ABSTRACTS

AIR QUALITY INDEX **AND** EMISSION INVENTORY FOR DELHI

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C O N T E N T S

SESSION 1: Air Quality Index

SESSION 2: Emission Inventory and Air Quality Modelling

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SESSION 1

AIR QUALITY INDEX

Role of Regulations, Advisories, and Notifications in Improving Air Quality

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Dr. Prasad is a physician by training, and has spent five years as a clinician, three years conducting air pollution health effects research, and twelve years in planning research and policy development. He has worked in India and South America, and has been living in the United States for last 15-years.

In California, state and local entities are responsible for controlling emissions from stationary and mobile sources to meet federal and state ambient air quality standards (AAQSs) to protect human health and welfare. In an effort to protect individuals from adverse air pollution impacts, local air pollution control agencies (for example, South Coast AQMD) routinely issue health advisories and public notifications when air pollutant levels are expected to exceed preset threshold levels for criteria pollutants and toxic air contaminants, respectively. The success of advisory and notification programmes is evident from the changes in activity patterns in schools, and from reductions in toxic pollutant emissions from many facilities. Guidelines for these programs have been developed in consultation with various state (Office of Environmental Health Hazard Assessment (OEHHA) and ARB) and federal agencies, cities, schools, the public-at-large, consumer interest groups, and the regulated community.

California is a state of great diversity and size spanning an area of about 156,000 square miles. For purposes of managing the geographically distinct air quality problems across the state, California is divided into 35-air pollution control districts, where an individual air basin may encompass administrative areas of one or more county governments. Without question, the most severe air pollution problem occurs in the South Coast Air Basin (SoCAB), which is commonly known as the Los Angeles Basin. In this regard, federal and state AAQSs for ozone, carbon monoxide (CO), and PM10 are routinely exceeded in the SoCAB. In 1997, the maximum 1-hr average ozone concentration recorded in the SoCAB was 0.205 ppm, with 144-days exceeding the state AAQS (0.09 ppm) and 64-days above the federal AAQS (0.12 ppm) (Table 1). For CO in 1997, the maximum 8-hr average concentration was 17.1 ppm, with 16 and 12-days recorded above the state (9.0 ppm) and federal (9 ppm) AAQSs, respectively. The highest 24-hr average PM10 concentration in 1997 was 224 g/m^3, with 54-days exceeding the state standard (50 g/m^3) and 6-days over the federal standard (150 g/m^3). The sizeable improvements in ambient air quality observed in the SoCAB are largely the result of an aggressive air pollution control programme to reduce emissions of both criteria pollutants and toxic air contaminants from stationary and mobile sources.

In the mobile source arena, the ARB has targeted two main parameters to control emissions from motor vehicles: exhaust emission levels from on-road motor vehicles and the properties of motor fuels. From light-duty motor vehicles (e.g., cars and small trucks) without tailpipe controls (i.e., pre-1968), emissions of hydrocarbons, nitrogen oxides (NOx), and CO are 10.6, 4.1, and 84 g/mile, respectively. Over the ensuing 26-years (Table 2), improvements in emission control technologies and vehicle durability enabled the ARB to adopt "Low Emission Vehicle" standards in 1994. These standards called for low and ultra-low emission vehicles that have to be certified to meet tailpipe emission standards that were < 1% for hydrocarbons, ~4% for NOx, and 2-4% for CO of the emission levels from pre-1968 motor vehicles.

The achievement of increasingly stringent tailpipe standards could not have been achieved without improvements in motor fuels. Over the same time span, the ARB has also adopted a suite of regulations to tighten the specifications of gasoline sold for use in motor vehicles (Table 3). Since 1991, with the adoption of Phase 2 of the California Reformulated Gasoline (CaRFG) Programme, stringent limits were placed on Reid Vapor Pressure (RVP), sulphur, aromatic, and olefin levels, along with the phase-out of leaded gasoline. Currently, levels of sulphur in gasoline are capped at 30 ppm by weight, RVP at 7.0 psi, and aromatics at 22.3 % by weight. The mandated reductions in fuel aromatic and olefin contents has the added benefit of reducing emissions of two major toxic air contaminants – benzene and 1-3, butadiene.

To address emissions from heavy-duty vehicles, which primarily utilize diesel, recent efforts have focussed on reformulating diesel fuel and lowering

Table 1. Selected Air Quality Values for Ambient Ozone, PM10, and CO in California's South Coast Air Basin

Year	Ozone		PM10		CO	
	Max 1-hr (ppm)	Days Above 0.09 ppm	Max 24-hr (g/m3)	Days* Above 50 g/m3	Max 8-hr (ppm)	Days Above 9.0 ppm
1980	0.490	210	—	—	25.8	98
1982	0.400	198	—	—	21.3	71
1984	0.340	209	—	—	19.7	73
1986	0.350	217	—	—	19.7	56
1988	0.350	216	289	65	27.5	66
1990	0.330	185	475	65	16.8	47
1992	0.300	190	649	52	18.8	32
1994	0.300	165	161	58	18.2	28
1996	0.239	141	162	51	17.5	23
1997	0.205	144	227	54	17.1	16

* PM10 is sampled on a 1-day in six basis; value is an estimate of number of days that the state standard is exceeded in one year

emissions from trucks and buses. Of special concern is the reduction of particulate emissions, which have been designated as a toxic air contaminant by the State of California.

For stationary sources, criteria pollutant emissions from major industrial facilities largely occurred in the 1970's. Since 1987, efforts have focussed on reducing emissions of toxic air contaminants through the adoption of control measures including those to reduce benzene emissions from gasoline service stations (adopted in 1987) and perchloroethylene emissions from dry cleaners (adopted in 1993). Other measures have been adopted to limit emissions of metals (for example, hexavalent chromium, arsenic, cadmium, and nickel), ethylene oxide, and dioxins.

To warn the general public in California about the health risks posed by criteria pollutants, local air pollution control agencies like the South Coast AQMD make regular predictions of air quality conditions and issue health advisories on a daily basis. Health advisories serve to provide the public with information on air quality conditions in different areas within an air basin. Qualitative terms such as good, moderate, or unhealthful are used to inform the public that air pollution levels have exceeded predetermined thresholds that could lead to adverse health impacts such as the impairment of lung function (resulting in a decrease in breathing capacity and exercise tolerance), excess coughing, or headache. For example, a "good" ozone day is characterized as a day in which the maximum 1-hr average ozone concentration is no greater than 0.12 ppm. At this maximum concentration, no reported adverse health effects are known to occur based on present knowledge. On "moderate" days, ozone concentrations may reach levels that are harmful to sensitive sectors of the general population like school children, the elderly, and people with heart and lung disease. When ambient levels are projected to reach concentrations that are harmful for these sectors of the population, a cautionary statement is issued to recommend changes in activity patterns at schools, such as to limit or avoid outdoor activities.

For toxic air contaminants, chronic exposures are associated with higher lifetime cancer risk, and the State of California recognizes the cancer-causing potential of a suite of airborne contaminants (for example, diesel particulate, benzene, perchloroethylene, and 1,3-butadiene). Because emissions of toxic air contaminants from stationary sources could be higher in surrounding areas, public notifications, to inform the public living in the vicinity of major source of airborne toxics, are required by law under Assembly Bill 2588 known as the "Hot Spots" bill. The aim of the notification process is to trigger action by facility operators to inform the people living near the facilities of the risk from toxic emissions released by the facility. Whenever the risk posed by the release of air toxics exceeds a predetermined level deemed as unsafe by a local air pollution control agency, the facility must notify the public of the risk posed by the emissions release. In the SoCAB, no existing facilities are allowed to exceed a maximum individual cancer risk (MICR) of 25 in a million (i.e., 2.5×10^{-5}) or a hazard index of 3.0. If they exceed this limit, emissions must be reduced in order to continue operations. The requirement for a public notification applies to all facilities with a MICR of 10 in a million (10^{-5}), a hazard index > 1 for toxic air contaminants, or a hazard index >

Table 2. Chronology of Light-Duty Vehicle Exhaust Emission Standards in California

Model Year	Hydrocarbons (grams/mile)	NOx (grams/mile)	CO (grams/mile)
Pre-Control	10.60	4.1	84.0
1968	6.30	—	51.0
1971	4.10	4.0	34.0
1972	2.90	3.0	34.0
1975	0.90	2.0	9.0
1977	0.41	1.5	9.0
1980	0.39	1.0	9.0
1993	0.25	0.4	3.4
1994 TLEV*	0.125	0.4	3.4
1994 LEV	0.075	0.2	3.4
1994 ULEV	0.040	0.2	1.7
1994 ZEV	0.000	0.0	0.0

*TLEV: Transitional Low Emission Vehicle; LEV: Low Emission Vehicle; ULEV: Ultra Low Emission Vehicle; ZEV: Zero Emission Vehicle

Table 3. Chronology of Gasoline Fuel Regulations in California

Year	Parameter(s) Controlled
1971	RVP, Bromine Number
1975	Sulfur, Manganese, Phosphorus
1976 & 1982	Lead
1990	Phase 1 California Reformulated Gasoline (CaRFG) — RVP, Lead Phase-Out, Deposit Control Additives
1991	Phase 2 CaRFG — Winter Oxygenates
1994	Phase 2 CaRFG Predictive Model

0.5 for lead. Different thresholds are applicable to new facilities or sources undergoing modification.

In the last three decades, California has made tremendous progress in reducing emissions of criteria and toxic pollutants using the command-and-control approach. While the ARB's long-term programs to reduce emissions from motor vehicles and toxic "hot spots" has played a major role in achieving the air quality improvement, the issuance of public notifications and health advisories has also been a contributing factor to improving environmental quality. By informing the public that criteria pollutant levels may reach unhealthful levels, the public-at-large has the information needed to make informed decisions as to what they can do to change their activity pattern and reduce personal exposure to those pollutant stressors. The levels at which notifications are issued is critical insofar as keeping residents living near toxic pollutant sources informed of the risk they face in their daily lives. However, because of the amount of effort required to issue public notifications and the inference that they may be "bad neighbors", many facilities have opted to reduce their emissions below threshold values, thereby eliminating the need for issuing a public notification. In this regard, the public notification process has indirectly led to voluntary reductions in the amount of toxic pollutants emitted in California. ■

Why Should an Air Pollution Index Include Exposure and How Would it be Done?

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Dr. Smith was elected in 1984 as one of "America's 100 Most Outstanding Scientists Under 40," and as UCB School of Public Health 1989 Alumnus of the Year. In 1997, Dr. Smith was elected to the U.S. National Academy of Sciences, the highest scientific honor bestowed upon a US scientist by his or her peers.

He has done research on air pollution in India since 1980: covering indoor and outdoor, urban and rural, and health-damaging and greenhouse-related.

From a health standpoint, it is not air quality but exposure quality that drives negative outcomes. General air quality is relatively convenient and inexpensive to measure compared to exposure itself, but a price is paid in accuracy. The question explored here is whether the decided advantages of ambient air quality measures always overcome their inherent disadvantages of being less tightly linked to health effects than exposure. In particular, I will discuss whether there are circumstances in which an index would be better constructed around exposure concepts rather than solely using ambient air quality measures.

