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a critical review of AIR POLLUTION INDEX SYSTEMS IN THE UNITED STATES AND CANADA

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An extensive survey was conducted of all the air pollution indices that are presently utilized or are available. The data were obtained from a literature review; from telephone discussions with personnel in State, local, and Provincial air pollution control agencies; and from material received from these agencies. Of the 55 metropolitan air pollution control agencies surveyed in the United States, 35 used some form of daily air pollution index. These indices were so varied that it was necessary to develop a system to classify indices according to four criteria: (1) number of variables, (2) calculation method, (3) calculation mode, and (4) descriptor categories reported with the index. Using the classification system, 14 basically different index types were identified. With two minor exceptions, it was found that no two indices were exactly the same. The survey results and agency comments were used to identify the general structural characteristics and criteria for a candidate uniform air pollution index.

In recent years, many state and local air pollution control agencies have responded to the need to inform the public of daily air quality levels by developing or adopting air pollution indices. Awareness of these levels is important not only to those who suffer from illnesses aggravated by air pollution but also to members of the general public, who, if cognizant of daily variations in air pollution levels, may choose to alter their activities accordingly. However, because many different index types have come into routine use, a citizen who travels to different cities will receive a confusing picture of air pollution levels in each city. Further, existing indices, because of their diversity, cannot be used to assemble a national picture of air pollution levels or trends.

When we initially reviewed the air pollution indices proposed in the literature, we found a confusing array of different index types. Further, although many indices had been developed, few of those proposed in the literature were being used in practice—either by governmental decision makers or by state and local agencies seeking to report air quality levels to the public. Instead, the agencies tended to develop their own indices. Two important questions were evident: (1) What are the technical characteristics of all the air pollution indices proposed or in use? (2) Does any "common index" emerge from these characteristics and, if so, what does it look like?

To develop an extensive data base on all the indices in existence, whether proposed or currently in use, we surveyed the 55 largest metropolitan air pollution control agencies in the United States. State air pollution control agencies and Canadian provincial agencies known to use air pollution indices were also surveyed. The complete results of this survey are reported in *Air Pollution Indices: A Compendium and Assessment of Indices Used in the United States and Canada.*[1] This review is a condensation and update of the *Compendium.*

The need for a uniform national air pollution index has been noted in several recent reports.[2–5] Although the literature reveals a variety of attempts to develop candidate air pollution indices,[6–8] none of these indices has received widespread acceptance by state and local air pollution control agencies, probably because none has received the active support or endorsement of the Federal Government. However, in response to our study of this problem, progress has been made at the federal level toward the goal of recommending a national air pollution index.[9] In July 1975, the Council on Environmental Quality established a Federal Task Force on Air Quality Indicators, with members from the Environmental Protection Agency's Offices of Research and Development, Air and Waste Management, and Planning and Management; the Department of Commerce's Office of Environmental Affairs; and the National Oceanic and Atmospheric Administration. The Environmental Protection Agency has proposed a uniform index structure to this Task Force and is considering publishing it in its guideline document series[10] as a recommended national air pollution index. Hopefully a uniform national air pollution index would reduce the confusion created by the diverse array of indices currently in use.

Definition of Index

An "air pollution index" may be defined as a scheme that transforms the (weighted) values of individual air pollution-related parameters (for example, carbon monoxide concentration or visibility) into a single number, or set of numbers (Figure 1). The result is a set of rules (for example, an equation) that translates parameter values—by means of a numerical manipulation—into a more parsimonious form. (In set theory, this process is viewed as mapping of elements contained in one sample space into another sample space.)

The following evaluations were made to determine whether an agency used an "index." If an agency reported just the actual air pollutant concentration values to the public—micrograms per cubic meter ($\mu g/m^3$) or parts per million (ppm)—or concentration values along with standards, this was not considered an "index." Rather, an index must be based on some set of rules which translates the values into a new variable or makes interpretations of these values. At the very least, an index is any system in which specific concentration ranges are grouped into air quality "descriptor categories." For example, a system which designates 0–3 ppm carbon monoxide as "good," 3–15 ppm as "satisfactory," and 15–40 ppm as "unsatisfactory" was considered to be an index. In its most elaborate form, an index is an equation which combines many pollutants in some mathematical expression to arrive at a single number for air quality.

Some cities use episode warning systems that report descriptor categories whenever concentrations exceed specified levels. If this happens frequently, the distinction between an episode warning system and a daily informational index becomes blurred. Thus, air pollution agencies with episode warning systems are classified as having indices.

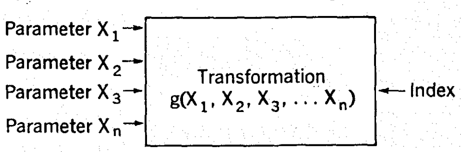

Figure 1. Index calculation.

A Classification System for Indices

To facilitate comparisons among the various air pollution indices, we developed an index classification system based on four criteria:

- Number of variables included in the index.
- Calculation method used to compute the index.
- Calculation mode (combined or uncombined).
- Descriptor categories reported with the index.

Number of Variables

This number designates the number of variables incorporated into an air pollution index. These variables include the NAAQS (National Ambient Air Quality Standards), visibility, particle scattering, and other measures of air pollution.

Calculation Method

Our index classification system employs four calculation methods, three of which (Types A, B, and C) involve an equation:

A. *Nonlinear.* Exponential function with coefficient or other nonlinear relationship. Coefficients may be constant or may vary, but the relationship contains at least one variable raised to a power.

The equations for the nonlinear (Type A) index may take several forms. One is the Oak Ridge Air Quality Index (ORAQI),[7] which may include one to five pollutants, where C denotes concentration and S denotes the air quality standard for pollutant i.

$$\mathrm{ORAQI} = [5.7 \sum_{i=1}^{n} (C_i/S_i)]^{1.37}$$

ORAQI values may also be determined with the aid of a nomograph. Another Type A index is the Ontario Air Pollution Index (API):[11]

$$\mathrm{API} = 0.2(30.5\ \mathrm{COH} + 126.0\ \mathrm{SO_2})^{1.35}$$

It includes only two pollutants—coefficient of haze (COH) and sulfur dioxide (SO_2). A third example is the Measure of Undesirable Respirable Contaminants (M.U.R.C.) Index.[12] It includes only one pollutant and is calculated using the equation:

$$\mathrm{M.U.R.C.} = 70(\mathrm{COH})^{0.7}$$

B. *Segmented linear function.* Linear function of one or more variables with nonconstant coefficients. There are no exponents, but the slopes are different for different ranges of the pollutant variable.

