Evaluating Air Quality Effects of Urban Trees: Developing Directionally Sound Programs for Use in State Ozone Attainment Goals

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Cost & Benefits of Urban Forests

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Principal Investigators:

Christopher J. Luley, Ph.D.
ACRT, Inc.
227 N. DePeyster St.
Kent, OH 44240
800-622-2562

S. Trivikrama Rao, Ph.D.
Bureau of Air Research
NY State Dept. of Environmental Conservation and Dept. of Atmospheric Sciences
SUNY at Albany
50 Wolf Rd.
Albany, NY 12233-3259
518-457-3200

David J. Nowak, Ph.D.
U.S. Dept. of Agriculture
Forest Service
Northeastern Forest Experiment Station
SUNY College of Environmental Science and Forestry
5 Moon Library
Syracuse, NY 13210
315-448-3212

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Executive Summary

EVALUATING AIR QUALITY EFFECTS OF URBAN TREES: DEVELOPING DIRECTIONALLY SOUND PROGRAMS FOR USE IN STATE OZONE ATTAINMENT GOALS

Drs. Christopher J. Luley, David J. Nowak and S. Trivikrama Rao

A previous NUCFAC cost-share project has determined that there is a significant potential for developing credits within State Implementation Plans, based on ozone reduction due to urban forests, which can be used to fund future long-term urban forest management. Before these credits can be developed, the U.S. Environmental Protection Agency (EPA) needs evidence that the approach is directionally sound. This project proposes to produce evidence that will aid in the development of directionally sound programs for state ozone attainment goals, thereby facilitating the development of these credits. In addition, this project will quantify the effects of urban trees on numerous other air pollutants. Results of this project will have nationwide impacts, potentially affecting urban forest funding in many urban areas that have poor air quality.

Detailed analyses of urban forest cover, structure (i.e., species composition, tree size and condition) and air quality effects will be conducted for seven cities: Baltimore, MD; Baton Rouge, LA; Boston, MA; New York City, NY; Jersey City, NJ; Philadelphia, PA; and Camden, NJ. Urban forest structural information is necessary to quantify the air quality effects and will also provide good management information for the cities. Air quality effects will focus on pollution removal and volatile organic emissions by trees. Carbon sequestration by trees will also be calculated. The main focus of the project will be on the overall effects of trees on ozone in cities. Current and next generation state-of-the-science photochemical models will be used to quantitatively evaluate this overall effect. Model results will aid in developing directionally sound ozone programs, thereby creating cost-effective ozone control strategies using urban vegetation.

Funding: Requested Amount: $225,000 Matching Amount: $225,000

Partners: Arboretum Park Conservancy, Baltimore Dept. of Parks and Recreation, Baton Rouge Green, Baton Rouge Landscape and Forestry Division, Boston Parks and Recreation Dept., Center for Urban Forestry at the Morris Arboretum of the Univ. of Penn., City of Santa Maria, CA, East Baton Rouge Recreation and Parks Commission, Environmental Services, New York City Parks, Louisiana Dept. of Environ. Quality, Maryland Dept. of Environ., Mass. Dept. of Environ. Protection, NOAA, NJ Forest Service, NY State Dept. of Environ. Conservation, Philadelphia Air Management Service, Philadelphia Fairmount Park Commission, Southern Univ. and A&M College, SUNY at Albany, Trees New York, U.S. EPA, and the Yale Univ. of Forestry and Environmental Studies Urban Resources Initiative.

Key scientific staff: Dr. C.J. Luley (ACRT, Inc.), Dr. D.J. Nowak (U.S. Forest Service), and Drs. S.T. Rao, G. Sistla and S. Jin (New York State Department of Environmental Conservation). This interdisciplinary staff is unique in their ability and they are experts in assessing, through measurement and modeling, the effects of trees on air quality; particularly ozone. Never before has such a team been assembled to address this issue.

Results and Products: Numerous reports and presentations will be made to local, regional and national audiences regarding this project's results quantifying the effect of urban trees on air quality. Particular focus is on the cumulative effect of trees on ozone and the feasibility of using trees as part of directionally sound programs to decrease city ozone levels.

Introduction

Poor urban air quality is a multibillion dollar problem in the United States. In 1985, 94 metropolitan areas, with approximately 130 million residents, were in violation of the health-based National Ambient Air Quality Standard for ozone (EPA, 1986). The U.S. Environmental Protection Agency has estimated that medical and work-loss costs from air pollution in the United States are approximately $6 billion annually. Total costs of all control strategies in non-attainment cities will be $7.7 - 8.9 billion annually by the year 2003 (OTA, 1988).

A previous NUCFAC cost-share project has determined that there is a significant potential for developing credits within State Implementation Plans, based on ozone reduction due to urban forests, which can be used to fund future long-term urban forest management (Luley *et al.,* in review). Before these credits can be developed, the U.S. Environmental Protection Agency (EPA) needs evidence that the approach is directionally sound. This project proposes to produce evidence that will aid in the development of directionally sound programs for state ozone attainment goals, thereby facilitating the development of these credits. In addition, this project will quantify the effects of urban trees on numerous other air pollutants. Results of this project will have nationwide impacts, potentially affecting urban forest funding in many urban areas that have poor air quality. This project will also complement many existing municipal and volunteer urban tree programs, regardless of city size and air pollution levels.

Analyzing the effects of urban trees on air quality is complex, particularly for ozone, as there are many interactive factors, some of which decrease pollution, other which increase pollution. Urban trees can improve air quality through the absorption of gaseous pollutants, the interception of particulate matter, and reducing air temperatures, thus consequently reducing temperature-dependent pollution emissions and altering pollution-forming chemical reactions. However, trees also emit volatile organic compounds that can contribute to ozone formation.