Ambient air quality (AAQ) is attractive as the starting point for an urban air pollution index because it lies along the environmental pathway between sources/emissions, which are the points of control, and people's breathing zones, which are the locations to be protected. Thus AAQ both responds to change in control for a particular source and is an indicator of ill-health from that source, seemingly ideal characteristics. Like many complex systems, however, what works fine for a single part breaks down when the whole system is considered. In this case the system consists of many dozens of different source categories, some large — some small, some near — some far, some stationary — some mobile, some indoors — some outdoors, some nighttime — some daytime, etc. The inherent assumption, however, is that all source categories are linked to AAQ and human ill-health (exposure) in the same way.

This is demonstrably not the case, however. Recent detailed work has confirmed older rough estimates that dose or exposure effectiveness (EE, sometime called exposure efficiency or inhalation transfer factor) varies by many orders of magnitude for different sources. In other words, the fraction of released pollutant reaching the breathing zone (or actually inhaled) greatly depends on the location/timing of the source emissions with respect to the places people spend time. Releases from a large stationary outdoor source, for example, typically have 3-4 orders of magnitude lower EE than those released in or near residences. Neighborhood and mobile sources lie in between.

Such differences in EE overwhelm any possible difference in the way an index based purely on toxicity might be constructed. For illustration, they are much larger than the range in toxicity that may come about because of different particle characteristics. For example, although diesel particles because of their chemical nature may well be more dangerous than other urban particles, they are clearly not 1,000 times more so. Neither is PM2.5 1,000 times more dangerous than PM10. The range of EE for different locations of particle sources compared can easily be this large, however. This is not to say that there are not important scientific questions to be answered by exploring the particle factors that affect toxicity, but that from a policy standpoint, they are not the drivers of the uncertainty at this point. Let us not forget, of course, that it is the need for good policy that is the driver behind creating a good index.

In conclusion, I will explore why these concerns are of even greater importance in a developing-country setting than in developed countries. This is both because of the nature of typical source distributions as well as the limitation of societal resources for dealing with them. Exposure effectiveness is substantially easier and cheaper to determine than exposure itself, however. Thus, it seems practical to propose its inclusion within an index without adding too much cost or complexity. The resulting index, which would rely on ambient measures as well, could be a quite powerful tool for policy. ■

Air Pollution Impacts Across the World: A Focus on Particulate and sulphur Oxide Pollution

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The link between cardiopulmonary disease and extremely high concentrations of particulate and sulphur oxide pollution had been well established by the 1970s. Then, in the relatively short time period of 1989-1992, the results of several loosely connected epidemiological research efforts from the U.S. were reported. The largely coincidental convergence of these results in such a short time period resulted in a critical mass of evidence that prompted serious scientific reconsideration of the contribution of air pollution on human health even at relatively low concentrations. These, and more recent studies, including numerous studies in various countries throughout the world, have prompted serious reconsideration of standards and health guidelines for air pollution. Currently there at least 175 published epidemiologic studies of the health effects of particulate and sulphur oxide air pollution and a rapidly growing body of related toxicological studies. The basic inference being drawn from this large literature is that exposure to combustion-source fine particulate air pollution (including secondary sulfates and nitrates) is an important risk factor for cardiopulmonary disease and mortality. The health consequences are especially severe in highly polluted cities of many developing countries where controlling air pollution has not been a high public policy priority.

Most of the recent epidemiological effort has focused on effects of acute exposures. Nevertheless, several studies suggest that chronic exposure may be more important in terms of overall public health. The large number of acute exposure studies relative to the chronic exposure studies has less to do with public health relevance than the relative ease and expense of conducting acute exposure studies. The effects of chronic exposure may be more important in terms of overall public health relevance. Long-term, repeated exposure increases the risk of chronic respiratory disease and the risk of cardiorespiratory mortality. Short-term exposures can exacerbate existing cardiovascular and pulmonary disease and increase the number of persons in a population who become symptomatic, require medical attention, or die.

The epidemiological studies, including studies of acute and chronic exposure, generally observe morbidity and mortality effects from very low ambient levels up to very high levels. The concentration-response curves appear to be monotonically increasing and near linear with no clear “threshold level’ under which there are no effects. This general finding has been problematic when attempting to establish health standards and meaningful qualitative and quantitative air quality indexes.

The recent epidemiological and toxicological studies provide early, somewhat speculative, information on biological mechanisms, and evaluating who's at risk or is susceptible to adverse health effects. A systemic response to fine particle-induced pulmonary inflammation, including cytokine release and altered cardiac autonomic function may be part of the pathophysiological mechanisms or pathways linking particulate pollution with cardiopulmonary disease. The elderly, infants, and persons with chronic cardiopulmonary disease, influenza or asthma are most susceptible to mortality and serious morbidity effects from short-term acutely elevated exposures. Others are susceptible to less serious health effects such as transient increases in respiratory symptoms, decreased lung function, or other physiologic changes. Chronic exposure studies suggest relatively broad susceptibility to cumulative effects of long-term repeated exposure to fine particulate and sulphur oxide air pollution, resulting in substantive estimates of population average loss of life expectancy in highly polluted environments. Additional knowledge is needed about the specific pollutants or mix of pollutants responsible for the adverse health effects and the biological mechanisms involved. ■

Structure of the U.S. Air Quality Index (AQI)

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1. **Name of the Index**

In the U.S., the name of the Index was very important. Overwhelmingly, people preferred the name "Air Quality Index" to "Pollutant Standards Index." State and local public information officers, participants in EPA-sponsored focus groups, and commenters on the AQI proposal all preferred the name with a focus on air quality, rather than air pollution.

2. **Span and Breakpoints of the Index**

The U.S. AQI includes sub-indices for O_3 (8-hour and 1-hour averages), PM2.5 and PM10, CO, SO_2, and nitrogen oxide (NO_2), which relate ambient pollutant concentrations to index values on a scale from 0 through 500. This represents a very broad range of air quality, from pristine air to air pollution levels that present imminent and substantial endangerment to the public.

Historically, the index is normalized across pollutants by defining an index value of 100 as the numerical level of the primary NAAQS1 for each pollutant and an index value of 500 as the SHL.2 The scientific basis for the selection of these index values derives from the health effects information from the review of the national ambient air quality standards. Thus the AQI is bounded by breakpoints from a peer-reviewed assessment of the appropriate health effects information. For information about the SHL for each pollutant, see Attachment 1.

Below an index value of 100, an intermediate value of 50 (upper bound of the "Good" category) was defined either as the level of the annual standard if an annual standard has been established (for PM2.5, PM10 and SO_2), or as a concentration equal to one-half the value of the short-term standard used to define an index value of 100 (for 1-hour average O_3 and CO), or the concentration where the risk to the public becomes very small (8-hour average O_3).

Between the index values of 100 and 500, concentrations are set equal to the index values that generally reflect a linear relationship between increasing index values and increasingly severe health effects. For the 8-hour O_3 sub-index, an index value of 150 was set at 0.10 ppm. Based on the risk assessment done in conjunction with the review of the O_3 NAAQS, this is the level at which staff judged that exposures are associated with an increase in the number of individuals who could potentially experience effects, including possible respiratory effects in the general population and a greater likelihood of respiratory symptoms and breathing difficulty in sensitive groups.

Another way to span an Index would be to define categories as multiples of the ambient standard. This is done in Lithuania, where the formula for calculating the Index is:

OUI = CCO / DLKCO + CNO2 / $DLKNO_2$ + CSO_2 / $DLKSO_2$. The category "Slightly Polluted" ranges from $1.1 < OUI < 1.5$, the category "Average Polluted" ranges from $1.6 < OUI < 2$, and so forth. Victoria, Australia also expresses an index for any given pollutant is its concentration expressed as a percentage of the relevant standard.

3. **Number of Categories**

The U.S. AQI has six categories. Five categories are

AQI Category Index Values, Descriptors, and Colors

Index Values	Descriptor	Color	Message
0 — 50	Good	Green	Air quality is considered satisfactory and air pollution poses little or no risk.
51 — 100	Moderate	Yellow	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of individuals. For example, people who are unusually sensitive to O3 may experience respiratory symptoms.
101 — 150	Unhealthy for Sensitive Groups	Orange	Certain groups of people are particularly sensitive to the harmful effects of certain air pollutants. This means they are likely to be affected at lower levels than the general public. Some people may be sensitive to more than one pollutant. When AQI values are in this range, members of sensitive groups may experience health effects. The general public is not likely to be affected.
151 — 200	Unhealthy	Red	Everyone may begin to experience health effects. Members of sensitive groups may experience more serious health effects.
201 — 300	Very Unhealthy	Purple	Health alert of more serious effects for sensitive groups and the general population
301 — 500	Hazardous	Maroon	Health warnings of emergency conditions

useful for communication of the range of air quality values found in the U.S., and generally only five categories are presented by EPA. The sixth category links the AQI with the Emergency Episode program.

Although State and local air agencies must use these categories, index values and descriptors to report the AQI, these agencies are not required to display categories that are not used. For example, the Washington Department of Ecology displays only three categories when describing the air quality in Washington State (http://airr.ecy.wa.gov/Public/aqn.html).

From our experience in the development of the AQI, it is important to have enough categories to display variability in air quality and health effects information.

It is also important not to have more categories than needed to do so. At a Workshop EPA sponsored to solicit input about the AQI from State and local agencies, the message was clearly — keep the index as simple as possible, but consistent with the health message.

From the review of web sites from other countries, this seems to mean that at least four categories are required to adequately report air quality, but more than 10 is not necessary.

– Four categories: the United Kingdom, Mexico, and New Brunswick, Canada
– Five categories: Victoria, Australia
– Six categories: Lithuania
– Ten categories: Belgium, France (however, only three colors used)

4. **Category descriptors or numerical scale**

The U.S. AQI employs health-based air quality descriptors (i.e., Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy and Hazardous). In the process of revising the AQI, we considered using air quality descriptors with the categories since different pollutants have different effects within a single AQI category. Therefore, finding one health-based descriptor that adequately and appropriately describes all the health impacts within a category and across all pollutants was difficult. We also considered using a simple, numerical index without categories, like a temperature scale. However, comments we received from both the general public, and staff from State and local air quality agencies strongly supported using health-based descriptors.

In the selection of health-based descriptors, we were trying to convey, in general, the proportion of the population likely to be affected, and whether particular sub-groups were affected. We were unable to find a single word to modify "unhealthy" that would convey the idea that certain susceptible sub-groups within the population are at greater risk. For example, the term "moderately unhealthy" conveyed the message that air quality was slightly bad for everyone. The term "increasingly unhealthy" conveyed the message that as the day worn on air quality conditions would become progressively worse.