Figure 2 shows a plot of the segmented linear function for carbon monoxide (CO) used in the Washington, DC index. Mathematically, this function can be represented by the following equation, where I denotes the index value, C denotes pollutant concentration (ppm CO), and each pair of values (x_j, y_j) are the coordinates of breakpoint j (represented as a dot):

$$I = \frac{y_{j+1} - y_j}{x_{j+1} - x_j}(C - x_j) + y_j \qquad \text{for } x_j < C \le x_{j+1}$$

where $j = 0, 1, \ldots, 5$

The function shown consists of five straight line segments, each with different slopes, $K_j = (y_{j+1} - y_j)/(x_{j+1} - x_j)$. The index value for any CO concentration can be determined directly from the curve. For example, at 80 ppm CO, the index value is 200.

C. *Linear.* Linear function of one or more variables in which the slope K_i for each variable i remains constant:

$$I = K_i C_i$$

Coefficients may be chosen as $K_i = 1/C_{s_i}$, where C_{s_i} is the standard for pollutant i, giving a proportionate relationship; or they may be chosen as $K_i = 100/C_{s_i}$, giving a percentage relationship; or they may be arbitrary and not related to any standard.

D. *Actual concentrations.* Concentrations reported in scientific units ($\mu g/m^3$, ppm) or standard units from some commonly used measurement technique (coefficient of haze, for example).

An agency reporting just actual concentration values is classified as not having an index and is not coded; however, when the agency reports actual concentrations and descriptor categories, its index is Type D.

Calculation Mode

Another important aspect of the calculation method is how the index variables are treated. Does the agency report individual index values for each variable? Does the agency report an index value only for the variable which has the maximum value of all the index variables? Does the agency's index combine the variables in some fashion? Thus, the mode identifies whether the index is combined or uncombined. Uncombined indices include those in the individual or maximum mode category; combined indices are sometimes referred to as aggregated indices. The mode is indicated by appending a subscript to the calculation method classification:

1. *Individual.* An index value is reported for each variable comprising the index.
2. *Maximum.* Only the index value for the maximum variable is reported.
3. *Combined.* The index variables are aggregated, through some type of mathematical manipulation, to give one index value.

Descriptor Categories

The descriptor categories result when the index range is subdivided. The words assigned to each category describe qualitatively the air quality. For example, an index may list 0–25 as "good," 26–50 as "satisfactory," 51–99 as "unsatisfactory," and 100–199 as "unhealthy." If an index reports actual pollutant concentrations, several concentration ranges may be used for the descriptor categories. Index descriptor categories can be based on standards, episode criteria, or an arbitrary basis:

A. *Standards.* The category breakdown is based on Federal, State, or local ambient air quality standards—for example, index values above 100 exceed the Federal Primary NAAQS and those below fall into several categories partially based on the Federal Secondary NAAQS. If actual concentrations are reported, then these concentrations are related to the standards.

B. *Standards and episode criteria.* Type A (above) is extended to accommodate index values above 100. These values are based on the Federal, State, or local episode criteria—for example, 100 is the Alert Stage, 200 is the Warning Stage, etc. For indices reporting actual pollutant concentrations, these concentrations are related to the episode criteria.

C. *Arbitrary.* Categories of this type are semiempirically based and usually designed to fit the specific requirements of the index values. This classification also covers indices with no descriptor categories.

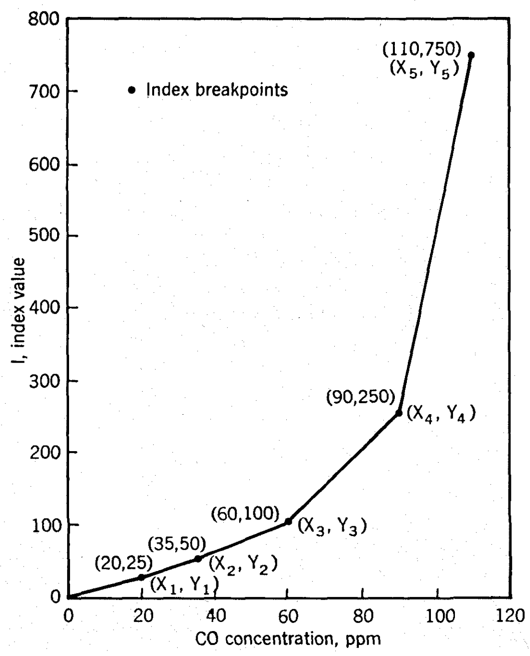

Figure 2. Example of a segmented linear function for carbon monoxide.

Summary and Example Application of the Index Classification System

The result of the classification system is a four character code which describes any index. Thus ORAQI can be coded as "$5A_3A$" (Figure 3). The number "5" indicates that the index includes five pollutants or variables; "A_3" denotes the calculation method and mode (i.e., it is nonlinear and the variables are combined to give one index value); "A" refers to the basis for the descriptor categories (i.e., the categories reported with this index are based on the NAAQS).

Survey of Existing Indices

Indices Reported in the Literature

The literature on air pollution indices[6–8,11–17] has previously focused on the development of long-term trend indices. Little has been published on the short-term indices commonly used by state and local air pollution agencies. Although many long-term indices have appeared in the literature, our discussions with governmental personnel have revealed few cases in which such indices have actually been used to evaluate air pollution data to make decisions or policies.

Each of the 11 air pollution indices reported in the literature (Table I) differs either in terms of the number of applicable pollutants, method of index calculation, or descriptor categories. As a result, the overall meaning of each index is different. Several of the indices were designed for specific purposes; for example, the Extreme Value Index was designed to describe air pollution episodes. For a more complete description of each index, the reader should consult the literature reference. Three of these indices are currently in use by agencies: M.U.R.C. (Detroit, Memphis), Ontario Air Pollution Index (Ontario), and ORAQI (Tampa, Minnesota).

