. The most dramatic differences would be in regions where states were completely in attainment with the current standard. For example, Oregon and Washington were in attainment for the 1987-89 period. However, if a standard of 0.10 ppm were applied, the Seattle/Tacoma, Portland, and Eugene areas would be classified as nonattainment. All Rocky Mountain states, other than the Salt Lake area of Utah, are currently in attainment. A revised standard would classify the Denver, Phoenix, and Las Cruces areas into nonattainment status.

3.3 MODIFYING THE CURRENT FORM OF THE SECONDARY STANDARD

3.3.1 INTRODUCTION

Published evidence shows that the current form of the standard appears to be inappropriate for protecting vegetation (Lefohn *et al.*, 1989; Lee *et al.*, 1991; Tingey *et al.*, 1991). Lee *et al.* (1991), using vegetation effects data obtained from 31 field experiments (involving 12 crops), mostly operated by the NCLAN program, evaluated the efficacy of the following four O_3 exposure indices:

- The sum of all hourly average concentrations using a sigmoidally-weighted function (SIGMOID);
- The sum of all hourly average concentrations $\geq$ 0.06 ppm (SUM06);
- The 7-h average concentration calculated over the experimental period; and
- The second highest daily maximum concentration (the current form of the standard).

The authors concluded that although no single exposure index was best in describing the exposure-response relationship for the 49 case studies, the performance of the second highest daily maximum concentration exposure index, the current form of the standard, was considerably worse than the other three indices. The SIGMOID, SUM06, and 7-h average concentration indices were nearly equivalent in performance, with a slight preference for the two cumulative indices (i.e., SIGMOID and SUM06).

Lee *et al.* (1991) reported that the current form of the standard did not perform adequately because it (1) poorly related to plant growth, (2) ignored exposure duration, and (3) placed too much emphasis on a single peak 1-h concentration. As indicated in Chapter 2, the high hourly average concentrations are more important than the lower values. The results of Lee *et al.* (1991) show that the correlation between the current form of the standard and the occurrences of these elevated hourly average concentrations is weak and therefore, the second highest daily maximum concentration appears to be an inappropriate index to use to protect vegetation from elevated O_3 exposures.

As discussed by Lee *et al.* (1991), exposure regimes can experience similar second highest daily maximum concentrations but exhibit exposure patterns of widely diverse characteristics that contain from two to many peak concentrations. As an alternative to the current form of the standard, the authors suggested that the SUM06 O_3 exposure index be used as the form of a secondary standard to protect agricultural crops. The value of the SUM06 exposure parameter, as determined by Tingey *et al.* (1991), was calculated by summing hourly average concentrations across a fixed 3-month period (i.e., April-June, May-July, June-August, July-September, and August-October). Tingey *et al.* (1991) reported that a 3-month SUM06 value of 24.4 ppm-h was estimated to cause a 10% yield loss in half the cases they investigated.

Based on the results of Tingey *et al.* (1991), we identified those areas in the United States that experienced a SUM06 value of 24.4 ppm-h or higher over a 3-month period for the years 1987, 1988, and 1989. We subsequently explored whether the occurrence of 3-month SUM06 values of 24.4 ppm-h or higher is correlated with elevated hourly average concentrations to establish whether the application of the index as a secondary standard would result in consistent protection for vegetation.

As discussed in the introduction of this chapter, using the current form of the standard, the definition of nonattainment is straightforward. However, no guidelines exist as to what the definition of nonattainment would be if a

SUM06 secondary standard were promulgated. Given the lack of guidelines, we focused our analysis on those areas that experienced one or more 3-month SUM06 values ≥ 24.4 ppm-h for a particular year.

Ozone hourly average concentrations from each site in the EPA's AIRS database, as well as the EPA's National Dry Deposition Network (NDDN) and Mountain Cloud Chemistry Program (MCCP), were characterized by summing, by month, all hourly average concentrations ≥ 0.06 ppm. For the period April-October, those sites found to experience a 3-month SUM06 cumulative value of 24.4 ppm-h or higher were organized into (1) Metropolitan Statistical Areas (MSA), (2) Consolidated Metropolitan Statistical Areas (CMSA), or (3) non-MSA subdivisions.

To explore how those areas, which experienced SUM06 values of 24.4 ppm-h or higher, compared with areas designated as being in nonattainment by EPA, we compared the results of the 1987 and 1988 SUM06 analysis with EPA's list of nonattainment areas for the period 1986-1988 and results of the 1989 SUM06 analysis with the EPA's list of nonattainment areas for 1987-1989. Using the SUM06 index, we identified the "problem" areas and compared them with those areas that previously had been identified as being in nonattainment. The 1987 and 1988 SUM06 results were compared with the 1986-1988 nonattainment list because the nonattainment areas for 1986-1988 represent a "worst case" scenario (in comparison to the 1987-1989 period). The 1989 SUM06 results were compared with the 1987-1989 nonattainment list because this was the only period in which the 1989 data were included.

One of the most important issues we reviewed was whether there was a consistent relationship between the SUM06 index and the occurrence of high hourly average concentrations. For example, we investigated whether (1) those sites experiencing SUM06 3-month cumulative values equal to or greater than 24.4 ppm-h identified exposure regimes that contained high hourly average O_3 concentrations and (2) those sites that exhibited SUM06 values less than 24.4 ppm-h over a 3-month period experienced exposure regimes that contained high hourly average concentrations. This part of the analysis involved both urban, as well as rural monitoring sites. We believed that any exposure index that is used in establishing a secondary standard should be applied to all O_3 monitoring sites, independent of land use characterization.

Because the value of any cumulative exposure index is sensitive to data capture, we explored the effect of missing data on our analysis. For any month with $\geq$ 75% data capture over the period through November, the SUM06 value for that specific month was divided by the data capture for the month. This scaled the SUM06 value to 100% for the month. Using these values, if any month had < 75% data capture and if the two adjacent months both experienced $\geq$ 75% data capture, the average of the adjacent months was used to calculate a predicted SUM06 value for the month with < 75% data capture. For the case of < 75% data capture for a month and, if at least one of the adjacent months had a data capture < 75%, the SUM06 value was set to missing. For those sites with < 75% data capture, we compared the interpolated value with the calculated value and selected the larger of the two (n.b., a missing value is less than any number).

Table 3-8 lists the 133 areas in 1987 where the SUM06 value for a 3-month period was $\geq$ 24.4 ppm-h. When the correction for missing data was applied, 23 of the 357 O_3 monitoring sites (6%), which previously had not experienced SUM06 values $\geq$ 24.4 ppm-h, were affected. The following five areas would have been added to the previously described 133 areas: Kansas

City (MO-KS), San Antonio (TX), Beaumont-Port Arthur-Orange (TX), Rockford (IL), and Muhlenberg County (KY). Of the 133 areas, there were 52 that were not identified previously as being in nonattainment for the 1986-1988 period. Table 3-9 lists the 52 areas that experienced SUM06 values ≥ 24.4 ppm-h for a 3-month period for 1987 but were in attainment for the 1986-1988 period. There were 20 areas that were identified as being in nonattainment for the 1986-1988 period whose monitoring sites did not experience a SUM06 value ≥ 24.4 ppm-h over a 3-month period.

Table 3-10 lists the 183 areas in 1988 where the SUM06 value for a 3-month period was ≥ 24.4 ppm-h. When the correction for missing data was applied, 12 of the 196 O_3 monitoring sites (6%), which previously had not experienced SUM06 values ≥ 24.4 ppm-h, were affected. The following five areas would have been added to the previously described 183 areas: Mobile (AL), Phoenix (AZ), Dickinson County (MI), Burlington (VT), and Union County (SC). Of the 183 areas, there were 90 that were not identified previously as being in nonattainment for the 1986-1988 period. Table 3-11 lists the 90 areas that experienced SUM06 values ≥ 24.4 ppm-h for a 3-month period for 1988, but were in attainment for the 1986-1988 period. There were 8 areas that were identified as being in nonattainment for the 1986-1988 period whose monitoring sites did not experience a SUM06 value ≥ 24.4 ppm-h over a 3-month period.

Table 3-12 lists the 98 areas in 1989 where the SUM06 value for a 3-month period was ≥ 24.4 ppm-h. When the correction for missing data was applied, 34 of the 555 O_3 monitoring sites (6%), which previously had not experienced SUM06 values ≥ 24.4 ppm-h, were affected. The following eight areas would have been added to the previously described 98 areas: Coconino

County (AZ), Tucson (AZ), Tuolumne County (CA), Sussex County (DE), Edmonson County (KY), Providence-Pawtucket-Fall River (RI-MA), Johnson City-Kingsport-Bristol (TN-VA), and Austin (TX). Of the 98 areas, there were 44 that were not identified previously as being in nonattainment for the 1987-1989 period. Table 3-13 lists the 44 areas that experienced SUM06 values ≥ 24.4 ppm-h for a 3-month period for 1989 but were in attainment for the 1987-1989 period. In 1989, there were 42 areas that were identified as being in nonattainment for the 1987-1989 period whose monitoring sites did not experience a SUM06 value ≥ 24.4 ppm-h over a 3-month period.

As indicated in Section 3.2, using 0.10 and 0.08 ppm as possible levels, the greatest change in nonattainment status occurred when the current standard of 0.12 ppm was lowered to 0.10 ppm. We explored whether there might exist a relationship between the current form of the standard, lowered to 0.10 ppm, and the SUM06 3-month cumulative index. If the current form of the standard were lowered to 0.10 ppm, for the period 1986-1988, there were a total of 180 nonattainment areas. In 1987, 50 (28%) of these nonattainment areas did not exceed the threshold 3-month SUM06 value. During this year, the SUM06 value of 24.4 ppm-h was exceeded in 133 areas; 13 (10%) of these areas would not have violated the 0.10 ppm standard. In 1988, 28 (16%) of the 1986-1988 nonattainment areas did not exceed the 3-month SUM06 threshold. In 1988, the SUM06 value of 24.4 ppm-h was exceeded in 183 areas; 31 (17%) of these areas would not have violated the 0.10 ppm standard. For 1987-1989, if the current form of the standard were lowered to 0.10 ppm, there would have been 181 nonattainment areas. In 1989, 106 (59%) of these nonattainment areas did not exceed the 3-month SUM06 threshold. In 1989, the SUM06 value of 24.4 ppm-h was exceeded in 98 areas; 23 (24%) of these areas would not have violated the

0.10 ppm standard. Based on the above results, lowering the current form of the standard to 0.10 ppm did not appear to guarantee that a specific monitoring site would achieve a SUM06 3-month cumulative value of 24.4 ppm-h or lower.

We further explored whether a correlation between the current form of the standard, lowered to 0.08 ppm, and the SUM06 3-month cumulative index existed. If the current form of the standard were lowered to 0.08 ppm, for the period 1986-1988, there would be a total of 220 nonattainment areas. In 1987, 94 (43%) of these nonattainment areas did not exceed the 3-month SUM06 value of 24.4 ppm-h. During this year, the SUM06 value of 24.4 ppm-h was exceeded in 133 areas; 7 (5%) of these areas would not have violated the 0.08 ppm standard. In 1988, 52 (24%) of the 1986-1988 nonattainment areas did not exceed the 3-month SUM06 value of 24.4 ppm-h. In 1988, the SUM06 value of 24.4 ppm-h was exceeded in 183 areas; 15 (8%) of these areas would not have violated the 0.08 ppm standard. For the 1987-1989 period, if the current form of the standard were lowered to 0.08 ppm, there would have been 231 nonattainment areas. In 1989, 148 (64%) of these nonattainment areas did not exceed the 3-month SUM06 value of 24.4 ppm-h. In 1989, the SUM06 value of 24.4 ppm-h was exceeded in 98 areas; 15 (15%) of these areas would not have violated the 0.08 ppm standard. Based on the above results, if the current form of the standard were lowered to 0.08 ppm, 57% (1987), 76% (1988) and 36% (1989) of those sites that would be in nonattainment would also exceed the 3-month SUM06 value of 24.4 ppm-h. Thus, a weak relationship exists between the current form of the standard and the SUM06 index.

We have explored whether the magnitude of the SUM06 index calculated over a 3-month period correlated with the occurrence of high hourly average concentrations. Using a subset of the data, Table 3-14 lists the percentiles of the hourly average concentrations over the April-October period for some sites that experienced (1) a second hourly maximum concentration ≥ 0.125 ppm and (2) a maximum uncorrected, 3-month SUM06 value < 24.4 ppm-h. Although the sites listed in the table violated the current standard, most of the sites experienced (1) few hourly average concentrations ≥ 0.125 ppm and (2) 5% or less of the hourly average concentrations ≥ 0.06 ppm. This type of exposure regime resulted in a 3-month SUM06 value < 24.4 ppm-h.

Table 3-15 lists the percentiles of the hourly average concentrations over the April-October period for some sites that experienced (1) a second hourly maximum concentration < 0.125 ppm and (2) a maximum uncorrected, 3-month SUM06 value ≥ 24.4 ppm-h. Although none of the sites listed in the table violated the current standard, most of the sites experienced approximately 10% or more of the hourly average concentrations ≥ 0.06 ppm and thus, experienced a 3-month SUM06 value ≥ 24.4 ppm-h.

The results summarized in Tables 3-14 and 3-15 show that a cumulative 3-month SUM06 value at a specific monitoring site will not necessarily relate to the occurrence or absence of high hourly average O_3 concentrations. A SUM06 value of 24.4 ppm-h or greater indicates only that there are a large number of hourly average concentrations ≥ 0.06 ppm. On the contrary, a low SUM06 value indicates a small number of hourly average concentrations ≥ 0.06 ppm.

In our analysis, we have identified those areas in the United States that experienced a SUM06 value of 24.4 ppm-h or higher over a 3-month period for the years 1987, 1988, and 1989. In addition, we have explored whether the occurrence of 3-month SUM06 values of 24.4 ppm-hr or higher was correlated with elevated hourly average concentrations. ***Our analysis has shown that the***

application of the SUM06 O_3 exposure index for use in defining a secondary standard may result in inconsistent protection for vegetation. Using 1989 hourly averaged O_3 data, we found that no strong relationship appeared to exist between the number of occurrences of high hourly average O_3 and a maximum uncorrected 3-month SUM06 value $\geq$ 24.4 ppm-h. Several O_3 monitoring sites that violated the current standard experienced a 3-month SUM06 value < 24.4 ppm-h. Similarly, we found that several O_3 monitoring sites that did not violate the current standard experienced a maximum uncorrected 3-month SUM06 value $\geq$ 24.4 ppm-h.

3.4 REFERENCES

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Table 3-1. Summary of areas in nonattainment for the period 1986-1988 using the existing standard of 0.12 ppm.

ALBANY-SCHENECTADY-TROY, NY
ALLENTOWN-BETHLEHEM, PA-NJ
ALTOONA, PA
ANDERSON, SC
ATLANTA, GA
ATLANTIC CITY, NJ
BAKERSFIELD, CA
BALTIMORE, MD
BATON ROUGE, LA
BEAUMONT-PORT ARTHUR-ORANGE, TX
BIRMINGHAM, AL
BOSTON-LAWRENCE-SALEM, MA-NH
BUFFALO-NIAGARA FALLS, NY
CANTON, OH
CHARLESTON, WV
CHARLOTTE-GASTONIA-ROCK HILL, NC-SC
CHICAGO-GARY-LAKE CO, IL-IN-WI
CINCINNATI-HAMILTON, OH-KY-IN
CLEVELAND-AKRON-LORAIN, OH
COLUMBIA, SC
COLUMBUS, OH
DALLAS-FORT WORTH, TX
DAYTON-SPRINGFIELD, OH
DETROIT-ANN ARBOR, MI
EDMONSON CO, KY
EL PASO, TX
ERIE, PA
ESSEX CO, NY
FAYETTEVILLE, NC
FRESNO, CA
GRAND RAPIDS, MI
GREENBRIER CO, WV
GREENSBORO-WINSTON SALEM-HIGH POINT, NC
GREENVILLE-SPARTANBURG, SC
HANCOCK CO, ME
HARRISBURG-LEBANON-CARLISLE, PA
HARTFORD-NEW BRITAIN-MIDDLETOWN, CT
HOUSTON-GALVESTON-BRAZORIA, TX
HUNTINGTON-ASHLAND, WV-KY-OH
HUNTSVILLE, AL
INDIANAPOLIS, IN
JACKSONVILLE, FL
JEFFERSON CO, NY
JOHNSTOWN, PA
KANSAS CITY, MO-KS
KEWAUNEE CO, WI
KNOX CO, ME
KNOXVILLE, TN
LAFAYETTE-WEST LAFAYETTE, IN
LAKE CHARLES, LA
LANCASTER, PA
LEWISTON-AUBURN, ME
LEXINGTON-FAYETTE, KY
LINCOLN CO, ME
LIVINGSTON CO, KY
LOS ANGELES-ANAHEIM-RIVERSIDE, CA
LOUISVILLE, KY-IN
MANCHESTER, NH
MEMPHIS, TN-AR-MS
MIAMI-FORT LAUDERDALE, FL
MILWAUKEE-RACINE, WI
MODESTO, CA
MONTGOMERY, AL
MUSKEGON, MI
NASHVILLE, TN
NEW YORK-NORTHERN NEW JERSEY-LONG ISLAND, NY-NJ-CT

Table 3-1. (Continued).