In contrast, the indices of most other countries do not use health-based descriptors

– Some use descriptors of air pollution levels. The United Kingdom describes air pollution as Low, Moderate, High or Very High.
– Some use air quality descriptors. The 10-category index of Belgium uses the air quality descriptors: Excellent, Very Good, Good, Fairly Good, Moderate, Poor, Very Poor, Bad, Very Bad, and Horrible. New Brunswick, Canada uses Good, Fair, Poor, and Very Poor. Mexico describes air quality as Satisfactory, Not Satisfactory (yellow), Not Satisfactory (pink) and Bad. In Lithuania, air quality is described as: Clean, Slightly Polluted, Average Polluted, Polluted, Very Polluted, Extremely Polluted.

None of the countries with Web sites listed in Attachment 2 use a simple numerical index to present air quality information.

5. **Use of color**

Because of the extensive use of color in television, print and Web-based AQI reports, we decided that it was important to have nationally uniform colors that are easily understood by the general public. Throughout the two-year period we coordinated with stakeholders on revisions to the AQI, the most heated and passionate arguments were over which colors should be associated with particular categories. Even though there was much disagreement about particular colors, there was general agreement about the need for a nationally uniform index and the importance of uniform colors to meet that goal. One of the many State commenters agreeing with us that such a requirement was necessary for national uniformity, noted that "Specific colors .... associated with each category should be required for national uniformity and ease of understanding. Anything less would defeat the purpose of a national index for comparing air quality in different locales." Another State commenter made the point that "Consistency of message is important, especially if the regional nature of many air pollution problems is to be communicated effectively."

The importance of developing appropriate colors for an AQI cannot be overstated. The State of North Carolina has been tremendously successful in quickly educating the public about the AQI through the use of colors. In the Raleigh/Durham area, the AQI has become a very well understood tool in just two years.

In selecting colors, consideration of weather maps might be very useful. A professional journalist in the Los Angeles focus group (described below) commented that the color scheme of the map makes sense, and he added that it is easy to understand because it is in keeping with the understanding that people have developed from reading the color-coded *USA Today* weather map. He added *"We recognize the red areas as hot/unhealthy. For me, when I first look at this, I'm going to assume that dark red is the worst."* Two or three other participants in the Los Angeles focus group agreed with this perspective.

6. **Index calculation**
The U.S. AQI is based on the pollutant with the highest Index value. It does not account for the effects associated with exposure to multiple pollutants. This is because scientists at EPA do not think that there is enough information to quantify and classify such effects. By using the reading of the highest monitor for each pollutant in an area to calculate the Index value for that pollutant, and by using the highest calculated Index value for the AQI, we believe that the Index is sufficiently precautionary. In addition, agencies are required to report the sensitive group statements for each pollutant with an Index value greater than 100. This gives members of sensitive groups the warning that they are at greater risk from the air quality. Since individual responsiveness to air pollution is highly variable, it may be extremely difficult to design a public communication system that will provide more accurate and effective warnings.

Lithuania adds the Index values of each measured pollutant to calculate the AQI. This is a more precautionary approach, but perhaps not based on quantitative assessment of health risk. On problem with using an very precautionary approach is that unless the predicted health effects occur, there can be a loss of credibility. Also, this type of approach could lead to the “crying wolf” syndrome, where if every day air quality is predicted to have serious health impacts, eventually the public will stop listening to the message. Lithuania is the only country that I could find that uses something other than the single highest pollutant to calculate the Index.

7. **Requirements for U.S. AQI reports (from the CFR)**
An AQI report must contain the following:

a. The reporting area(s) (the MSA or subdivision of the MSA).
b. The reporting period (the day for which the AQI is reported).
c. The critical pollutant (the pollutant with the highest index value).
d. The AQI (the highest index value).
e. The category descriptor and index value associated with the AQI and, if you choose to report in a color format, the associated color. Use only the following descriptors and colors for the six AQI categories:

For This AQI	Use This Descriptor	And This Color*
0 to 50	“Good”	Green
51 to 100	“Moderate”	Yellow
101 to 150	“Unhealthy for Sensitive Groups”	Orange
151 to 200	“Unhealthy”	Red
201 to 300	“Very Unhealthy”	Purple
301 and above	“Hazardous”	Maroon

* Specific colors can be found in the most recent reporting guidance (Guideline for Public Reporting of Daily Air Quality — Air Quality Index (AQI)).

f. The pollutant specific sensitive groups for any reported index value greater than 100. Use the following sensitive groups for each pollutant:

When This Pollutant Has an I ndex Value Above 100...	Report These Sensitive Groups...
Ozone	Children and people with asthma are the groups most at risk.
PM2.5	People with respiratory or heart disease, the elderly and children are the groups most at risk.
PM10	People with respiratory disease are the group most at risk.
CO	People with heart disease are the group most at risk.
SO2	People with asthma are the group most at risk.
NO2	Children and people with respiratory disease are the groups most at risk.

The AQI must be reported daily, however daily is defined as a minimum of five days a week. The reason for the five-day requirement is the concern that some State and local agencies may not be able to provide AQI reports on weekends.

Forecasting — forecasting is strongly recommended, but not required. The regulation states: You should forecast the AQI to provide timely air quality information to the public, but this is not required. If you choose to forecast the AQI, then you may consider both long-term and short-term forecasts. You can forecast the AQI at least 24-hours in advance using the most accurate and reasonable procedures considering meteorology, topography, availability of data, and forecasting expertise. The primary reason that EPA did not require forecasting is that most State and local agencies are already forecasting the AQI in major metropolitan areas.

Generally, agencies are encouraged to report index values for sub-areas of the MSA, if there is variability in air quality in sub-areas. Also, if a significant air quality problem exists (AQI greater than 100) in areas significantly impacted by the reporting MSA but not in it (for example, O3 concentrations are often highest downwind and outside an urban area), reporting should identify these areas and report the AQI for these areas as well.

8. **Process for Developing the AQI is Important**
The U.S. EPA coordinated extensively with experts from State and local air agencies, and regional organizations in the two years spanning from the beginning of the process to promulgation of the AQI final rule. EPA sponsored, or EPA staff attended:

AQI Workshop in Research Triangle Park NC, January 1998

AQI Workshop in Los Angeles CA, August 1998

Ozone Mapping Workshops in Baltimore MD (October 1997), Philadelphia PA (April 1998), Atlanta GA (December 1998)

Many meetings and conferences around the country (for example, STAPPA/ALAPCO Education and Outreach Committee meeting, VT, September 1998)

In addition to these workshops and conferences, in 1998 EPA sponsored eight focus groups held around the country. Five focus groups were comprised of members of the general public (Denver, Atlanta, Houston, San Bernardino, and St. Louis). Participants in these groups were selected to fit a profile that matched the demographic characteristics of each city in terms of ethnicity, age, gender, and education level. Another focus group, held in Miami, was comprised of people over 50 years of age with chronic lung disease (asthma, chronic bronchitis, or emphysema). A seventh focus group, held in Chicago, was comprised of parents of asthmatic children. All participants in this group had 12 years or less of education. The eighth focus group, held in Los Angeles, was comprised of journalists and was held during the 1998 Annual Meeting of the Society of Professional Journalists. (Individuals specializing in environmental journalism were intentionally not included in the focus group.)

The purpose of the focus groups was to evaluate how effectively the Ozone Map, the cautionary statements for ozone, and the ozone health effects booklet communicate information to the general public and target audiences. The following specific items were discussed during the meetings:

Different mock-ups of the Ozone Map were compared to evaluate how well the descriptors and colors used in the AQI convey the air quality message.

The cautionary statements associated with AQI were discussed to evaluate their effectiveness in providing cautionary information on ozone exposure in an understandable form.

The ozone health effects booklet (*Smog—Who Does It Hurt?*) was evaluated for how well the text conveys potential ozone exposure-related effects in an easily readable and understandable form, clearly identifies sensitive sub-populations, and adequately identifies ways to minimize ozone exposure.

9. **Important Considerations in Revising the U.S. AQI**

HEALTH CONSIDERATIONS: An expanded health message was incorporated into the basis for the rationales for the revisions to the O3 and PM standards. The expanded health message which emerged from the NAAQS reviews recognized the following: 1) there is no discernible health effects threshold, 2) the standards are not risk free, and 3) a focus on concentrations just below and just above the level of the standard, in the context of the AQI, is particularly useful for communication of effects to sensitive individuals and groups, without unduly alarming the general public. This expanded health message is reflected in the forms of the ozone and PM standards, which can result in attainment areas having several days above the level of the standard. Further, this message is consistent with the advice of the Clean Air Scientific Advisory Committee (CASAC), which urged expansion of the public health advisory system and communication to the public about the nonthreshold nature of the health effects of these pollutants.

At concentrations near the level of the standard, incorporate health effects messages that caution sensitive individuals or groups most likely to be affected. Below the level of the standard, when appropriate, add a health message within the Moderate category to caution extremely sensitive individuals. Above the level of the standard add a category to caution members of sensitive groups.

Use pollutant-specific health effects and cautionary statements to appropriately caution sensitive groups. Different conditions make individuals and groups susceptible to the effects of air pollutants, including: genetic sensitivity, medical conditions and exposure conditions. Because of this, different individuals and populations are susceptible to the effects of different pollutants. For example, the sensitive group for carbon monoxide includes individuals with cardiovascular disease, whereas the sensitive groups for ozone include active children, outdoor workers and people with respiratory disease, such as asthma.

Add a health-based criterion for the upper bound of the Good category. Historically, the upper bound of the Good category has been set at either the level of the annual standard (e.g., SO2 standard), or 50% of the short-term standard when there is no annual standard (for example, 1-hr ozone standard). To reflect the O3 NAAQS, a health-based criterion is more appropriate. The health-based criterion is set at the level where the estimated risk becomes very small, and/or the magnitude of the health effects becomes highly uncertain.

Media considerations: The AQI was updated to allow for effective use in the contemporary media. Some important considerations that became clear during the process of revising the AQI included:

Keep the Index as simple as possible. Have as few categories as possible, consistent with health message. Use short, media-ready statements. This is the genesis of the sensitive groups statements (for example, for ozone — children and people with asthma are the groups most at risk)

Use plain language (e.g., “unhealthy” instead of “unhealthful,” “Air Quality Index” instead of “Pollutant Standard Index”).

Use uniform colors that are consistent with those currently used in presenting weather information.