Indices Used by Agencies

The air pollution literature provides little information about the routine use of indices by air pollution control agencies. To learn which air pollution indices are in common use and to gain insight into the experiences of air pollution control agencies with these indices, an in-depth survey of these agencies was required. In this survey, agencies throughout the United States and Canada were telephoned and asked to send information describing their index. The data base in this investigation was assembled from notes taken during the tele-

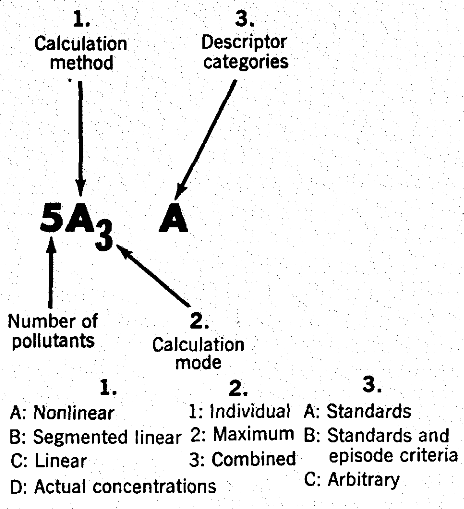

Figure 3. Index classification system.

phone conversations and from written materials received from the agencies.

Survey Population. The population surveyed in this investigation consisted of the 55 largest metropolitan (city and county) air pollution control agencies in the United States, along with state air pollution agencies in the United States known to operate state-wide air pollution index systems. It also included the Canadian Provinces with air pollution control agency staffs of 10 or more persons and one Canadian city which uses an index. To select the survey population, the total number of staff members from every city and county air pollution agency was computed using the *1973 Directory of Governmental Air Pollution Agencies,* published by the Air Pollution Control Association.[18] Only those U.S. air pollution agencies having 10 or more staff members were included in this survey population (Table II).

In the United States, the resulting survey population consisted of 55 agencies. Telephone inquiries revealed that, in 14 of these cities, the index was operated as part of a general state-wide or regional index system. Six states were operating this type of system: Connecticut, District of Columbia, Minnesota, New Jersey, New York, and Ohio. These state indices serve 67 cities (Table III), but many of these air pollution agencies have staffs less than 10 persons. Also, the agencies in Baltimore, MD, Boston, MA, and Portland, OR, are operated by the state but are not part of a state-wide system. In Portland, the state not only reports the air pollution index but it operates the entire city air pollution control agency as well. In Baltimore, on the other hand, the state reports the index, but the local air pollution agency is organizationally separate from the state agency.

In Canada, only Montreal operates a city air pollution control agency. Therefore, all provinces with staffs of 10 or greater were included in the survey population. Alberta and Ontario operate province-wide air quality indices. Eight cities within these Provinces issue daily indices (Table IV).

Survey Approach. Telephone calls were made to the agencies in the survey population from August to December 1974. For each agency, a respondent was sought who was very familiar with the agency's air pollution index, if any. In small agencies, this usually turned out to be the agency's director; in the larger agencies, a public information specialist or a professional in the field of monitoring and data analysis usually was the respondent. With the respondent on the telephone, the investigator went through an informal question-and-answer session. Each respondent was asked, "Can you provide any literature or description of your index?" Of the 55 agencies on the major list (Table II), 28 supplied written material. Typically, it covered the nature of the index, its method of calculation, the history of its development, and the way in which it is reported. In some cases, the telephone discussion provided sufficient information about the index and no mailed material was necessary. Some agencies not using indices provided material that discussed their reasons for not adopting an index or their experience with a previously discontinued index.

Analysis and Evaluation of Indices

Initially, information from the mailed responses and from notes taken during each telephone conversation was condensed and compiled into tables. The tabular compilation was found to be inadequate, however, due to the varied and sometimes extensive information received from the agencies. Consequently, the information was assembled into the three appendices which appear in the *Compendium.*[1] An index analysis record was developed to present detailed factual information about each index in a uniform format; informal comments from the agencies were copied into an extended table; examples of the ways in which indices are reported by the news media were also recorded. A summary and analysis of the data extracted from these appendices are presented here. For more detailed information, the reader should consult the *Compendium.*

Table I. Characteristics of indices reported in the literature.

		Variables[a]						
	Classification	CO	SO_2	NO_2	O_x	COH	TSP	Other
Green's Combined Index[13]	$2A_3C$		•			•		
M.U.R.C.[12]	$1A_1C$					•		
Combustion Products Index[14]	$2C_1C$							b
Ontario Air Pollution Index[11]	$2A_3B$		•			•		
Air Quality Index[15]	nC_3C (n = 1 to 5)	•	•	•	•		•	
PINDEX[6]	$7C_3C$	•	•	•	•		•	c
Oak Ridge Air Quality Index[7] (ORAQI)	nA_3A (n = 1 to 5)	•	•	•	•		•	
Mitre Air Quality Index[8]	nA_3A (n = 1 to 5)	•	•	•	•		•	
Extreme Value Index[8]	nA_3A (n = 1 to 4)	•	•		•		•	
STARAQS Air Quality Index Model[16]	$7B_1A$	•	•	•	•	•	•	d
Canadian Air Quality Indices[17]	$8A_3A$	•	•	•	•	•	•	e
Total		7	9	6	7	5	7	

[a] O_x, oxidant; COH, coefficient of haze; TSP, total suspended particulate.
[b] Fuel burned and ventilating volume.
[c] Hydrocarbons and SO_2 × TSP.
[d] Visibility.
[e] Visibility and industrial emissions.

Index Variables

The variables included in the 11 indices reported in the literature are given in Table I. Ten of the 11 indices include a measure of suspended particulate—COH or total suspended particulate (TSP)—and nine include SO_2. It is interesting to note that the two newest indices, STARAQS and the Canadian Indices, include all of the pollutant variables listed, in addition to other indirect measures of ambient pollution levels, visibility, and industrial emissions.

Table II. The 55 U.S. city/county air pollution control agencies with staffs greater than 10.

