

Henry S. Cole & Associates, Incorporated
Science and Solutions for the Environment & Sustainable Communities

7611 South Osborne Road, Suite 201, Upper Marlboro, MD 20772
Phone: (301) 780-7990, Fax: (301) 780-7988,

Henry S. Cole, Ph.D., President

Website: www.hcole-environmental.com

A Description of the Effects of Great Lakes on Ontario Shoreline Emission Sources

Henry S. Cole, Ph.D.

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Summary: The Great Lakes have a strong impact on how air pollutants are carried by the wind and dispersed by atmospheric turbulence. It is important to understand the effect of the Great Lakes on air quality in southern Ontario for several reasons: (a) in Canada the highest population densities occur close the shorelines of Lakes Ontario and Erie (see Figure 1) and (b) many emission sources including power plants and heavy industries are located close to shorelines due to their need for large quantities of cooling and process water. Thus emissions from coastal sources have the potential to affect large numbers of people.

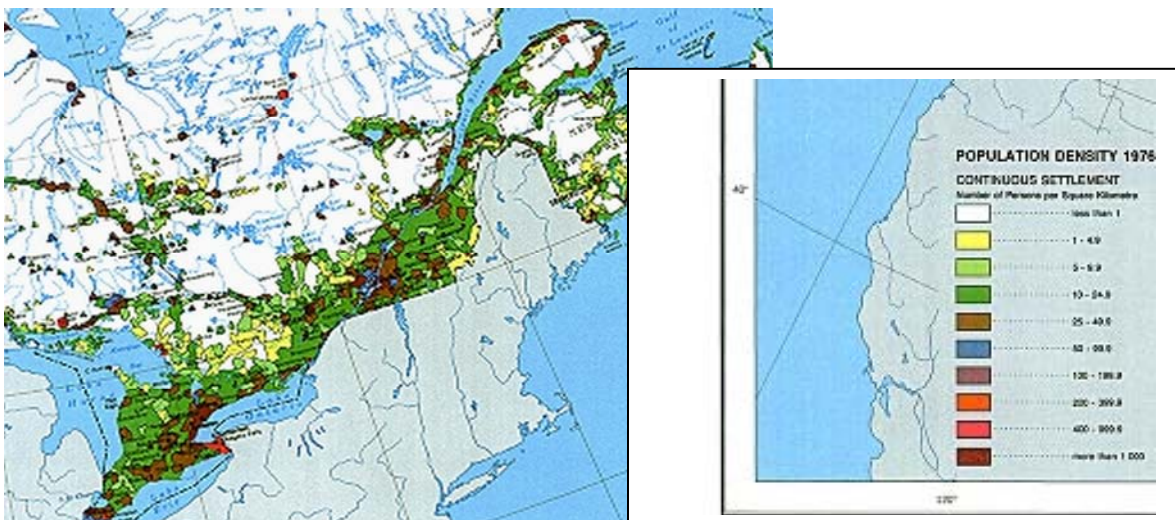


Figure 1: Population Density Map (Natural Resources Canada): Darkest areas, highest population density; see http://atlas.nrcan.gc.ca/site/english/aboutus/100anniversary/carto_exhibit/image028.jpg/image_view

During the spring and summer days the temperature of water in the Great Lakes is typically colder than the air above the lake. See Figure 2a. Flow over the cold lake means that temperature of the air increases with height. Increasing temperature with height is known as a temperature inversion which causes the air to be very stable. During such times the atmosphere has a tendency to suppress up and downward motions and there is little turbulence to disperse (dilute) pollutants. Pollutant plumes tend to remain intact over large distances. See Figure 2b.