10. **Advantages and Disadvantages of the U.S. AQI**

ADVANTAGES

The AQI is bounded by breakpoints that are based on health effects information developed during the review of the national ambient air quality standards, a scientifically rigorous, peer-reviewed process. The extensive body of health effects information supporting the AQI is the basis for in-depth health effects documents (for example, Smog — Who Does It Hurt?, or the video Ozone and Your Patients' Health)

Attachment 1: Health Effects Associated with Current and Proposed SHLs

Pollutant	SHL	Health Effects
CO 1-hr average 8-hr average 45 FR 55066 8/18/80	125 ppm 50 ppm	1) aggravation of angina pectoris, intermittent claudication, and peripheral arteriosclerosis; 2) decreased exercise capacity in healthy persons; 3) changes in heart function and possible impairment; 4) reduced birth weight; 5) impairment of vigilance, manual dexterity, ability to learn and perform complex sensorimotor tasks such as driving
NO2 1-hr average 24-hr average 50 FR 25532 6/9/85	2.0 ppm 0.5 ppm	Increased Raw; decreased hemoglobin hematocrit, and erythrocyte acetyl cholinesterase; increased susceptibility to respiratory infection
O3 1-hr average	0.6 ppm	Cough, irritated nose and throat; chest pain on deep inspiration; reduced lung function even at rest; increased susceptibility to respiratory infection
PM2.5 24-hr average (AQI value of 500) 63 FR 67828 12/9/98 64 FR 42542 8/4/99	500 μg/m3	Cough; chest pain on deep inspiration; reduced lung function even at rest; increased acute daily mortality of sick and elderly
PM10 24-hr average 50 FR 13130 4/2/85	600 μg/m3	Cough; chest pain on deep inspiration; reduced lung function even at rest; increased acute daily mortality of sick and elderly
SO2 24-hr average (proposed) 60 FR 12492 3/7/95	0.29 ppm	Increased acute daily mortality associated with combination of SO2 and high particle concentrations

The process used in its development ensured that the AQI is simple; the descriptors and color used are readily understood by the general public and other groups that need to quickly comprehend the information. The AQI was designed for successful use by the print, radio and television media.

Reporting agencies are required to report sensitive group statements for all pollutants with an Index value greater than 100, so that all population considered to be at greater risk are cautioned.

Reporting agencies are required to report the Index value of the pollutant with the highest monitored ambient concentration.

DISADVANTAGES

Because reporting agencies are required only to report information about the pollutant with the highest calculated Index value, the potential additive or synergistic effects posed by exposure to multiple ambient pollutants may be missed. ■

Forecasting and Disseminating AQI in Delhi

JOSEPH CASSMASSI

South Coast Air Quality Management District, U.S.A.

Joseph Cassmassi is the Senior Meteorologist for the South Coast Air Quality Management District, Diamond Bar, CA. He is responsible for the daily air quality forecast program which encompasses day-in-advance predictions of maximum ozone, 8-hour average carbon monoxide, 24-hour average nitrogen dioxide and 24-hour average PM10 at 40 locations in the South Coast Air Basin. He is also responsible for meteorological modeling in support of the regional and point source modeling programs at the District. He received his B.S. in Meteorology from the City College of New York in 1975 and his M.S. in Meteorology from the University of California at Los Angeles (UCLA) in 1977. Mr. Cassmassi is also a member of the UCLA Department of Atmospheric Sciences faculty, where he teaches a general education course in air pollution. Prior to joining the District, Mr. Cassmassi worked as an air quality meteorologist in the environmental consulting community.

Program Objectives
- Communicate AQI to public
  - — real-time cautionary measures
  - — forecast health statements
- Short-term control program
  - — actions based on attained air quality
  - — forecast initiated emissions reductions

Delhi Profile
- Growing!
- Approximately 10 million residents
- 1,500 squared kilometers
- Traffic congestion
- Expanding urbanization
- Expanding industrial output

Terrain
- Generally flat - Yamuna river valley
- Great Indian Desert to west
- Alwar Hills to the southwest
- Mewat Plain to the south
- Ganges River Valley to the east

Pollutant Background
- Pollutants monitored
  - — particulate matter
  - — ozone
  - — sulphur oxides (sulfates)
  - — carbon monoxide
  - — nitrogen dioxide
- Toxics Pollutants
- Particulate levels significant

Expectations
- Success of forecasting and reporting AQI hinges upon
  - — reliable telemetry
  - — effective communications system
  - — relaying the message
  - — timeliness
- Public/School/Industry outreach programs are necessary

Forecasting Expectations
- Targets
  - — preventive health warnings
  - — mandatory emissions reductions
- Realistic goals:

— what level of pollution reduction is achievable?
— what level of pollution reduction is acceptable?

Forecast Accuracy
- Set realistic goals
- Prediction accuracy for categories of AQI
  — minimum acceptable accuracy 50%
  — target accuracy 65% or higher
- Prediction accuracy is dependent upon the number of AQI categories forecast
- Concentration forecast error ~ 10% of maximum observed concentration

Pollutants to Be Forecast
- Highest Priority
  — Particulate Matter PM10/PM2.5 (current levels > 300 ug/m^3)
  — Carbon Monoxide
  — Ozone
- Lesser Priority
  — Nitrogen dioxide
  — sulphur Dioxide
  — Sulfates

Components of Multi-pollutant Forecasting
- Understanding the Problem
- Developing the forecasting tools
- Communicating the right message

Understanding the Problem
- Seasonality of the different pollutants
- Pollutant specific impact zones
- Overlapping impacts
  — time
  — space

Developing Tools
- Availability of historical data
- Blending forecast requirements
- Adjusting for trends Developing Tools

AQI Prediction Algorithm
- Empirical Analysis/Pattern Recognition
  — fewer data requirements
  — site specific prediction
  — no requirement for emissions
  — flexible — requires limited time
- Numerical Simulation
  — data intensive including emissions
  — not flexible

Modeling Techniques
- Persistence
- Multivariate Regression
- Updated Stratified Multivariate Regression
- MOS Linked Multivariate Regression
- Nearest Neighbor Analog Prediction Algorithm

Air Quality Data Availability
- Minimum of 2-3 years of data
- Gases
  — hourly data
- Particulates
  — Hi Vol PM10 (6th – day)
  — Real-time PM10 sampling (BAM or TEOM)
- Special studies

Meteorological Data Availability
- Vertical temperature structure: soundings and pressure surface analyses
- Winds or surrogates: pressure gradients
- Humidity: surface and aloft
- Numerical Forecast Model Output

Daily Operational Requirements

Task	**Time (hours)**
Analyse air quality and weather	3
Run forecast model and evaluate	1
Disseminate AQI forecast	2
Observe developing air quality and developing next day's forecast	2

Importance of Forecast Data

Variable	**PM**	**Ozone**	**CO**
Inversion strength	High	High	High
Temperature	Medium	High	High
Humidity	High	Medium	Low
Heights Aloft	Medium	High	Medium
Cloud Cover	Low	High	Medium
Wind Speed	High	Medium	High
Persistence	High	High	High

Man Power/Liaisons
- Continuous communication between monitoring and forecast groups
- Liaison and communication between agencies (air quality - meteorology) to provide data
- Forecasting is a daily job requiring sufficient staff
- Liaison to media dissemination

Forecast/AQI Coverage
- Global forecast or AQI message
  — covers total area
  — single air quality description
- Forecast zones
  — source areas (notification for emissions curtailment actions)
  — receptor areas (area specific air quality notification)

Source/Receptor Areas (SRA)
Forecast Zones
Knowledge of Emissions Sources
- Which sources contribute
  — inventory
  — speciation profiles
- To what reasonable level can a source be asked to curtail emissions?
  — process
  — technology
- Monitoring & enforcement
- Exemptions

Burning Issues
- Control agricultural burning
  — criteria in forecast
  — smoke management program
- Banning open burning of refuse

— stagnant meteorological conditions
— seasonally

Typical Media Forecast
First Steps
- Evaluate ability to develop reliable data liaisons: forecasting and reporting
- Expand the monitoring network to provide enhanced characterization of problem
- Decide on the scope of the AQI/forecast message: global or site specific

Second Steps
- Develop basic conceptual model
- Evaluate forecaster's ability to identify the general profile
- Start with a categorical AQI prediction
- Develop confidence in forecast
- Data analysis to develop a simple model
- Develop confidence in model predictions

Minimum AQI Forecast Data Requirements
- Daily upper air sounding (00 UTC)
- Daily 500 mb (00 UTC) pressure surface analysis to characterize weather pattern
- Forecast of next day's 500 mb (00 UTC) pressure surface analysis
- Yesterday's air quality maximums
  — running 24-hour average PM & SO2
  — 1-hour and 8-hour ozone & CO

Acceptance
- AQI acceptance is tied to its simplicity in conveying a message
- AQI forecast needs to reasonably accurate
  — avoid "cry wolf"
  — capture events if not peak concentrations
- Industry will usually accept a program that is designed to be unbiased. ■

Some Fundamental Applications of Saturation Particulate Matter Sampling and Source-receptor modeling

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U.S. EPA

Mr. Yarbrough is an Environmental Scientist with the United States Environmental Protection Agency's Regional Office in Dallas, Texas. His main responsibilities include conceiving and implementing air quality field studies to more fully understand the pollution dynamics of specific geographic areas, thereby facilitating more effective control strategies. One of his major geographic areas of focus has been the border area between the United States and Mexico, where he has managed several large field studies. Mr. Yarbrough has bachelor's and master's degrees from the University of Georgia and is a member of the American Meteorological Society.

Mr. Michel did his undergraduate work at Texas A&M University in the Department of Marine Biology studying ichthyology of Texas Bays, Beaches, and Salt Marshes, and at Southwest Texas State University, graduating with a major in Marine Biology and a Chemistry minor. Mr. Michel has performed gas chromatographic, atomic absorption, and ultra violet analysis on food, soil, and water for the National Aeronautics and Space Administration and has investigated causes and treatment of women?s breast cancer in conjunction with Baylor College of Medicine in Houston, Texas. He has also done investigative research into sulphur and oil reservoir formation identification though the use of magnetic sector mass spectrometry.

Currently Mr. Michel is an Atmospheric Scientist with the Texas Natural Resource Conservation Commission Monitoring Division. His current responsibilities include management of the implementation and operation of the Particulate Matter 2.5 microns or smaller (PM 2.5) network in Texas.

OVERVIEW
- Saturation sampling deploys many samplers for a short period of time to find highest pollutant concentrations, to gauge population exposure to pollutants or to aid in source attribution.
- Source-receptor modeling uses chemical and morphological techniques on collected air samples, along with statistical techniques and meteorology to determine likely proportional source-type responsibility.

CHARACTERISTICS OF STUDY AREA
- El Paso, Texas, USA-Ciudad Juarez, Chihuahua, Mexico (population of 2 million).
- Area has a high percentage of unpaved roads, uncontrolled quarries, and uncontrolled motor vehicles.
- Area is a desert, which greatly increases natural dust burden.
- Area is also in complex topography, which complicates pollutant dispersion and understanding of windflow.

PURPOSES AND SCOPE OF STUDIES
- The purposes of the saturation sampling were to (1) identify the high PM concentration areas (2) estimate population exposure to high PM levels (3) estimate potential source areas by air parcel analyses.
- The main purposes of the preliminary source receptor-modeling were to determine elemental composition of size-segregated PM and to estimate the source types' proportional impacts.
- The saturation sampling was conducted in December 1989.
- The source-receptor study was conducted in December 1990.
- In El Paso-Ciudad Juarez, Fall-Winter have the highest man-made PM pollution.