NORFOLK-VIRGINIA BEACH-NEWPORT NEWS, VA
OWENSBORO, KY
PARKERSBURG-MARIETTA, WV-OH
PHILADELPHIA-WILMINGTON-TRENTON, PA-NJ-DE-MD
PHOENIX, AZ
PITTSBURGH-BEAVER VALLEY, PA
PORTLAND, ME
PORTLAND-VANCOUVER, OR-WA
PORTSMOUTH-DOVER-ROCHESTER, NH-ME
POUGHKEEPSIE, NY
PROVIDENCE-PAWTUCKET-FALL RIVER, RI-MA
RALEIGH-DURHAM, NC
READING, PA
RICHMOND-PETERSBURG, VA
SACRAMENTO, CA
SALT LAKE CITY-OGDEN, UT
SAN DIEGO, CA
SAN FRANCISCO-OAKLAND-SAN JOSE, CA
SANTA BARBARA-SANTA MARIA-LOMPOC, CA
SCRANTON-WILKES BARRE, PA
SHEBOYGAN, WI
SOUTH BEND-MISHAWAKA, IN
SPRINGFIELD, MA
ST. LOUIS, MO-IL
STOCKTON, CA
SUSSEX CO, DE
TAMPA-ST. PETERSBURG-CLEARWATER, FL
TOLEDO, OH
TULSA, OK
VISALIA-TULARE-PORTERVILLE, CA
WALDO CO, ME
WASHINGTON, DC-MD-VA
WORCESTER, MA
YORK, PA
YOUNGSTOWN-WARREN, OH

Table 3-2. Summary of areas in nonattainment for the period 1986-1988 using 0.10 ppm.

ALBANY-SCHENECTADY-TROY, NY
ALLENTOWN-BETHLEHEM, PA-NJ
ALTOONA, PA
ANDERSON, SC
APPLETON-OSHKOSH-NEENAH, WI
ASHEVILLE, NC
ATLANTA, GA
ATLANTIC CITY, NJ
AUGUSTA, GA-SC
AUSTIN, TX
BAKERSFIELD, CA
BALTIMORE, MD
BATON ROUGE, LA
BEAUMONT-PORT ARTHUR-ORANGE, TX
BENNINGTON CO, VT
BIRMINGHAM, AL
BLOOMINGTON-NORMAL, IL
BOSTON-LAWRENCE-SALEM, MA-NH
BUFFALO-NIAGARA FALLS, NY
CAMDEN CO, NC
CANTON, OH
CHARLESTON, SC
CHARLESTON, WV
CHARLOTTE-GASTONIA-ROCK HILL, NC-SC
CHARLOTTESVILLE, VA
CHATTANOOGA, TN-GA
CHICAGO-GARY-LAKE CO, IL-IN-WI
CINCINNATI-HAMILTON, OH-KY-IN
CLEVELAND-AKRON-LORAIN, OH
COLUMBIA, SC
COLUMBUS, GA-AL
COLUMBUS, OH
COLUSA CO, CA
CORPUS CHRISTI, TX
DALLAS-FORT WORTH, TX
DAYTON-SPRINGFIELD, OH
DENVER-BOULDER, CO
DETROIT-ANN ARBOR, MI
EDGECOMBE CO, NC
EDMONSON CO, KY
EFFINGHAM CO, IL
EL PASO, TX
ELMIRA, NY
ERIE, PA
ESSEX CO, NY
EUGENE-SPRINGFIELD, OR
EVANSVILLE, IN-KY
FAUQUIER CO, VA
FAYETTEVILLE, NC
FLINT, MI
FOND DU LAC CO, WI
FORT WAYNE, IN
FRESNO, CA
GADSDEN, AL
GLENN CO, CA
GRAND RAPIDS, MI
GREELEY, CO
GREEN BAY, WI
GREENBRIER CO, WV
GREENSBORO-WINSTON SALEM-HIGH POINT, NC
GREENVILLE-SPARTANBURG, SC
HANCOCK CO, ME
HARRISBURG-LEBANON-CARLISLE, PA
HARTFORD-NEW BRITAIN-MIDDLETOWN, CT
HICKORY, NC
HOUSTON-GALVESTON-BRAZORIA, TX
HUNTINGTON-ASHLAND, WV-KY-OH
HUNTSVILLE, AL

Table 3-2. (Continued).

IMPERIAL CO, CA
INDIANAPOLIS, IN
JACKSONVILLE, FL
JANESVILLE-BELOIT, WI
JEFFERSON CO, KS
JEFFERSON CO, NY
JOHNSON CITY-KINGSPORT-BRISTOL, TN-VA
JOHNSTOWN, PA
KANSAS CITY, MO-KS
KEWAUNEE CO, WI
KNOX CO, IN
KNOX CO, ME
KNOXVILLE, TN
LAFAYETTE, LA
LAFAYETTE-WEST LAFAYETTE, IN
LAKE CHARLES, LA
LANCASTER, PA
LANSING-EAST LANSING, MI
LAS CRUCES, NM
LAWRENCE CO, PA
LEWISTON-AUBURN, ME
LEXINGTON-FAYETTE, KY
LIMA, OH
LITTLE ROCK-NORTH LITTLE ROCK, AR
LIVINGSTON CO, KY
LONGVIEW-MARSHALL, TX
LOS ANGELES-ANAHEIM-RIVERSIDE, CA
LOUISVILLE, KY-IN
MADISON, WI
MANCHESTER, NH
MC CRACKEN CO, KY
MEDFORD, OR
MEMPHIS, TN-AR-MS
MIAMI-FORT LAUDERDALE, FL
MILWAUKEE-RACINE, WI
MINNEAPOLIS-ST. PAUL, MN-WI
MOBILE, AL
MODESTO, CA
MONROE CO, MO
MONTGOMERY, AL
MUSKEGON, MI
NASHVILLE, TN
NEW ORLEANS, LA
NEW YORK-NORTHERN NEW JERSEY-LONG ISLAND, NY-NJ-CT
NORFOLK-VIRGINIA BEACH-NEWPORT NEWS, VA
ODESSA, TX
OKLAHOMA CITY, OK
ORLANDO, FL
OWENSBORO, KY
PARKERSBURG-MARIETTA, WV-OH
PASCAGOULA, MS
PENSACOLA, FL
PEORIA, IL
PHILADELPHIA-WILMINGTON-TRENTON, PA-NJ-DE-MD
PHOENIX, AZ
PITT CO, NC
PITTSBURGH-BEAVER VALLEY, PA
PORTLAND, ME
PORTLAND-VANCOUVER, OR-WA
PORTSMOUTH-DOVER-ROCHESTER, NH-ME
POUGHKEEPSIE, NY
PROVIDENCE-PAWTUCKET-FALL RIVER, RI-MA
PROVO-OREM, UT
RALEIGH-DURHAM, NC
READING, PA
REDDING, CA

Table 3-2. (Continued).

RICHMOND-PETERSBURG, VA
ROANOKE, VA
ROCHESTER, NY
ROCKFORD, IL
SACRAMENTO, CA
SALEM, OR
SALT LAKE CITY-OGDEN, UT
SAN ANTONIO, TX
SAN BENITO CO, CA
SAN DIEGO, CA
SAN FRANCISCO-OAKLAND-SAN JOSE, CA
SANTA BARBARA-SANTA MARIA-LOMPOC, CA
SCRANTON-WILKES BARRE, PA
SEATTLE-TACOMA, WA
SHEBOYGAN, WI
SHREVEPORT, LA
SMYTH CO, VA
SOUTH BEND-MISHAWAKA, IN
SPRINGFIELD, IL
SPRINGFIELD, MA
SPRINGFIELD, MO
ST. LOUIS, MO-IL
STEUBENVILLE-WEIRTON, OH-WV
STOCKTON, CA
SUSSEX CO, DE
SYRACUSE, NY
TAMPA-ST. PETERSBURG-CLEARWATER, FL
TERRE HAUTE, IN
TOLEDO, OH
TRIGG CO, KY
TULSA, OK
UNION CO, SC
UTICA-ROME, NY
VISALIA-TULARE-PORTERVILLE, CA
WARREN CO, VA
WASHINGTON CO, IN
WASHINGTON, DC-MD-VA
WHEELING, WV-OH
WICHITA, KS
WICOMICO CO, MD
WILLIAMSPORT, PA
WORCESTER, MA
YORK, PA
YOUNGSTOWN-WARREN, OH
YUBA CITY, CA
YUMA CO, AZ

Table 3-3. Summary of areas in nonattainment for the period 1986-1988 using 0.08 ppm.

ADAMS CO, IL
ALBANY-SCHENECTADY-TROY, NY
ALBUQUERQUE, NM
ALLENTOWN-BETHLEHEM, PA-NJ
ALTOONA, PA
ANDERSON, SC
APPLETON-OSHKOSH-NEENAH, WI
ASHEVILLE, NC
ATCHISON CO, MO
ATLANTA, GA
ATLANTIC CITY, NJ
AUGUSTA, GA-SC
AUSTIN, TX
BAKERSFIELD, CA
BALTIMORE, MD
BATON ROUGE, LA
BEAUMONT-PORT ARTHUR-ORANGE, TX
BENNINGTON CO, VT
BIRMINGHAM, AL
BLOOMINGTON-NORMAL, IL
BOSTON-LAWRENCE-SALEM, MA-NH
BUFFALO-NIAGARA FALLS, NY
BURLINGTON, VT
CAMDEN CO, NC
CANTON, OH
CEDAR RAPIDS, IA
CHAMPAIGN-URBANA-RANTOUL, IL
CHARLESTON, SC
CHARLESTON, WV
CHARLOTTE-GASTONIA-ROCK HILL, NC-SC
CHARLOTTESVILLE, VA
CHATTANOOGA, TN-GA
CHICAGO-GARY-LAKE CO, IL-IN-WI
CHICO, CA
CINCINNATI-HAMILTON, OH-KY-IN
CLEVELAND-AKRON-LORAIN, OH
COLORADO SPRINGS, CO
COLUMBIA, SC
COLUMBUS, GA-AL
COLUMBUS, OH
COLUSA CO, CA
COOS CO, NH
CORPUS CHRISTI, TX
CUMBERLAND, MD-WV
DALLAS-FORT WORTH, TX
DAVENPORT-ROCK ISLAND-MOLINE, IA-IL
DAYTON-SPRINGFIELD, OH
DECATUR, IL
DENVER-BOULDER, CO
DETROIT-ANN ARBOR, MI
DICKINSON CO, MI
DODGE CO, WI
EDGECOMBE CO, NC
EDMONSON CO, KY
EFFINGHAM CO, IL
EL PASO, TX
ELMIRA, NY
ERIE, PA
ESSEX CO, NY
EUGENE-SPRINGFIELD, OR
EVANSVILLE, IN-KY
FAUQUIER CO, VA
FAYETTEVILLE, NC
FLINT, MI
FLORENCE CO, WI
FOND DU LAC CO, WI
FORT COLLINS-LOVELAND, CO
FORT WAYNE, IN

Table 3-3. (Continued).

FRANKLIN CO, ME
FRESNO, CA
GADSDEN, AL
GILES CO, TN
GLENN CO, CA
GRAND RAPIDS, MI
GREELEY, CO
GREEN BAY, WI
GREENBRIER CO, WV
GREENSBORO-WINSTON SALEM-HIGH POINT, NC
GREENVILLE-SPARTANBURG, SC
HANCOCK CO, ME
HARRISBURG-LEBANON-CARLISLE, PA
HARTFORD-NEW BRITAIN-MIDDLETOWN, CT
HICKORY, NC
HOUSTON-GALVESTON-BRAZORIA, TX
HUNTINGTON-ASHLAND, WV-KY-OH
HUNTSVILLE, AL
IMPERIAL CO, CA
INDIANAPOLIS, IN
IOWA CITY, IA
JACKSON, MS
JACKSONVILLE, FL
JANESVILLE-BELOIT, WI
JEFFERSON CO, KS
JEFFERSON CO, NY
JOHNSON CITY-KINGSPORT-BRISTOL, TN-VA
JOHNSTOWN, PA
KANSAS CITY, MO-KS
KEWAUNEE CO, WI
KNOX CO, IN
KNOX CO, ME
KNOXVILLE, TN

LA CROSSE, WI
LAFAYETTE, LA
LAFAYETTE-WEST LAFAYETTE, IN
LAKE CHARLES, LA
LAKE CO, MN
LANCASTER, PA
LANSING-EAST LANSING, MI
LAS CRUCES, NM
LAWRENCE CO, PA
LEWISTON-AUBURN, ME
LEXINGTON-FAYETTE, KY
LIMA, OH
LITTLE ROCK-NORTH LITTLE ROCK, AR
LIVINGSTON CO, KY
LONGVIEW-MARSHALL, TX
LOS ANGELES-ANAHEIM-RIVERSIDE, CA
LOUISVILLE, KY-IN
MADISON, WI
MANCHESTER, NH
MARTIN CO, NC
MC CRACKEN CO, KY
MEDFORD, OR
MELBOURNE-TITUSVILLE-PALM BAY, FL
MEMPHIS, TN-AR-MS
MENDOCINO CO, CA
MESA CO, CO
MIAMI-FORT LAUDERDALE, FL
MILWAUKEE-RACINE, WI
MINNEAPOLIS-ST. PAUL, MN-WI
MOBILE, AL
MODESTO, CA
MONO CO, CA
MONROE, LA

Table 3-3. (Continued).

MONROE CO, MO
MONTGOMERY, AL
MUHLENBERG CO, KY
MUSKEGON, MI
NASHVILLE, TN
NEW ORLEANS, LA
NEW YORK-NORTHERN NEW JERSEY-LONG ISLAND, NY-NJ-CT
NORFOLK-VIRGINIA BEACH-NEWPORT NEWS, VA
ODESSA, TX
OKLAHOMA CITY, OK
OMAHA, NE-IA
ORLANDO, FL
OWENSBORO, KY
PARKERSBURG-MARIETTA, WV-OH
PASCAGOULA, MS
PENSACOLA, FL
PEORIA, IL
PHILADELPHIA-WILMINGTON-TRENTON, PA-NJ-DE-MD
PHOENIX, AZ
PITT CO, NC
PITTSBURGH-BEAVER VALLEY, PA
PORTLAND, ME
PORTLAND-VANCOUVER, OR-WA
PORTSMOUTH-DOVER-ROCHESTER, NH-ME
POUGHKEEPSIE, NY
PROVIDENCE-PAWTUCKET-FALL RIVER, RI-MA
PROVO-OREM, UT
RALEIGH-DURHAM, NC
READING, PA
REDDING, CA
RICHMOND-PETERSBURG, VA
ROANOKE, VA
ROCHESTER, NY

ROCKFORD, IL
SACRAMENTO, CA
SALEM, OR
SALINAS-SEASIDE-MONTEREY, CA
SALT LAKE CITY-OGDEN, UT
SAN ANTONIO, TX
SAN BENITO CO, CA
SAN DIEGO, CA
SAN FRANCISCO-OAKLAND-SAN JOSE, CA
SAN LUIS OBISPO CO, CA
SANTA BARBARA-SANTA MARIA-LOMPOC, CA
SARASOTA, FL
SCRANTON-WILKES BARRE, PA
SEATTLE-TACOMA, WA
SHEBOYGAN, WI
SHREVEPORT, LA
SISKIYOU CO, CA
SMYTH CO, VA
SOUTH BEND-MISHAWAKA, IN
SPOKANE, WA
SPRINGFIELD, IL
SPRINGFIELD, MA
SPRINGFIELD, MO
ST. LOUIS, MO-IL
STEUBENVILLE-WEIRTON, OH-WV
STOCKTON, CA
SUSSEX CO, DE
SYRACUSE, NY
TALLAHASSEE, FL
TAMPA-ST. PETERSBURG-CLEARWATER, FL
TERRE HAUTE, IN
TOLEDO, OH
TRIGG CO, KY

Table 3-3. (Continued).