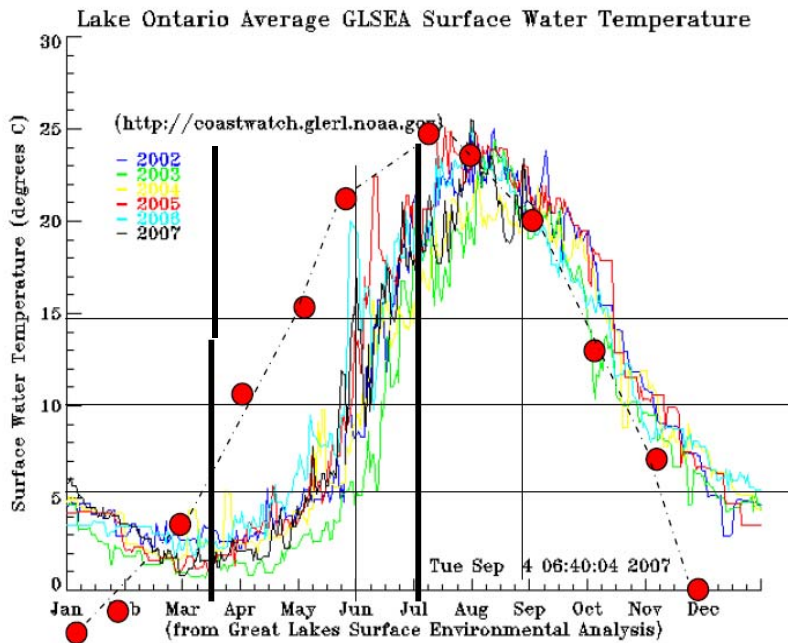


Figure 2a: Lake Ontario Surface water temperature and maximum daily air temperature at Kingston, Ontario. March-July period: air over land warmer than surface of L. Ontario.

Colored lines indicate average monthly L. Ontario surface water temperature from:

Daily average maximum air temperature Kingston, Ontario (red dots, dashed line).
Source: Kingston, Ontario, Canada

<http://www.theweathernetwork.com/statistics/C02014/caon0349>

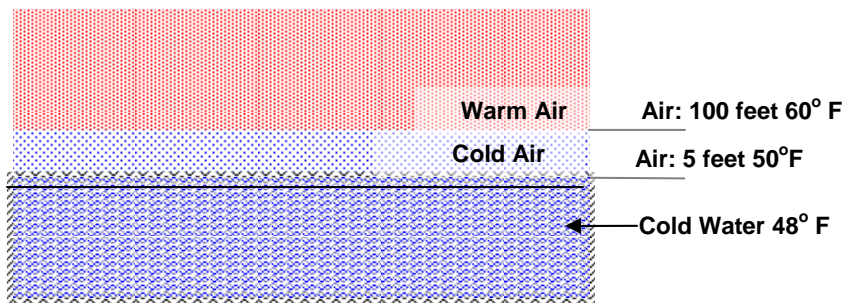


Figure 2b: Stable atmosphere with temperature inversion.

The effect of the stable air over Great Lakes can be seen in the following satellite photos. Over the much of the land areas convective turbulence leads to cumulus cloud formation. However, over Lake Ontario the cloud forming turbulence (vertical motions) is absent and so are the clouds. Note also that there is an absence of cumulus clouds over the land along the southern shoreline of L. Ontario; this resulting from a stable flow onshore (which limits cloud forming convective activity).



Figure 3: Satellite view of Great Lakes, early spring.

The stable air flowing over the lake also limits the ability of the atmosphere to disperse (dilute) air emissions. This photo in Figure 4 shows haze in stable air over L. Como in the Italian Lake District.

