

CHAPTER 3

PAMS: Enhanced Ozone & Precursor Monitoring

Of the six criteria pollutants, ozone (O₃) is the most pervasive. The most prevalent photochemical oxidant and an important contributor to “smog,” ozone is unique among the criteria pollutants in that it is not emitted directly into the air, but instead results from complex chemical reactions in the atmosphere between volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of sunlight. Further, there are thousands of sources of VOCs and NO_x located across the country. To track and control ozone, EPA must develop an understanding of not only the pollutant, but the chemicals, reactions, and conditions that contribute to its formation as well.

Section 182(c)(1) of the 1990 CAAA called for improved monitoring of ozone and its precursors, VOC, and NO_x in order to obtain more comprehensive and representative data on ozone air pollution. Responding to this requirement, EPA promulgated regulations to initiate the PAMS (Photochemical Assessment Monitoring Stations) program in February 1993. The PAMS program requires the establishment of an enhanced monitoring network in all ozone nonattainment areas classified as serious, severe, or extreme. The 22 affected ozone areas listed in Table 3-1 cover 113 thousand square miles and have a total population of 79 million people.

Each PAMS network consists of as many as five monitoring stations, depending on the area’s population. These stations are carefully located based on meteorology, topography, and relative proximity to emissions of VOC and NO_x. Generally, each PAMS network consists of four different monitoring sites (Types 1, 2, 3, and 4) designed to fulfill unique data collection objectives. The Type 1 site is located upwind of the metropolitan area to measure ozone and precursors being transported into the area. The

Type 2 site is referred to as the maximum precursor emissions impact site. As the name implies, it is designed to collect data on the type

Table 3-1. Metropolitan Areas Requiring PAMS

Extreme
1. Los Angeles-South Coast Air Basin, CA ¹
Severe
2. Baltimore, MD
3. Chicago-Gary-Lake County (IL), IL-IN-WI ²
4. Houston-Galveston-Brazoria, TX
5. Milwaukee-Racine, WI ²
6. New York-New Jersey-Long Island, NY-NJ-CT
7. Philadelphia-Wilmington-Trenton, PA-NJ-DE-MD
8. San Diego, CA
9. SE Desert Modified AQMA, CA ¹
10. Ventura County, CA
Serious
11. Atlanta, GA
12. Baton Rouge, LA
13. Beaumont-Port Arthur, TX ³
14. Boston-Lawrence-Worcester, MA-NH
15. Greater Connecticut, CT
16. El Paso, TX
17. Portsmouth-Dover-Rochester, NH-ME
18. Providence-Pawtucket-Fall River, RI-MA
19. Sacramento, CA
20. San Joaquin Valley, CA
21. Springfield, MA
22. Washington, DC-MD-VA

1. Los Angeles-South Coast and SE Desert Modified AQMA are combined into one PAMS area referred to as South Coast / SEDAB.
2. Chicago and Milwaukee are combined into one PAMS area referred to as Lake Michigan.
3. Beaumont was reclassified to moderate on 6/3/96, thus mitigating its PAMS requirements.

and magnitude of ozone precursor emissions emanating from the metropolitan area. The Type 2 sites are typically located downwind of the central business district and operate according to a more intensive monitoring schedule than other PAMS stations. The Type 2 sites measure a greater array of precursors and are also suited for the evaluation of urban air toxics. For larger nonattainment areas, a second Type 2 site is required in the second-most predominant wind direction. The Type 3 stations are intended to measure maximum ozone concentrations and are sited further downwind of the urban area and the Type 2 sites. The Type 4 PAMS sites are located downwind of the nonattainment area to assess ozone and precursor levels exiting the area and potentially contributing to the ozone problem in other areas. In addition to the surface monitoring sites described above, each PAMS area is also required to monitor upper air meteorology at one representative site. Regulations allow a 5-year transition or phase-in schedule for the program at a rate of at least one station per area per year. The first official year of implementation for PAMS was 1994.