TUCSON, AZ
TULSA, OK
UNION CO, SC
UTICA-ROME, NY
VISALIA-TULARE-PORTERVILLE, CA
WARREN CO, VA
WASHINGTON CO, IN
WASHINGTON, DC-MD-VA
WAUSAU, WI
WHEELING, WV-OH
WICHITA, KS
WICOMICO CO, MD
WILLIAMSON CO, IL
WILLIAMSPORT, PA
WILMINGTON, NC
WORCESTER, MA
YORK, PA
YOUNGSTOWN-WARREN, OH
YUBA CITY, CA
YUMA CO, AZ

Table 3-4. Summary of areas in nonattainment for the period 1987-1989 using the existing standard of 0.12 ppm.

ALBANY-SCHENECTADY-TROY, NY	HANCOCK CO, ME
ALLENTOWN-BETHLEHEM, PA-NJ	HARRISBURG-LEBANON-CARLISLE, PA
ALTOONA, PA	HARTFORD-NEW BRITAIN-MIDDLETOWN, CT
ATLANTA, GA	HOUSTON-GALVESTON-BRAZORIA, TX
ATLANTIC CITY, NJ	HUNTINGTON-ASHLAND, WV-KY-OH
BAKERSFIELD, CA	INDIANAPOLIS, IN
BALTIMORE, MD	JEFFERSON CO, NY
BATON ROUGE, LA	JOHNSON CITY-KINGSPORT-BRISTOL, TN-VA
BEAUMONT-PORT ARTHUR-ORANGE, TX	JOHNSTOWN, PA
BIRMINGHAM, AL	KANSAS CITY, MO-KS
BOSTON-LAWRENCE-SALEM, MA-NH	KEWAUNEE CO, WI
BUFFALO-NIAGARA FALLS, NY	KNOX CO, ME
CANTON, OH	KNOXVILLE, TN
CHARLESTON, WV	LAKE CHARLES, LA
CHARLOTTE-GASTONIA-ROCK HILL, NC-SC	LANCASTER, PA
CHICAGO-GARY-LAKE CO, IL-IN-WI	LEWISTON-AUBURN, ME
CINCINNATI-HAMILTON, OH-KY-IN	LEXINGTON-FAYETTE, KY
CLEVELAND-AKRON-LORAIN, OH	LINCOLN CO, ME
COLUMBUS, OH	LIVINGSTON CO, KY
DALLAS-FORT WORTH, TX	LOS ANGELES-ANAHEIM-RIVERSIDE, CA
DAYTON-SPRINGFIELD, OH	LOUISVILLE, KY-IN
DETROIT-ANN ARBOR, MI	MANCHESTER, NH
EDMONSON CO, KY	MEMPHIS, TN-AR-MS
EL PASO, TX	MIAMI-FORT LAUDERDALE, FL
ERIE, PA	MILWAUKEE-RACINE, WI
ESSEX CO, NY	MODESTO, CA
EVANSVILLE, IN-KY	MONTGOMERY, AL
FAYETTEVILLE, NC	MUSKEGON, MI
FRESNO, CA	NASHVILLE, TN
GRAND RAPIDS, MI	NEW YORK-NORTHERN NEW JERSEY-LONG ISLAND, NY-NJ-CT
GREENBRIER CO, WV	NORFOLK-VIRGINIA BEACH-NEWPORT NEWS, VA
GREENSBORO-WINSTON SALEM-HIGH POINT, NC	OWENSBORO, KY
GREENVILLE-SPARTANBURG, SC	PARKERSBURG-MARIETTA, WV-OH

Table 3-4. (Continued).

PHILADELPHIA-WILMINGTON-TRENTON, PA-NJ-DE-MD
PITTSBURGH-BEAVER VALLEY, PA
PORTLAND, ME
PORTSMOUTH-DOVER-ROCHESTER, NH-ME
POUGHKEEPSIE, NY
PROVIDENCE-PAWTUCKET-FALL RIVER, RI-MA
RALEIGH-DURHAM, NC
READING, PA
RICHMOND-PETERSBURG, VA
SACRAMENTO, CA
SALT LAKE CITY-OGDEN, UT
SAN DIEGO, CA
SAN FRANCISCO-OAKLAND-SAN JOSE, CA
SANTA BARBARA-SANTA MARIA-LOMPOC, CA
SCRANTON-WILKES BARRE, PA
SHEBOYGAN, WI
SMYTH CO, VA
SOUTH BEND-MISHAWAKA, IN
SPRINGFIELD, MA
ST. LOUIS, MO-IL
STOCKTON, CA
SUSSEX CO, DE
TAMPA-ST. PETERSBURG-CLEARWATER, FL
TOLEDO, OH
VISALIA-TULARE-PORTERVILLE, CA
WALDO CO, ME
WASHINGTON, DC-MD-VA
WORCESTER, MA
YORK, PA
YOUNGSTOWN-WARREN, OH

Table 3-5. Summary of areas in nonattainment for the period 1987-1989 using 0.10 ppm.

ALBANY-SCHENECTADY-TROY, NY
ALLENTOWN-BETHLEHEM, PA-NJ
ALTOONA, PA
ANDERSON, SC
APPLETON-OSHKOSH-NEENAH, WI
ASHEVILLE, NC
ATLANTA, GA
ATLANTIC CITY, NJ
AUGUSTA, GA-SC
AUSTIN, TX
BAKERSFIELD, CA
BALTIMORE, MD
BATON ROUGE, LA
BEAUMONT-PORT ARTHUR-ORANGE, TX
BENNINGTON CO, VT
BIRMINGHAM, AL
BOSTON-LAWRENCE-SALEM, MA-NH
BUFFALO-NIAGARA FALLS, NY
CAMDEN CO, NC
CANTON, OH
CHARLESTON, SC
CHARLESTON, WV
CHARLOTTE-GASTONIA-ROCK HILL, NC-SC
CHARLOTTESVILLE, VA
CHATTANOOGA, TN-GA
CHICAGO-GARY-LAKE CO, IL-IN-WI
CINCINNATI-HAMILTON, OH-KY-IN
CLEVELAND-AKRON-LORAIN, OH
COLUMBIA, SC
COLUMBUS, GA-AL
COLUMBUS, OH
COLUSA CO, CA
CORPUS CHRISTI, TX
DALLAS-FORT WORTH, TX
DAVENPORT-ROCK ISLAND-MOLINE, IA-IL
DAYTON-SPRINGFIELD, OH
DENVER-BOULDER, CO
DETROIT-ANN ARBOR, MI
DODGE CO, WI
DOOR CO, WI
EDGECOMBE CO, NC
EDMONSON CO, KY
EFFINGHAM CO, IL
EL PASO, TX
ELMIRA, NY
ERIE, PA
ESSEX CO, NY
EUGENE-SPRINGFIELD, OR
EVANSVILLE, IN-KY
FAUQUIER CO, VA
FAYETTEVILLE, NC
FLINT, MI
FOND DU LAC CO, WI
FORT WAYNE, IN
FRESNO, CA
GILES CO, TN
GLENN CO, CA
GRAND RAPIDS, MI
GREEN BAY, WI
GREENBRIER CO, WV
GREENSBORO-WINSTON SALEM-HIGH POINT, NC
GREENVILLE-SPARTANBURG, SC
HANCOCK CO, ME
HARRISBURG-LEBANON-CARLISLE, PA
HARTFORD-NEW BRITAIN-MIDDLETOWN, CT
HICKORY, NC
HOUMA-THIBODAUX, LA
HOUSTON-GALVESTON-BRAZORIA, TX

Table 3-5. (Continued).

HUNTINGTON-ASHLAND, WV-KY-OH
HUNTSVILLE, AL
IMPERIAL CO, CA
INDIANAPOLIS, IN
JACKSONVILLE, FL
JANESVILLE-BELOIT, WI
JEFFERSON CO, NY
JOHNSON CITY-KINGSPORT-BRISTOL, TN-VA
JOHNSTOWN, PA
KANSAS CITY, MO-KS
KEWAUNEE CO, WI
KNOX CO, IN
KNOX CO, ME
KNOXVILLE, TN
LAFAYETTE, LA
LAFAYETTE-WEST LAFAYETTE, IN
LAKE CHARLES, LA
LANCASTER, PA
LANSING-EAST LANSING, MI
LAS CRUCES, NM
LAWRENCE CO, PA
LEWISTON-AUBURN, ME
LEXINGTON-FAYETTE, KY
LIMA, OH
LITTLE ROCK-NORTH LITTLE ROCK, AR
LIVINGSTON CO, KY
LONGVIEW-MARSHALL, TX
LOS ANGELES-ANAHEIM-RIVERSIDE, CA
LOUISVILLE, KY-IN
MADISON, WI
MANCHESTER, NH
MC CRACKEN CO, KY
MEMPHIS, TN-AR-MS

MIAMI-FORT LAUDERDALE, FL
MILWAUKEE-RACINE, WI
MINNEAPOLIS-ST. PAUL, MN-WI
MOBILE, AL
MODESTO, CA
MONROE CO, MO
MONTGOMERY, AL
MUSKEGON, MI
NASHVILLE, TN
NEW ORLEANS, LA
NEW YORK-NORTHERN NEW JERSEY-LONG ISLAND, NY-NJ-CT
NORFOLK-VIRGINIA BEACH-NEWPORT NEWS, VA
OKLAHOMA CITY, OK
ORLANDO, FL
OWENSBORO, KY
PARKERSBURG-MARIETTA, WV-OH
PASCAGOULA, MS
PENSACOLA, FL
PEORIA, IL
PHILADELPHIA-WILMINGTON-TRENTON, PA-NJ-DE-MD
PHOENIX, AZ
PITT CO, NC
PITTSBURGH-BEAVER VALLEY, PA
PORTLAND, ME
PORTLAND-VANCOUVER, OR-WA
PORTSMOUTH-DOVER-ROCHESTER, NH-ME
POUGHKEEPSIE, NY
PROVIDENCE-PAWTUCKET-FALL RIVER, RI-MA
PROVO-OREM, UT
RALEIGH-DURHAM, NC
READING, PA
REDDING, CA
RICHMOND-PETERSBURG, VA

Table 3-5. (Continued).

ROANOKE, VA
ROCHESTER, NY
ROCKFORD, IL
SACRAMENTO, CA
SALT LAKE CITY-OGDEN, UT
SAN ANTONIO, TX
SAN BENITO CO, CA
SAN DIEGO, CA
SAN FRANCISCO-OAKLAND-SAN JOSE, CA
SAN LUIS OBISPO CO, CA
SANTA BARBARA-SANTA MARIA-LOMPOC, CA
SCRANTON-WILKES BARRE, PA
SEATTLE-TACOMA, WA
SHEBOYGAN, WI
SHREVEPORT, LA
SMYTH CO, VA
SOUTH BEND-MISHAWAKA, IN
SPRINGFIELD, IL
SPRINGFIELD, MA
SPRINGFIELD, MO
ST. LOUIS, MO-IL
ST. MARY PAR (CO.), LA
STEUBENVILLE-WEIRTON, OH-WV
STOCKTON, CA
SUSSEX CO, DE
SYRACUSE, NY
TAMPA-ST. PETERSBURG-CLEARWATER, FL
TERRE HAUTE, IN
TOLEDO, OH
TRIGG CO, KY
TULSA, OK
TYLER CO, TX
UNION CO, SC
UTICA-ROME, NY
VICTORIA, TX
VISALIA-TULARE-PORTERVILLE, CA
WARREN CO, VA
WASHINGTON CO, IN
WASHINGTON, DC-MD-VA
WAUSAU, WI
WHEELING, WV-OH
WILLIAMSPORT, PA
WORCESTER, MA
YORK, PA
YOUNGSTOWN-WARREN, OH
YUBA CITY, CA
YUMA CO, AZ

Table 3-6. Summary of areas in nonattainment for the period 1987-1989 using 0.08 ppm.

ADAMS CO, IL
ALBANY-SCHENECTADY-TROY, NY
ALBUQUERQUE, NM
ALEXANDRIA, LA
ALLENTOWN-BETHLEHEM, PA-NJ
ALTOONA, PA
ANDERSON, IN
ANDERSON, SC
APACHE CO, AZ
APPLETON-OSHKOSH-NEENAH, WI
ASHEVILLE, NC
ATCHISON CO, MO
ATLANTA, GA
ATLANTIC CITY, NJ
AUGUSTA, GA-SC
AUSTIN, TX
BAKERSFIELD, CA
BALTIMORE, MD
BATON ROUGE, LA
BEAUMONT-PORT ARTHUR-ORANGE, TX
BENNINGTON CO, VT
BIRMINGHAM, AL
BLOOMINGTON-NORMAL, IL
BOSTON-LAWRENCE-SALEM, MA-NH
BUFFALO-NIAGARA FALLS, NY
BURLINGTON, VT
CAMDEN CO, NC
CANTON, OH
CEDAR RAPIDS, IA
CHAMPAIGN-URBANA-RANTOUL, IL
CHARLESTON, SC
CHARLESTON, WV
CHARLOTTE-GASTONIA-ROCK HILL, NC-SC
CHARLOTTESVILLE, VA

CHATTANOOGA, TN-GA
CHICAGO-GARY-LAKE CO, IL-IN-WI
CHICO, CA
CHITTENDEN CO, VT
CINCINNATI-HAMILTON, OH-KY-IN
CLEVELAND-AKRON-LORAIN, OH
COLORADO SPRINGS, CO
COLUMBIA, SC
COLUMBUS, GA-AL
COLUMBUS, OH
COLUSA CO, CA
COOS CO, NH
CORPUS CHRISTI, TX
CUMBERLAND, MD-WV
DALLAS-FORT WORTH, TX
DAVENPORT-ROCK ISLAND-MOLINE, IA-IL
DAYTON-SPRINGFIELD, OH
DECATUR, IL
DENVER-BOULDER, CO
DETROIT-ANN ARBOR, MI
DICKINSON CO, MI
DODGE CO, WI
DOOR CO, WI
EDGECOMBE CO, NC
EDMONSON CO, KY
EFFINGHAM CO, IL
EL PASO, TX
ELMIRA, NY
ERIE, PA
ESSEX CO, NY
EUGENE-SPRINGFIELD, OR
EVANSVILLE, IN-KY
FAUQUIER CO, VA
FAYETTEVILLE, NC

Table 3-6. (Continued).