Unfortunately, very little work has been conducted that quantifies the degree to which urban trees influence local air quality. This type of work and documentation are necessary before managers, planners and policy makers can begin to develop and implement necessary air quality improvement strategies involving urban vegetation. In addition, this documentation will illustrate the vital need for urban trees and appropriate urban tree management.

One of the poorest areas of air quality in the United States is the northeastern seaboard from Baltimore, MD to Boston, MA. In this area where millions of people reside, ozone nonattainment is predominantly classified as extreme and severe (National Research Council, 1992). Another area with serious ozone nonattainment is Baton Rouge, LA. This project proposes to assess the cumulative effect of trees in these areas on various air pollutants, particularly ozone, to determine the direction and magnitude of the tree effects on air quality. These analyses will aid in developing directionally sound ozone programs for numerous cities and reveal regional variation of the air quality effects. Methods used for this project will build upon methods currently being developed for analysis of Chicago, IL. This type of demonstration is unique and had not been done prior to the model development in Chicago. Results from this project will have a nationwide impact, affecting cities of all sizes by revealing the degree to which urban trees affect local air quality.

Objectives

- Determine urban forest cover and structure of seven U.S. cities that are geo-referenced to specific city land units.
- Allow various volunteer groups (e.g., non-profit groups, students, etc.) to participate in field data collection to foster environmental education and an interest in environmental careers and issues. A particular focus of this effort will be to encourage minority youth to participate.
- Model urban vegetation removal of carbon dioxide, carbon monoxide, nitrogen dioxide, ozone, and sulfur dioxide; and volatile organic compound emissions from urban vegetation in seven cities.
- Improve urban vegetation data base (e.g., leaf biomass, tree emissions, pollution removal) for the Urban Airshed Models. These models are used to develop and demonstrate various ozone control strategies in cities.
- Use the Urban Airshed Model and other photochemical models to demonstrate the effect of increased and decreased urban tree cover on ozone concentrations in seven cities.
- Synthesis the results and methods to aid in the development of directionally sound programs using urban vegetation in ozone nonattainment cities.

Methods

Study Area

The demonstration of urban forest effects on air quality will occur in seven U.S. cities: Baltimore, MD; Baton Rouge, LA; Boston, MA; New York City, NY; Jersey City, NJ; Philadelphia, PA; and Camden, NJ. In each of these areas, urban forest structural data will be collected and the effects of urban trees on air quality will be modeled.

Urban Forest Structure

Data on urban forest structure is critical to assessing the effects of urban trees on air quality. The first component of the structural analyses is to measure urban forest canopy cover within each city. Detailed air photo analyses of urban forest cover will be conducted using a dot grid sampling technique (Nowak *et al,* in review). Data on cover type (e.g., tree, building, grass, etc.) and land use type (e.g., residential, commercial, park, etc.) will be collected within geo-referenced land units based on each city's modeling and urban forest management needs. This cover data will reveal the amount and variation of urban cover types, by land use type, across the city landscape. This data will provide the basis for the vegetation-air quality assessment, as well as provide much needed information to improve urban forest management in the study cities.

To improve upon this aerial photographic vegetation data base, randomly located field plots (1/10 acre) will be sampled throughout each of the study cities. These plots will be used to collect more detailed information on urban forest structure (e.g., number of trees, species composition, tree size and condition, ground cover, building characteristics, etc.). This detailed information will consequently be used to determine critical air quality attributes of the urban forest (e.g., species specific leaf biomass, leaf-surface area) (Nowak, in review). The field and photo data will be combined to produce an urban forest structure data base for each city. This structural data collection will follow methods presented by Nowak (1994a). This data will be used in the following air quality assessments and to develop urban forest structure reports which will be given to each city to aid in urban forest planning and management.

Air Pollution Removal by Urban Trees

Local hourly meteorological data (e.g., air temperature, wind speed, cloud cover) will be used in conjunction with the structural data base (i.e., variation in tree leaf surface area) to calculate hourly aerodynamic, quasi-laminar and canopy resistances to pollutant transfer to the trees. Information on these resistances are necessary to calculate the hourly base removal rates or deposition velocity (V_d). Local geo-referenced data on air pollution concentrations (i.e., carbon monoxide, nitrogen dioxide, ozone, and sulfur dioxide) measured throughout the cities will be used to determine hourly pollution concentrations (C). Hourly pollutant flux or removal (F) is then calculated as the product of deposition velocity and individual pollutant concentration ($F = Vd \times C$) (e.g., Baldocchi *et al,* 1987).

Average daily, monthly and yearly pollutant removal, as well as peak day removal and percent air quality improvement, will be calculated for each available pollutant in 1995. Implied valuation will be used to estimate the dollar value of reduced air pollution due to urban trees. Methods will follow those reported in Nowak (1994b). Results will be compared with urban tree air quality results from Chicago, IL (Nowak, 1994b). Deposition velocities will be estimated by land use type and these data incorporated in the Urban Airshed Model to provide a better assessment of the effect of trees on ozone.

Urban Tree Volatile Organic Compound Emissions

Although trees remove ozone, primarily through leaf stomates, trees also emit volatile organic compounds (VOCs) which contribute to ozone formation. Thus, knowing urban vegetative VOC emissions is important for understanding and modeling the degree to which urban vegetation contributes to local ozone formation. Urban vegetative VOC emissions in each city will be estimated by combining the urban forest structural data base (i.e., species specific leaf biomass) with local meteorological data (i.e., air temperature, cloud cover) (Guenther *et al.,* 1993), and base species emission factors (Guenther *et al.,* 1994).

