Outdoor Air Pollution Activities at the Wisconsin State Laboratory of Hygiene

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Abstract

Outdoor air quality testing at the Wisconsin State Laboratory of Hygiene (WSLH) began in the 1970s with the advent of the federal Clean Air Act. Since then, air quality has emerged as a major environmental issue equal to or more important, from a public health standpoint, than water pollution. Epidemiological studies have shown that health issues are not limited to highly urbanized areas. In Wisconsin, local climatic conditions caused by the Great Lakes can result in unhealthy conditions even in relatively pristine areas. Air pollution affects thousands of Wisconsin residents each year, and it can be severe enough to require a physician's care. Although certain air testing (e.g., ozone) is done regionally by in situ monitors, the WSLH analyzes a variety of air pollutants including ozone precursor hydrocarbons, air particulates, and toxic metals. Exposure to aerosols containing metals may not follow typical patterns of air pollution based on routinely monitored particle mass.

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Introduction

Looking back 100 years, it was not until recently that outdoor air testing was added to the WSLH's capabilities. During the 1960s, national concern over outdoor air quality grew rapidly, particularly in areas like Los Angeles and New York City where smog and related problems became apparent. With the passage of the first edition of the federal Clean Air Act in 1970, the WSLH began its program to analyze pollutants in air.

The federal Clean Air Act provided the mandate for Wisconsin to develop statutes and administrative laws that are the basis for the state's air pollution regulations. These regulations are designed to not only protect public health and welfare, but also to prevent harm to the environment and private property (protecting the environment and property will not be discussed in detail here, but is perhaps best exemplified by the acid rain issue). The Wisconsin Department of Natural Resources (WDNR) has the responsibility to enforce the regulations, so it followed that WSLH, which provides the WDNR's laboratory support, directed major resources to the analysis of outdoor air samples.

Air Pollutants in Wisconsin

A few common air pollutants are found throughout the United States, including all regions of Wisconsin. In the latest editions of the federal Clean Air Act (1990 and 1997), these pollutants have been termed criteria air pollutants. Criteria pollutants include ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, lead, and particulates. These pollutants are regulated based on health criteria—hence the name criteria pollutants.

Ozone is a particularly interesting pollutant, because it is the primary ingredient in photochemical smog. Ground-level ozone is produced by the combination of light, heat, and pollutants from many sources, including fuel combustion and emissions from smokestacks. Local weather can also contribute to the problem (e.g., air inversions). However, as much as ozone production at ground level is a serious problem, a perhaps even more serious problem is the depletion of ozone in the upper atmosphere (stratosphere). Here, a thin layer of ozone protects the earth's surface by absorbing UV radiation. The formation of the stratospheric ozone layer is complex; suffice it to say that pollutants such as nitrous oxides, chlorofluorocarbons, and methane can deplete the ozone layer. An increase in UV light is not only a public health issue, but a threat to all life forms.

One might speculate that while photochemical smog is a problem in densely populated and industrial-

Table 1. Components of Atmospheric Particulate Matter in Wisconsin

Component	Predominance In PM10*	Predominance In PM2.5*	Primary or Secondary	Common Sources in Wisconsin	WSLH Measurement Technique
Sulfate Ion (SO4=)	Major	Major	Secondary	Atmospheric oxidation of SO2 to sulfuric acid	Ion Chromatography
Nitrate Ion (NO3-)	Major	Major	Secondary	Atmospheric oxidation of NO and NO2 to nitric acid	Ion Chromatography
Ammonium Ion (NH4+)	Major	Major	Secondary	Reaction of gaseous ammonia with sulfuric acid and nitric acid	Ion Chromatography
Organic Compounds	Major	Major	Primary	1) Motor vehicles 2) Wood and biomass burning 3) Food cooking	Thermal Evolution and Combustion (NIOSH Method 5040)
			Secondary	4) Photochemical oxidation of gaseous organic compounds	
Elemental Carbon	Minor	Minor	Primary	1) Motor vehicles 2) Fuel oil combustion 3) Wood and biomass burning 4) Uncontrolled coal combustion	Thermal Evolution and Combustion (NIOSH Method 5040)
Chloride Salts	Minor†	Minor	Primary	1) Resuspension of road salt	Ion Chromatography
Soil Dust	Major	Minor	Primary	2) Resuspension of road dust 3) Wind blown dust	Inductively Coupled Plasma Mass Spectrometry
Trace Metals	Trace	Trace	Primary	1) Industrial sources 2) Motor vehicle brake dust	Inductively Coupled Plasma Mass Spectrometry

*Based on typical annual composition in urban atmosphere: Major: Greater than 5% of particle mass, Minor: From 1-5% of particle mass, Trace: Less than 1% of particle mass.