FLINT, MI
FLORENCE CO, WI
FOND DU LAC CO, WI
FORT COLLINS-LOVELAND, CO
FORT MYERS-CAPE CORAL, FL
FORT WAYNE, IN
FRANKLIN CO, ME
FRESNO, CA
GILES CO, TN
GLENN CO, CA
GRAND RAPIDS, MI
GREELEY, CO
GREEN BAY, WI
GREENBRIER CO, WV
GREENSBORO-WINSTON SALEM-HIGH POINT, NC
GREENVILLE-SPARTANBURG, SC
HANCOCK CO, ME
HARRISBURG-LEBANON-CARLISLE, PA
HARTFORD-NEW BRITAIN-MIDDLETOWN, CT
HICKORY, NC
HOUMA-THIBODAUX, LA
HOUSTON-GALVESTON-BRAZORIA, TX
HUNTINGTON-ASHLAND, WV-KY-OH
HUNTSVILLE, AL
IMPERIAL CO, CA
INDIANAPOLIS, IN
IOWA CITY, IA
JACKSON, MS
JACKSONVILLE, FL
JANESVILLE-BELOIT, WI
JEFFERSON CO, KS
JEFFERSON CO, NY
JOHNSON CITY-KINGSPORT-BRISTOL, TN-VA
JOHNSTOWN, PA
KANSAS CITY, MO-KS
KEWAUNEE CO, WI
KNOX CO, IN
KNOX CO, ME
KNOXVILLE, TN
LA CROSSE, WI
LAFAYETTE, LA
LAFAYETTE-WEST LAFAYETTE, IN
LAKE CHARLES, LA
LAKE CO, MN
LANCASTER, PA
LANSING-EAST LANSING, MI
LAS CRUCES, NM
LAWRENCE CO, PA
LEWISTON-AUBURN, ME
LEXINGTON-FAYETTE, KY
LIMA, OH
LITTLE ROCK-NORTH LITTLE ROCK, AR
LIVINGSTON CO, KY
LONGVIEW-MARSHALL, TX
LOS ANGELES-ANAHEIM-RIVERSIDE, CA
LOUISVILLE, KY-IN
MADISON, WI
MANCHESTER, NH
MARIPOSA CO, CA
MARTIN CO, NC
MC CRACKEN CO, KY
MEDFORD, OR
MELBOURNE-TITUSVILLE-PALM BAY, FL
MEMPHIS, TN-AR-MS
MENDOCINO CO, CA
MIAMI-FORT LAUDERDALE, FL

Table 3-6. (Continued).

MILWAUKEE-RACINE, WI
MINNEAPOLIS-ST. PAUL, MN-WI
MOBILE, AL
MODESTO, CA
MONO CO, CA
MONROE CO, MO
MONROE, LA
MONTGOMERY, AL
MUHLENBERG CO, KY
MUSKEGON, MI
NASHVILLE, TN
NEW ORLEANS, LA
NEW YORK-NORTHERN NEW JERSEY-LONG ISLAND, NY-NJ-CT
NORFOLK-VIRGINIA BEACH-NEWPORT NEWS, VA
OCONEE CO, SC
OKLAHOMA CITY, OK
OMAHA, NE-IA
ORLANDO, FL
OWENSBORO, KY
PARKERSBURG-MARIETTA, WV-OH
PASCAGOULA, MS
PENSACOLA, FL
PEORIA, IL
PHILADELPHIA-WILMINGTON-TRENTON, PA-NJ-DE-MD
PHOENIX, AZ
PITT CO, NC
PITTSBURGH-BEAVER VALLEY, PA
PITTSFIELD, MA
PORTLAND, ME
PORTLAND-VANCOUVER, OR-WA
PORTSMOUTH-DOVER-ROCHESTER, NH-ME
POUGHKEEPSIE, NY
PROVIDENCE-PAWTUCKET-FALL RIVER, RI-MA

PROVO-OREM, UT
RALEIGH-DURHAM, NC
READING, PA
REDDING, CA
RICHMOND-PETERSBURG, VA
ROANOKE, VA
ROCHESTER, NY
ROCKFORD, IL
SACRAMENTO, CA
SALEM, OR
SALINAS-SEASIDE-MONTEREY, CA
SALT LAKE CITY-OGDEN, UT
SAN ANTONIO, TX
SAN BENITO CO, CA
SAN DIEGO, CA
SAN FRANCISCO-OAKLAND-SAN JOSE, CA
SAN LUIS OBISPO CO, CA
SANTA BARBARA-SANTA MARIA-LOMPOC, CA
SARASOTA, FL
SCRANTON-WILKES BARRE, PA
SEATTLE-TACOMA, WA
SHEBOYGAN, WI
SHREVEPORT, LA
SISKIYOU CO, CA
SMYTH CO, VA
SOUTH BEND-MISHAWAKA, IN
SPRINGFIELD, IL
SPRINGFIELD, MA
SPRINGFIELD, MO
ST MARY PAR (CO.), LA
ST. LOUIS, MO-IL
STEUBENVILLE-WEIRTON, OH-WV
STOCKTON, CA

Table 3-6. (Continued).

SUSSEX CO, DE
SYRACUSE, NY
TALLAHASSEE, FL
TAMPA-ST. PETERSBURG-CLEARWATER, FL
TERRE HAUTE, IN
TOLEDO, OH
TRIGG CO, KY
TUCSON, AZ
TULSA, OK
TUOLUMNE CO, CA
TYLER CO, TX
UNION CO, SC
UTICA-ROME, NY
VICTORIA, TX
VISALIA-TULARE-PORTERVILLE, CA
WARREN CO, VA
WASHINGTON CO, IN
WASHINGTON CO, ME
WASHINGTON, DC-MD-VA
WAUSAU, WI
WHEELING, WV-OH
WICHITA, KS
WICOMICO CO, MD
WILLIAMSPORT, PA
WILMINGTON, NC
WORCESTER, MA
YORK, PA
YOUNGSTOWN-WARREN, OH
YUBA CITY, CA
YUKON-KOYUKUK CO, AK
YUMA CO, AZ

Table 3-7. Compliance schedules set by the clean air bill for the 96 areas violating federal health standards for ozone (1987-1989).

EXTREME - Deadline for compliance 2010
LOS ANGELES-ANAHEIM-RIVERSIDE, CA

SEVERE 2 - Deadline 2007
BALTIMORE, MD
HOUSTON-GALVESTON-BRAZORIA, TX
NEW YORK CITY-NEW JERSEY-LONG ISLAND

SEVERE 1 - Deadline 2005
CHICAGO-GARY, IN
MILWAUKEE-RACINE, WI
MUSKEGON, MI
PHILADELPHIA-WILMINGTON, DE,-TRENTON, NJ
SAN DIEGO, CA

SERIOUS - Deadline 1999
ATLANTA, GA
BAKERSFIELD, CA
BATON ROUGE, LA
BEAUMONT-PORT ARTHUR, TX
BOSTON-LAWRENCE, MA,-SALEM, NH
EL PASO, TX
FRESNO, CA
HARTFORD-NEW BRITAIN-MIDDLETOWN, CT
HUNTINGTON, WV- ASHLAND, KY, AND OHIO SUBURBS
PARKERSBURG, WV,-MARIETTA, OH
PORTSMOUTH, MAINE,-DOVER-ROCHESTER, NH
PROVIDENCE-PAWTUCKET-FALL RIVER, RI
SACRAMENTO, CA
SHEBOYGAN, WI
SPRINGFIELD, MA
WASHINGTON, DC, VA, MD

MODERATE - Deadline 1996
ATLANTIC CITY, NJ
CHARLESTON, WV
CHARLOTTE-GASTONIA, NC,- ROCK HILL, SC
CINCINNATI, OH
CLEVELAND, OH
DALLAS, TX
DAYTON-SPRINGFIELD, OH
DETROIT, MI
EDMONSON COUNTY, KY
GRAND RAPIDS, MI
GREENSBORO- WINSTON-SALEM-HIGH POINT, NC
JEFFERSON COUNTY, NY
KEWAUNEE COUNTY, WI
KNOX COUNTY, ME

Table 3-7. (Continued)

LOUISVILLE, KY, IN
MEMPHIS, TN, AND ARKANSAS AND MISSISSIPPI SUBURBS
MIAMI-FORT LAUDERDALE, FL
MODESTO, CA
NASHVILLE, TN
PITTSBURGH-BEAVER VALLEY, PA
PORTLAND, ME
RALEIGH-DURHAM, NC
READING, PA
RICHMOND-PETERSBURG, VA
SALT LAKE CITY-OGDEN, UT
SAN FRANCISCO-OAKLAND-SAN JOSE, CA
SANTA BARBARA-SANTA MARIA-LOMPOC, CA
SMYTH COUNTY, VA
ST. LOUIS
TOLEDO, OH
VISALIA-TULARE-PORTERVILLE, CA
WORCESTER, MA

MARGINAL - Deadline 1993
ALBANY-SCHENECTADY-TROY, NY
ALLENTOWN-BETHLEHEM, PA
ALTOONA, PA
BIRMINGHAM, AL
BUFFALO-NIAGARA FALLS, NY
CANTON, OH
COLUMBUS, OH
ERIE, PA
ESSEX COUNTY, NY
EVANSVILLE, IN, AND KENTUCKY SUBURBS
FAYETTEVILLE, NC
GREENBRIER COUNTY, WV
GREENVILLE-SPARTANBURG, SC
HANCOCK COUNTY, ME
HARRISBURG-LEBANON- CARLISLE, PA
INDIANAPOLIS, IN
JOHNSON CITY-KINGSPORT-BRISTOL, TN
JOHNSTOWN, PA
KANSAS CITY, MO, KS
KNOXVILLE, TN
LAKE CHARLES, LA
LANCASTER, PA
LEWISTON-AUBURN, ME
LEXINGTON-FAYETTE, KY
LINCOLN COUNTY, ME
LIVINGSTON COUNTY, KY
MANCHESTER, NH
MONTGOMERY, AL

Table 3-7. (Continued)

NORFOLK-VIRGINIA BEACH-NEWPORT NEWS, VA
OWENSBORO, KY
POUGHKEEPSIE, NY
SCRANTON-WILKES-BARRE, PA
SOUTH BEND-MISHAWAKA, IN
STOCKTON, CA
SUSSEX COUNTY, DE
TAMPA-ST. PETERSBURG-CLEARWATER, FL
WALDO COUNTY, ME
YORK, PA
YOUNGSTOWN- WARREN, OH

Table 3-8. Summary of areas in 1987 with a 3-month SUM06 value ≥ 24.4 ppm-h.

ALBUQUERQUE, NM
ALLENTOWN-BETHLEHEM, PA-NJ
ALTOONA, PA
ATLANTA, GA
ATLANTIC CITY, NJ
AUSTIN, TX
BAKERSFIELD, CA
BALTIMORE, MD
BATON ROUGE, LA
BOSTON-LAWRENCE-SALEM, MA-NH
BUFFALO-NIAGARA FALLS, NY
CANTON, OH
CHARLESTON, SC
CHARLESTON, WV
CHARLOTTE-GASTONIA-ROCK HILL, NC-SC
CHARLOTTESVILLE, VA
CHATTANOOGA, TN-GA
CHICAGO-GARY-LAKE CO, IL-IN-WI
CHICO, CA
CINCINNATI-HAMILTON, OH-KY-IN
CLEVELAND-AKRON-LORAIN, OH
COLUMBIA, SC
COLUMBUS, GA-AL
COLUMBUS, OH
COLUSA CO, CA
CORPUS CHRISTI, TX
DALLAS-FORT WORTH, TX
DAVENPORT-ROCK ISLAND-MOLINE, IA-IL
DAYTON-SPRINGFIELD, OH
DENVER-BOULDER, CO
DETROIT-ANN ARBOR, MI
DODGE CO, WI
EDGECOMBE CO, NC
EDMONSON CO, KY
EFFINGHAM CO, IL
EL PASO, TX
ERIE, PA
ESSEX CO, NY
EVANSVILLE, IN-KY
FAUQUIER CO, VA
FAYETTEVILLE, NC
FORT WAYNE, IN
FRESNO, CA
GLENN CO, CA
GRAFTON CO, NH
GRAND RAPIDS, MI
GREENBRIER CO, WV
GREENSBORO-WINSTON SALEM-HIGH POINT, NC
GREENVILLE-SPARTANBURG, SC
HARRISBURG-LEBANON-CARLISLE, PA
HARTFORD-NEW BRITAIN-MIDDLETOWN, CT
HICKORY, NC
HOUSTON-GALVESTON-BRAZORIA, TX
HUNTINGTON-ASHLAND, WV-KY-OH
HUNTSVILLE, AL
INDIANAPOLIS, IN
JACKSONVILLE, FL
JANESVILLE-BELOIT, WI
JEFFERSON CO, NY
JOHNSON CITY-KINGSPORT-BRISTOL, TN-VA
JOHNSTOWN, PA
KEWAUNEE CO, WI
KNOX CO, IN
KNOXVILLE, TN
LAFAYETTE-WEST LAFAYETTE, IN
LANCASTER, PA
LANSING-EAST LANSING, MI
LAS CRUCES, NM

Table 3-8. (Continued).

LEXINGTON-FAYETTE, KY
LIMA, OH
LITTLE ROCK-NORTH LITTLE ROCK, AR
LIVINGSTON CO, KY
LOS ANGELES-ANAHEIM-RIVERSIDE, CA
LOUISVILLE, KY-IN
MADISON, WI
MC CRACKEN CO, KY
MEMPHIS, TN-AR-MS
MILWAUKEE-RACINE, WI
MODESTO, CA
MONO CO, CA
MORGAN CO, TN
MUSKEGON, MI
NASHVILLE, TN
NEW YORK-NORTHERN NEW JERSEY-LONG ISLAND, NY-NJ-CT
NORFOLK-VIRGINIA BEACH-NEWPORT NEWS, VA
OKLAHOMA CITY, OK
OMAHA, NE-IA
OWENSBORO, KY
PAGE CO, VA
PARKERSBURG-MARIETTA, WV-OH
PASCAGOULA, MS
PENSACOLA, FL
PEORIA, IL
PHILADELPHIA-WILMINGTON-TRENTON, PA-NJ-DE-MD
PHOENIX, AZ
PITTSBURGH-BEAVER VALLEY, PA
PORTSMOUTH-DOVER-ROCHESTER, NH-ME
PROVIDENCE-PAWTUCKET-FALL RIVER, RI-MA
PULASKI CO, VA
RALEIGH-DURHAM, NC
RAPPAHANNOCK CO, VA
READING, PA
REDDING, CA
RICHMOND-PETERSBURG, VA
ROANOKE, VA
ROCHESTER, NY
SACRAMENTO, CA
SALT LAKE CITY-OGDEN, UT
SAN DIEGO, CA
SANTA BARBARA-SANTA MARIA-LOMPOC, CA
SCRANTON-WILKES BARRE, PA
SHEBOYGAN, WI
SHREVEPORT, LA
SMYTH CO, VA
SOUTH BEND-MISHAWAKA, IN
SPRINGFIELD, IL
ST. LOUIS, MO-IL
STATE COLLEGE, PA
STOCKTON, CA
SUSSEX CO, DE
SYRACUSE, NY
TAMPA-ST. PETERSBURG-CLEARWATER, FL
TERRE HAUTE, IN
TOLEDO, OH
TULSA, OK
UNION CO, SC
VISALIA-TULARE-PORTERVILLE, CA
WARREN CO, VA
WASHINGTON, DC-MD-VA
YANCY CO, NC
YORK, PA
YOUNGSTOWN-WARREN, OH
YUBA CITY, CA

Table 3-9. Summary of areas in 1987 with a 3-month SUM06 value ≥ 24.4 ppm-h but not located in nonattainment areas for the 1986-1988 period.