Hourly, daily and monthly VOC emissions will be estimated throughout the summer ozone season and compared with local anthropogenic VOC emission rates (Nowak, 1991) and compared with tree VOC emissions in Chicago (Nowak, in preparation) and other cities. This data will be contrasted against existing emission models and incorporated in the Urban Airshed Model to provide a better assessment of the effect of trees on ozone.

been predicted using the Urban Airshed Model (Rao and Sistla, 1993), but have never been applied toward understanding urban vegetation effects on ozone concentrations. In this context, we will apply current and next generation photochemical models such as the Urban Airshed Model - IV (Morris *et al.,* 1990), Urban Airshed Model - V (Morris *et al.,* 1993); Rao and Mount, 1995), and SAQM (Jin *et al.,* 1995) to better understand the relationship between vegetation and ozone production.

Urban Trees as Part of a Directionally Sound Program

Results from and methods used in the Urban Airshed Model will be incorporated in a publication which will discuss the feasibility of using urban trees as part of a directionally sound program. This publication can potentially be used by various cities as a part their directionally sound program and can serve as a template from which other cities can explore the use of urban trees as part of a comprehensive air quality program. With EPA approval, the programs can be used in State Implementation Plans to improve air quality. In addition, the program offers the first necessary step toward developing pollution credits within State Implementation Plans that can be used to fund urban forest management. Establishment of credits for ozone reduction will depend on the magnitude of the reduction by urban trees and will be subject to stricter regulatory guidelines than directionally sound programs. This publication will also discuss the necessary information and steps needed to develop pollution reduction credits using urban trees.

Products

- Report describing urban forest structure and demonstrating tree pollution removal (for carbon monoxide, nitrogen dioxide, ozone, and sulfur dioxide), VOC emissions and carbon sequestration by urban trees in the seven study cities. The report will include urban forest structural information (e.g., species composition, forest health) to aid in better urban forest management, and estimated tons of pollution removed annually, associated pollution removal dollar value, tons of carbon stored arid sequestered annually by urban trees, and tons of VOC emitted annually by trees. The report will also specify the percent air quality improvement due to trees in each city. Reports will be distributed to the seven cities, other interested cities and groups, and disseminated nationally via the Forest Service publications group. Reports will be disseminated locally by cooperating organizations.

- Report compiling UAM results. Reports will be distributed to the seven cities, the U.S. Environmental Protection Agency and other interested cities and groups, and disseminated nationally via the Forest Service publications group. Reports will be disseminated locally by the cooperating organization.

- Directionally sound program report will discuss Urban Airshed Model results and address using urban trees as part of directionally sound air quality improvement programs and the potential for developing pollution reduction credits using urban trees. Reports will be distributed to the seven cities, state air quality personnel, the U.S. Environmental Protection Agency and other interested cities and groups, and disseminated nationally via the Forest Service publications group. Reports will be disseminated locally by the

cooperating organization.

- Information from each report will also be published in various articles in refereed journals (e.g., *Journal of Arboriculture, Journal of Air and Waste Management Association, Atmospheric Environment)* and in proceedings of national and international professional organization conferences.

- Information will also be disseminated to various press organizations for publication (e.g., work from the Chicago Urban Forest Climate Project was published in the New York Times (Stevens, 1994)).

- Presentations of project results will be made to professional organizations (e.g., International Society of Arboriculture, Air and Waste Management Association, American Meteorological Society).

- Various updates of the project will be disseminated to cooperating agencies and the National Urban and Community Forestry Advisory Council.

Project Completion Date: December 31, 1997

Funding

	Requested Amount: $225,000	Matching Amount: $225,000
	Grant	In-Kind
Salaries	$146,096	$ 113,441
Travel	$ 31,000	$ 0
Supplies and Equipment[1]	$ 18,000	$ 90,245
Total Direct Cost	$ 195,096	$ 203,686
Indirect Cost	$ 29,904	$ 21,314
Total	$225,000	$225,000

In-kind Matching Contributions
ACRT ($36,000)
Arboretum Park Conservancy ($2,500)
Baltimore Department of Parks and Recreation ($1,000)
Baton Rouge Green ($1,000)
Baton Rouge Landscape and Forestry Division ($1,000)
Boston Parks and Recreation Department ($1,000)
Center for Urban Forestry at the Morris Arboretum of the University of Pennsylvania ($1,000)
City of Santa Maria, California ($5,000)
East Baton Rouge Recreation and Parks Commission
Environmental Services, New York City Parks ($4,500)
Louisiana Department of Environmental Quality ($6,000)
Maryland Department of Environment
Massachusetts Department of Environmental Protection
New Jersey Forest Service Community Forestry Program ($2,000)
New York State Department of Conservation ($100,000)
Philadelphia Air Management Service ($1,000)
Philadelphia Fairmount Park Commission ($1,000)
Southern University and A&M College ($7,000)
State University of New York at Albany
Trees New York ($5,000)
Yale University of Forestry and Environmental Studies Urban Resources Initiative ($50,000)

Federal Contributing Agencies (not counted in matching funds: >$100,000)
USDA Forest Service, Northeastern Forest Experiment Station and Southern Region
National Oceanic and Atmospheric Administration
U.S. Environmental Protection Agency

[1] Most of the supplies and equipment from the grant will go toward the purchase of aerial photography.