EQUIPMENT USED
- For saturation sampling: AirMetrics mini-vol portable PM-10 sampler and four existing sites with windspeed, wind direction from 10-meter meteorological towers
- For receptor modeling study:

— PM-10 hi-vol sampler
— Dichotomous sampler (<2.5 um, 2.5-10 um)

- — Beta-gage PM-10 continuous sampler
- — 10-meter meteorological towers
- • Supplementary equipment:
- — Nephelometer (visibility scattering)
- — Annual denuder (for inorganic gases and aerosols)
- — Hi-vol sampler with PUF cartridge (for semi-volatiles)
- — Acoustic sounder (upper air winds)
- — Rawinsonde (upper air winds)
- — Tethersonde (winds, temperature)

SATURATION PM SAMPLING - METHODOLOGY

- • Mini-vol portable PM sampling with two sampling periods:
- — 3.5 hours for pinpointing maximum, short-term sites
- — 22 hours for determining adequacy of spatial coverage for longer-term periods
- • 3.5 hour samplers were deployed at 11 sites
- • 5 separate 3.5 hour periods were sampled December 8-10, 1989
- • Periods were:
- — 20:30-24:00, December 8
- — 06:30-10:00, December 9
- — 12:30-16:00, December 9
- — 20:30-24:00, December 9
- — 06:30-10:00, December 10
- • 22-hour samplers were deployed at 28 sites
- • These samplers were operated December 11-18, 1989, during the 14:00-12:00 22-hour period.
- • Analyses of air parcel back-trajectories using available wind speed and wind direction data from 10-meter meteorological towers

RESULTS

- • Initial use of mini-vol samplers for 3.5 hour sampling resulted in only 2 of 11 sites with data capture > 75%.
- • The biggest problem was poor battery performance at low temperatures.
- • Low temperatures averaged 27 deg. F. (-3 deg. C), with absolute minimum of 8 deg. F (-14 deg. C), causing many batteries to reduce deliverable voltage to samplers.
- • Data completeness improved in study period.
- • 3.5-hour samples: PM-10 maxima in western part of airshed; impacts from quarries, residential heating and international bridges
- • 22-hour samples: highest values occur in western part of airshed and in Ciudad Juarez.
- • High values in west probably due to downvalley flow from quarries, industry, residential heating emissions

SOURCE-RECEPTOR — METHODOLOGY

- • 12 24-hr PM-10 hi-vol samplers
- • 5 12-hr PM-10/PM-2.5 dichotomous samplers
- • continuous meteorological data at 11 10-meter towers
- • Continuous monitoring of CO, Nox, O_3, and SO_2 at 8 sites
- • Beta-gauge continuous PM-10 sampling at 1 site
- • Study period was December 3-21, 1990
- • Dichotomous sampling employed different filters:
- — teflon for general fine and coarse PM; analyzed by XRF
- — quartz for organic and elemental carbon; analyzed by 2-stage combustion analysis
- • Data analysis techniques:
- — spatial analysis
- — elemental species measurements by XRF to determine element present and mass loading
- — Factor analysis and principal component analysis were used to identify "factors" in the data set that account for as much of the variability in the data as possible
- — Estimates of the degree to which reentrained dust, smelters, vehicles, and biomass burning contributed to the PM-fine and PM-coarse concentrations
- • % FPM (soil) = [Si (ppm)/FPM*M] *100 where Si (ppm) is Si concentration in 12-hr dichot. sample, FPM is total FPM in 12-hr sample, and M is a multiplier from literature

POSSIBLE IMPLICATIONS FOR THE DELHI AREA

- • Saturation sampling can be done with low-cost, battery-operated samplers (TSP, PM-10 or PM-2.5) to identify maximum concentration areas, population exposure and geographic sources of interest
- • Introductory source-receptor techniques can be relatively quickly applied and yield more specific information on proportional source type contribution to PM problems
- • Mini-vol battery-operated samplers are designed for use with different filters and could be employed in an initial source-receptor study. ■

Ambient Air Quality Status in Delhi : NEERI's Experience

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He is ME in Environmental Engineering from Jabalpur University and has 60 technical reports and 25 research publications to his credit. He has been working on Air Pollution Impact Assessment, Air Quality Modelling, Environmental Impact Assessment and Environmental Audit

He was elected as Member of The Institution of Engineers (I) in 1996

In 1997 he represented NEERI to make presentation to and have discussion with Parliamentary Delegation Investing Fire Accident at Visakh Refinery, Visakhapatnam.

*He was awarded the "**Best Research Fellow**" award for conspicuous Contribution to R&D excellence of the Institute during 1990-1991*

He was also the country representative to Participate in "First Regional Conference of South Asian Countries on Environmental Assessment" held at Kathmandu, Nepal, December 4-7, 1999, Visit Sponsored by International Union of Conservation of Nature (IUCN), Nepal.

NEERI carried out an extensive ambient air quality monitoring study at 14, 16 and 2 locations in industrial, residential / commercial and sensitive areas respectively in Delhi as a part of Ministry of Environment and Forests (MoEF) sponsored project 'Carrying Capacity Based Developmental Planning for National Capital Region' in 1994. The parameters included in ambient air quality monitoring were SPM, SO_2 and NOx.

The ambient air quality data indicate SPM levels exceeded the stipulated standards of Central Pollution Control Board (CPCB) for designated landuse at all the ambient air quality monitoring locations. SO_2 concentrations exceeded the stipulated standards of CPCB at 7, 10 and 2 locations in industrial, residential and sensitive areas respectively. Similarly NOx concentrations exceeded the stipulated standards of CPCB at 4, 10 and 2 locations in industrial, residential / commercial and sensitive areas respectively.

Air Quality Index

Oak Ridge Air Quality Index (ORAQI) has been used (Air Pollution Indices, A Compendium and Assessment of Indices used in United States and Canada by G.C. Thom, W.R. Ott, 1976) to determine cumulative impact of SPM, SO_2 and NOx. The analysis of air quality indices indicates that most of the locations in Delhi either fall under dangerous (AQI>100) or Bad (AQI=80-100) categories representing poor air quality.

Emission Inventory

The emissions from Air Polluting Industries in Delhi State had been estimated to be 6800 kg/hr, 6922 kg/hr, 6840 kg/hr and 40140 kg/hr for particulates, SO_2, NOx and CO respectively. The emission rates were determined by carrying out stack monitoring in a sample industry in different categories.

The cumulative point area and line source emissions for particulates, SO_2, NOx and CO have been estimated to be 11047 kg/hr, 9994 kg/hr, 12788 kg/hr and 70965 kg/hr respectively.

The air quality monitoring carried out outside Delhi in some parts of National Capital Region also indicate poor air quality. ■

Air Quality Index for Data Interpretation and Public Information

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Vast amount of data that are generated as a result of air quality monitoring progmmnics complicates the meaningful interpretation (of data) and demands extensive statistical and computational efforts. Air Quality Index (AQI), although a useful tool devised to simplify interpretation of data, may result in some loss of scientific information. There are several types of AQls cited in the literature having different criteria and mathematical functions, at times, leading to confusion. There is no single universal AQI. In this research, adaptability of some of the existing AQls that have been used by various agencies is examined. The observations from preliminary study of the application of existing indices concluded that most of the indices suffer from problem of eclipsing and ambiguity. Air quality data analysis using various indices showed a large variation in the description of air quality for the same data set. In other words, for the same air quality data set, one index system may refer the air quality as *acceptable* and the other system as *very poor*.

The Oak Ridge Air Quality Index (ORAQI) that is based on additive function of subindices was examined for city of Delhi. It was observed that the index suffered from eclipsing problem and on more than 90 percent of time, the index estimated air quality as acceptable even when air quality standard for some of the pollutants were violated. The problem of eclipsing/ambiguity is the most undesirable characteristics of additive and multiplicative indices. In order to overcome the problem of eclipsing/ambiguity, the rnaximunn operator concept is invoked. The general form of the maximum operator is as follows:

I = max {I1, I2, ... In}

Where maximum value operator, *I* takes on the value of the largest of any of the subindices and *I* becomes the overall AQI. This formulation is free from the problem of eclipsing/ambiguity. The limitation of this formulation is the fact that it discards the values of subindices other than the one, which is the maximum. Since the maximum operator concept has distinct merit, many countries (USA, Taiwan, Malaysia, UK and Canada) have adopted this type of formulation; the mathematical functions for calculating subindices may vary from, one country to another.

In Indian context, the same approach of maximum operator has been adopted. The mathematical functions for calculating subindices are proposed after considering health criteria and subindex values from the literature particularly from the website of USEPA. Care has been exercised to make the index (and functions to calculate subindex) compatible with the Indian National Ambient Air Quality Standards. The pollutants included in the index are: S02, SFM, 03, N02, PMio, CO and SO2 x SPM. The index is classified in five categories; 0-100 good, 101-200 moderate, 201-300 poor, 301- 400 very poor and 401-500 severe. Since only three pollutants (SO2, SPM, and N02) are being monitored under the air quality monitoring programme, information on at least three pollutants must be available to calculate the index.

The investigations into data interpretation vis-a-vis the air quality index for a few cities in India have shown that the air quality worsens (very poor to severe) in winter months and also during the pre-summer months (in north India). The pre-summer months like March, April and part of May are characterized by dusty winds resulting in high SPM concentration. The air quality improves in monsoon and post monsoon period (good to moderate). The SPM was the responsible pollutant for index value over 95 percent of time. However, in Delhi the responsible pollutant for air quality index at a traffic intersection varies from one month to another; the responsible pollutants include SPM, CO, and PM10). It suggests that for large cities like Delhi the critical pollutant will not necessarily be SPM and information on other pollutants is also required for a proper representation of air quality through AQI.

The other important aspect of AQI is the dissemination of index with additional information to general public. For this purpose, a website is developed (presently under limited access) for display of nation-wide air quality index. The display system is implemented using HTML, JavaScript, Java and CGI (Common Gateway Interface)/Perl script. As the air quality data become available, online calculation of AQI is carried out and displayed as an Air Quality Meter showing index value with the pointer with animation on the screen. The website is comprehensively designed to indicate the pollutant responsible for index and the pollutants exceeding the standards. The developed website facilitates for inter/intra city comparison of AQI using multiple windows for online as well as historical data of air quality. The general public can access the information through interact and the other media agencies like newspaper, TV, radio can also down load the information and disseminate the information. ■

SESSION 2

EMISSION INVENTORY AND AIR QUALITY MODELLING

Measurements and Analysis of Criteria Pollutants in New Delhi, India, and the National Ambient Air Quality Standard

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Viney Aneja obtained his B. Tech from the Indian Institute of Technology, Kanpur, and MS and Ph.D. degrees from the Department of Chemical Engineering, North Carolina State University. Before joining the faculty of the Department of Marine, Earth and Atmospheric Sciences at North Carolina State University in May 1987, he conducted and supervised research at Corporate Research and Development, General Electric Company, New York, and at Northrop Service, Inc., Research Triangle Park, North Carolina, in the areas of environmental engineering and separations technology. He continued his environmental engineering research at North Carolina State University, investigating the transport and fate of pollutants in the environment and biogeochemical cycling of pollutants. He was promoted to the rank of Research Professor in 1995.