ALBUQUERQUE, NM
AUSTIN, TX
CHARLESTON, SC
CHARLOTTESVILLE, VA
CHATTANOOGA, TN-GA
CHICO, CA
COLUMBUS, GA-AL
COLUSA CO, CA
CORPUS CHRISTI, TX
DAVENPORT-ROCK ISLAND-MOLINE, IA-IL
DENVER-BOULDER, CO
DODGE CO, WI
EDGECOMBE CO, NC
EFFINGHAM CO, IL
EVANSVILLE, IN-KY
FAUQUIER CO, VA
FORT WAYNE, IN
GLENN CO, CA
GRAFTON CO, NH
HICKORY, NC
JANESVILLE-BELOIT, WI
JOHNSON CITY-KINGSPORT-BRISTOL, TN-VA
KNOX CO, IN
LANSING-EAST LANSING, MI
LAS CRUCES, NM
LIMA, OH
LITTLE ROCK-NORTH LITTLE ROCK, AR
MADISON, WI
MC CRACKEN CO, KY
MONO CO, CA
MORGAN CO, IN
OKLAHOMA CITY, OK
OMAHA, NE-IA
PAGE CO, VA
PASCAGOULA, MS
PENSACOLA, FL
PEORIA, IL
PULASKI CO, VA
RAPPAHANNOCK CO, VA
REDDING, CA
ROANOKE, VA
ROCHESTER, NY
SHREVEPORT, LA
SMYTH CO, VA
SPRINGFIELD, IL
STATE COLLEGE, PA
SYRACUSE, NY
TERRE HAUTE, IN
UNION CO, SC
WARREN CO, VA
YANCY CO, NC
YUBA CITY, CA

Table 3-10. Summary of areas in 1988 with a 3-month SUM06 value $\geq$ 24.4 ppm-h.

ADAMS CO, IL
ALBANY-SCHENECTADY-TROY, NY
ALLENTOWN-BETHLEHEM, PA-NJ
ALTOONA, PA
ANDERSON, SC
APPLETON-OSHKOSH-NEENAH, WI
ASHEVILLE, NC
ATLANTA, GA
ATLANTIC CITY, NJ
AUGUSTA, GA-SC
AUSTIN, TX
BAKERSFIELD, CA
BALTIMORE, MD
BATON ROUGE, LA
BEAUMONT-PORT ARTHUR-ORANGE, TX
BENNINGTON CO, VT
BIRMINGHAM, AL
BLOOMINGTON-NORMAL, IL
BOSTON-LAWRENCE-SALEM, MA-NH
BOYLE CO, KY
BUFFALO-NIAGARA FALLS, NY
CANTON, OH
CEDAR RAPIDS, IA
CHAMPAIGN-URBANA-RANTOUL, IL
CHARLESTON, SC
CHARLESTON, WV
CHARLOTTE-GASTONIA-ROCK HILL, NC-SC
CHARLOTTESVILLE, VA
CHATTANOOGA, TN-GA
CHICAGO-GARY-LAKE CO, IL-IN-WI
CHICO, CA
CINCINNATI-HAMILTON, OH-KY-IN
CLEVELAND-AKRON-LORAIN, OH
COLUMBIA, SC
COLUMBUS, GA-AL
COLUMBUS, OH
CORPUS CHRISTI, TX
DALLAS-FORT WORTH, TX
DAVENPORT-ROCK ISLAND-MOLINE, IA-IL
DAYTON-SPRINGFIELD, OH
DECATUR, IL
DENVER-BOULDER, CO
DETROIT-ANN ARBOR, MI
DODGE CO, WI
EDMONSON CO, KY
EFFINGHAM CO, IL
EL PASO, TX
ELMIRA, NY
ERIE, PA
ESSEX CO, NY
EVANSVILLE, IN-KY
FAUQUIER CO, VA
FAYETTEVILLE, NC
FLINT, MI
FLORENCE CO, WI
FOND DU LAC CO, WI
FORT WAYNE, IN
FRESNO, CA
GILES CO, TN
GILMER CO, WV
GRAFTON CO, NH
GRAND RAPIDS, MI
GREEN BAY, WI
GREENBRIER CO, WV
GREENSBORO-WINSTON SALEM-HIGH POINT, NC
GREENVILLE-SPARTANBURG, SC
HANCOCK CO, ME
HARRISBURG-LEBANON-CARLISLE, PA

Table 3-10. (Continued).

HARTFORD-NEW BRITAIN-MIDDLETOWN, CT
HOUSTON-GALVESTON-BRAZORIA, TX
HUNTINGTON-ASHLAND, WV-KY-OH
HUNTSVILLE, AL
IMPERIAL CO, CA
INDIANAPOLIS, IN
IOWA CITY, IA
JACKSON, MS
JACKSONVILLE, FL
JANESVILLE-BELOIT, WI
JEFFERSON CO, NY
JOHNSTOWN, PA
KANSAS CITY, MO-KS
KEWAUNEE CO, WI
KNOX CO, IN
KNOX CO, ME
KNOXVILLE, TN
LAFAYETTE, LA
LAFAYETTE-WEST LAFAYETTE, IN
LAKE CHARLES, LA
LANCASTER, PA
LANSING-EAST LANSING, MI
LAS CRUCES, NM
LAWRENCE CO, PA
LETCHER CO, KY
LEWISTON-AUBURN, ME
LEXINGTON-FAYETTE, KY
LIMA, OH
LITTLE ROCK-NORTH LITTLE ROCK, AR
LIVINGSTON CO, KY
LONGVIEW-MARSHALL, TX
LOS ANGELES-ANAHEIM-RIVERSIDE, CA
LOUISVILLE, KY-IN
MACON CO, NC
MADISON, WI
MANCHESTER, NH
MANISTEE CO, MI
MC CRACKEN CO, KY
MEMPHIS, TN-AR-MS
MILWAUKEE-RACINE, WI
MINNEAPOLIS-ST. PAUL, MN-WI
MODESTO, CA
MONO CO, CA
MONROE CO, MO
MONROE, LA
MONTGOMERY, AL
MORGAN CO, TN
MUSKEGON, MI
NASHVILLE, TN
NEW ORLEANS, LA
NEW YORK-NORTHERN NEW JERSEY-LONG ISLAND, NY-NJ-CT
NORFOLK-VIRGINIA BEACH-NEWPORT NEWS, VA
OKLAHOMA CITY, OK
OMAHA, NE-IA
ORLANDO, FL
OWENSBORO, KY
PAGE CO, VA
PARKERBURG-MARIETTA, WV-OH
PASCAGOULA, MS
PENSACOLA, FL
PEORIA, IL
PHILADELPHIA-WILMINGTON-TRENTON, PA-NJ-DE-MD
PITT CO, NC
PITTSBURGH-BEAVER VALLEY, PA
PORTLAND, ME
PORTSMOUTH-DOVER-ROCHESTER, NH-MA

Table 3-10. (Continued).

PROVIDENCE-PAWTUCKET-FALL RIVER, RI-MA
PROVO-OREM, UT
PULASKI CO, VA
RALEIGH-DURHAM, NC
RAPPAHANNOCK CO, VA
READING, PA
REDDING, CA
RICHMOND-PETERSBURG, VA
ROANOKE, VA
ROCHESTER, NY
ROCKFORD, IL
SACRAMENTO, CA
SALT LAKE CITY-OGDEN, UT
SAN DIEGO, CA
SCRANTON-WILKES BARRE, PA
SHEBOYGAN, WI
SHREVEPORT, LA
SMYTH CO, VA
SOUTH BEND-MISHAWAKA, IN
SPRINGFIELD, IL
SPRINGFIELD, MA
SPRINGFIELD, MO
ST. LOUIS, MO-IL
STATE COLLEGE, PA
STEUBENVILLE-WEIRTON, OH-WV
STOCKTON, CA
SUSSEX CO, DE
SYRACUSE, NY
TALLAHASSEE, FL
TAMPA-ST. PETERSBURG-CLEARWATER, FL
THOMPKINS CO, NY
TOLEDO, OH
TRIGG CO, KY
TUCKER CO, WV
TULSA, OK
UTICA-ROME, NY
VISALIA-TULARE-PORTERVILLE, CA
WABASH CO, IN
WARREN CO, VA
WASHINGTON CO, IN
WASHINGTON, DC-MD-VA
WHEELING, WV-OH
WICHITA, KS
WILLIAMSPORT, PA
WORCESTER, MA
YANCY CO, NC
YORK, PA
YOUNGSTOWN-WARREN, OH
YUBA CITY, CA

Table 3-11. Summary of areas in 1988 with a 3-month SUM06 value ≥ 24.4 ppm-h but not located in nonattainment areas for the 1986-1988 period.

ADAMS CO, IL
APPLETON-OSHKOSH-NEENAH, WI
ASHEVILLE, NC
AUGUSTA, GA-SC
AUSTIN, TX
BENNINGTON CO, VT
BLOOMINGTON-NORMAL, IL
BOYLE CO, KY
CEDAR RAPIDS, IA
CHAMPAIGN-URBANA-RANTOUL, IL
CHARLESTON, SC
CHARLOTTESVILLE, VA
CHATTANOOGA, TN-GA
CHICO, CA
COLUMBUS, OH
CORPUS CHRISTI, TX
DAVENPORT-ROCK ISLAND-MOLINE, IA
DECATUR, IL
DENVER-BOULDER, CO
DODGE CO, WI
EFFINGHAM CO, IL
ELMIRA, NY
EVANSVILLE, IN-KY
FAUQUIER CO, VA
FLINT, MI
FLORENCE CO, WI
FOND DU LAC CO, WI
FORT WAYNE, IN
GILES CO, TN
GILMER CO, WV
GRAFTON CO, NH
GREEN BAY, WI
IMPERIAL CO, CA
IOWA CITY, IA
JACKSON, MS
JANESVILLE-BELOIT, WI
LAFAYETTE, LA
LANSING-EAST LANSING, MI
LAS CRUCES, NM
LAWRENCE CO, PA
LETCHER CO, KY
LIMA, OH
LITTLE ROCK-NORTH LITTLE ROCK, AR
LONGVIEW-MARSHALL, TX
MACON CO, NC
MADISON, WI
MANISTEE CO, MI
MC CRACKEN CO, KY
MINNEAPOLIS-ST. PAUL, MN-WI
MONO CO, CA
MONROE CO, MO
MONROE, LA
MORGAN CO, TN
NEW ORLEANS, LA
OKLAHOMA CITY, OK
OMAHA, NE-IA
ORLANDO, FL
PAGE CO, VA
PASCAGOULA, MS
PENSACOLA, FL
PEORIA, IL
PITT CO, NC
PROVO-OREM, UT
PULASKI CO, VA
RAPPAHANNOCK CO, VA
REDDING, CA

Table 3-11. (Continued).

ROANOKE, VA
ROCHESTER, NY
ROCKFORD, IL
SHREVEPORT, LA
SMYTH CO, VA
SPRINGFIELD, IL
SPRINGFIELD, MO
STATE COLLEGE, PA
STEUBENVILLE-WEIRTON, OH-WV
SYRACUSE, NY
TALLAHASSEE, FL
THOMPKINS CO, NY
TRIGG CO, KY
TUCKER CO, WV
TULSA, OK
UTICA-ROME, NY
WABASH CO, IN
WARREN CO, VA
WASHINGTON CO, IN
WHEELING, WV-OH
WICHITA, KS
WILLIAMSPORT, PA
YANCY CO, NC
YUBA CITY, CA

Table 3-12. Summary of areas in 1989 with a 3-month SUM06 value ≥ 24.4 ppm-h.

ALBANY CO, WY
ALBUQUERQUE, NM
ALLENTOWN-BETHLEHEM, PA-NJ
APPLETON-OSHKOSH-NEENAH, WI
ARENAC CO, MI
ATLANTA, GA
ATLANTIC CITY, NJ
AUGUSTA, GA-SC
AVERY CO, NC
BAKERSFIELD, CA
BALTIMORE, MD
BOSTON-LAWRENCE-SALEM, MA-NH
BOYLE CO, KY
BUFFALO-NIAGARA FALLS, NY
CANTON, OH
CHAMPAIGN-URBANA-RANTOUL, IL
CHARLOTTE-GASTONIA-ROCK HILL, NC-SC
CHICAGO-GARY-LAKE CO, IL-IN-WI
CHICO, CA
CINCINNATI-HAMILTON, OH-KY-IN
CLEVELAND-AKRON-LORAIN, OH
COLUMBIA, SC
COLUMBUS, OH
CRAWFORD CO, OH
DALLAS-FORT WORTH, TX
DAVENPORT-ROCK ISLAND-MOLINE, IA-IL
DAYTON-SPRINGFIELD, OH
DEKALB CO, AL
DENVER-BOULDER, CO
DETROIT-ANN ARBOR, MI
DODGE CO, WI
DOOR CO, WI
EFFINGHAM CO, IL
EL PASO, TX
ELK CO, PA
ERIE, PA
ESSEX CO, NY
EVANSVILLE, IN-KY
FAUQUIER CO, VA
FAYETTEVILLE, NC
FORT WAYNE, IN
FRESNO, CA
GRAND RAPIDS, MI
GREENSBORO-WINSTON SALEM-HIGH POINT, NC
GRUNDY CO, TN
HARTFORD-NEW BRITAIN-MIDDLETOWN, CT
HICKORY, NC
HOUSTON-GALVESTON-BRAZORIA, TX
INDIANAPOLIS, IN
JANESVILLE-BELOIT, WI
JEFFERSON CO, NY
KNOX CO, IN
KNOXVILLE, TN
LAS CRUCES, NM
LEXINGTON-FAYETTE, KY
LIMA, OH
LOS ANGELES-ANAHEIM-RIVERSIDE, CA
LOUISVILLE, KY-IN
MADISON, WI
MADISON CO, VA
MANISTEE CO, MI
MARIPOSA CO, CA
MELBOURNE-TITUSVILLE-PALM BAY, FL
MEMPHIS, TN-AR-MS
MILWAUKEE-RACINE, WI
MODESTO, CA
MONO CO, CA
MUSKEGON, MI

Table 3-12. (Continued).

NASHVILLE, TN
NEW YORK-NORTHERN NEW JERSEY-LONG ISLAND, NY-NJ-CT
NORFOLK-VIRGINIA BEACH-NEWPORT NEWS, VA
OMAHA, NE-IA
OWENSBORO, KY
PHILADELPHIA-WILMINGTON-TRENTON, PA-NJ-DE-MD
PHOENIX, AZ
PITT CO, NC
PITTSBURGH-BEAVER VALLEY, PA
PRINCE EDWARD CO, VA
PULASKI CO, VA
RALEIGH-DURHAM, NC
REDDING, CA
RICHMOND-PETERSBURG, VA
SACRAMENTO, CA
SALT LAKE CITY-OGDEN, UT
SAN DIEGO, CA
SAN LUIS OBISPO CO, CA
SHEBOYGAN, WI
SPRINGFIELD, MA
ST. LOUIS, MO-IL
SUBLETTE CO, WY
THOMPKINS CO, NY
VISALIA-TULARE-PORTERVILLE, CA
WABASH CO, IN
WARREN CO, VA
WASHINGTON, DC-MD-VA
YORK, PA
YOUNGSTOWN-WARREN, OH
YUBA CITY, CA

Table 3-13. Summary of areas in 1989 with a 3-month SUM06 value $\geq$ 24.4 ppm-h but not located in nonattainment areas for the 1987-1989 period.