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APPENDIX A: Role of Organizations and Partners of Project
Including How Project Fits with Organization's Priorities

ACRT Inc.: ACRT, Inc. has been a leader in urban forestry consulting since 1985. The proposed study is a continuation of a feasibility project that evaluated the potential to generate credits for air pollution reduction by urban trees. Cost-benefit research and developing market-based systems to support urban forest management are priorities of the company. Project tasks include: photo design and analysis; field data collection design; field data collection, input and tree management analysis. ACRT, Inc. has the existing staff with demonstrated experience in aerial photo interpretation and computerized data collection to complete the proposed data collection in the project.

Arboretum Park Conservancy: Assisting with local project coordination and promotion Searching and locating local data bases on air pollution concentrations, meteorological data, urban tree management districts, aerial photographs, maps, etc. Dissemination of project results on the local scale. This project fits well with the Conservancy's mission to carry out educational and ecological purposes in connection with woodland park lands.

Baltimore Department of Parks and Recreation: Assisting with local project coordination and promotion. Facilitating local field data collection, merging of existing data sets and coordinating data collection to fit within local management units. Dissemination of project results on the local scale and consolidation of results into local tree management. This project fits well with the Department's need to effectively manage urban forests to maximize local benefits.

Baton Rouge Green: Local project coordination and promotion. Searching and locating local data bases on air pollution concentrations, meteorological data, urban tree management districts, aerial photographs, maps, etc. Provision and oversight of volunteers for field data collection. This project fits well with Baton Rouge Green's mission of urban forest education and as "an advocate for our urban forest which improves air quality...".

Baton Rouge Landscape and Forestry Division: Assisting with local project coordination and promotion. Facilitating local field data collection, merging of existing data sets and coordinating data collection to fit within local management units. Dissemination of project results on the local scale and consolidation of results into local tree management. This project fits well with the Department's need to effectively manage urban forests to maximize local benefits.

Boston Department of Parks and Recreation: Assisting with local project coordination and promotion. Facilitating local field data collection, merging of existing data sets and coordinating data collection to fit within local management units. Dissemination of project results on the local scale and consolidation of results into local tree management. This project fits well with the Department's need to effectively manage urban forests to maximize local benefits.

Center for Urban Forestry; Morris Arboretum of the University of Pennsylvania: Assisting with local project coordination and promotion. Searching and locating local data bases on air pollution concentrations, meteorological data, urban tree management districts, aerial photographs, maps, etc. Dissemination of project results on the local scale. This project fits well with the Center for Urban Forestry's mission "to facilitate and promote better management of woodland and urban forests through community participation in education, planning and management, and demonstration projects".

City of Santa Maria, California: Assistance with project development and promotion. Work with U.S. E.P.A. on development of directionally sound program and potential for pollution credits. This project fits well with the city's past work on promoting urban vegetation and its effects on air quality.

East Baton Rouge Recreation and Parks Commission: Assisting with local project coordination and promotion. Supplemental data on park vegetation structure to be merged into overall data set. Dissemination and use of project results. This project fits well with the Commission's objective of sound park management.

Environmental Services, New York City Parks: Donating the use of aerial photographs of the New York area. Assisting with local project coordination and promotion. This project fits well with organization's desire to improve the New York City environment.

Louisiana Department of Environmental Quality: Assistance with Urban Airshed modeling for Baton Rouge. This project fits well with work of its Office of Air Quality and Radiation Protection.

Maryland Department of Environment: Local air quality assistance. Incorporation of results into local air quality planning. This project fits well the Department's desire to improve air quality.

Massachusetts Department of Environmental Protection: Local air quality assistance. Incorporation of results into local air quality planning. This project fits well the Department's desire to improve air quality.

National Oceanic and Atmospheric Administration: Assistance and coordination of collection of pollution monitoring data. This program fits well with NOAA's work on hydrocarbon emissions modeling.

New Jersey Forest Service Community Forestry Program: Assisting with local project coordination and promotion. Facilitating local field data collection and merging of existing data sets. Dissemination of project results. This project fits well with the Department's need to assist urban communities in effectively managing urban forests to maximize local benefits.

New York State Department of Environmental Conservation: Urban Airshed modeling of Baltimore, Philadelphia-Camden, New York-Jersey City and Boston. Use of Urban Airshed Model and other photochemical models; expertise in air quality modeling and model applications. BEIS and other sensitivity testing. This project fits well with work being conducted by the Department's Division of Air Resources.

Philadelphia Air Management Services: Local air quality assistance. Incorporation of results into local air quality planning. This project fits well the Department's desire to improve air quality.

Philadelphia Fairmount Park Commission: Assisting with local project coordination and promotion. Facilitating local field data collection, merging of existing data sets and coordinating data collection to fit within local management units. Dissemination of project results on the local scale and consolidation of results into local tree management. This project fits well `with the Department's need to effectively manage urban forests to maximize local benefits.

Southern University and A&M College: Technical air quality assistance. Assisting with local project coordination and promotion. Searching and locating local data bases on air pollution concentrations, meteorological data, urban tree management districts, aerial photographs, maps, etc. Incorporation of results in local research and urban forestry education. This project fits well with Southern University's new urban forestry program.

State University of New York at Albany: Urban Airshed modeling of Washington, Baltimore, Philadelphia, New York and Boston. Use of Urban Airshed Model and expertise in air quality modeling and model applications. This project fits well with the University's work on regional ozone formation and concentrations. Note: this group is associated with the New York State Department of Environmental Conservation, both of which are contributing to the modeling logistics and evaluation.

Trees New York: Assisting with local project coordination and promotion. Searching and locating local data bases on air pollution concentrations, meteorological data, urban tree management districts, aerial photographs, maps, etc. Dissemination of project results on the local scale. This project fits well with Trees New York's goal to "provide a vehicle for community empowerment which effects a significant and noticeable change in the quality of life for community residents of all ages, races, et al.".