City/County	Agency size	Material received	Index in use	Comments
Birmingham, AL	17	•		
Phoenix, AZ	25	•		Discontinued Index
Anaheim, CA	24		•	Replaced Index
Los Angeles, CA	380	•	•	Replaced Index
Riverside, CA	26			
San Bernardino, CA	53			
San Diego, CA	53			
San Francisco, CA	220	•	•	Replaced Index
Denver, CO[a]	54	•	•	
New Haven, CN[b]	11	•	•	Replaced Index
Washington, DC[b]	14	•	•	
Bradenton, FL	11			
Jacksonville, FL	15	•	•	
Miami, FL	50	•	•	
Sarasota, FL	21			
Tampa, FL	16	•	•	
Atlanta, GA	14	•	•	
Chicago, IL	175	•	•	
Gary, IN	18			
Indianapolis, IN	15			
Louisville, KY	39	•	•	
Baltimore, MD[a]	90	•	•	Replaced Index
Montgomery Co., MD[b]	10		•	
Boston, MA[a]	87	•		
Springfield, MA	12			
Detroit, MI	77	•	•	
St. Paul, NM[b]	13	•	•	
Kansas City, MO	15			
St. Louis, MO	35			
Albuquerque, NM	15			
Albany, NY[b]	237		•	
Buffalo, NY[b]	44	•	•	
Mineola, NY[b]	37		•	
New York City, NY	382		•	
Rochester, NY[b]	12		•	
Charlotte, NC	14			
Akron, OH[b]	13		•	
Cincinnati, OH[b]	65	•	•	Replaced Index
Cleveland, OH[b]	80	•	•	
Dayton, OH[b]	45		•	Replaced Index
Toledo, OH[b]	25		•	
Oklahoma City, OK	15	•		Discontinued Index
Portland, OR[a]	20	•	•	
Philadelphia, PA	94	•	•	Replaced Index
Pittsburgh, PA	82	•	•	
Chattanooga, TN	22		•	
Memphis, TN	14		•	
Nashville, TN	17	•	•	
Dallas, TX	21	•	•	
El Paso, TX	10			
Houston, TX	76	•		
Pasadena, TX	45			
Fairfax Co., VA[b]	12		•	
Seattle, WA	39	•	•	
Milwaukee, WI	25			

[a] City index is operated by State but is not part of State-wide index system
[b] City index is part of State-wide or regional index system

The variables included in U.S. city/county air pollution indices are shown in Table V. If COH and high-volume sampler measurements of TSP are lumped together as measures of particulate matter, then particulate becomes the most common air pollutant included by these agencies in their indices. Of these 35 agencies, 33 (94%) include either COH or TSP; COH is used by 22 agencies and TSP by 11 (Jacksonville, FL uses both). The popularity of the COH measurement may be due to the increasing use of telemetered air monitoring networks which cannot readily handle TSP data determined by the high volume sampler and to the shorter averaging time (2 hr). CO and SO_2 are the next most common pollutants to be included in these indices—26 agencies (74%) for each. The next most popular pollutants are oxidant (20 agencies, 57%) and NO_2 (16 agencies, 45%). Visibility is included in one agency's index, and particle scattering is the only variable making up another agency's index.

When the air pollution indices used by states (or regions) and Canadian provinces are examined (Table VI), a similar pattern emerges. The most common pollutants are CO, SO_2, and particulates (COH and TSP). The least common pollutant is NO_2, with only two agencies—Ohio and the District of Columbia—reporting it in their indices. The two Canadian Province indices report different numbers of pollutants; the smaller agency, Alberta, reports five air pollutants, while the larger, Ontario, reports only two.

Results of Classification

The classification system described earlier was applied to all the indices reviewed in this study.

Indices Reported in the Literature. Table I shows the classification of the 11 indices reported in the literature. Eight of the 11 use a combined calculation mode (Type 3), and seven of these use a nonlinear (Type A) calculation method. Three of the last four indices listed (i.e., excluding STARAQS) employ what has been termed a root-mean-square (RMS) index equation. Although this equation tends to emphasize high pollutant concentrations, it is so complex that it confounds the interpretation of these concentrations, thereby confusing the layman. This, and the general complexity of other "A_3" type index equations, may have contributed to the limited use of these indices by local air pollution control agencies.

Indices Used by Agencies. Application of the index classification system to the 32 index systems reviewed in the survey of air pollution control agencies revealed 14 basic types* (Table VII). To simplify comparison of these index types, they are grouped according to their calculation method. Agencies which either discontinued or replaced their indices did so either because the indices were not consistent with air pollution levels as perceived by the public, or to improve their old index system, or to conform to state-wide index implementation.

Classification of the various indices used by the survey respondents revealed a striking diversity and few clear patterns. Of the 35 city/county agencies, 13 (37%) include five variables in their index calculation (Table VIII). This is due mainly to the fact that five agencies in Ohio and four in the Baltimore-Washington, D.C., area use indices incorporating five variables. In fact, each of these nine agencies used the $5B_2B$ type of index.

* A basic type refers to the calculation method and descriptor categories, but not to the number of variables.

Table III. State-wide air pollution index systems

State	Applicable City or County	Agency Size[a]
Connecticut	Bridgeport	<10
	Danbury	–
	Derby	–
	Enfield	–
	Greenwich	<10
	Groton	–
	Hartford	105[b]
	New Britain	–
	New Haven	11
	Stamford	<10
	Torrington	–
	Waterbury	–
District of Columbia	Alexandria, VA	<10
	Arlington Co., VA	<10
	Fairfax Co., VA	12
	Montgomery Co., MD	10
	Prince Georges Co., MD	<10
	Washington, DC	14[b]
Minnesota	Duluth	<10
	Minneapolis	37[b]
	Rochester	<10
	St. Paul	13
New Jersey	Ancora	–
	Asbury Park	–
	Atlantic City	–
	Bayonne	–
	Burlington	–
	Camden	–
	Elizabeth	<10
	Freehold	–
	Hackensack	–
	Jersey City	<10
	Morristown	–
	Newark	–
	Paterson	–
	Paulsboro	–
	Penns Grove	–
	Perth Amboy	<10
	Phillipsburg	–
	Somerville	–
	Toms River	–
	Trenton	170[b]
New York	Albany	237[b]
	Buffalo	44
	Kingston	–
	Mamaroneck	–
	Mineola-Eisenhower Park	36
	New York City-Roosevelt Isl.	–
	Niagara Falls	<10
	Rensselear	<10
	Rochester	12
	Schenectady	–
	Syracuse	10
	Utica	–
Ohio	Akron	13
	Canton	<10
	Cincinnati	65
	Cleveland	80
	Columbus	228[b]
	Dayton	45
	Lorain	<10
	Mansfield	<10
	Painesville	<10
	Portsmouth	<10
	Steubenville	<10
	Toledo	25
	Youngstown	<10

[a] Where no agency size is given, size is unknown.
[b] State agency.