† Chloride salts can be a major component of PM10 in winter periods

ized areas, the issues in Wisconsin are relatively minor. That is not the case. Problems frequently occur, particularly along the Lake Michigan shoreline where local meteorological lake effects in the summer favor ozone production. Even areas with very little industry, such as Door County, can have unhealthy ozone levels. From a physician's standpoint, air quality levels can be obtained through a scale created by the US Environmental Protection Agency (EPA) called the air quality index or AQI. The scale ranges from "good" (no health effects expected) to "very unhealthy" (people should limit outdoor exercise, especially people with respiratory disease and children). Maps showing daily ozone levels can be obtained from a web site (www.epa.gov/airnow/) or by calling the Wisconsin Daily Air hotline at 866 DAILY AIR (866.324.5924).

Another criteria pollutant of special importance to the health care community is particulate matter. Atmospheric particulate matter, or atmospheric aerosol, is composed of complex mixtures of salts, soil debris, carbonaceous material, trace metals, and water. Particulate matter is often size segregated for classification and regulation. Total suspended particulate matter (TSP) is nominally all particles with aerodynamic diameters of 60 microns or less. TSP is no longer regulated in the United States but is often measured for historical purposes. In 1987, the EPA required states to monitor and eventually control the concentration of atmospheric particles with aerodynamic diameters less than 10 microns, called PM10. The current EPA standard for PM10 is an annual average of 50 micrograms per cubic meter (µg/m3) of air and a 24-hour average of 150 mg/m3. In 1997 the EPA promulgated a standard for particles with aerodynamic diameters less than 2.5 microns, called PM2.5 or fine particulate matter. The current EPA standard for PM2.5 is an annual average of 15 mg/m3 and a 24-hour average of 65 mg/m3. Many regions of the United States that have been in compliance with the PM10 regulation are likely to exceed the new PM2.5 standard. It is important to recognize that these standards, which are set by EPA, are established to protect individuals with compromised health, whereas exposure to these levels of particulate matter may not adversely impact the health of healthy individuals.

The composition of fine particulate matter (PM2.5) and coarse particulate matter (PM10 minus PM2.5) are closely linked to their sources. Coarse particles predominately originate from mechanical generation process such as wind

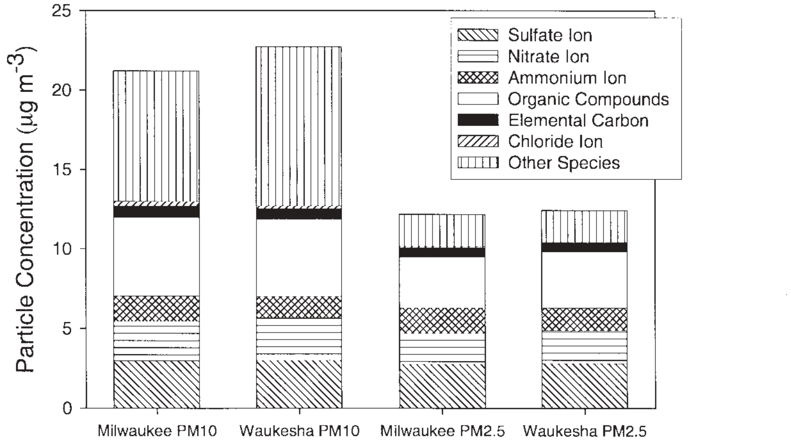

Figure 1. Annual average PM2.5 and PM10 composition Milwaukee and Waukesha—February 2001 through January 2002.