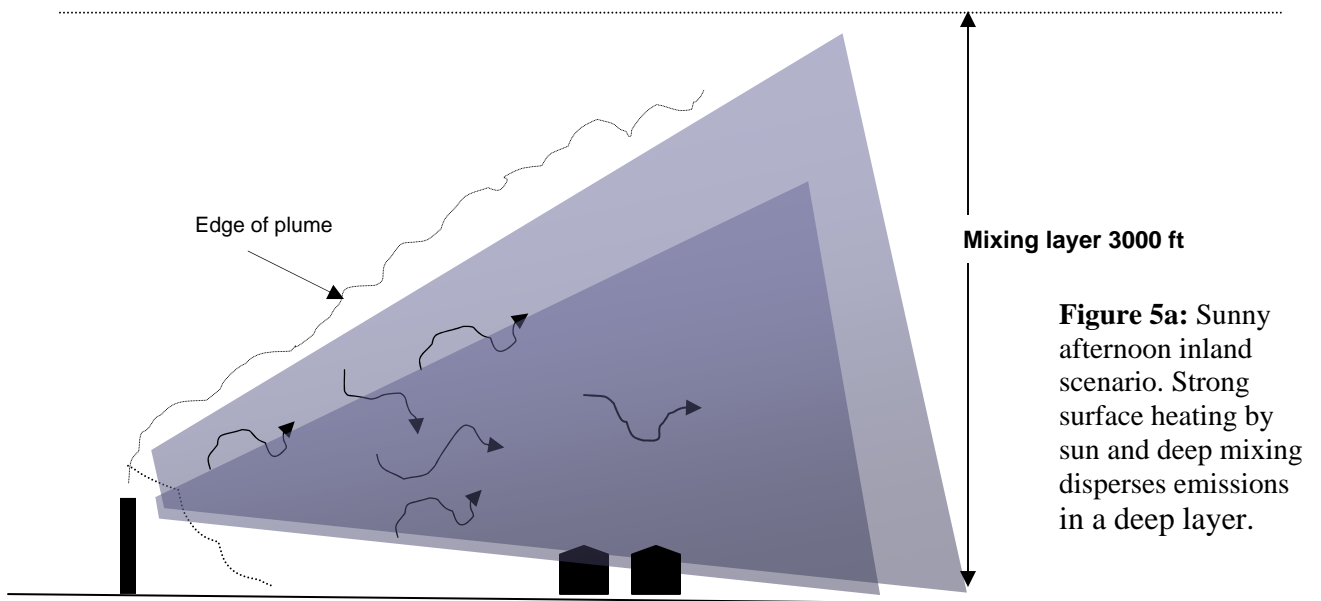


Figure 4: Lake Como with temperature inversion

Note the distinct bands of haze related to urban and industrial plumes. Clearly there is very little vertical mixing.

When the stable air flows onshore, it has a dramatic effect on the levels of air pollution from emission sources. Over the land, at least during the day time, the atmosphere tends to be unstable because the surface is heated by the sun. This promotes strong vertical mixing of the atmosphere, perhaps to a level of 3000 feet (about 900 m) shown in Figure 5a. However, when stable lake air flows inland during the warm season, the height of the mixing layer is limited, especially near the shoreline. On cloudy days low level plumes can be trapped below a shallow (Figure 5b). On sunny days with onshore stable low level emissions have a deeper layer to mix with as the onshore wind carries the plume inland (Figure 5c).

Shoreline fumigation: A plume from an elevated stack (e.g., from a power plant, incinerator, or cement kiln) will disperse quite differently from the low level plume (5c). This is shown in Figure 6. The stack from the source emits its elevated plume into stable air. Dispersion (mixing) is initially limited and the plume is narrow. As the air flows over the land surface it is heated from below and a turbulent mixing develops from the bottom up. The height of this mixing layer increases as the air moves inland and heating continues. At some point, (e.g. several kilometers inland, depending on the plume height) the mixing layer intercepts the plume. At this point the strong turbulence in the mixing layer brings the pollution in the plume to the ground; however the stable air above the plume prevents the plume from mixing with the air above. This condition known as shoreline fumigation often results in very high pollutant concentrations at the surface.



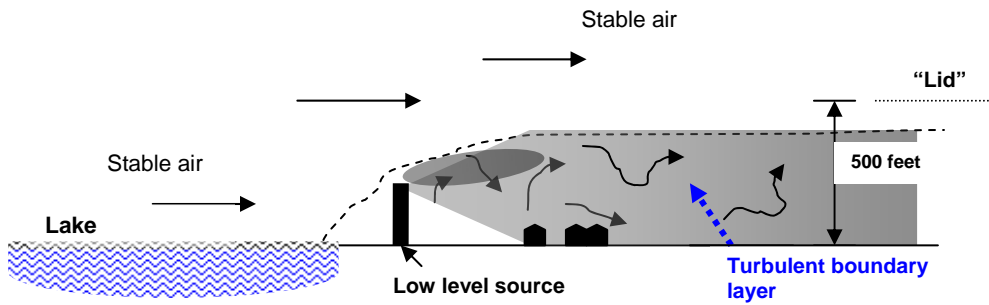


Figure 5b: Stable lake shore flows inland on a day with limited sun shine, relatively low emission sources are trapped below a shallow lid of stable air.