The data collected at the PAMS sites include measurements of ozone, NO_x, a target list of VOCs including several carbonyls (see Table 3-2) as well as surface and upper air meteorology. Most PAMS sites measure 56 target hydrocarbons on either an hourly or 3-hour basis during the ozone season. The Type 2 sites also collect data on three carbonyl compounds (formaldehyde, acetaldehyde, and acetone) every three hours during the PAMS monitoring period. Included in the monitored VOC species are nine compounds classified as hazardous air pollutants (HAPs). All stations also measure ozone, NO_x, and surface meteorological parameters on an hourly basis.

Since its inception, the PAMS program has exhibited steady and successful growth. As of October 1996 there were a total of 65 operating PAMS sites, up from 37 in 1994 and 54 in 1995. The implementation process was expected to culminate in the summer of 1998 when approximately 90 sites would be operational in the originally designated PAMS areas. Because

redesignations are anticipated for several ozone nonattainment areas, the list of areas that require PAMS may change and the implementation schedule may be extended.¹ Despite the ambitious schedule and “cutting edge” nature of the monitoring technologies employed, data from most sites operating in 1995 have been reported to the Aerometric Information Retrieval System (AIRS), EPA’s national repository for air pollution data. Because of its complex technical nature and the magnitude of monitoring requirements, programmatic pragmatism is essential to PAMS continued success. For this reason, flexibility was designed into the PAMS regulations, allowing for submission and approval of alternative network designs and sampling schemes. For example, although there are 22 areas classified as serious, severe, or extreme for ozone, the flexibility of the program allowed areas in close proximity to one

Table 3-2. PAMS Target List of VOCs

Ethylene	2,3-Dimethylbutane	3-Methylheptane
Acetylene	2-Methylpentane	n-Octane
Ethane	3-Methylpentane	*Ethylbenzene
Propylene	2-Methyl-1-Pentene	*m/p-Xylene
Propane	*n-Hexane	*Styrene
Isobutane	Methylcyclopentane	*o-Xylene
1-Butene	2,4-Dimethylpentane	n-Nonane
n-Butane	*Benzene	Isopropylbenzene
trans-2-Butene	Cyclohexane	n-Propylbenzene
cis-2-Butene	2-Methylhexane	m-Ethyltoluene
Isopentane	2,3-Dimethylpentane	p-Ethyltoluene
1-Pentene	3-Methylhexane	1,3,5-Trimethylbenzene
n-Pentane	*2,2,4-Trimethylpentane	o-Ethyltoluene
Isoprene	n-Heptane	1,2,4-Trimethylbenzene
trans-2-Pentene	Methylcyclohexane	n-Decane
cis-2-Pentene	2,3,4-Trimethylpentane	1,2,3-Trimethylbenzene
2,2-Dimethylbutane	*Toluene	m-Diethylbenzene
Cyclopentane	2-Methylheptane	p-Diethylbenzene
Total NMOC		n-Undecane
Carbonyls		
*Acetaldehyde	Acetone	*Formaldehyde
*Hazardous Air Pollutants		

another to consolidate their monitoring operations; therefore, only 20 PAMS networks exist.

EPA is continually evaluating and refining the PAMS program with input from the participating organizations. In 1994, EPA and the states identified sample-handling procedures which caused the data to be unreliable for certain monitored VOC species; EPA subsequently removed these species from the required target list. Currently, EPA is considering overall program modifications in an effort to optimize the networks and reduce costs.

EPA believes that data gathered by PAMS will greatly enhance the ability of state and local air pollution control agencies to effectively evaluate ozone nonattainment conditions and identify cost-effective control strategies. Further, the agency anticipates that the measurements will be of substantial value in verifying ozone precursor emissions inventories and in corroborating estimates of area-wide emissions reductions. The data will be used to evaluate, adjust, and provide input to the photochemical grid models utilized by the states to develop ozone control strategies and demonstrate their success. PAMS will provide information to evaluate population risk exposure, expand the data base available to confirm attainment/nonattainment decisions, and develop ozone and ozone precursor trends. EPA is extremely committed to the analysis and interpretation of PAMS data. Approximately three million federal dollars are allocated annually to state, local, and consolidated environmental agencies for data characterization and analysis.