U.S.D.A. Forest Service: Assistance with photo analysis and field data collection design; analysis of field data for air quality attributes. Modeling pollution removal, VOC emissions, and carbon sequestration by urban vegetation in individual cities. Report writing and presentations. This project fits well with the Forest Service project that investigates the structure and functions of urban forests.

U.S. Environmental Protection Agency: Assistance in urban hydrocarbon modeling; review of methods. This project fits well with EPA's work on hydrocarbon emissions and pollution concentrations.

Yale School of Forestry and Environmental Studies Urban Resources Initiative: Local project coordination and promotion. Searching and locating local data bases on air pollution concentrations, meteorological data, urban tree management districts, maps, etc. Provision of numerous field data collected and mapped in Baltimore, and cooperation in local modeling efforts. This project fits well with URI's mission of education and their objective to "restore the urban environment by developing an integrated approach to reduce the effects of pollution and restoring the urban environment while providing economic, educational, and health benefits".

APPENDIX B: Pertinent Professional Experience

CHRISTOPHER J. LULEY, Urban Forester/Plant Pathologist
ACRT Inc.
227 N. DePeyster, P.O. Box 219, Kent, OH 44240-0219
(800) 622-2562 FAX: (216) 673-3205

EDUCATION:

Iowa State University, Ph.D. Plant Pathology, August 1986
SUNY Environmental Science and Forestry-Syracuse, M.S. Forest Pathology, June 1982
SUNY Environmental Science and Forestry-Syracuse, B.S. Forest Biology, May 1979

PROFESSIONAL EXPERIENCE:

ACRT, INC., Kent, Ohio
April 1991 to date
Urban forestry consulting- expert witness on tree failure, tree appraisals and insect and disease diagnosis, managing and evaluating computerized street and park tree inventories for municipalities, and research on the environmental and economic benefits of urban trees.

CJL TREE CONSULTANTS, Rochester, New York
April 1991 to April 1992
Consulting on tree care and urban forestry including pest diagnosis, hazard tree evaluation, appraisal, integrated pest management programs, and training.

FOREST PATHOLOGIST, Dept. of Conservation, Jefferson City, Missouri
December 1986 to March 1991
Responsible for diagnosis, survey, and detection of forest and shade tree diseases, and training arborists in disease identification and tree care for the State of Missouri.

EXTENSION DIAGNOSTICIAN, Iowa State University, Ames, Iowa
June 1982 to October 1986
Managed the Plant Diagnostic Laboratory for Iowa which included diagnosis of insect, disease and environmental problems on over 2,000 horticultural and field crop samples annually.

RESEARCH TECHNICIAN, Ciba-Geigy Corp., Livingston, NY
May 1979 to September 1980
Evaluated experimental fungicides, herbicides and insecticides on fruit, vegetable, and field crops on the company's northeast research facility.

PROFESSIONAL AFFILIATIONS AND ASSOCIATIONS:

International Society of Arboriculture
American Phytopathological Society (member since 1980)
Certified New York State Pesticide Applicator
City of Rochester Urban Forestry Technical Advisory Committee
Research Excellence Award Iowa State University 1986
Phi Kappa Phi Agricultural Honor Society

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Luley, C. J., Mielke, M. E., Castello, J. D., Cummings-Carlson, J., Appleby, J., and Hatcher, R. 1992. Ash crown condition and the incidence of ash yellows and other insects and diseases in Illinois, Iowa, Missouri, and Wisconsin. *Plant Disease* 76:1209-1212.

Luley, C. J. and McNabb, H. S. 1991. Estimation of seasonal ascospore production of Mycosphaerella populorum. *Can. J. For. Res.* 9:1349-1353.

Luley, C. J. and McNabb, H. S. 1989. Ascospore production, release, germination, and infection of Populus by Mycopshaerella populorum. *Phytopathology* 79:1013-1018.

Rycyk, F., Luley, C. J. and P. Gowen-Overton. 1989. Peridermium harknessii on Scots pine in Missouri. *Plant Disease* 73:610.

Luley, C. J. and Gleason, M. L. 1988. Diplodia canker of concolor fir in Iowa. *Plant Disease* 72:79.

Luley, C. J., McNabb, H. S., and Tiffany, L. H. 1987. In vitro production of Mycopshaerella populorum ascomata. *Mycologia* 79:654-658.

Luley, C. J. and Manion, P. D. 1984. Inoculum potential of Gremmeniella abietina in New York. In: *Scleroderris canker of conifers.* P. D. Manion, ed. Pgs 82-96.

POPULAR PRESS:

Abbott, R. E., Luley, C. J., Buchanan, E. L., Miller, K. C., and Joehlin, K. A. 1991. The importance of large tree maintenance in mitigating global climate change. White Paper. 6p.

Luley, C. J. 1991. A thorny issue. *Missouri Conservationist* 52(3):22-23.

Luley, C. J. 1990. Global warming-Is the sky really falling? *Missouri Conservationist* 51(7):10-13.

Luley, C. J. 1989. Decline of the might oak? *Missouri Conservationist* 50(6):16-17

Gass, R., and Luley, C. J. 1989. Unwelcome guests. *Missouri Conservationist* 50(6) 32-33.