Despite the heavy influence of these nine agencies on the data, Table VII shows that the segmented linear function (Type B) and the actual concentrations (Type D) are the most popular calculation methods (37% and 32%, respectively). Only four cities (11%) use a nonlinear index calculation, suggesting a definite preference for the less complex calculation schemes. This preference is also evident in St. Paul, which uses a nonlinear index (Type A: ORAQI) but in addition reports actual concentration values (Type D). If St. Paul is reclassified as Type D (shown in parentheses, Table VIII), then only three (9%) of the agencies use the nonlinear type calculation method.

Table VIII shows that the "maximum" mode of calculation was used by 15 (43%) of the agencies. Another 12 agencies (34%) used the "individual" mode, thus indicating a preference for uncombined (77%) over combined (23%) indices. However, Jacksonville and St. Paul use both the individual and combined mode. If they are reclassified as using the individual mode (as shown in parentheses, Table VIII), then only six (17%) of the agencies use the combined mode and 83% use the two uncombined modes.

Table VIII also shows that 25 agencies (71%) used index descriptor categories based either on standards or on standards and episode criteria; the remaining one-third used arbitrary categories.

The number of categories used in the indices is shown in the histogram of Figure 4. There appears to be a definite preference for three or four descriptor categories. However, there does not appear to be any tendency toward using the same words for the descriptor categories. A total of 44 different words (Table IX) are used in the descriptor categories of 30 U.S. index systems. Indices containing the more common words are shown in Table X. It is interesting to note that certain words occur more frequently in multipollutant indices and other words more frequently in indices involving only particulate matter.

For the six states and two provinces, no detailed analysis was possible due to small sample size. However, examination of Table VI shows that all of the states report at least three pollutants in their index; two states report all five NAAQS pollutants. Since Minnesota reports individual pollutant concentrations in addition to its combined index (ORAQI), all state indices can be classified as using the segmented linear or actual concentration calculation methods, while the calculation mode is either individual or maximum. Thus, both the States and cities make only limited use of the more complex, nonlinear combined indices (Type A_3). On the other hand, in Canada there appears to be a preference for this type of index, with both Alberta and Ontario using nonlinear combined indices.

Summary of Preferred Index Characteristics. Combining

Table IV. Province-wide air pollution index systems.

Province	Applicable city	Agency size[a]
Alberta	Calgary	
	Edmonton	26[b]
Ontario	Hamilton	
	Happy Valley	
	Sudbury	
	Toronto	70[b]
	Welland	
	Windsor	

[a] Where no agency size is given, size is unknown.
[b] Province agency.

Table V. Characteristics of the 35 U.S. city/county air pollution indices.

	Classification	Variables[a]								No. of Descriptor Categories
		CO	SO_2	NO_2	O_x	COH	TSP	Vis	PS	
Anaheim, CA	$3D_1B$	•	•		•					3
Los Angeles, CA	$3D_1B$	•	•		•					3
San Francisco, CA	$4D_2C$	•		•	•	•				6
Denver, CO	$2B_2C$	•				•				5
New Haven, CT	$3B_2B$		•		•	•				5
Washington, DC	$5B_2B$	•	•	•	•	•				7
Jacksonville, FL	$6C_3C$	•	•	•	•	•	•			None
Miami, FL	$5C_3C$	•		•	•	•		•		5
Tampa, FL	$5A_3A$	•	•	•	•	•				6
Atlanta, GA	$3C_3C$	•	•				•			None
Chicago, IL	$4D_1B$	•	•		•	•				4
Louisville, KY	$5C_3B$	•	•	•	•	•				4
Baltimore, MD	$5B_2B$	•	•	•	•	•				8
Montgomery Co., MD	$5B_2B$	•	•	•	•	•				7
Detroit, MI	$1A_1C$					•				5
St. Paul, MN	$3A_3B$	•	•				•			4
Albany, NY	$3D_1A$	•	•			•				3
Buffalo, NY	$3D_1A$	•	•			•				3
Mineola, NY	$3D_1A$	•	•			•				3
New York City, NY	$5D_2A$	•	•	•	•	•				4
Rochester, NY	$3D_1A$	•	•			•				3
Akron, OH	$5B_2B$	•	•	•	•		•			12
Cincinnati, OH	$5B_2B$	•	•	•	•		•			12
Cleveland, OH	$5B_2B$	•	•	•	•		•			12
Dayton, OH	$5B_2B$	•	•	•	•		•			12
Toledo, OH	$5B_2B$	•	•	•	•		•			12
Portland, OR	$1D_1C$								•	5
Philadelphia, PA	$4B_2B$	•	•		•		•			5
Pittsburgh, PA	$2C_3B$		•			•				6
Chattanooga, TN	$1D_1C$						•			4
Memphis, TN	$1A_1C$					•				4
Nashville, TN	$1C_1C$					•				4
Dallas, TX	$2C_3B$			•			•			4
Fairfax Co., VA	$5B_2B$	•	•	•	•	•				7
Seattle, WA	$2B_2B$		•			•				3
Total		26	26	16	20	22	11	1	1	

[a] O_x, oxidant; COH, coefficient of haze; TSP, total suspended particulate; Vis, visibility; PS, particle scattering (integrating nephelometer)

the results from the index classification (Table V) with the analysis of descriptor words (Tables IX and X) enables one to determine the most frequently encountered characteristics of the indices currently used by air pollution control agencies (Table XI). This summary is particularly useful when considering the possibility of developing a uniform national air pollution index. Such an index, if it is to gain wide acceptance, must have a structure which closely resembles that of the greatest number of indices currently in use. Table XI shows that such an index would be classified as a $5B_2B$ index. This index would (1) be based on the five NAAQS pollutants (excluding hydrocarbons), (2) be a segmented linear function, (3) be calculated using the maximum mode, and (4) have four descriptor categories based on the NAAQS and Episode Criteria, using the more frequently occurring words such as Good, Moderate, Unhealthy(ful), and Unsatisfactory. These characteristics were used to formulate the proposed uniform index discussed in the Conclusion.