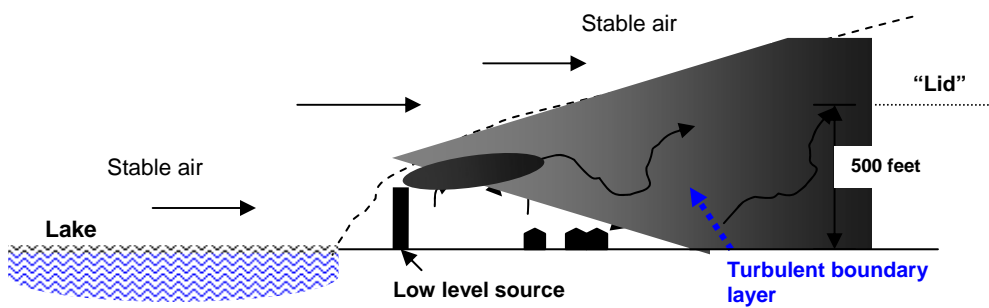


Figure 5c: Day with ample solar heating of surface; height of mixing layer grows as the air moves inland and increasingly deep mixing occurs.

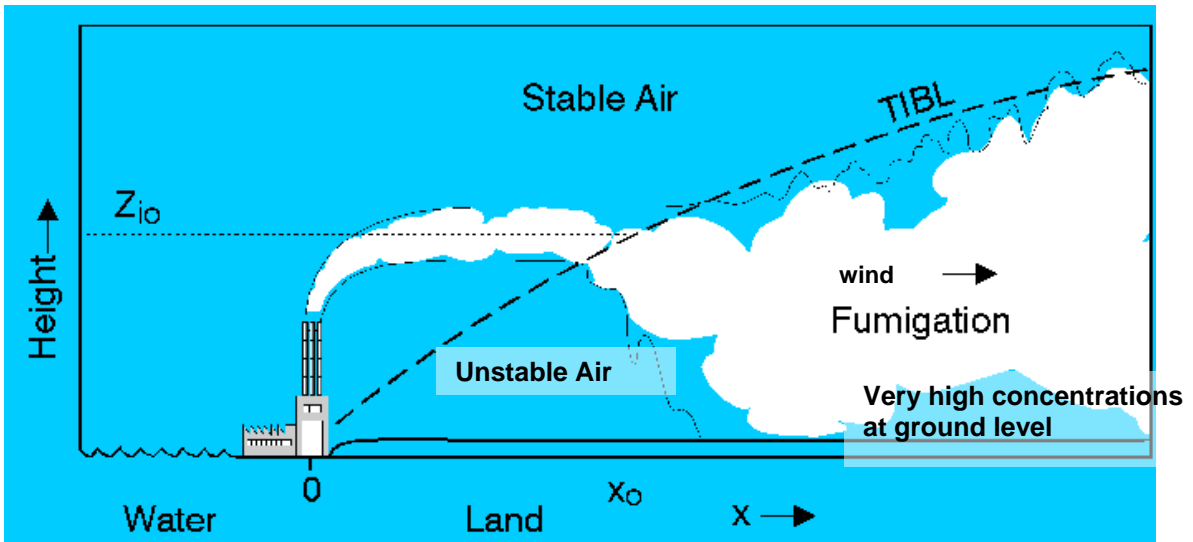


Figure 6: Conceptual diagram showing shoreline fumigation: stable, onshore flow, ample solar heating of surface.

Although, fumigation mainly affects elevated sources, the dilution of low level sources can also be restricted especially near the shoreline since the height of the mixing layer is restricted as shown in Figures 5b and 5c.

Shoreline fumigation is well known and has been investigated in coastal areas around the world including Lake Ontario. Photographs in Figures 7 and 8 are from a study on the west coast of Australia. Shoreline fumigation can persist along with high concentrations in the breathing zone – for many hours (mid to late morning to late afternoon).