DAVID J. NOWAK, Research Forester

U.S.D.A. Forest Service
5 Moon Library, SUNY-CESF, Syracuse, *NY* 13210 (315) 448-3212 FAX: (315) 448-3216

EDUCATION:

Ph.D. 1991	University of California, Berkeley. Major: Urban Forest Ecology
M.S. 1986	SUNY College of Environmental Science and Forestry, Syracuse, NY Major: Urban Forest Ecology
B.S. 1984	SUNY College of Environmental Science and Forestry, Syracuse, NY Dual major: Resource Management and Forest Biology; magna cum laude

PROFESSIONAL EXPERIENCE:

U.S.D.A. Forest Service	1991-	Research Forester
U.S.D.A. Forest Service	1989-1991	Forestry Technician
University of California, Berkeley	1986-1989	Research Assistant
Research Foundation of the State University of New York	1985-1986	Research Assistant

PROJECTS:

Previously a scientist on the recently completed Chicago Urban Forest Climate Project. Research focused on Chicago's urban forest structure and urban forest air quality effects (air pollution removal, hydrocarbon emissions and carbon dioxide sequestration).

Currently working on the Chicago Urban Forest Air Quality Study: measuring pollution removal by urban forests in the Chicago area using eddy-correlation techniques; using Urban Airshed Model to evaluate effects of trees on local ozone concentrations.

SELECTED PUBLICATIONS (1991-1994):

Nowak, D.J. (in review). Estimating dry deposition of air pollutants to trees in Chicago, Illinois. *Atmospheric Environment.*

Nowak, D.J. (in review). Estimating leaf area and leaf biomass of open-grown urban deciduous trees. *Forest Science.*

Nowak, D.J., R.A. Rowntree, E.G. McPherson, S.M. Sisinni, E. Kerkmann and J.C. Stevens. (in review). Urban tree cover analysis. *Landscape and Urban Planning.*

Nowak, D.J. (in press). Urban trees and air quality. *Abstract Proceedings of the XX IUFRO World Congress.* Tampere, Finland.

Nowak, D.J. (in press). Urban Forestry. In: Lund G. (ed.) Chapter 6 - Forestry. In: *New Manual of Photointerpretation.* American Society for Photogrammetry and Remote Sensing. Washington, DC.

Abdollahi, K.K., D.J. Nowak, and Z.H. Ning. (in press). Quantifying ozone removal capacity of selected urban tree species. In: *1994 SAF National Conference Proceedings.* Anchorage, AK.

Nowak, D.J. 1994. Understanding the structure of urban forests. *J. Forestry*. 92(10):42-46.

Nowak, D.J. 1994. Modeling air quality effects of trees in Chicago, Illinois. In: *Abstracts of the Association of American Geographers 90th Annual Meeting.* San Francisco, CA. p. 277.

Nowak, D.J. 1994. Air pollution removal by Chicago's urban forest. In: McPherson, E.G, D.J. Nowak and R.A. Rowntree. *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project.* USDA Forest Service General Technical Report NE-186. p. 65-85.

Nowak, D.J. 1994. Atmospheric carbon dioxide reduction by Chicago's urban forest. In: McPherson, E.G, D.J. Nowak and R.A. Rowntree. *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project.* USDA Forest Service General Technical Report NE-186. p. 87-98.

Nowak, D.J. 1994. Urban forest structure: the state of Chicago's urban forest. In: McPherson, E.G, D.J. Nowak and R.A. Rowntree. *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project.* USDA Forest Service General Technical Report NE-186. p. 3-20; 139-164.

McPherson, E.G. D.J. Nowak and R.A. Rowntree (eds). 1994. *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project.* USDA Forest Service General Technical Report NE-186. 213 p.

McPherson, E.G. and D.J. Nowak. 1993. Value of urban greenspace for air quality improvement: Lincoln Park, Chicago. *Arborist News.* 2(6):30-32.

Nowak, D.J. 1993. Historical vegetation change in Oakland and its implications for urban forest management. J. *Arboric.* 19(5):313-319.

Nowak, D.J. 1993. Atmospheric carbon reduction by urban trees. *J. Environ. Manage.* 37(3):207-217.

Nowak, D.J. 1993. Compensatory value of an urban forest: an application of tree-value formula. *Arboric.* 19(3):173-177.

Nowak, D.J. and E.G. McPherson. 1993. Quantifying the impact of trees: the Chicago Urban Forest Climate Project. *Unasylva* 173. 44:39-44.

McPherson, E.G., D.J. Nowak, P. Sacamanp, S. Prichard, and E. Makra. 1993. *The Chicago Urban Forest Climate Project: Initial Results.* USDA Forest Service General Technical Report NE-169. 55 p.

Nowak, D.J. and S. Sisinni. 1993. Plant chemical emissions: their influence on local air quality and surrounding plants. *Miniature Roseworld.* 10(1):4-6.

Nowak, D.J. and J.R. McBride. 1993. Testing microdensitometric ability to determine Monterey pine urban tree stress. *Photogramm. Eng. Remote Sens.* 59(1):89-91.

Nowak, D.J. 1993. Remote sensing and urban forestry. In: *1992 SAF National Conference Proceeding.* Richmond, VA. pp. 103-108.

Nowak, D.J. and T.D. Sydnor. 1992. *Tree Species and Cultivar Popularity in the United States by Geographical Region.* USDA Forest Service General Technical Report NE-166. 44 p.

Nowak, D.J. 1992. "Smog Check Your Trees": Clouding the Issue. *Arborist News. 1(1):13-15.*

Nowak, D.J. and J.R. McBride. 1992. Differences in Monterey pine pest populations in urban and natural forests. *For. Ecol. Manage. 50:133-144.*

Rowntree, R.A. and D.J. Nowak. 1991. Quantifying the role of urban forests in removing atmospheric carbon dioxide. J. *Arboric.* 17(10):269-275.

Nowak, D.J. 1991. Urban forest structure and the functions of hydrocarbon emissions and carbon storage. *Proc. 5th Nat. Urban Forestry Conf.* Los Angeles, CA. pp. 48-51.