Table VI. Characteristics of the six State-wide and two Province-wide air pollution indices.

	Classification	Variables						No. of Descriptor Categories
		CO	SO_2	NO_2	O_x	COH	TSP	
State								
Connecticut	$3B_2B$		•		•	•		5
District of Columbia	$5B_2B$	•	•	•	•	•		7
Minnesota	$3A_3B$	•	•				•	4
New Jersey	$4D_1A$	•	•		•	•		4
New York	$3D_1A$	•	•			•		3
Ohio	$5B_2B$	•	•	•	•		•	12
Total		5	6	2	4	4	2	
Province								
Alberta	$5A_3C$	•	•	•	•	•		5
Ontario	$2A_3B$		•			•		5

Comments from Agencies

Some insight into the reasons for the great variety of air pollution indices was gained by examining the subjective views of the survey respondents. Their comments, which were assembled by the authors from notes taken during the informal telephone conversations, are listed in greater detail in the *Compendium.*[1]

Agencies Using Indices. As one might expect, most respondents from agencies now using indices expressed satisfaction with their own index, although one respondent acknowledged that most people probably do not follow the index in the newspapers. There was widespread opinion that the numbers expressed by indices are not necessarily meaningful, and one agency stated that its index was not developed on any scientific basis and was not intended as such. In general, an index was viewed as an informational tool designed to advise the public as to the severity of air pollution levels, but not to convey any information about the deleterious effects of air pollution. Some agencies felt that the layman does not understand the technical language of air pollution, and thus indices fulfill an important need by communicating with him in a nontechnical way. However, in many cases the public may not understand the index either. One agency using the complex ORAQI index solved this problem by distributing a public information bulletin on the subject. A number of the respondents expressed concern about the lack of spatial representativeness of index values. This concern apparently reflects a lack of representativeness of the monitoring data used to calculate the index.

Table VII. The 14 basic types of indices and their users.

Type	Users
A_1C	Detroit, Oklahoma City,[a] Memphis
A_3A	Tampa
A_3B	Minnesota, Ontario
A_3C	Alberta
B_2B	Baltimore,[b] Philadelphia,[b] Seattle, Connecticut,[b] Ohio,[c] Washington, DC
B_2C	Denver
C_1C	Nashville
C_3B	Louisville, Pittsburgh, Dallas
C_3C	Jacksonville, Miami, Atlanta, Phoenix[a]
D_1A	New Jersey, New York State
D_1B	Anaheim,[b] Los Angeles,[b] Chicago
D_1C	Portland, Chattanooga
D_2A	New York City
D_2B	San Francisco[b]

[a] Discontinued index.
[b] Replaced index.
[c] Replaced index in Cincinnati and Dayton.

Several agencies had found it necessary to make major changes in their indices within the past 5 years. These agencies indicated they had some difficulty overcoming the public confusion which resulted from these changes, particularly where the changes were great. One such agency stated that the introduction, right now, of any new indices "would bury us." Another agency changed its index from the combined form to a maximum type because the combined index gave misleading results—low values when one standard is violated and other pollutants are low, or high values when all pollutants are high but no standard is violated.

Agencies Not Using Indices. The diversity of opinion was wider among agencies not presently using air pollution indices. Respondents often expressed dismay about the large number of air pollution indices in existence: With so many different air quality indices around, "people really can get confused when they move from city to city." Many respondents felt it better to familiarize the public with the scientific notation for pollutant concentrations—$\mu g/m^3$, ppm—than to teach the public how to understand an index. Some agencies felt they would adopt an index if they could find one that was understandable and agreeable to all, but that there is not yet a sufficient scientific basis for such an index. Some of the reasons offered for not adopting an air pollution index were purely practical—not enough monitoring data to implement the index or not enough staff to compute the index. The problem of finding an index that is consistent with the public's perception of air quality was cited frequently as a reason for not using an index. One agency used ORAQI for several years but found it did not correlate well with observed air quality and resulted in many complaints; thus, it was abandoned:

> We soon found that [index values] did not relate to what the public saw. Many times, mountains surrounding [the city] would be barely visible during winter months and yet the index would register in the light air pollution range. This resulted in considerable controversy concerning the validity of the index with the general public and the news media. We went to consider-

Table VIII. Classification breakdown for the 35 U.S. city/county air pollution indices.

Number of Variables	No.[a]	Percent[a]
1	5	14
2	4	11
3	9	26
4	3	9
5	13	37
6	1	3
Calculation Method		
A. Nonlinear	4 (3)	11 (9)
B. Segmented Linear	13	37
C. Linear	7	20
D. Actual Concentrations	11 (12)	32 (34)
Calculation Mode		
1. Individual	12 (14)	34 (40)
2. Maximum	15	43
3. Combined	8 (6)	23 (17)
Descriptor Categories		
A. Standards	6	17
B. Standards and Episode Criteria	19	54
C. Arbitrary	10	29

[a] Numbers in parentheses show the results when indices can be classified two ways (see text)

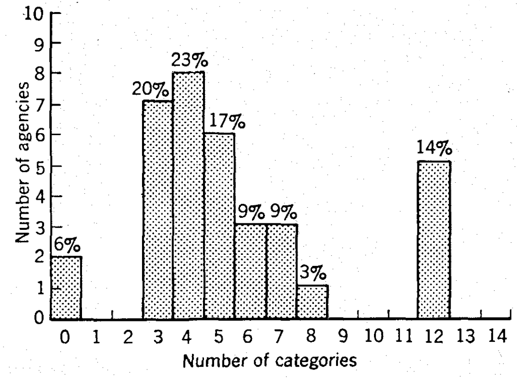

Figure 4. Histogram of the number of descriptor categories used in the 35 U..S. city and county air pollution indices.

able length to explain that the index was a combination of a number of pollutant levels and that the gaseous pollutants could be low and there could still be sufficient fine suspended particulates in the air to obscure visibility, resulting in a low combined index. After one year of increasing problems with the combined index, which included several attempts to modify it, we discontinued its use.