Dr. Aneja received letters of Commendation at Northrop Services, Inc. in 1977 and 1979. In 1983 he was awarded the "Noryl Division Proprietary Innovation Award" by General Electric, and in 1984 he received the Air Pollution Control Association Award for Distinguished Service for his work on natural emissions. In 1986 he received the Managerial Award at GE. He received the 1991 Faculty Research and Professional Development Award, and the 1991-92 Outstanding Extension Service Award at North Carolina State University. In 1993 he was certified as a Qualified Environmental Professional by the Institute of Professional Environmental Practice.

In 1998 the Air and Waste Management Association gave him its Frank A.Chambers Award, the Association's highest scientific honor. In 1999 he became a Fellow of the Air and Waste Management Association.

He was a visiting professor at University of Uppsala, Sweden in 1979; at Jawahar Lal Nehru University in New Delhi, India in 1980; and at The Arrhenius Laboratory in Stockholm, Sweden in 1985. He was invited to visit the University of Munich, Germany in 1988 to discuss the forest decline problem; to Berlin, Germany, during 1992 to discuss environmental issues in Eastern Europe; the Ministry of International Trade and Industry, Japan, in 1994 to discuss urban and rural air quality; to University of Sydney, Australia, and Hebrew University, Jerusalem, Israel during 1996 to discuss environmental issues; and the Ministry of Agriculture, Rome, Italy, during 1999 to discuss the role of intensively managed agriculture on the environment. During 1990 he served on the NASA panel for the selection of NASA Specialized Centers for Research and Training, and since 1994 he has served on the Exam Advisory Committee of the Institute of Professional Environmental Practice. From 1987-90 he served as the Site Director for the Mountain Cloud Chemistry Program. In 1990 he was appointed the Mission Scientist for the "Southern Oxidant Study"; in 1994 he was appointed Program Scientist for U.S. EPA and NSF funded Project "NOVA"; and in 1996 he was appointed the Science Team Leader for the North Carolina Department of Environment and Natural Resources Program on "Atmospheric Nitrogen Compounds: Emissions, Transport, Transformation, Deposition, and Assessment." He is Member of the Editorial Boards for Environmental Pollution, Chemosphere, Journal of the Air and Waste Management Association, and Environmental Manager; Member Technical Advisory Committee, Environmental Defense Fund; North Carolina State Scholar of the North Carolina Progress Board; and Member, Publications Committee for the Air and Waste Management Association. He is a consultant to the Federal and State governments, American Institute of Biological Sciences, and the private sector.

Dr. Aneja contributes regularly to the technical (125 scientific papers) and patent (5 U.S.) literature, and frequently organizes and chairs symposia at national and international meetings. He was instrumental in establishing a cooperative agreement in 1990 between North Carolina State University and Georgia Institute of Technology in environmental sciences; and in 2000 he was a member of the North Carolina Delegation to the Netherlands.

Ambient concentrations of Carbon Monoxide (CO), Nitrogen Oxides (NOx), Sulfur Dioxide (SO_2) and Suspended Particulate Matter (SPM) were measured from January 1997 to November 1998 in the center of downtown (the Indian Telegraphic Office (ITO) located on B.S.G. Marg) New Delhi, India. The data consists of 24-hour averages of SO_2, NOx, SPM, and 8 & 24-hour averages of CO. The measurements were made in an effort to characterize air pollution in the urban environment of New Delhi, and assist in the development of an Air Quality Index. The yearly CO, NOx, SO_2 and SPM concentrations for 1997 and 1998 were found to be 4810 ± 2287 mg m^{-3} and 5772 ± 2116 mg m^{-3}; 83 ± 35 mg m^{-3} and 64 ± 22 mg m^{-3}; 20 ± 8 mg m^{-3} and 23 ± 7 mg m^{-3}; 409 ± 110 and 365 ± 100 mg m-3 respectively. In general, the maximum CO, SO_2, NOx and SPM values occurred during the winter with minimum values occurring during the summer which can be attributed to meteorological conditions in the region. Ratios of CO to NOx (~50) indicate that mobile sources are the predominant contributor to the urban air pollution problem in Delhi. SO_2 to NOx ratios (~0.6) indicating that point sources are contributing to SO_2 pollution in the city. Background CO concentrations in

New Delhi were also calculated (~1939 mg m^{-3}) which exceed those for Eastern USA (~500 mg m^{-3}). Further, all measured concentrations exceeded the NAAQS except for SO_2. SPM was identified as exceeding the standard on the most frequent basis. ■

Development of Emission Inventories for Air Quality Plans CSE Workshop on Air Quality Index and Pollution Inventory New Delhi, India June 2000

LINDA C. MURCHISON
Ph.D., Chief of the Emission Inventory Branch, California Air Resources Board, California Environmental Protection Agency

Dr. Linda Murchison is Chief of the California Air Resources Board's Emission Inventory Branch. She has been at the Air Resources Board for nearly 20 years and during that time has worked on State Implementation Plans and on regulations concerning consumer products. In 1985, she became manager of the Stationary Source Emission Inventory Section, and in 1987, manager of the Toxic Emission Inventory Section. During her time as manager of the Toxic Section, she was responsible for the development of the first toxic emission reporting regulation that required facilities to report their toxic emissions for purpose of assessing public risk. Dr. Murchison is a member of the steering committee for the Emission Inventory Improvement Program — a partnership between American State and local air pollution agencies and the U. S. EPA. The Emission Inventory Improvement Program has produced 10 volumes of inventory methods and tools. Dr. Murchison is also Chair of the California Emission Inventory Technical Advisory Committee and serves on many other national and state committees.

An emission inventory is a comprehensive listing of the sources of air pollution and an estimate of their emissions. This information is usually developed for specific geographic areas and for given time intervals. Inventories along with air quality monitoring are the scientific foundation upon which air quality plans are built. While monitoring data identifies the location and severity of the problem, emission inventories show the relative contribution of different sources. Inventories are used as inputs to photochemical modeling to predict air quality impacts of emission reductions and to determine which types of control measures are needed to lower the ambient air pollution levels in the area. In addition, inventories can be used to show emission trends over time and as inputs to health risk assessments.

Emissions come from a multitude of sources including stationary sources such as refineries, chemical plants, and electric utilities; area-wide sources such as paved and unpaved roads, consumer products and paints; and mobile sources which consist of on-road motor vehicles, other mobile vehicles, and off road equipment. These sources can emit many pollutants including organic gases, oxides of nitrogen, oxides of sulfur, carbon monoxide, particulate matter, and specific toxic substances. Emissions are expressed in inventories as annual average emissions, seasonal emissions, forecasted (or future year) emissions, and gridded/ modeling emissions.

Dr. Murchison will discuss California's experience in the preparation of inventories. California State law mandates that the ARB prepare an emission inventory, using to the extent possible information from other state and local agencies. The ARB has been doing that since the late 1960s, and works with many state and local agencies as well as industry representatives to develop the inventory. Inventories are prepared annually in California to support air quality planning, regulation development, and for tracking emission reductions. The statewide inventory is one of the most comprehensive in the United States, and includes criteria and toxic emissions from over 800 emission categories and over 12,000 individual stationary sources. California also has an extensive research program to develop new methods and estimation tools to better characterize the emissions contributing to California's air quality. Each inventory year incorporates these new emission data and tools, resulting in improvements in the accuracy of the inventory. Examples of several categories and how emissions have changed because of better estimation tools will be given. It is California's experience that time and resources must be committed to the development of inventories in order to ensure the air quality plans are based on reliable, defensible information.

Dr. Murchison's presentation will also include a summary of California emissions and emission trends. Over the past 15 years, California's emissions have been decreasing, and as a result, air quality has been steadily improving. This improvement in air quality has occurred in spite of increases in population, vehicle miles driven, and the overall economy. California's inventory has been an effective tool in identifying the sources that needed control and tracking those emissions over time.

In the third section of the presentation, the focus will be on planning for the development of inventories, data collection and data management. Careful planning of the inventory procedures will greatly facilitate the process and can prevent the need for costly inventory revisions. Dr. Murchison will outline a process that will help determine the nature and extent of the inventory needed. Defining the overall project objectives and how the inventory is to used is the first step. That in turn determines the scope and type of inventory needed. Those responsible for preparing inventories need to consider the size of the geographic region to be considered, the type of pollutants of concern, and the sources. If the inventory is to be used in photochemical modeling, spacial and temporal data must be collected, and the inventory must also be speciated into its constituent components. Selection of the most appropriate methods and estimation models is dependent on the intended use of the inventory, availability of data, practicality of method, priority of the categories, and time and resources. Dr. Murchison will provide information on where to find available methodologies and models for emission estimation.

Data collection and management are also important elements in preparing an inventory. In planning for data collection, it will be important to consider the level of detail that will be needed to support the objectives. Quality assurance programs need to be established to ensure that the data are of a quality that will result in an accurate inventory. Data quality objectives should include accuracy/uncertainty, completeness, representativeness, comparability, consistency, and reasonableness. In addition, documentation of the methods used, sources of information, assumptions, and calculations is essential. Equally important is design of the database that will be used to store and manage the data.

The presentation will also include a short explanation on how to prepare modeling inventories for input to air quality models. This is the most resource intensive type of inventory and deserves some extra discussion. A modeling inventory must be spatially and temporally resolved, and represent hourly emissions during a specific air quality episode. Preparation of such an inventory must be done in close cooperation with those running the models in order to define all the inventory-input data needed.

At the conclusion of the presentation, Dr. Murchison will talk about the cost of producing emission inventories. The resources needed are dependent on the objectives and overall expectations of those using the inventory. Dr. Murchison will share some information on cost, and lead the workshop participants in a discussion concerning the resources that might be needed to prepare an inventory for the city of Delhi.

In summary, emission inventories are the foundation upon which air quality plans and strategies are based. Air quality plans rely on emission inventories to identify the sources and pollutants contributing to the problem. Planning for the preparation of these inventories is an essential step in o ensuring that air quality plans have a sound, scientific basis. ■

Relative impact on health and environment from various technical measures on vehicles and fuels

PETER AHLVIK
Ecotraffic ERD3 AB, Sweden

Worked as a development engineer at Scania, one of the leading manufacturers of heavy-duty trucks, from 1985 to 1992. Advanced development concerning emissions and performance was among his responsibilities at Scania. From 1992 to 1995 he worked at NUTEK, a governmental agency for government-funded research and development (R&D) in Sweden, as a principal program manager. His responsibilities were mainly: alternative and conventional driveline concepts, alternative and conventional fuels and environmental issues concerning road, maritime and airborne traffic.