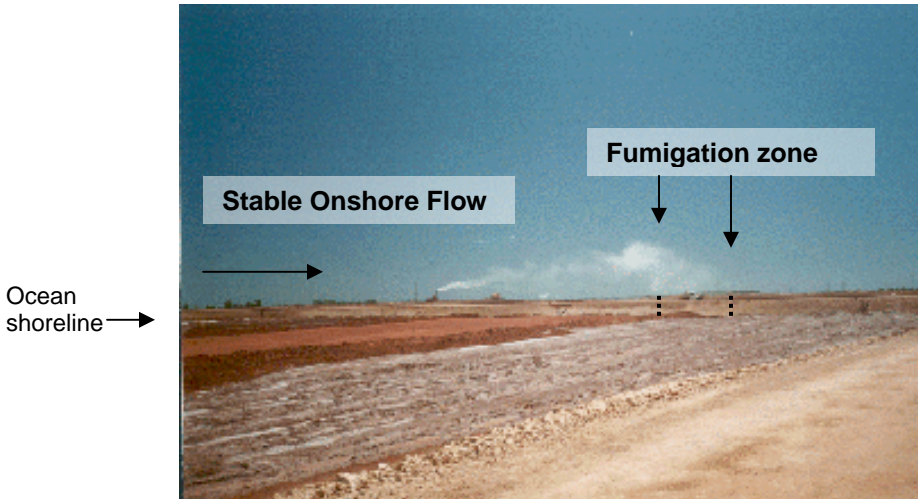
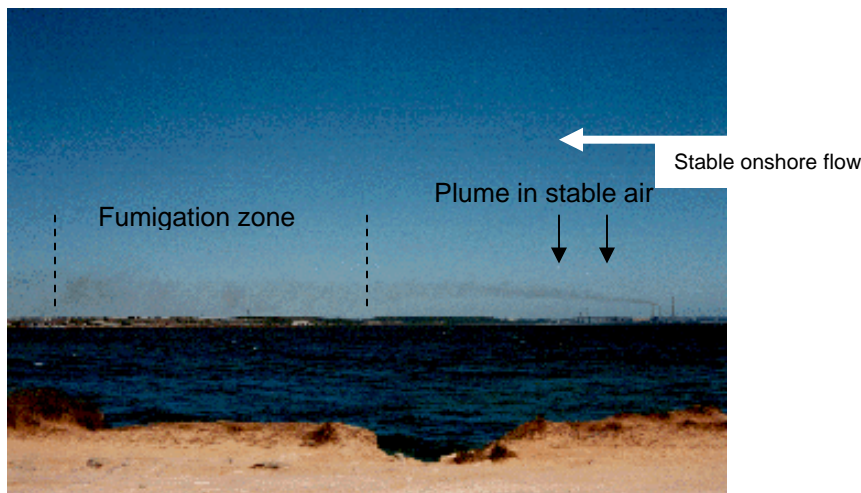


Figure 7: An early stage of fumigation of the State A plume as viewed from the Alcoa Residue Site. **Source:** Kwinana (Australia) Coastal Fumigation Study http://www.cmar.csiro.au/e-print/open/sawford_1997a.html



The clear demarcation between the particulate plume and clear air above illustrates how the stable air over the fumigation zone limits upward mixing. The only mixing is downward toward the surface.

Figure 8: Typical fumigation of the Stage A plume as viewed from Woodman Point. The plume is visible due to fly ash injection. **Source:** Kwinana (Australia) Coastal Fumigation Study http://www.cmar.csiro.au/e-print/open/sawford_1997a.htm Printing over the photo by Henry S. Cole, Ph.D.

Regulatory Agencies and shoreline dispersion: The effects of stable onshore flow have been recognized by regulatory agencies in Canada, Ontario, and the U.S. To predict

concentrations before an incinerator or power plant is approved, these regulatory agencies require estimates of annual and maximum pollutant concentrations using computer-based air quality models. For example, Ontario guidance on air quality modeling indicates the need to consider shoreline fumigation with models capable of simulating this condition. However, many permit applicants fail to do so and often result in estimates of maximum ground level concentration that are lower than actual concentrations. Other problems are as follows: (a) modelers often use meteorological data from inland weather stations that are not representative of shoreline areas where many sources are located and (b) air pollution monitoring networks are often inadequate to measure the impacts of coastal dispersion phenomena.

Conclusions: Neither the public nor a regulatory agency should accept an application or environmental impact statement for a shoreline emission source without requiring the application of models that simulate shoreline dispersion conditions including fumigation and that use meteorological sources in close proximity to the source.

Secondly, environmental assessments, air quality modeling, permitting and zoning should include lake effects on shoreline and near-shoreline sources. Most importantly government agencies would be prudent to avoid the location of emission sources such as incinerators along the Great Lakes shorelines. Especially in areas with high populations that already have unacceptable levels of pollution (i.e. non-attainment zones) and where numerous emission sources are already present.