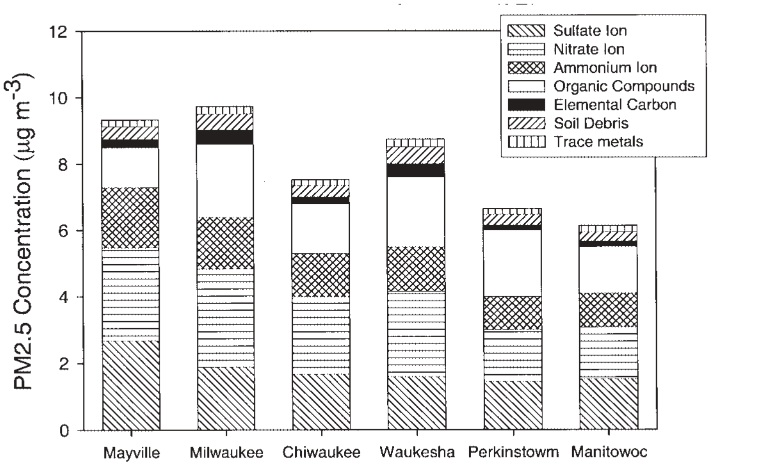

Figure 2. Monthly average PM2.5 composition measured at 6 Wisconsin air quality monitoring sites—March 2002.

blown dust, resuspension of road dust, tire wear, and other processes that tend to entrain dirt and dust into the air. In contrast, PM2.5 predominately originates from combustion sources and atmospheric chemical reactions involving gaseous pollutants that yield low vapor pressure products that condense in the atmosphere to form particulate matter. Particulate matter that is formed in the atmosphere from the reactions of gaseous pollutants is called a secondary aerosol. As a corollary, particles that are directly emitted from air pollution sources are called primary aerosols. Table 1 lists the constituents often measured in atmospheric particulate matter and their predominance in PM2.5 and PM10, along with an indication of their primary and secondary sources. As seen in Table 1, sulfate ion, nitrate ion, and ammonium ion are generally classified as secondary aerosols and are major constituents of PM2.5 and PM10. Organic compounds in atmospheric particles originate from both primary and secondary emissions and are also major constituents in both PM2.5 and PM10. Elemental carbon, trace metals, and soil debris originate from only primary sources.

Distribution of Particulate Matter Components in Wisconsin

Figure 1 summarizes the annual average PM2.5 and PM10 bulk composition collected at the WDNR air monitoring sites for the period of February 2001 through January 2002.[1] Sulfate, nitrate, and ammonia are similar in the PM10 and PM2.5 fractions. Since PM10 contains PM2.5, these substances must be part of the PM2.5 fraction. The PM10 fraction, however, contains more of the "other species" category and more organic compounds. "Other species" consists of coarse soil particles and trace metals.

In Figure 2, average PM2.5 measurements of concentration and bulk composition of particulate matter at 6 sites in March 2002 are given.[2] Although the absolute concentrations were in the range of 6 to 10 mg/m3, the relative composition of sulfate ions, nitrate ions, ammonium ions were almost identical. In contrast, the elemental carbon concentration in Milwaukee and Waukesha (major urban centers) were significantly greater than the concentrations in Mayville, Chiwaukee, Perkinstown, and Manitowoc (rural/small city areas). This demonstrates that spatial distributions of aerosol species that are dominated by secondary formation in the atmosphere (e.g., sulfate, nitrate, etc.) are relatively uniform over large spatial scales. Local sources do affect some atmospheric chemicals, such as elemental carbon. The message here is that an understanding of the distribution of atmospheric pollutants and how local sources influence, or do not influence, these pollutants is necessary to understand human exposure patterns.

Outdoor Air Monitoring at WSLH

The WSLH does not measure ozone directly in the laboratory.