From 1995 to 1997 he worked at Motortestcenter (today: MTC AB) as a project manager. MTC is a subsidiary of the Swedish Motor Vehicle Inspection Co.. Some projects where he was the project manager were:

- *Electric vehicle testing. A test program is carried out comprising 15 different tests, such as for example energy consumption, range, magnetic fields and noise.*
- *The influence of engine block heaters on exhaust emissions and fuel consumption under cold start conditions (two SAE papers published on this subject, SAE 970747 & 972908).*
- *Emissions of greenhouse gases from heavy-duty vehicles. A survey of the technical scope for reduction of greenhouse gases and the possibilities of future legislation.*
- *Participation in the "TERP" project. This was a project joint project by several organizations in Sweden and Iran with the objective to assess the air pollution (mainly from motor vehicles) in Teheran and to propose a plan to reduce these emissions. The World Bank and the city of Teheran in Iran jointly funded the project.*
- *Particle size distribution measurements (one SAE papers published on this subject, SAE 980410).*

Since the beginning of 1998 he has been working at Ecotraffic. Some of the projects he has been involved in are:

- *Evaluation of technology for reduction of cold-start emissions for light-duty vehicles by using a heat storage.*
- *Participation in an EU-project with the scope of reducing the energy consumption from goods transportation of products from natural resource based industries.*
- *Emission inventory and emission calculations for public transportation. Several projects for cities and public transportation authorities in Sweden.*
- *Participation in the Governmental Investigation about Emission Research as an expert.*
- *Various investigations for Governmental Authorities in Sweden.*

Introduction
The presentation covers both light-duty and heavy-duty vehicles. Since the methodology is reasonably similar in both cases, the presentation is divided into the three following main parts:

- Methodology
- Results for heavy-duty vehicles (i.e. city buses)
- Some selected results for light-duty vehicles

Methodology
The emission tests carried out on light and heavy-duty vehicles have been evaluated in order to assess the impact on the environment and on several health effects from switching to improved technology and to alternative fuels. Emission factors for the most important emission components (regulated and unregulated) have been determined for each option.

Several effects from the emission components have been calculated using weighting factors for each component. Acidification, eutrophication, ozone forming potential, cancer risk, greenhouse gases and several other effects have been evaluated.

Results for city buses
The study on city buses is focusing on the technical measures that have been implemented during the last decade to reduce the emissions from heavy-

duty buses in Sweden. A paper on this subject will be presented at the CEC/SAE Fuel & Lubricants Meeting & Exposition in Paris in June 19 22 (SAE Paper 2000-01-1882).

Diesel fuelled buses with and without aftertreatment devices (oxidation catalyst and particulate filter) and exhaust gas recirculation (EGR) are the diesel options that have been evaluated. Swedish EC1 fuel has been used in most cases but a comparison with European fuel has also been carried out. Compressed natural gas (CNG) and ethanol are the alternative fuels evaluated.

The analysis showed considerable improvements by reformulation of the diesel fuel and by fitting aftertreatment devices. Particulate emissions and its effects are probably the most severe emission component from the diesel engines. Diesel particulate filters (DPFs) are the only commercially available solution to that problem today.

Overall conclusions drawn from the results are:

- The analysis showed considerable improvements by reformulation of the diesel fuel and by fitting aftertreatment devices. Swedish EC1 fuel has a very low PAH content, which reduces the PAC emissions in the exhaust and, therefore, the cancer risk. This fuel is also required by several types of aftertreatment devices. DPF in combination with EGR has also a considerable impact on the evaluated effects.
- Some of the alternative fuels have a positive impact regarding several of the effects investigated, such as acidification. In other cases (e.g. ozone forming potential), the difference between the best options is small.
- It is expected that continuing development of engines and aftertreatment devices will diminish the advantage of the alternative fuels regarding many of the effects investigated here.
- The impact on the GHG emissions from some biofuel options will be more pronounced in the future and this problem can only be solved by switching to a biofuel.

A discussion about the possible technical measures available (engine and fuel technology) and their consequences for the emissions from heavy-duty vehicles is made.

Some selected results for light-duty vehicles

Ecotraffic has made a similar investigation as the one above for light-duty vehicles for the Swedish Governmental Agency KFB. However, since the conditions in Sweden differ great from the conditions in India a separate evaluation is necessary to adapt the results to India. This has been carried out for light-duty vehicles for one of the effects mentioned above, i.e. cancer risk index, as the basic material for an article in Down to Earth by CSE. A presentation of these results and the necessary assumptions regarding the input data and methodology for the calculations is made.

A discussion about the possible technical measures available (engine and fuel technology) and their consequences for the emissions from light-duty vehicles is made. ■

Emission Inventories and Actions Plans

LENNART ERLANDSSON
MTC AB, Sweden

By profession a mechanical engineer, he has been working from 1999 as Manager of Business Area, Air Quality, at MTC AB located in Haninge, a subsidiary company to Swedish Motor Vehicle Inspection Company.

In 1993 he was appointed as Swedish delegate in the working group "An environmental Friendly Transport System in the Baltic States). During 1993 – 1996 he served as Secretary in a Governmental Committee ("Miljöklassutredningen"), dealing with environmental classification of vehicles and fuels. From 1995, he has been serving as an expert for the Swedish Consumers Organisation in matters related to emissions and fuel consumption. During 1995 – 1997 he was the project manager at MTC in Tehran Transport Emission Reduction Project. (responsibility for MTC: vehicles, fuels, I&M, health effects and institutional arrangements). He was a member of the Swedish delegation in COST 319 (Emission Factors and Function) in 1997. In the same year, he was the Swedish delegate at UNECE Task Force on Emission Inventories and member of the Swedish delegation at CATEC-97 Beijing, China

In 1998 he did a pre study in Santiago de Chile, Chile elaborating the possibility to introduce city buses fuelled by Compressed Natural Gas (CNG)

He has a number or International papers and presentations to his credit. These include two papers in 1995, Possibilities to Control the Emissions from Vehicles. Legislative and Technical Aspects. *(Tallin, Estonia) and* Exhaust Emissions in Cold Ambient Conditions: Considerations for a European Test procedure *(SAE 950929). In 1996 he published* Overview of MTC´s work in the range of Pollution *(Vilnius, Lithuania). Three papers published by him in 1997 were,* Influence of Block Heaters on the Emissions from Gasoline Fueled Cars with Varying Emission Control Technology at Low Ambient Temperatures *(SAE 970747),* Technical Evaluation in Order to Reduce Exhaust Emissions from Cars *(CATEC-97),* Presentation of Tehran Action Plan at Air Pollution Conference, Tehran.

Air pollution is a big problem in many cities all over the world. In order to develop comprehensive Action Plans with measures to reduce the emissions from various sources, first a thoroughly emission inventory must be carried out. Different pollution sources generate different types of emissions and it is essential to identify and quantify the impact.

Pollution can be classified as local, regional and global emissions. In many city areas the most common pollutant is particles, and therefore a Municipality would like to introduce measures reducing particles. On the other hand, the Kyoto Protocol requires a great reduction of carbon dioxide in order to avoid global warming. Governmental Politicians therefore would like to se efforts reducing CO2 as the main priority. This dilemma sometimes will cause conflicts as one measure cannot solve two different problems at the same time.

Traffic is blamed to cause pollution. This is often the case, but on the other hand there are also cities were a prohibition to use motorised vehicles not will improve the ambient air quality because of a great concentration of heavy industry. In other cases new engine technology will not improve the air quality since the fuel quality is too poor to enable the use, or the introduction of aftertreatment technique.

A general experience is that the fastest way to improve the ambient air quality is to introduce measures for the existing vehicle fleet (inspection and maintenance system, retrofit etc,) and to improve the fuel quality. Another experience from Latin America, but applicable in many places, is that when the average speed of the public transport is increased, the emissions from the buses will be reduced.

In order to establish an emission inventory, emission factors are used. There are many different databases available with emission factors, but very seldom they take local conditions into account. Emission factors depend upon the technical status of the vehicles used, the fuel used and the way the driver uses his vehicle. If one of those parameters is changed, the emission factor will vary very much. Based on this, it is essential to develop local emission factors to be used in a modelling system.

Elaborating an Action Plan need the cooperation between experts with different skills. Experts familiar with vehicle technology and fuel properties will establish a base, then experts with knowledge how to make model simulation and process the date further in close cooperation with experts skilled in traffic management and traffic planning. To estimate the future air quality there is also a need to elaborate new vehicle technology in combination with improved conventional as well as alternative fuels.

During the workshop an actual case will be presented. The presentation will elaborate different measures, related costs, emission reductions and examples of a time table. ■

Cost-Effective Air Quality Monitoring and Emission Inventories

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From 1999 he has been the Vice President at the Swedish Environmental Research Institute. He has also been appointed the Chairman of the Swedish Environmental Protection Agency research program "Metals in urban areas and rural regions — Cycling and Critical Load" for the period 1994-2000. From 1993-1999 he was Director of the Department of Environmental Monitoring, Fluxes and Synthesis at the Swedish Environmental Research Institute He was Head of the Section for Environmental Monitoring at the Provincial Government of Stockholm, Sweden from 1992-1993. He has also served as Head of the Section for Effects of Atmospheric Deposition at the Swedish Environmental Research Institute from 1989-1992.

Åke Iverfeldt is specialised in air quality monitoring strategies, techniques and systems. He is also working with optimising air quality monitoring to support decision making, for example in the form of an assessment of the situation in the Russian Federation, commissioned by the OECD. He was also partner in the EU-Eurostat Environmental Pressure Indicator Project, and responsible for the area "Dispersion of Toxics". At IVL, he is responsible for the development of new business areas, e.g. the international marketing of air quality monitoring techniques -such as the IVL passive sampler; as well as Environmental Quality Management Systems -both as concepts and software solutions. He has recently been senior air quality scientist in the Kunming Air Quality and Urban Noise Project in China, and responsible for the design of a cost-effective monitoring network. He is or has recently been co-ordinator, partner, and associated partner in several ongoing European Commission/DG XII and XVII funded projects.

Introduction

A modern air quality strategy for urban areas should be very focused on rising the public awareness, improving the air quality planning process, and prioritising cost-effective mitigation measures. An accurate emission inventory is essential in estimating the source wise contribution to the air quality and its health impacts, but is still often the weakest link in the air quality management system. The reason is that traditional emission inventory methods are time consuming, costly, and not adapted to the heterogeneous and very fast changing situation in large cities in developing countries. New methods for rapid development of emission inventories are needed, prioritising the work on sources of largest relative impact on air quality and exposure of the public.