Another agency suggested that the decision of whether or not to use an index probably depends on the level of public education, and that any approach is satisfactory as long as the public fully understands it. Another agency felt that it was preferable to forecast tomorrow's pollutant values (or index values) than to announce today's or yesterday's values, as many indices are designed to do. A common reason given for not using an index had to do with the lack of clear understanding of indices by the public, leading to confusion and misunderstanding. One agency noted that most of the current indices, because they are arbitrary, are really not interpretable. As such, this respondent felt most indices represent a "nonunderstandable, nondimensional number." One agency discontinued its index because the news media "sensationalized" it by reading more into the index than was intended: "The index is now at 80 and when it gets to 100 you will have to start worrying."

Criteria for a Uniform Index. Although some respondents expressed much skepticism about the understandability and meaningfulness of air pollution indices in general, particularly about combined air pollution indices, there was general agreement that prevailing confusion might be reduced if the Federal Government were to develop, endorse, and support a single, uniform air pollution index. Only two dissenting arguments were offered against this concept: one respondent felt that adoption of a uniform index would make comparisons of air pollution levels in different cities too easy, creating discord among the cities. Another respondent felt that each index should be tailored to the public it serves and therefore should be different in different cities. From the comments, it appears that one obstacle to adopting any standardized index is the fact that many cities already using indices would have difficulty changing them to conform to some new index system. The process of reeducating the public poses a difficult problem which would need to be addressed. Another serious problem lies in formulating an index that is truly satisfactory to these agencies and to their public. From the viewpoints expressed by respondents, it appears that any uniform air pollution index would have to possess the following desirable features:

1. *Easily understood by the public.* The index should transform the scientific concentration units of each pollutant into a nondimensional number which is easily understood by the public. To facilitate comprehension of the index, the basis for the transformation should be identical for each pollutant and should relate to a nationally uniform set of air quality standards.

2. *Include major pollutants and capable of including future pollutants.* The index should include all those pollutants which have been identified as major pollutants by the Federal Government and for which nationally uniform standards and episode criteria have been established. Furthermore, the structure of the index should be flexible so that when new pollutant standards are set they can be included in the index without modifying its basic form.

Table X. Indices using the more commonly occurring words in descriptor categories.

Multipollutant Indices	Indices for Particulate Matter Only
New York City	Detroit, Memphis, Oklahoma City[a]
Good	Extremely Light
Acceptable	Light
Unsatisfactory	Medium
Unhealthy	Heavy
	Extremely Heavy
Minnesota, New Jersey	Chattanooga
Good	Light
Satisfactory	Moderate
Unsatisfactory	Heavy
Unhealthful	Alert
Miami	
Good	
Normal	
Moderate	
Heavy	
Severe	

[a] Discontinued index.

Table IX. Frequency distribution of the 44 words used for descriptor categories.

Heavy	11	Normal	2
Good	10	Stage 1	2
Light	9	Stage 2	2
Moderate	7	Stage 3	2
Unhealthy(ful)	7	Very Heavy	2
Unsatisfactory	7	Warning	2
Emergency	6	Above Average	1
Poor	5	Acute	1
Alert	4	Average	1
Extremely heavy	4	Below Average	1
Fair	4	Endangerment	1
Medium	4	Extremely Poor	1
Satisfactory	4	Harmful	1
Severe	4	High	1
Clean	3	Red Alert	1
Extremely light	3	Significant	1
Very Poor	3	Slight	1
Acceptable	2	Very Dangerous	1
Dangerous	2	Very Good	1
Excellent	2	Very Light	1
Hazardous	2	Watch	1
Low	2	Yellow Alert	1

3. *Relate to ambient air quality standards and goals.* The index should relate to the NAAQS which have been established for CO, SO_2, TSP, and O_x.[19] The index values should also be an indicator of the relationship between air pollution levels and these national air quality goals.

4. *Relate to Federal Episode Criteria.* The recommended Federal Alert, Warning, and Emergency Criteria,[20] and the Significant Harm Levels,[21] which have been established for CO, SO_2, TSP, SO_2-TSP product, NO_2, and O_x, should be an additional basis for the index. This will provide a uniform system of both public information and agency administrative procedures during air pollution episodes.

5. *Calculated in a simple manner using reasonable assumptions.* Pollutant concentrations should be easily convertible into their corresponding index values using simple equations or appropriate plots of the index values vs. pollutant concentration. The index equation and/or curves should be based on the relationships described in Criteria 3 and 4.

6. *Based on a reasonable scientific premise.* Because the index should relate to the NAAQS and Federal Episode Criteria (Criteria 3 and 4), its basis would be as solid as the scientific basis on which the standards and episode criteria were established.

Table XI. Summary of preferred structural characteristics of the indices in 35 agencies.

Structural Characteristic	Preferred Structure	Number of Agencies	Percent
Number of variables	5	13	37
Calculation Method	B. Segmented linear	13	37
Calculation Mode	2. Maximum	15	43
Descriptor Categories	B. Standards and Episode Criteria	19	54
Number	4	8	23
	3	7	20
Words	Good	10	36[a]
	Moderate	7	26[a]
	Unhealthy(ful)	7	22[a]
	Unsatisfactory	7	21[a]

[a]Percent use in 28 indices.

7. *Not inconsistent with perceived air pollution levels.* Index values become inconsistent with perceived air pollution levels when, in combined or aggregated indices, high pollutant concentrations are "masked" by lower concentrations. To circumvent this problem, the index should calculate separate values for each pollutant, thus enabling each index value to be reported separately, if desired.

8. *Spatially meaningful.* The spatial meaningfulness of an index depends on how the data are selected or manipulated prior to the index computation. For example, the pollutant concentration may be averaged over several monitoring statins, or the highest pollutant concentration from any station in a city may be selected for the index calculation. The latter method should be used because it prevents the masking of high pollutant concentrations which occurs in the averaging process and allows index values to be associated with locations of specific monitoring sites.