Nowak, D.J. and J.R. McBride. 1991. Comparison of Monterey pine stress in urban and natural forests. *I Environ. Manage.* 32:383-395.

Nowak, D.J. 1991. *Urban Forest Development and Structure: Analysis of Oakland, California.* Ph.D. Dissertation, University of California, Berkeley. 232 pp.

SELECTED PRESENTATIONS (1991-1994):

Nowak, D.J. and J.D. Dwyer. 1994. *Physical and Social Benefits of Urban Forests.* American Horticultural Therapy Association and American Community Gardening Association National Conference. Glencoe, IL.

Nowak, D.J. 1994. *Results of the Chicago Urban Forest Climate Project.* New York ReLeaf Conference. Syracuse, NY.

Nowak, D.J. and N.A. Richards. 1994. *The Costs and Benefits of Urban Trees.* New York ReLeaf Conference. Syracuse, NY.

Nowak, D.J. 1994. *Urban Trees and Outdoor Air Quality*. The Air We Breath Symposium. Architects for Social Responsibility, Boston, MA.

Nowak, D.J. 1994. *Your Health Depends on Trees.* New York University Environmental Action Coalition International Center for Environmental Education Seminar. New York, NY.

Nowak, D.J. 1994. *Modeling Air Quality Effects of Trees in Chicago, Illinois.* Association of American Geographers Annual Meeting. San Francisco, CA.

Nowak, D.J. 1993. *Urban Forest Effects on the Local Environment.* 68th Annual Meeting of the New Jersey Shade Tree Federation. Cherry Hill, NJ.

Nowak, D.J., H.W. Schroeder and J. F. Dwyer. 1993. *The Physical, Biological, Economic and Social Aspects of Urban Forests.* Governor Jim Edgar's Conference on Urban Forestry. Chicago, IL.

Nowak, D.J. 1993. *Urban Forest Atmospheric Interactions.* Guest Lecture: Northeastern Illinois University undergraduate class in Forest Resources.

Nowak, D.J. 1993. *Environmental Attributes of Urban Trees.* Environmental Geography Seminar. Northeastern Illinois University. Chicago, IL.

Nowak, D.J. 1993. *Urban Trees.* Elmhurst Great Western Prairie Tour and Festival. Elmhurst, IL.

Nowak, D.J. 1993.Air *Pollution Removal by Urban Trees.* 69th Annual International Society of Arboriculture Conference. Bismarck, ND.

Nowak, D.J. 1993. *Chicago's Urban Forest.* Kiwanis Club of Chicago. Chicago, IL.

Nowak, D.J. 1993. *Impacts of Savannah's Urban Forest.* Public Meeting. Savannah, GA.

Nowak, D.J. 1993. *Urban Forest Functions.* Western Illinois urban forestry students. Chicago, IL.

Nowak, D.J. 1992. *Urban Forest Structure and Function in the Chicago Region.* Northeastern Illinois Municipal Foresters Meeting. Westmont, IL.

Nowak, D.J. 1992. *Remote Sensing and Urban Forestry*. 1992 SAF National Convention, Richmond, VA.

Nowak, D.J. 1992. *Urban Forests and Acid Rain.* NAPAP Workshop on Urban Perspectives of Acid Rain. Raleigh, NC.

Nowak, D.J. 1992. *Chicago's Urban Forest and Air Quality Issues.* Chicago Bureau of Forestry. Chicago, IL.

Nowak, D.J. 1992. *Urban Forest Ecology*. University of Missouri Ecology and Evolution Seminar Series. Columbia, MO.

Nowak, D.J. 1992. *Evolution of Oakland's Urban Forest.* 68th Annual International Society of Arboriculture Conference. Oakland, CA.

Nowak, D.J. 1992. *Urban Forest History in Oakland, California.* USDA Forest Service Pacific Southwest Station Seminar Series. Albany, CA.

Nowak, D.J. 1992. *Atmospheric Issues of Urban Forest Energy Conservation.* Utility Arborist's Workshop: Tree Planting and Management for Energy Conservation. 68th Annual International Society of Arboriculture Conference. Oakland, CA.

Nowak, D.J. and E.G. McPherson. 1992. *The Chicago Urban Forest Climate Project.* Western Illinois urban forestry students. Chicago, IL.

Nowak, D.J. 1992. *The Chicago Urban Forest Climate Project: Quantifying the Environmental Effects of an Urban Forest.* USDA Forest Service Pacific Southwest Station Seminar Series. Albany, CA.

Nowak, D.J. 1992. *Air Quality Improvement through Urban Trees.* California Urban Forestry Council Annual Meeting and Conference. Sacramento, CA.

Nowak, D.J. and E.G. McPherson. 1991. *The Chicago Urban Forest Climate Project.* Northeastern Illinois Municipal Foresters Meeting. Park Ridge, IL.

Nowak, D.J. and E.G. McPherson. 1991. *The Chicago Urban Forest Climate Project.* Illinois State Water Survey. Champaign, IL.

Nowak, D.J. 1991. *Air Quality Impacts of Trees on: Carbon Dioxide, Pollution Absorption, Particulates, and Hydrocarbon Emissions.* Cooler by Design workshop at 5th National Urban Forestry Conference. Los Angeles, CA.

Nowak, D.J. 1991. *Urban Forest Structure and the Functions of Hydrocarbon Emissions and Carbon Storage.* 5th National Urban Forestry Conference. Los Angeles, CA.

Nowak, D.J. and E.G. McPherson. 1991. *The Chicago Urban Forest Climate Project.* Northeastern Illinois Planning Commission. Chicago, IL.