The Author's Background: Henry S. Cole, Ph.D. was co-author with Walter A. Lyons, Ph.D. of a number of earliest journal articles to describe to describe shoreline fumigation. This research was conducted on the western (Wisconsin shoreline) of Lake Michigan. Cole's work also focused on the impact of Lake Michigan on photochemical smog (ground level ozone). During the 1970's and early 80's Cole served a senior scientist with the Office of Air Quality, Planning & Standards (OAQPS) at the US Environmental Protection Agency. There he served as Chief of the Model Application Section and helped to develop an early version of a point source model that incorporated shoreline fumigation. Dr. Cole's resume and a list of pertinent reports and publications follows.

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Henry S. Cole, Ph.D.
Summary of Professional Experience

- Since 1993 Dr. Cole has served as president of Henry S. Cole & Associates an environmental consulting firm that provides scientific support for a diverse clientele that includes environmental and community-based organizations, corporations and government agencies. Dr. Cole and the firm have provided research and technical assistance including environmental assessments and expert testimony on a variety environmental issues, including hazardous waste sites, municipal landfills, and industrial air pollution. He has provided expert testimony on the need to incorporate the impact of air emissions from coal burning power plants in utility rate structures following deregulation and provided a report on air quality impacts of the Kodak's Rochester facility to the NY State Attorney General's Office. From 2002-2005 he served as special Liaison for the Franklin County Ohio Court of Common Pleas to oversee air pollution and plant safety compliance and impact issues at Georgia-Pacific's resin plant in Columbus, OH.
- The company also promotes environmentally sound alternative products and technologies. Dr. Cole was co-recipient of the 2002 *Presidential Green Chemistry Challenge Award* (with Chemical Specialties, Inc.) for his work documenting the environmental advantages of ACQ, an arsenic-free and chromium-free alternative wood preservative. His work also helped prevent EPA's registration of a hexavalent chromium based preservative with technical comments to the Agency's Pesticide Office.
- Dr. Cole served as Science Director of Clean Water Action and Clean Water Fund from 1983 to 1992. In this role he worked with national coalitions to strengthen Superfund and RCRA to encourage waste reduction, recycling and safe disposal practices. His reports on municipal incinerators and mercury contamination received widespread media coverage and spurred successful campaigns to reduce incinerator emissions and mercury use. He also authored a series of reports and testified frequently before the U.S. Congress on Superfund and RCRA issues. Dr. Cole provided technical assistance to dozens of community organizations, corporations, and municipal governments in their efforts to obtain protective cleanups of Superfund sites and other hazardous waste and environmental release sites.
- From 1977-1983, Dr. Cole served as a senior scientist and section chief with U.S. EPA's Office of Air Quality Planning and Standards. In this capacity, he directed several programs that used air quality models to develop control strategies for stationary source, urban and regional air pollution problems. A principal area of expertise lies in the relationship between sources (emissions) and ambient air quality. Dr. Cole authored numerous journal articles and reports related to these issues.
- During the 1970's, Dr. Cole was an Associate Professor of Environmental Earth Sciences at University of Wisconsin-Parkside. In this capacity he conducted research programs involving air pollution meteorology and photochemical oxidants, led several environmental organizations and served as a member of the Wisconsin State Air Pollution Control Council and as an environmental advisor to former Congressman Les Aspin.
- Present and past professional associations: American Chemical Society, American Meteorological Society, Air Pollution Control Association, American Association for the Advancement of Science.

Dr. Cole received a Ph.D. in meteorology from the University of Wisconsin in 1969 with a minor in geology. His dissertation involved the reconstruction of past climates. He obtained his B.S. with High Honors from Rutgers University - College of Agriculture. He attained membership in Phi Beta Kappa and Sigma Xi (Honorary Research Society). His undergraduate majors included soil science and meteorology.

See publications list: Attachment 1.

Attachment 1

PUBLICATIONS, REPORTS, and TESTIMONY OF HENRY S. COLE, PH.D.

Atmospheric Science and Air Pollution

Final Report Of Environmental Liaisons' Investigation: Georgia-Pacific Resins Inc., Columbus, Ohio: Plant Safety And Environmental Issues, Submitted to Franklin County Court of Common Pleas, October 2005. (3 Volumes).

"The NJ Board of Public Utilities Must Act Decisively to Protect Public Health and Environment," Comments on the NJ Master Plan Phase II Submitted to PUC, February 27, 1997, (With D. Phillips). (Testimony focuses on air pollution impact of coal burning power plants and the need for incorporate limits on air emissions in NJ's deregulation plan.)