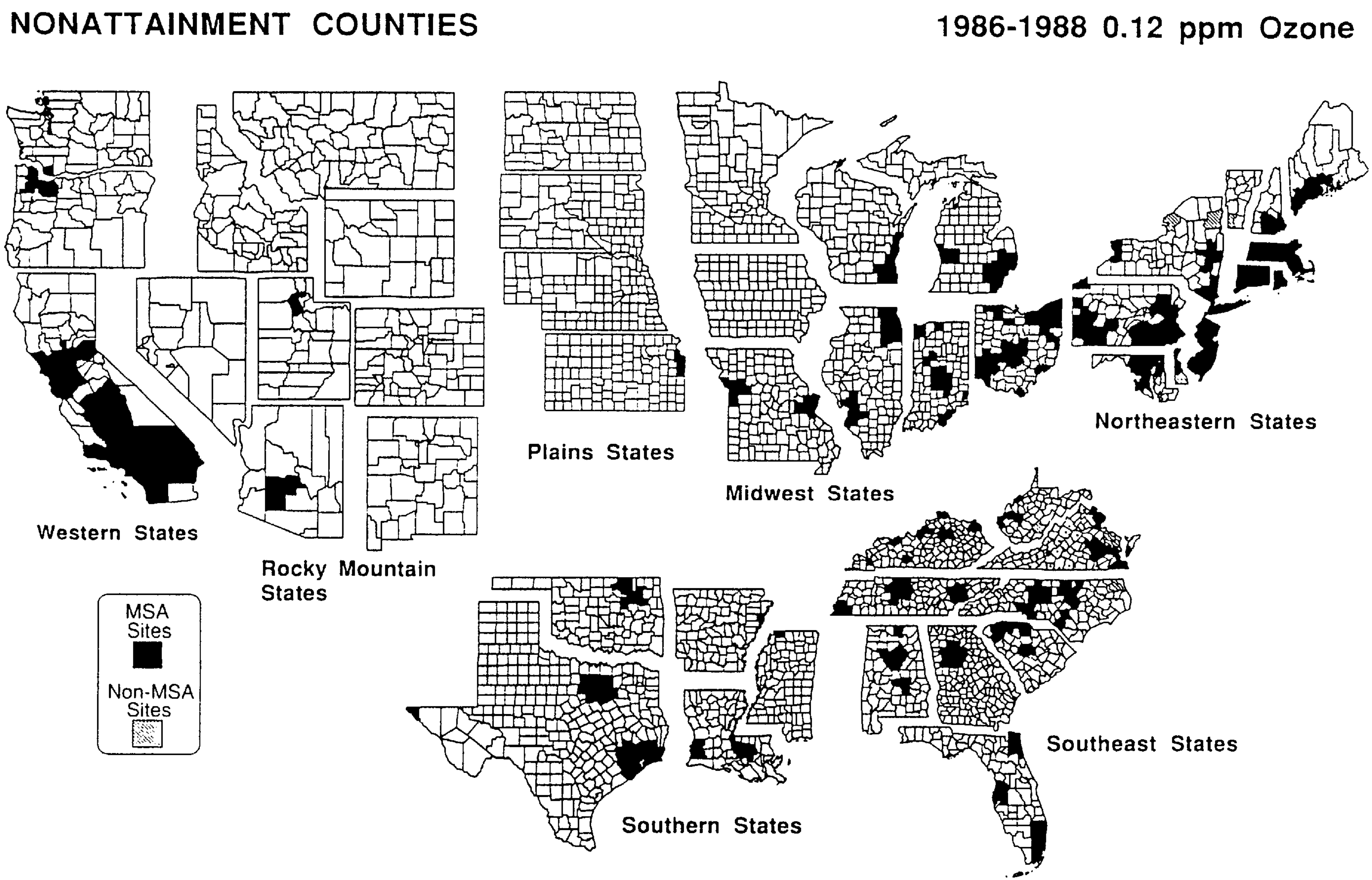
ALBANY CO, WY
ALBUQUERQUE, NM
APPLETON-OSHKOSH-NEENAH, WI
ARENAC CO, MI
AUGUSTA, GA-SC
AVERY CO, NC
BOYLE CO, KY
CHAMPAIGN-URBANA-RANTOUL, IL
CHICO, CA
COLUMBIA, SC
CRAWFORD CO, OH
DAVENPORT-ROCK ISLAND-MOLINE, IA-IL
DEKALB CO, AL
DENVER-BOULDER, CO
DODGE CO, WI
DOOR CO, WI
EFFINGHAM CO, IL
ELK CO, PA
FAUQUIER CO, VA
FORT WAYNE, IN
GRUNDY CO, TN
HICKORY, NC
KNOX CO, IN
JANESVILLE-BELOIT, WI
LAS CRUCES, NM
LIMA, OH
MADISON CO, VA
MADISON, WI
MANISTEE CO, MI
MARIPOSA CO, CA
MELBOURNE-TITUSVILLE-PALM BAY, FL
MONO CO, CA
OMAHA, NE-IA
PHOENIX, AZ
PITT CO, NC
PRINCE EDWARD CO, VA
PULASKI CO, VA
REDDING, CA
SAN LUIS OBISPO CO, CA
SUBLETTE CO, WY
THOMPKINS CO, NY
WABASH CO, IN
WARREN CO, VA
YUBA CITY, CA

Table 3-14. Summary of percentiles for O_3 monitoring sites in 1989 (April-October) with a 3-month SUM06 value < 24.4 ppm-h but with second hourly maximum concentration ≥ 0.125 ppm.

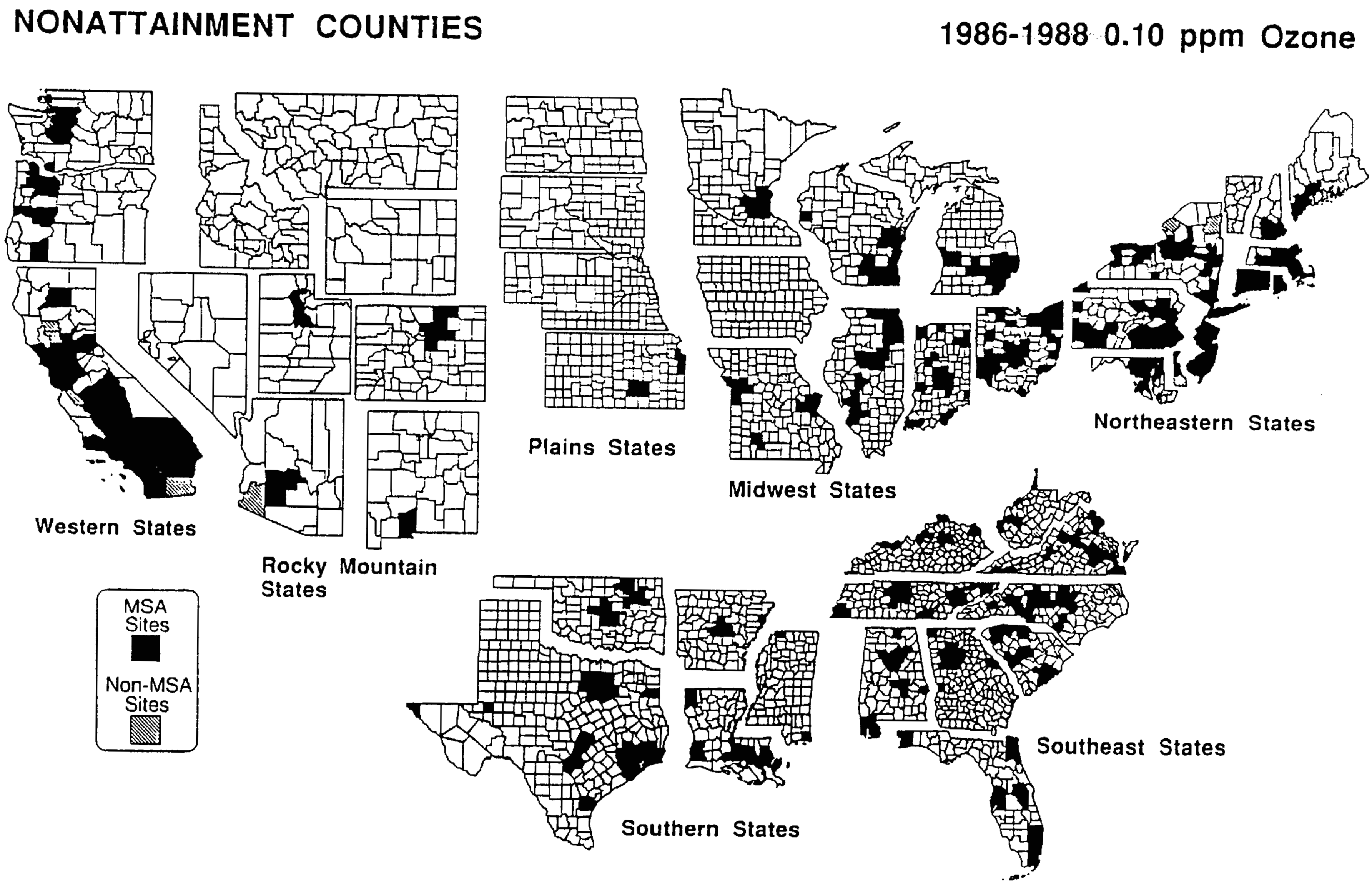
		Percentiles										
AIRS Site	Name	Min	10	30	50	70	90	95	99	Max	Maximum Uncorrected 3-Month SUM06 Value (ppm-h)	No. of Observ. Over 7-Month Period
060010003	LIVERMORE,CA	.000	.000	.010	.030	.040	.050	.060	.090	.140	17.0	5067
060371301	LYNWOOD,CA	.000	.000	.010	.020	.030	.050	.070	.100	.140	18.1	4793
060374002	LONG BEACH, CA	.000	.010	.020	.020	.030	.050	.060	.080	.160	13.6	4876
060375001	HAWTHORNE, CA	.000	.000	.020	.030	.040	.060	.060	.080	.190	18.1	4894
060830008	SANTA BARBARA, CA	.000	.010	.020	.030	.040	.050	.060	.080	.190	17.1	4823
060830010	SANTA BARBARA, CA	.000	.010	.020	.030	.040	.050	.060	.080	.220	13.3	4663
060833001	SANTA BARBARA CO, CA	.000	.010	.020	.030	.040	.050	.060	.080	.140	12.3	5077
090010113	BRIDGEPORT, CT	.000	.002	.011	.022	.033	.048	.059	.091	.156	16.5	4865
090091123	NEW HAVEN, CT	.000	.003	.010	.019	.029	.045	.056	.091	.156	12.9	4502
220191003	WESTLAKE, LA	.000	.003	.013	.022	.033	.052	.061	.082	.137	12.2	4811
220330003	BATON ROUGE, LA	.000	.001	.009	.021	.034	.059	.069	.094	.168	17.4	4964
220330004	BATON ROUGE, LA	.000	.002	.008	.016	.028	.047	.057	.078	.138	8.4	4791
220331001	E BATON ROUGE, LA	.000	.003	.012	.022	.034	.056	.066	.092	.171	14.4	4890
220470002	IBERVILLE PAR, LA	.000	.005	.014	.023	.034	.057	.068	.093	.149	15.9	5040
220770001	NEW ROADS, LA	.000	.001	.011	.021	.033	.052	.062	.083	.141	12.0	4964
230052003	CAPE ELIZABETH, ME	.001	.017	.027	.034	.042	.055	.064	.093	.146	16.7	4627
471630009	KINGSPORT, TN	.001	.001	.005	.017	.032	.054	.062	.078	.125	13.4	4252
481410027	EL PASO, TX	.000	.010	.020	.030	.040	.050	.060	.080	.260	14.9	4484
481990002	KOUNTZE, TX	.000	.000	.010	.020	.030	.050	.060	.080	.130	10.6	4630
482010024	HARRIS CO, TX	.000	.000	.010	.020	.030	.060	.070	.110	.230	19.2	4728
482010062	HOUSTON, TX	.000	.000	.010	.020	.030	.050	.070	.110	.170	16.8	4600
482011034	HOUSTON, TX	.000	.000	.010	.010	.030	.050	.060	.100	.220	14.0	4595
482011037	HOUSTON, TX	.000	.000	.010	.010	.030	.050	.060	.110	.250	16.3	4729
490350003	SALT LAKE CO, UT	.000	.001	.008	.029	.042	.056	.062	.083	.125	17.4	4585
490353001	SALT LAKE CITY, UT	.000	.002	.014	.029	.041	.053	.061	.079	.140	13.0	4544

Table 3-15. Summary of percentiles for O_3 monitoring sites in 1989 (April-October) with a 3-month SUM06 value ≥ 24.4 ppm-h but with second hourly maximum concentration < 0.125 ppm.

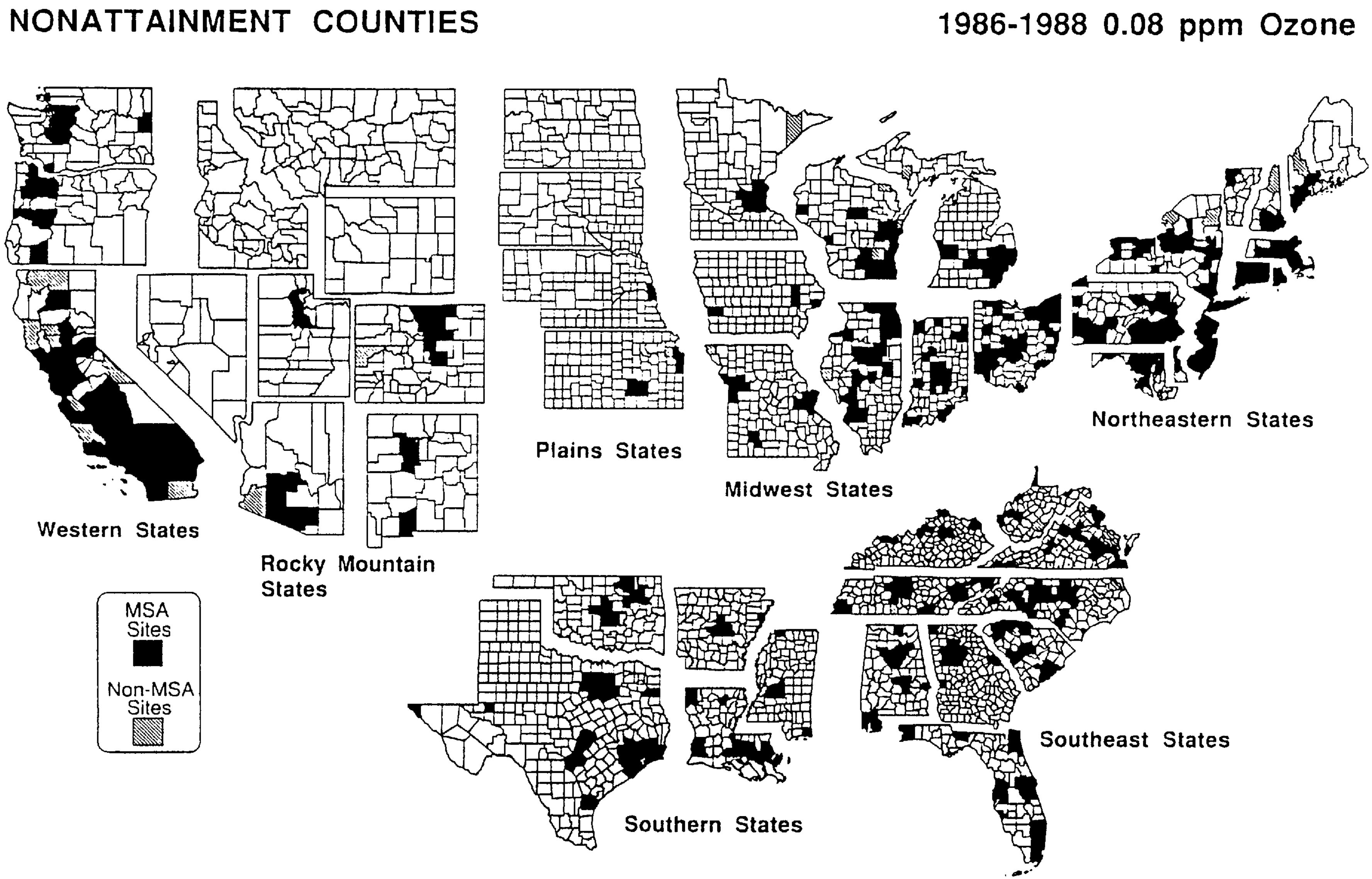
AIRS Site	Name	Min	10	30	50	70	90	95	99	Max	Maximum Uncorrected 3-Month SUM06 Value (ppm-h)	No. of Observ. Over 7-Month Period
		Percentiles										
040132004	SCOTTSDALE, AZ	.000	.006	.018	.031	.045	.062	.071	.084	.107	31.7	5070
060070002	CHICO, CA	.000	.010	.020	.030	.040	.060	.070	.080	.100	33.5	4690
060170009	SOUTH LAKE TAHOE, CA	.000	.020	.030	.040	.050	.060	.070	.080	.100	44.8	4768
060430004	YOSEMITE NP, CA	.000	.008	.022	.035	.049	.065	.072	.083	.111	37.6	4853
060710006	SAN BERNARDINO CO, CA	.000	.020	.040	.050	.060	.070	.080	.090	.100	70.5	4856
061011002	YUBA CITY, CA	.000	.000	.020	.030	.040	.060	.070	.080	.100	29.0	4623
120094001	COCOA BEACH, FL	.002	.017	.024	.032	.042	.059	.068	.077	.094	28.7	5012
170190004	CHAMPAIGN, IL	.000	.008	.020	.029	.039	.065	.072	.078	.088	32.0	5091
170491001	EFFINGHAM CO, IL	.000	.009	.023	.036	.046	.063	.070	.081	.104	25.3	4600
180970042	INDIANAPOLIS, IN	.001	.006	.021	.034	.046	.063	.072	.085	.103	25.4	4592
240030014	ANNE ARUNDEL, MD	.000	.006	.021	.032	.045	.064	.073	.090	.120	25.5	4360
240053001	ESSEX, MD	.000	.002	.010	.024	.038	.059	.069	.089	.121	25.2	5028
310550032	OMAHA, NE	.002	.021	.030	.037	.047	.062	.067	.075	.098	24.9	4160
350431001	SANDOVAL CO, NM	.000	.010	.020	.030	.040	.060	.060	.070	.090	25.1	5059
360310002	ESSEX CO, NY	.016	.033	.042	.050	.056	.067	.073	.086	.106	45.6	4070
370270003	LENOIR, NC	.000	.007	.019	.032	.045	.062	.067	.078	.092	25.8	4806
370810011	GUILFORD CO, NC	.004	.010	.023	.034	.046	.063	.070	.083	.113	27.7	4853
371470099	FARMVILLE, NC	.000	.010	.023	.034	.044	.062	.070	.083	.100	26.4	4833
390030002	ALLEN CO, OH	.000	.007	.022	.032	.043	.060	.068	.086	.107	24.5	4854
391510016	CANTON, OH	.000	.008	.019	.030	.042	.060	.070	.088	.110	26.3	4875
420070003	NEW BRIGHTON, PA	.000	.008	.021	.032	.043	.062	.070	.087	.102	29.4	5055
420770004	ALLENTOWN, PA	.000	.003	.016	.028	.039	.060	.070	.087	.102	25.1	5040
470090101	SMOKY MT NP, TN	.000	.025	.036	.044	.053	.065	.070	.081	.098	35.9	4764
510130020	ARLINGTON CO, VA	.000	.001	.010	.023	.037	.059	.071	.088	.116	25.7	5029
510610002	FAUQUIER CO, VA	.000	.009	.021	.033	.045	.061	.069	.084	.122	24.6	5050
511870002	SHEN NP (DKY RDG), VA	.009	.027	.038	.046	.054	.064	.070	.080	.100	33.5	3798
550270001	HORICON, WI	.002	.019	.029	.037	.047	.062	.070	.088	.111	24.6	4142
551390007	OSHKOSH, WI	.002	.016	.028	.038	.048	.063	.070	.084	.121	27.9	4206