Additionally, the air quality monitoring system must be better designed to follow up implementation of actions taken, correlating trends in emission and resulting air quality. Therefore, the focus of an air quality monitoring system should be changed, from a rapid assessment tool of the present situation, to a tool quantifying the improvement in air quality by the measures taken. As a follow up tool of improvements against air quality targets, it is vital that the monitoring system is sustainable over time, and that it incorporates a warning system related to acute health risks

IVL Swedish Environmental Research Institute has developed screening methods both for the air quality situation in a geographical area, as well as for finding the location and relative contribution of various emission sources. Based on this, cost-effective concepts have been developed for

- rapid establishment of an accurate air pollution emission inventory, and

- rapid establishment of a robust air pollution monitoring system, with a public alert function, from which an Air Quality Index can be calculated

Air Pollution Emission Inventory

For the initial screening of the relative importance of various emission sources, IVL mainly uses

- air pollution measurements in tunnels
- on-road emission measurements with the FEAT-technique, and
- source-receptor modelling

The measurements in tunnels and on-roads with the FEAT-instrument are also used for emission factor and emission model validation, which later are to be used in the build up of an emission inventory.

In the next step of the establishment of an emission inventory, results from a geographical air quality mapping exercise using diffusive samplers are combined with satellite based remote sensing. Through the land use maps derived, and based on identified activities with related emission factors, geographical emission maps are produced. Additional measurements with diffusive samplers are used to calibrate the results relative to different types of areas and classes. By using this new technology to rapidly create a first version of an emission database, further manual work to improve the database can be focused and prioritised to areas, sectors or sources of the largest importance to health.

Air Quality Monitoring and Air Quality Index

In many developing countries, an initial geographical "snap shot" of the present air quality situation is the best starting point for identification of the most prioritised mitigation measures to reduce emissions of air pollutants. At the same time it is a logical start in building up an Air Quality Index. An appropriate Air Quality Index should preferably communicate the acute risk to your health and not only the pollution level in itself. In developing an Air Quality Index for an urban area like Delhi, the local situation and composition of various air pollutants are important to consider.

In order to perform the initial mapping of air quality in an urban area, the diffusive sampler is a unique tool in its cost-effectiveness. From the initial mapping exercise, hot spots, levels of exposure and dose, information on emission sources, dispersion patterns, an appropriate Air Quality Index, and an area representative siting of instrumental stations with high time resolution, can be derived. An African example is the mapping of air quality in Johannesburg, South Africa, in July 1999. Already the same year, the air pollution maps were used in the mitigation planning process to reduce emissions. Here heating and cooking in households in Soweto, using low-grade coal, were the dominating sources of sulphur dioxide in Johannesburg. Suitable measures to lower the levels of sulphur dioxide should therefore by focused on stimulating alternative sources of energy. For nitrogen oxides, the dominating sources in Johannesburg were traffic and industrial activities, with clearly separated areas of influence. In this case, the implementation of measures must be guided by geographical considerations.

In order to monitor an appropriate Air Quality Index for Delhi and the implementation effectiveness of measures to counteract poor air quality, a robust monitoring system should be design based on the mapped air quality and emission source impact in the geographical area of the city. The monitoring programme should handle the air pollutants of potential highest priority from a population dose perspective, e.g. particles (PM10/2.5), NO_2, and CO. An optimal monitoring and public warning system would be based on a combination of techniques:

- Diffusive samplers for good geographical coverage, run in campaigns with a monthly resolution; parallel method
- Manual methods in areas were daily data resolution is acceptable; parallel method
- Automatic instruments with high resolution, sited in areas of high air pollution levels and exposure
- An alert system automatically trigged by the instrumental stations
- An air quality forecasting system based on next day weather prognosis and meteorological statistics
- As a final step, dispersion models. After validation both against high geographical and time resolve measurements, this model tool can be used to trace further weaknesses in the emission database. It will also provide the possibility for forecasts and scenario building.

Finally, failure in operation of high technology instrumentation should not lead to an immediate total collapse of the monitoring system capacity. Therefore, the platform for air quality monitoring should be based on the above mixture of manual active, passive, and instrumental methods for monitoring of air pollutants. In this way some capacity can be kept and air quality information generated even during periods of instrumentation failure. failure.

For PM2.5, an index value of 100 is equal to 40 $\mu g/m^3$, which is the mid-point of the range between the annual and the 24-hour PM2.5 standards. An index value of 100 was set equal to 40 $\mu g/m^3$ to reflect the dual role of the annual and 24-hour PM2.5 standards in protecting against health risks associated with short-term exposures. See 64FR 42542-42543 (August 4, 1999).

Intermediate index values of 200, 300, and 400 were defined and are the basis for the Alert, Warning, and Emergency episode levels included in 40 CFR part 51, appendix L, as part of the Prevention of Air Pollution Emergency Episodes program. This program requires specified areas to have contingency plans in place and to implement these plans during episodes when high levels of air pollution, approaching the SHL, are in danger of being reached. ■

Emission Inventory Models for Air Quality Assessment from Mobile Sources

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Engineering from Kerala university, M.Tech (Mechanical Engg.) I.C Engines from I.I.T Madras and Ph D from University of Roorkee. He has been working in various posts at Indian Institute of Petroleum, Dehradun since 1976. He has worked on Research & Development of automotive engines on fuels, Emission & Combustion related topics. He has carried out various industrial project for oil companies, auto manufacturers, catalytic converter manufactures and government agencies. Currently he is the Group Leader of Fuel Quality & Engine Emission Group of Engines Laboratory at IIP

He has done collaborative research at the Mechanical Engineering Dept. University of Calgary, Canada and School of Engineering, University of Exeter, and U.K.

He has to his credit more than 35 published papers in various international and national journals and at conferences, seminar & workshops.

The urban air quality in India is fast deteriorating in almost all-major cities. The air quality in the city of Delhi has reached to an alarming level, which is causing immense hardship to the residents. The motor vehicles are considered as one of the major sources of emission. The emission to the atmospheric air not only act as a direct toxic pollutant for human respiration but also contribute to global warming and acidic deposition. The major pollutants from motor vehicles are large quantities of Carbon monoxide (CO), Unburned hydrocarbons, Oxides of Nitrogen, Sulphur dioxide and Particulates. Each of these gases has a distinct role on air quality. As vehicle population is fast growing, the atmosphere is more and more loaded with these emission gases. The large emission levels provoked people to make efforts to minimise the problem of motor vehicle pollution. The measures to improve air quality need to consider the extent and degree to which each and every category of vehicle is responsible. This paper discusses some issues involved in emission inventory. The international and Indian experience on emission inventory and control strategy for future specific to Delhi and India as a whole is discussed.

It is interesting to note that consumption of gasoline in Delhi was two times that of diesel in the year 1990-91 and it is projected to increase to 4 times by the year 2000-2001. This trend is in sharp contrast to the consumption pattern of the country as a whole, which shows that diesel consumption, is about 6 times that of gasoline consumption. This implies that emission estimates in a city like Delhi will have predominant effect of gaseous emissions like CO, and HC coming out of gasoline vehicles than particulates from diesel vehicles. One can therefore infer from the above that Delhi needs a specific program for emission control.

In order to improve the air quality in Delhi, it is of primary importance to evolve methods to accurately estimate the emission of various constituents from vehicles into the atmosphere. As there are various types and makes of vehicles with varying vehicle life and utility cycles, it is difficult to accurately estimate the emission factors from vehicles. Computer models to determine emission factor can play an important role to achieve this objective. Such models would also be a key starting point to build more accurate air quality inventory and to predict quantitatively, the impact of various emission control measures on the emission of various constituents to the atmosphere.

To better understand the magnitude of the air pollution problem in Delhi, it is of paramount importance to be able to have an emission model that is capable of predicting emission from the on-road mobile sector. Only then can one begin to implement appropriate control programs to combat emission emanating from motor vehicles and other on-road sources. This type of model would also be a key ingredient and starting point to build more accurate air quality inventories which are also helpful in updating a country's emission inventory from mobile vehicle sources.

The emission inventory can be calculated for the various pollutants by appropriate emission factor models. Emission inventory internationally is being estimated by various countries. Some typical examples are IPCC approach and the EMEP/CORINAIR approach. Both the above method calculated the emission from mobile source for gaseous pollutants like CO, NOx, Hydrocarbons, SOx and Green house gases (GHGs) like CH4&N2O. As a pre-requisite to emission quantity calculation, it is required to calculate the emission factor from various classes of vehicles. The approach used by Environmental Protection Agency (EPA), USA using a model called MOBILE x which was first developed as MOBILE1 in the late 1970s. This model has been periodically updated to reflect the changes in vehicle, engine, and emission control system technologies. Changes in applicable regulations and emission standards and test procedures, and improved understanding of in-use emission levels and the factors that influence them were also included in the subsequent updates. The later updates are MOBILE 3, MOBILE 4 & MOBILE 5a. In Europe, the emission factors were determined by the COPERT Model. The results of emission factor for various categories of vehicles are discussed.

The Indian Institute of Petroleum (IIP) Dehradun, has been involved in emission measurements from various categories of vehicles in India for the last 15 years and has earlier compiled vehicles emission estimates for India. IIP has compiled these estimates in 1985 and 1994 for in-use road vehicles based on the experimental measurements of emission rates done at IIP.

In 1984, the vehicle emission inventory for metropolitan cites in India including Delhi was estimated for the base year 1981-82 and projected the total emission from various categories of vehicles for the year 1991-92 and 2000-2001. These estimates were made based on the measured mass emission values of various constituent such as CO, NOx, and HC and smoke for Diesel engines for a limited sample size of different vehicle makes. In the 1981-82 survey, the fuel consumption and vehicle utilization kilometers for various categories were used to calculate the total emission quantity of the emission constituents in a city. In the 1992-93 inventory, the fuel consumption and vehicle emission factors were used to calculate emission quantity.

In late 1980s, there were technology changes in almost all the vehicle categories. In India, changes were mainly due to emergence of various new makes of foreign origin with advanced technology in the field of two -wheelers, LCVs and passenger cars. This necessitated the need for updating the emission inventory estimates. IIP did another inventory estimate for 1992-93. The countrywide contribution of vehicles emissions show that gasoline vehicles contribute 71.4% of CO and 78.3% of HC. On the other hand, the diesel vehicles contribute 94.3% of NOx. Hydrocarbons are mostly emitted by the two and three wheelers.

The draw back of emission inventory done so far is that it is estimated based on a limited sample size without any consideration on the age of the vehicle. The estimate is made with a number of assumptions especially on the vehicle utility factor. Hence, the confidence level of such estimate is not high. Besides, the approach used is for a static sample of a particular year without any scope to project for future years, when new control technologies and new designs are added to the vehicle fleet in the country. Hence, there is need to make a model that can incorporate deviations due to various parameters such as fuel quality, vehicle control technology effect, aging of vehicle, traffic pattern, emission standards, fuel consumption norms etc. Such model can more accurately predict the emission factors in a city or any other defined location. The strategy to be adopted for developing an appropriate emission inventory model, which can ultimately lead to developing an air quality model for Delhi and India, is highlighted in the paper.

It is recommeded that

1. EPA Equivalent Body in India needed
   - For Emission Regulations
   - For Fuel Quality Regulation & Monitoring
   - For Air Quality Monitoring

2. Continuous Emission Inventory & Air Quality Monitoring Updates necessary: Emission Regulations to be based upon this.

3. To Strengthen Working Co-ordination with R&D Institutes & Environmental protection agencies. ■