Mercury Warning: A Study of Mercury Contamination in the United States, Published by Clean Water Fund and Clean Water Action, Washington, DC, August, 1992. (Report focuses on atmospheric sources of mercury, and its fate, transport and biomagnification in the aquatic food chain.)

Testimony before the Environment and Public Works Committee, US Senate, on the "Mercury and the Resource Conservation and Recovery Act Amendments of 1991, September 12, 1991. (Report focuses on incineration and air emissions.)

Testimony before the US Environmental Protection Agency, October 19, 1990, on proposed NSPS and Emissions Guidelines for MSW Incinerators, "Strict Numerical Emission Limits are Needed for Mercury from Municipal Waste Combustors."

Testimony before the Subcommittee on Transportation and Hazardous Materials, Committee on Energy and Commerce, U. S. House of Representatives, May 11, 1989, on the Municipal Solid Waste Incinerator Act of 1989.

U.S. EPA, A Review of Recent Applications of the SAI Urban Airshed Model (Ozone/photochemical modeling), EPA-450/4-84-004, December 1983. "Needs and Application of Regional Air Quality Simulation Models for Oxidants in North America", International Conference on Long Range Transport Models, Research Triangle Park, North Carolina, April, 1983.

"Coastal (Air Pollutant) Transport and Diffusion: EPA Research and Development Needs," Workshop on Coastal Transport Processes, Brookhaven National Laboratories, Long Island, New York, July 1982.

"Application of the Airshed Model for Ozone Control in St. Louis", 75th Annual Meeting of the Air Pollution Control Assoc., New Orleans, June 1982.

"Evaluation of the Airshed Model Performance for St. Louis", Third Joint Conference on Applications of Air Pollution Meteorology, American Meteorological Society/Air Pollution Control Association, San Antonio, Texas, January, 1981.

"Basis for Simplified Modeling Approaches for Short Term NO₂ Concentrations" 75th Annual Meeting, Air Pollution Control Association, June 1981, Philadelphia (with E. Meyer and R. Kelly).

"Status of the Short-Term NO₂ Standard and Microscale NO₂ Modeling", Transportation Research Board (National Academy of Sciences), January, 1981, Washington, DC

U. S. EPA, "Summary Report on Modeling for the Avon and East Lake Power Plants", June, 1980.

"The Use of Atmospheric Dispersion Modeling for Incinerators Emitting Hazardous Wastes", Chapter for US EPA Background Document, Section 264.34 Standards for Hazardous Waste Incineration, Resource Conservation and Recovery Act, Oct. 1980 (with John Summerhays).

"Technical Basis for Developing Control Strategies for High Ambient Concentration of NO₂ "US EPA, OAQPS Guidance Document", September, 1980, (with Don Sennett and Ned Meyer), EPA 450/4-80-017.

"A Review of Techniques Available for Estimating Short-Term NO₂ Concentrations" Journal of Air Pollution Control Association, August, 1979 (with John Summerhays).

U. S. EPA, "The Impact of an NO_x Diesel Waiver on NO₂ Concentrations Downwind of a Major Line Source", A Report to the Office of Mobile Source Air Pollution Control, May 1979.

U. S. EPA, "Pittston Oil Refinery, Eastport, Maine: Potential for Violation of the PSD Increment", Report to Region I, EPA. June 1978.

"Photochemical Air Pollution Transport in the Chicago-Milwaukee Corridor, a Case Study", Annual Meeting American Association for the Advancement of Science, Washington, DC, February 1978.

"Photochemical Oxidant Transport: Mesoscale Lake Breeze and Synoptic Scale Aspects." Journal of Applied Meteorology, July 1976, (with Walter A. Lyons).

"Fumigation and Plume Trapping: Aspects of Mesoscale Dispersion on the Shores of Lake Michigan during Periods of Stable, Onshore Flow", Journal of Applied Meteorology, April 1973 (with W. Lyons).

"Air Pollution and Weather", The Science Teacher, December 1973.

"The Impact of the Great Lakes on the Air Quality of Urban Shoreline Areas: some practical applications with regard to air pollution control policy and environmental decision-making", 15th Conference on Great Lakes Research, Madison, Wisconsin, April, 1972.