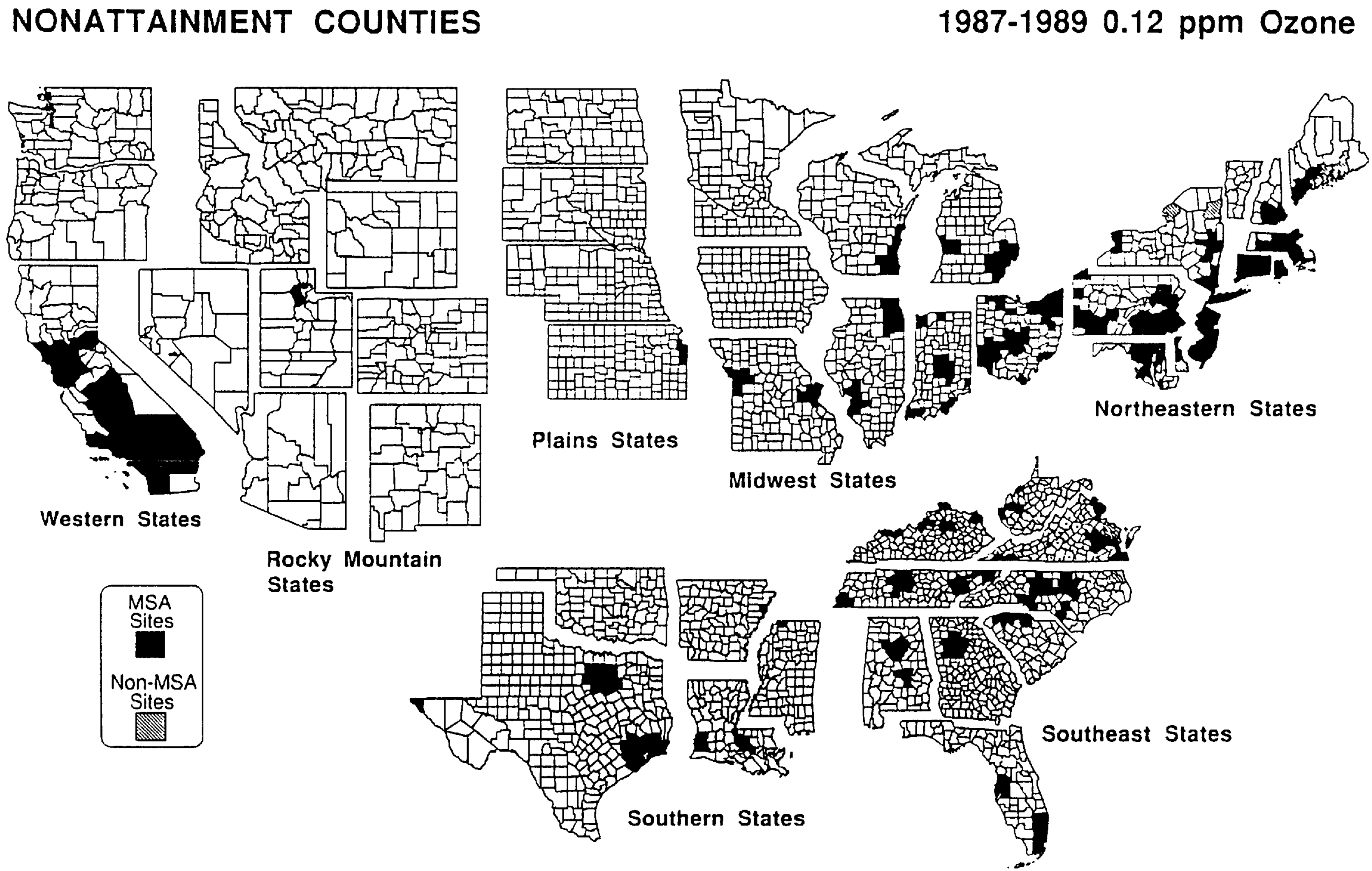
3-1. Nonattainment areas for the 1986-1988 period using 0.12 ppm.



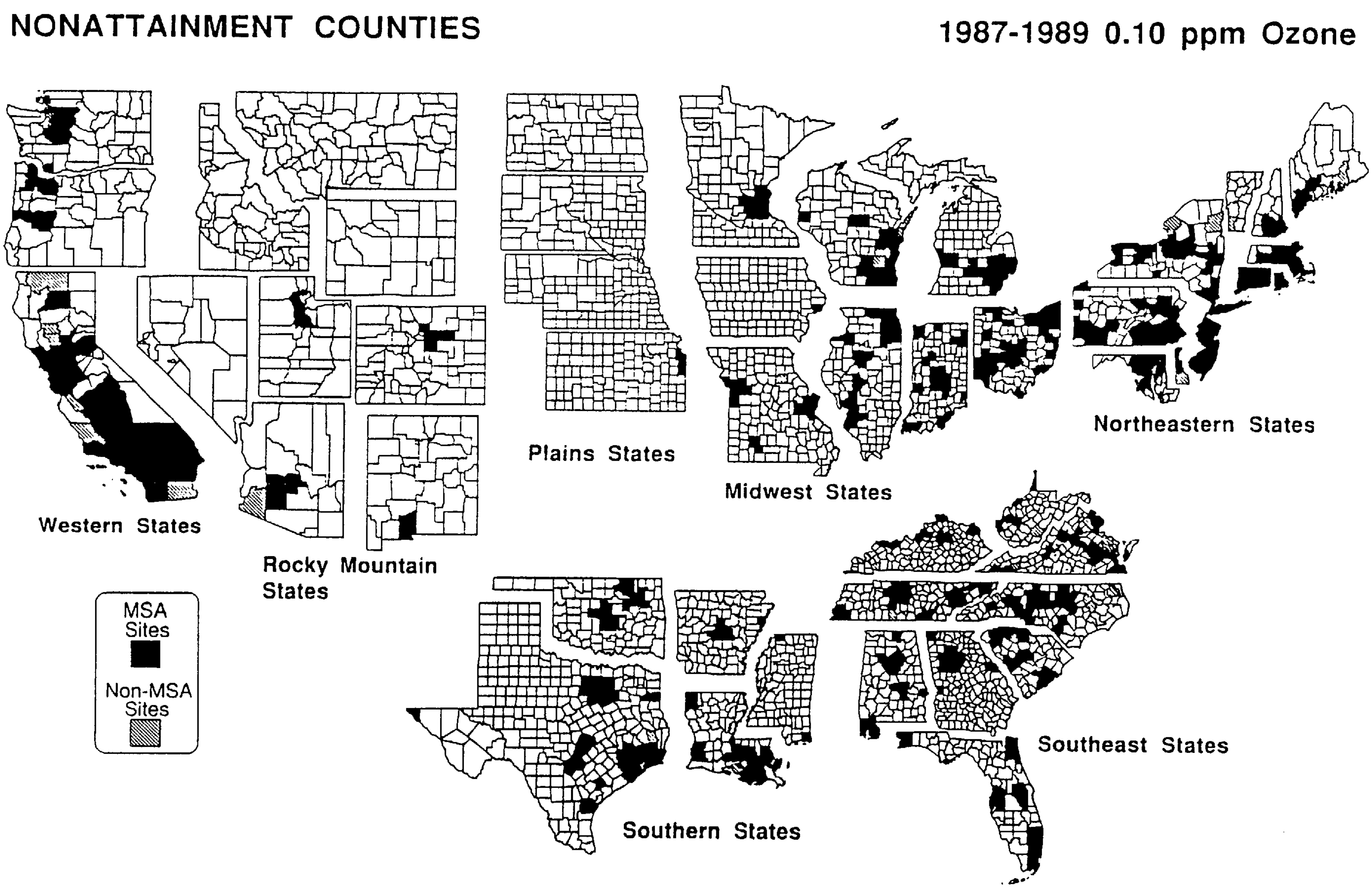
3-2. Nonattainment areas for the 1986-1988 period using 0.10 ppm.



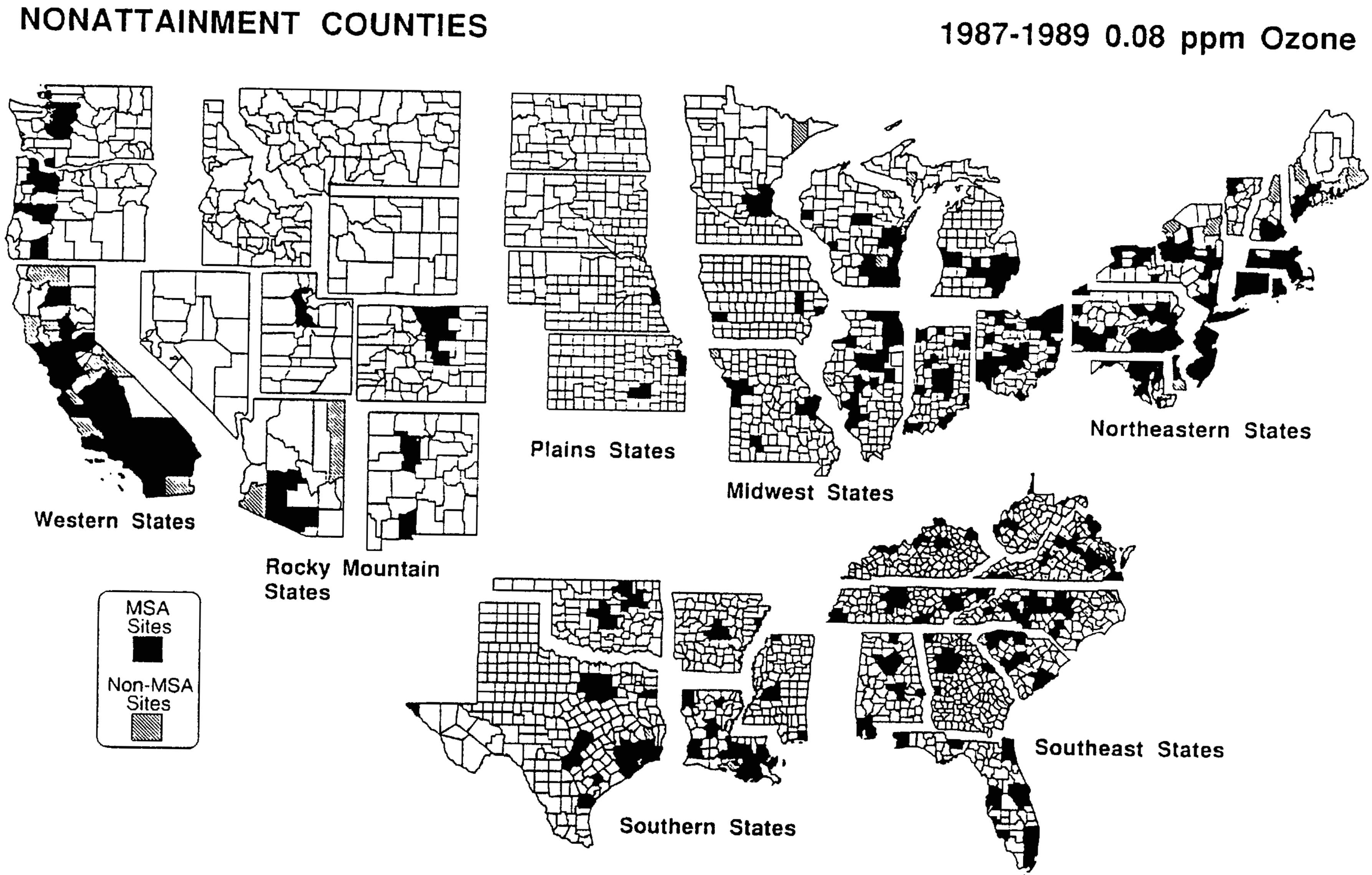
3-3. Nonattainment areas for the 1986-1988 period using 0.08 ppm.



3-4. Nonattainment areas for the 1987-1989 period using 0.12 ppm.



3-5. Nonattainment areas for the 1987-1989 period using 0.10 ppm.



3-6. Nonattainment areas for the 1987-1989 period using 0.08 ppm.

CHAPTER 4

SINGLE- VERSUS MULTIPLE-PARAMETER INDEX APPLICATIONS

4.1 INTRODUCTION

As indicated in Chapter 3, a strong correlation between peak concentrations and the value of the SUM06 index does not necessarily occur under ambient conditions. However, Lee *et al.* (1991) have reported that the SUM06 index has performed well, using NCLAN data, in relating O_3 exposure and yield reduction. In Chapter 2, using the NCLAN results, we found, at the 20% yield reduction level, that there were O_3 distributions (of hourly average concentrations) which contained a sufficient number of high hourly average concentrations. The NCLAN experimental protocol applied incremental and proportional additions that resulted in many of the treatments experiencing elevated O_3 exposures; many of the artificial regimes used by NCLAN contained the elevated hourly average concentrations that were reflected in the determination of the absolute values of the cumulative indices calculated by Lee *et al.* (1991). Therefore, at many of the treatment levels, the magnitude of the SUM06 index, calculated using NCLAN protocols, appeared to be influenced by the peak exposures that correlated well with the observed growth reductions.