9. *Exhibit day-to-day variation.* The structure of the index should allow for noticeable variation from day to day (and hourly if desired). When the index is calculated for each pollutant separately (Criterion 7) and the maximum value reported, variation also is possible in the pollutant reported. Combined indices do not possess these important characteristics. Reporting the maximum actual pollutant concentrations or the ratio of the pollutant concentration to the NAAQS gives pollutant variation. However, because both of these systems report the index value as a fraction, neither exhibits the large numerical variation necessary for the values to be clearly understood by the public.

10. *Can be forecast a day in advance* (optional). When the index is based on the NAAQS and episode criteria (Criteria 3 and 4), the pollutant concentrations are determined using the Federal Reference Methods (FRM). However, the FRM methods for SO_2 and TSP require 24 hr averaging times, preventing the index from being reported more frequently than once every 24 hr. More current information, or even index forecasts, are of much greater interest and use to the public. More current index values can be obtained using other equivalent FRM monitoring methods having shorter averaging times. A 24 hr index forecast will be difficult to make without extensive meteorological data, but qualitative index forecasting is possible using the National Weather Service's Operation Manual for Air Pollution Weather Forecasts.[22] This system can provide an 18 hr forecast of index values using the following word descriptors: "remain the same," "decrease," or "increase."

Conclusion

The findings of this review are that a great diversity and lack of consistency exist in the way air quality conditions are reported to the public by means of air pollution indices. States, provinces, and U.S. cities use daily informational indices which differ strikingly from each other and differ from the more complex, long-term trend indices that appear in the scientific literature. Of the 55 U.S. metropolitan air pollution control agencies surveyed, 35 (64%) routinely use some form of air pollution index. The metropolitan indices are simpler in form than those appearing in the literature, but there are dramatic differences from city to city. The index classification system reveals *14 basically different index types* among the 35 U.S. cities and six states currently using daily air pollution indices. With two minor exceptions, when descriptor words are taken into account, *no two indices are exactly the same.* Each has a different mathematical formulation and a different meaning to the public. Thus, an index value of 100 reported in Washington, DC means something entirely different from a value of 100 reported in Cleveland, OH.

The Federal Government is currently making a serious attempt to standardize the methods by which air pollutants are monitored. While air monitoring networks require substantial public investments both in personnel and equipment, air pollution indices are one of the most important ways by which the public receives its air quality information from these networks. Thus, lack of uniformity among different indices creates serious problems. Not only does the diversity raise questions about the meaningfulness of today's indices, but an interested member of the public who travels from city to city will readily become confused about air pollution levels in each city. Informed members of the public, when they wish to compare air pollution levels in different cities, cannot do so using today's air pollution indices. Regulatory officials, with so many disparate indices in existence, are unable readily to use these numbers to draw a national picture of air pollution levels and trends. Further, the diversity itself suggests that

Table XII. Breakpoints for SUAQI.

	SUAQI	CO ppm	SO_2 ppm	TSP $\mu g/m^3$	$SO_2 \times$ TSP $(\mu g/m^3)^2$	NO_2 ppm	Ox ppm
		Averaging time (hr)					
Federal level	NA	8	24	24	NA	1	1
50% of primary NAAQS	50	4.5	0.07	150[a]	b	b	0.04
Primary NAAQS	100	9	0.14	260	b	b	0.08
Alert	200	15	0.3	375	65,000	0.6	0.10
Warning	300	30	0.6	625	261,000	1.2	0.40
Emergency	400	40	0.8	875	393,000	1.6	0.50
Significant harm	500	50	1.0	1,000	490,000	2.0	0.60

[a]Secondary NAAQS.
[b]No NAAQS exists—SUAQI is not reported below the Alert level.

no consistent scientific rationale has been employed in developing these indices. Thus, the present lack of uniformity among air pollution indices has at least three undesirable consequences: (1) it creates potential confusion, (2) it raises questions of technical validity, and (3) it prevents the indices from being used to gain insight into national air pollution problems and changes in these problems over time.

A potential solution to these problem is to develop a uniform air pollution index that could be applied in many different cities. An index which meets the 10 criteria above and matches preferred characteristics of the indices currently in use (Table XI) would have the following structural characteristics:

- Includes six variables (CO, SO_2, TSP, $SO_2 \times$ TSP, NO_2, O_x).
- Incorporates a segmented linear function.
- Calculated using a maximum mode.
- Uses the NAAQS, Episode Criteria, and Significant Harm Levels as breakpoints.
- Includes four descriptor categories.

Figure 5 shows the segmented linear functions for such an index, the Standardized Urban Air Quality Index (SUAQI), which appears in the *Compendium;*[1] Table XII gives the SUAQI breakpoints. Four descriptor categories are used in this index: 0–50, *Good;* 51–100, *Satisfactory;* 101–199, *Unhealthful;* 200–500, *Hazardous.*

The SUAQI index shown here forms the basis for the Pollutant Standards Index (PSI) now under consideration by theFederal Government.[23] An early version of PSI proposed by the authors[24] was nearly identical to SUAQI and contained the above four descriptor categories. At the time of this writing, PSI has evolved to contain six descriptor categories, with health effects language included for each category.[10]

We believe that the SUAQI/PSI formulation offers the greatest chance for acceptance by state and local air pollution control agencies. Adoption of a nationally uniform air pollution index should (1) facilitate comparisons of air quality levels in different cities, (2) reduce confusion among residents of cities about daily air quality levels, and (3) provide policy makers with a uniform measure for evaluating the impact of regulatory actions.

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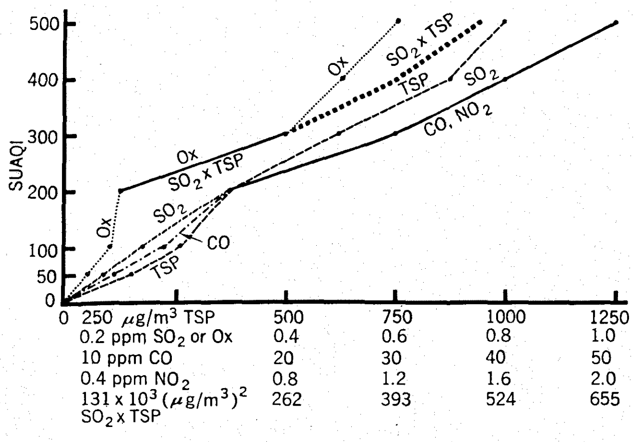

Figure 5. The SUAQI index functions.

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