Nowak, D.J. and E.G. McPherson. 1991. *The Chicago Urban Forest Climate Project.* Chicago Bureau of Forestry. Chicago, IL.

Nowak, D.J. 1991. *Urban Trees: Impact on Air Quality and Fire.* Guest lector: Northeastern Illinois University undergraduate class in Forest Resources. Chicago, IL.

Nowak, D.J. 1991. *Urban Forest Structure, Function and Value.* 67th Annual International Society of Arboriculture Conference. Philadelphia, PA.

INVITED AIR QUALITY WORKSHOPS AND COMMITTEES (1991-1994):

1993	Workshop on Urban Tree Selection and Hydrocarbon Emissions. Los Angeles, CA.
1992	National Acid Precipitation Assessment Program Ecological Effects Working Group.
1992	National Acid Precipitation Assessment Program Workshop on Urban Perspectives of Acid Rain. Raleigh, NC.

Condensed Resume of S. TRIVIKRAMA RAO, Research Professor

Department of Atmospheric Science, State University of New York at Albany,
1400 Washington Avenue, Albany, NY 12222; and Director, Bureau of Air Research,
New York State Department of Environmental Conservation, 50 Wolf Road, Albary, NY 12233

EDUCATION:

State University of New York at Albany, Albany, NY
Ph.D. Atmospheric Science 1973

Andhra University, Waltair, India
M.Sc (Tech), Geophysics (with honors) 1965

Andhra Loyola College, Vijayawada, India
B.Sc, Mathematics, Physics and Chemistry 1962

SELECTED RECENT PUBLICATIONS:

Rao, S.T., Zurbenko, I. G., Henry, R., Porter, P.S. "Solving the ozone non-attainment problem in the Northeast," Submitted to *Environmental Manager,* April, 1995.

Flaum, J., Rao, S.T., Zurbenko, I.G. "Moderating the influence of meteorology on ambient ozone concentrations," Submitted to the *I Air and Waste Manage. Assoc.,* March, 1995.

Zurbenko, I., Rao, S.T., Henry R. "Mapping ozone in the eastern United States," *Environmental Manager, 1:* 24-30, February, 1995.

Rao, S.T., Zalewsky, E., Zurbenko, I. "Determining spatial and temporal variations in ozone air quality." *J. Air and Waste Manage. Assoc.,* January, 1995.

Rao, S.T. and Zurbenko, I.G. "Detecting and Tracking Changes in Ozone Air Quality." J. *Air and Waste Manage. Assoc.,* September, 1994.

Rao, S.T. 1993. "Is a NOx-focused Control Stategy the Solution to Reducing Urban Ozone Levels in the Northeastern United States?" *J. Air and Waste Manage. Assoc.* Vol. 43:1563.

Rao, S.T. and Sistla, G. 1993. "Efficacy of Nitrogen Oxides and Hydrocarbons Emissions Controls in Ozone Attainment Stategies as Predicated by the Urban Airshed Model." *Water, Air, and Soil Pollut.,* 67:95.

OTHER PUBLICATIONS:

Pagnotti, V. and Roa, S.T. 1986. "Spatial and Temporal Variability for Precipitation for Selected Regions of New York State and Relationship to Variability in Sulfate Deposition Measurements." *J. Air Poll. Cont. Assoc.*

Rao, S.T., Sistla, G., Eskridge, R.E., and Petersen, W.B. 1986. "Turbulent Diffusion Behind Vehicles: Verification of Roadway Model." *Atmos. Environ.*

Irwin, J.S., Rao, S.T., Petersen, W.B. and Turner, D.B. 1987. "Relating Error Bounds for Maximum Concentration Estimates to Diffusion Meteorology Uncertainty." *Atmos. Environ.*

Ku, J.Y., Rao, S.T., and Rao, K.S. 1987. "Numerical Simulation of Air Pollution in Urban Areas: I. Model Development, and II. Model Performance." *Atmos. Environ.*

Over 100 papers have been published in peer-reviewed literature to date.

RECENT GRANTS:

Niagara Mohawk Power Corporation. "Least-Cost Solutions for Ozone Attainment in New York State." 1994-1996. Principal Investigator. $350,000.

Empire State Electric Energy Research Corporation. "Mixing Heights, Ambient Levels of Ozone and VOC/NOx, and Their Impact on Ozone Attainment Stategies." 1994-1996. Principal Investigator. $100,000.

U.S. Environmental Protection Agency (OER). "Statistical Methods for the Analysis of Trace Level Environmental Data with Multiple Detection Limits.'" 1993-1996. Co-principal Investigator. $310,000.

National Oceanic and Atmospheric Association. "Statistical Techniques for Detecting Trends and Biases in Time Series of Upper Air Data. 1992-1995. Principal Investigator. $200,000.

U.S. Environmental Protection Agency (OAQPS). "Modeling Analysis of Photochemical Oxidants in the Northeast." 1992-1996. Principal Investigator. $300,000.

U.S. Environmental Protection Agency (OPPE). "Photochemical Modeling Evaluation of Urban Ozone Levels." 1989-1991. Principal Investigator. $105,000.

U.S. Environmental Protection Agency (OPPE). "Evaluation of Strategies for Controlling the Oxidant Problem." 1987-1989. Principal Investigator. $125,000.

U.S. Environmental Protection Agency (OAQPS). "Oxidant Modeling for New York Metropolitan Area." 1984-1986. Principal Investigator. $315,000.

National Oceanic and Atmospheric Association. "Development and Evaluation of Urban Air Pollution Models." 1984-1985. Principal Investigator. $40,000.

U.S. Environmental Protection Agency (ORD). "Performance Measures for Air Quality Models." 1983-1984. Principal Investigator. $70,000.