A major concern about the use of any exposure index (e.g., cumulative or seasonal average concentration) is whether the value of the index can be linked to a specific exposure regime. The absolute value of the index reflects only the mathematical calculation performed using hourly average O_3 concentrations. If we assume that the distribution of the highest hourly average concentrations (i.e., the upper tail of the distribution) is an important factor in affecting vegetation, then a single-parameter exposure index, such as the SUM06 or W126, in some instances, may not be specific enough to describe those important distributions that cause an O_3-related effect.

Our results indicate that under ambient conditions, the use of the SUM06 exposure index did not relate well with the occurrences of elevated hourly average concentrations. To improve the predictive capability that depends upon linking experimental exposure-response relationships with ambient air quality, it appears that indices, such as the SUM06 or W126 indices, will have to be combined with other exposure parameters in order to mathematically define unique distribution patterns of hourly average concentrations.

Lefohn *et al.* (1989) have discussed the merits of applying indices for the purposes of summarizing exposure and have suggested that the index selected adequately focus on the important parts of the O_3 exposure regime that are thought to be responsible for affecting crops adversely. In addition, an important goal should be that the exposure index selected be consistent so that a low value indicates relatively low risk to agricultural crops, while a high value represents a high risk. Although moderate success has been achieved using the SUM06 and W126 exposure indices, consistency is important so that experimental exposure-response relationships can be strongly linked with ambient exposures. If this consistency is not present, it will be difficult to use any exposure index in the development of a secondary standard.

4.2 SUCCESSFUL APPLICATIONS OF THE SINGLE-PARAMETER INDEX

Although difficulties may exist for linking experimental exposure-response relationships with ambient air for predicting vegetation effects, single-parameter exposure indices have been used successfully for describing regional O_3 exposure in the United States (Lefohn *et al.*, 1987; Lefohn *et al.* 1990a). Figure 4-1 shows the results of interpolating characterized hourly average O_3 data, using kriging of the W126, 7-month seasonal O_3 exposure index in 1/2 x 1/2 degree grids for the eastern United States. Ozone exposures in the East were higher in 1987 than in the two previous years, 1985 and 1986. Trends analysis performed by the U.S. EPA (1991) confirms this observation. Yet, given the fact that we have shown that the magnitude of cumulative exposure indices, such as the W126 or SUM06 exposure index, is not necessarily strongly associated with the occurrence of high hourly average O_3 concentrations, why is it possible to successfully describe regional exposures using single-parameter cumulative indices?

The O_3 exposures experienced at each site are influenced by a multitude of factors. The elevation of a specific site, its ground cover (i.e., sorptive capacity), as well as its latitude, may influence O_3 production and destruction of the absolute O_3 exposure value experienced at a specific site. Many of the O_3 monitors used in the kriging analyses were situated near urban-oriented locations (Lefohn *et al.*, 1990a). Thus, the distribution of the hourly average concentrations may have been similar. For example, most of the urban-oriented monitoring sites may experience similar scavenging processes that result in 30% or more of the hourly average concentrations occurring below 0.015 ppm. In addition, the maximum hourly average concentrations experienced at many of these sites were similar. Thus, with similar hourly average distribution patterns, it would be assumed that the magnitude of a cumulative exposure index, such as the W126 or SUM06, would order itself properly, with the higher value corresponding to the higher exposure. This appears to be what occurred.

In addition to using cumulative exposure indices to describe regional O_3 exposures, a cumulative exposure index has been used in trends analysis. Lefohn and Shadwick (1991) summarized trends for O_3 exposures over 5- and 10-year periods (i.e., 1984-1988 and 1979-1988) for rural locations in the United States. The investigators explored the evidence for trends at each monitoring location. Evidence for regional trends was based on studying the individual time trends observed for each of the sites in the region. The seasonal W126 cumulative exposure index was used to investigate trends. The results reported by Lefohn and Shadwick (1991) were consistent with the findings reported by the U.S. EPA (1990).

The explanation for the successful application of the cumulative index in the trends analysis was similar to the one given for the kriging analysis. For a specific monitoring site, the hourly average distribution pattern was similar over the years studied by Lefohn and Shadwick (1991). The scavenging processes remained the same over time at a specific site. Thus, the difference in magnitude of the W126 index, at any one site over time, was reflected in changes in the distribution curve of the hourly average O_3 concentrations. Changes that occurred at the upper end of the distribution curve were reflected in the magnitude of the W126 index.

4.3 ALTERNATIVE APPROACHES FOR USING INDICES TO DESCRIBE EXPOSURE-RESPONSE RELATIONSHIPS

For some purposes, the single-parameter index appears to work appropriately. However, as indicated above, the predictive power involving exposure-response relationships that use single-parameter exposure indices may not be as strong as desired. A multiple-parameter index may be necessary to adequately describe distribution patterns of hourly average concentrations.

For developing a secondary standard to protect vegetation, the combined exposure statistics should be selected based on the observation that high concentrations are expected to cause greater impact on vegetation than lower concentrations. The following important factors, summarized by Lee *et al.* (1991), may be important when selecting an appropriate standard to protect vegetation:

- Peak concentrations are more important than low concentrations in determining plant response;
- Ozone effects are cumulative (i.e., increasing the duration of the exposure period is expected to cause greater biological response);
- Exposure cannot be characterized as the unweighted product of concentration and time because the effect of O_3 on vegetation yield depends on the cumulative impact of high concentrations during the growing season;
- Plant sensitivity is not constant, but varies according to stage of development.

Lefohn *et al.* (1988) and Lee *et al.* (1988, 1989, 1991) have shown, when high hourly average concentrations are present in an exposure regime, that single-parameter cumulative indices can be used to relate O_3 exposures with vegetation growth reductions. However, when attempting to link experimental models with ambient air quality, it appears that the application of a single-parameter exposure index in the form of a standard for protecting vegetation will provide inconsistent results. This does not imply that all currently used cumulative exposure indices are not appropriate for describing O_3 exposure. Rather, it appears that cumulative indices, such as the SUM06 and the W126 indices, will have to be combined with other parameters to quantify accurately the occurrence of the high hourly average concentrations. As indicated previously, the combination of exposure parameters (i.e., multiple indices) used to describe those regimes that cause vegetation effects must adequately characterize the upper tail of the hourly average distribution curve.

The estimated ranges of O_3 exposures that result in injury and damage effects to vegetation, published by Guderian *et al.* (1985), provide us with an indication that hourly average concentrations of 0.10 ppm and higher are important in eliciting adverse effects on vegetation. This does not mean that concentrations below 0.10 ppm are not important. **In general, however, the recommendations of Guderian *et al.* (1985) tend to support the hypothesis that hourly average concentrations ≥ 0.10 ppm may have to be experienced before serious injury or damage to vegetation can occur.** This generalization appears to be supported by our reanalysis of some of the NCLAN data as discussed in Chapter 2.

Recognizing that some of the lower hourly average O_3 concentrations may contribute to adverse vegetation effects, it is important to attempt to subjectively define a lower limit. Ozone hourly average concentrations of 0.05 ppm routinely occur at many "clean" site locations in the world (Lefohn *et al.*, 1990b), including several Class I areas in the United States (Lefohn and Foley, 1991). In addition, occasional occurrences of hourly average concentrations near 0.08 ppm are experienced at these "clean" monitoring locations. Lefohn and Foley (1991) report that in almost all cases, none of the "clean" O_3 monitoring sites experienced hourly average concentrations ≥ 0.08 ppm and the maximum hourly average concentrations were in the range from 0.060 to 0.075 ppm. In addition, the results reported by Lefohn *et al.* (1988) and Lee *et al.* (1988, 1989, 1991) support the concept that hourly average O_3 concentrations ≥ 0.06 ppm are important in the growth reduction of agricultural crops. However, at this time, we know little about the relative importance of the hourly average concentrations between 0.06 ppm and 0.10 ppm, when compared to those hourly average values ≥ 0.10 ppm.

The possible combination of exposure parameters, such as the (1) sigmoidally-weighted exposure index (as proposed by Lefohn and Runeckles, 1987) or (2) SUM06 index (as recommended by Lee *et al.*, 1991), with other indices should provide sufficient means to describe those unique distribution curves that have the potential for eliciting an adverse effect. Additional insight may be gained from the work of Krupa and Nosal (1989), who discussed the use of multi-parameter indices to describe the relationships between O_3 exposure and crop growth.

In Chapter 2, our reanalysis of the NCLAN data provided us with evidence that summaries of distribution patterns provide important information concerning the relationships between exposure and response. Future research efforts in this area point to the quantification of the distribution of the hourly average concentrations. The percentile distribution of the hourly average concentrations offers a way to characterize both high and low O_3 concentrations. Experience with hourly average concentration O_3 data has revealed both seasonal and daily patterns in time plots of O_3 concentrations. Ozone tends to be episodic on a short time basis (i.e., time frames of days or weeks). The occurrence of high O_3 values tends to be relatively close in time, as determined by meteorological events. The regularity in the time structure of high O_3 concentrations gives the appearance of peaks in time plots of hourly O_3 concentrations. With high confidence, from the percentile distribution of O_3, one can infer that the values in the tail of the distribution represent peaks in the time plots of hourly O_3 concentrations.

In addition, percentile distributions offer the opportunity to differentiate exposures experienced at remote or isolated sites from exposures experienced at sites influenced by urban sources (Lefohn and Jones, 1986; Lefohn *et al.*, 1990). Monitoring sites under the influence of local urban sources experience approximately 50-70 percent of their hourly average O_3 concentrations above 0.015 ppm.

Techniques other than indices that accumulate exposures over time and percentile distributions have been used to investigate varying exposure patterns. Investigators have utilized diagrams that illustrate composite diurnal patterns as a means to describe qualitatively the differences of O_3 exposures between sites (Lefohn and Jones, 1986; Böhm *et al.*, 1991). Although it might appear that composite diurnal pattern diagrams could be used to quantify the differences of O_3 exposures between sites, Lefohn and Benkovitz (1990) caution their use for this purpose. The composite diurnal patterns are derived from long-term average calculations of the hourly concentrations and the resulting diagram cannot adequately identify, at most sites, the presence of high hourly average concentrations and thus, may not adequately be able to distinguish O_3 exposure differences among sites.

Although we have discussed the possible combinations of parameters to better link experimental exposure-response models with ambient air quality for predicting possible impacts on vegetation, at this time, information is not available to identify the specific parameters that should be combined. However, the results of the NCLAN experiments provide researchers with the opportunity to better understand the level of exposures that result in agricultural yield reduction. We have summarized the distribution of the hourly average concentrations that occurred in some of the NCLAN experiments. The characterized distributions reflected the importance of the upper end of the distribution curve in affecting crop yield reductions. We believe this additional information should assist researchers in identifying a multi-parameter exposure index that will properly relate ambient exposure to response.

A strong case has been made for selecting multi-parameter exposure indices for establishing a secondary standard to protect vegetation from high levels of O_3 exposure. However, caution is urged. Although we believe that an effort should be made to identify multi-parameter indices, it is important to note that a consistent relationship between multi-parameter exposure indices and vegetation effects may not always exist. As indicated in Chapter 2, the (1) amount and chemical form of the pollutant that enters the target organism, (2) length of the exposure within each episodic event, (3) time between exposures (i.e., the respite or recovery time), and (4) sensitivity of the target organism are important factors that affect our ability to predict O_3 effects on vegetation. Showman (1991) reported indications that sensitivity may be an important factor. For field surveys in the midwestern United States, in 1988, O_3 levels were high but injury to vegetation was low due to drought stress. In 1989, O_3 exposures were much lower than in 1988 and optimum growing conditions resulted in greater foliar injury. Overall, it is unclear how important these four factors are in an overall weighting scheme when predicting vegetation effects. Given the current state of knowledge, and based on research in the South Coastal Basin, where extremely high O_3 exposures occur (Oshima, 1975; Oshima *et al*., 1976; Thompson *et al*., 1976;

Lefohn and Benedict, 1982), at this time, concentration should be the focus, instead of either sensitivity or actual dose, for the standard-setting process.

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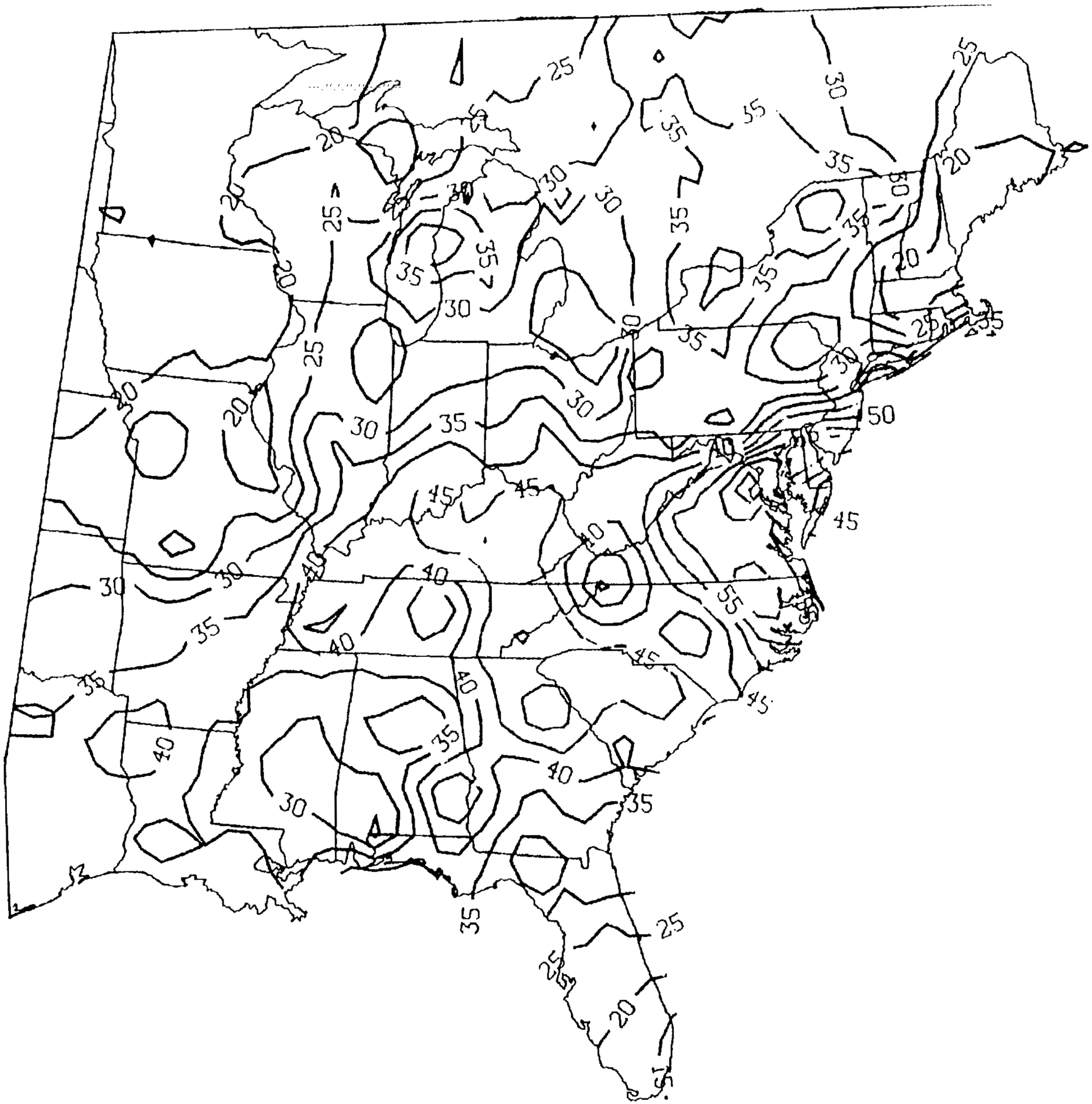

Figure. 4-1 Interpolation of April-October Ozone Exposures for 1987 for the Eastern United States Using the W126 Index.

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