Ground ozone levels are determined based on in situ monitors located throughout the state, but especially concentrated along the Lake Michigan shoreline. The WSLH does measure ozone precursors, including about 70 volatile hydrocarbons of relatively low molecular weight. Samples are collected in special containers called SUMA canisters. These samplers are carefully prepared in the laboratory and then put under a vacuum. When the vacuum is released, a predetermined amount of air fills the container. The WDNR collects the ground level samples at predetermined photochemical assessment monitoring stations (PAMS). Some samples are also collected at higher altitudes (mostly over Lake Michigan) by airplane. In the laboratory a special apparatus allows the air to be bled directly into a gas chromatograph for analysis. The ozone precursor hydrocarbon analyses are used by experts at the WDNR to predict ozone levels and to evaluate management strategies to reduce the ozone precursors.

In addition to ozone precursors, the WSLH analyzes specific compounds that are toxic pollutants transported by air. One group of compounds frequently measured are the polychlorinated biphenyls (PCBs), a well known industrial pollutant. Mercury is another atmospheric pollutant that is measured, as many Wisconsin's lakes, including many of our pristine lakes, are being polluted from mercury inputs from the air. Wisconsin is one of the first states to try to adopt rigorous mercury control standards.

Health Effects of Ground Level Ozone and Air Particulates

Ground level ozone, an important pollutant in smog, is clearly established as a health hazard. Breathing elevated levels of ozone can cause 1) throat irritation, 2) wheezing and coughing, 3) difficulty breathing, 4) increased numbers and severity of asthma attacks, and 5) aggravation of respiratory diseases such as emphysema and chronic bronchitis. Ozone has been likened to sunburn of the lungs, in that it can inflame and damage the lung lining. Within days the damaged cells are shed and replaced, similar to the way sunburn damages epidermal tissue. Repeated "burns" are thought to cause scarring, and, ultimately, loss of lung function. Those most at risk are children under 14, adults over 65, adults who spend time outdoors working or exercising and those with lung diseases. The US EPA[3] reports that about 1 out of every 3 people in the United States fall into the group that is most at risk. Consequently, smog-related air pollution qualifies as a health issue affecting a large part of the population.

Atmospheric particulate matter concentrations have been linked to human mortality and morbidity based on a variety of epidemiological studies reported in the past decade.[4] Although numerous time-series and cross-sectional studies have been conducted throughout the world, a few key studies have included health and air quality data from Wisconsin.[5-8] These studies, as well as most particulate matter epidemiological studies, used a centralized air quality monitoring site to represent the particulate matter exposure of the study cohort. The health-effect and exposure-assessment communities have recognized that these centralized monitoring sites do not properly represent the actual exposure of the cohort.[9] To this end, a number of studies have been reported that quantified the relationship between ambient concentrations of particulate matter at centralized monitoring sites and indoor particle concentration and personal exposures to particulate matter.[10-15] Other studies, such as Goswaami et al[16] have demonstrated that the spatial distribution of airborne particle mass is moderately uniform in many urban areas, which provides a basis to develop exposure models that reference centralized monitoring sites. It is important to recognize, however, that most particulate-matter epidemiological and exposure studies have been conducted in the context of exposure to atmospheric particulate mass and a few atmospheric particulate matter constituents such as sulfate ion, organic carbon, and elemental carbon.

The lack of similar measurements for trace metals and other toxic components of particulate matter have led many within the health-effect community to assume that all airborne pollutants are equally homogenous across an urban air shed—an assumption that is not true. At the WSLH, researchers have started analyzing the chemicals contained in lung fluids, and how some of these chemicals may provide information on how the lungs have been exposed and which air pollutants (such as ozone or ozone products and particles) affect the lungs most severely. Experiments have been ongoing with an articficial lung fluid, prepared to simulate interbronchial lavage fluid, and how this fluid might extract pollutants from respired particles. Such work is obviously important to understanding asthma and what triggers attacks. The WSLH is also participating in a research study to characterize exposure of welders to welding fumes, notably exposure to trace toxic metals.

Summary

Outdoor air quality testing is a major part of the WSLH's environmental and public health testing capabilities. Since the advent of the federal Clean Air Act in the 1970s, procedures for testing air have been constantly evolving. Air pollution is an important issue for physicians, since ambient conditions can cause acute health effects, especially with respect to photochemical smog. In Wisconsin, local climatic conditions brought about by large lake effects can cause smog formation even in non-industrial areas. Outdoor air pollution research, in which the WSLH is active, should lead to better understanding and treatment of respiratory disease.

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