EPA participates with programs and organizations such as the Northeast States for Coordinated Air Use Management (NESCAUM), the North American Research Strategy for Tropospheric Ozone (NARSTO), and the Mid-Atlantic Regional Air Management Association (MARAMA) in their analytical endeavors. The Agency also recently began conducting PAMS analysis workshops to share and elicit feedback on current analytical techniques and their applicability. Although the PAMS program is still young, comprehensive analysis and inter-

pretation of its data are already being performed. EPA recently released the inaugural issue of the *PAMS 1996 Data Analysis Results Report* which chronicles real PAMS analysis examples from these earlier studies. This report, intended for annual updates, focuses on all sectors of PAMS analysis and its associated benefits. Topics include: ozone episode characterization; VOC characterization; emissions inventory review/refinement; emission-based model support; observation-based model support; and quality assurance/quality control. Although detailed discussion of the *PAMS 1996 Data Analysis Results Report* content is beyond the scope of this chapter, copies of the report and other information concerning PAMS data analysis can be obtained from EPA's Emissions, Monitoring, and Analysis Division.²

Because the emphasis of this report is on air quality and ambient trends, this chapter will focus on those topics as they relate to PAMS. It is currently too early in the development and implementation of the PAMS program to assess overall and network-specific trends in the ambient concentrations of ozone precursors. However, some limited 1994 and 1995 summary data for selected precursors at PAMS sites, as well as basic ozone statistics, are provided in this report's data appendix. Table A-12 shows ozone exceedance counts and annual maximum concentrations for operational PAMS sites. Table A-13 presents summer season statistics for various precursors computed from 1-hour and 3-hour samples. Table A-14 provides annual and seasonal speciated VOC statistics calculated from 24-hour samples. The VOC parameters highlighted in Tables A-13 and A-14 were selected based on their toxicity and/or their high ozone-forming potential (as discussed further in this chapter). Space limitations of this report prohibit inclusion of a more expansive set of comprehensive statistics. The statistics in these three tables are presented merely to relay shifts in the severity of the ozone problem in the affected areas and highlight year-to-year changes in concentration levels of "important" precursors. The reader is cautioned that these

results are preliminary and subject to change. Site data shown may not reflect actual conditions within the entire represented nonattainment area; aggregate data may not accurately reflect conditions across all PAMS networks. For specific data qualifications, see table endnotes.

Between 1994 and 1995, composite average annual daily maximum ozone concentrations at operational (both years) PAMS sites increased about 7 percent; this is slightly more than the 4 percent overall national increase noted in Chapter 2 for aggregate annual second daily maximum ozone concentrations. Note also, as discussed in Chapter 2, that concentrations of ozone adjusted for the effects of meteorology at 44 major urban areas showed a downward trend during this same time period. The number of measured ozone NAAQS exceedances increased more than 12 percent between 1994 and 1995 at matched (both years reported) PAMS sites. Only two of the 20 PAMS areas, South Coast/SEDAB and El Paso, showed aggregate drops in exceedance counts. Preliminary checks of 1996 ozone data

revealed significant reductions in concentration levels and measured exceedances from the 1995 levels (in some cases below the 1994 levels). Although there were substantial increases in ozone concentrations at most PAMS sites between 1994 and 1995, the majority of PAMS sites showed decreases in the ozone precursors highlighted in Tables A-13 and A-14. A summary of the 1994–1995 changes for these compounds is shown in Table 3-3. Of the 14 ozone precursors evaluated, summer mean concentration levels of only isoprene had more sites with statistically significant increases (1994 to 1995) than statistically significant decreases. Annual mean concentration levels of only n-hexane had more sites with statistically significant increases than statistically significant decreases.

Of the featured parameters, benzene showed the most dramatic declines. Federally mandated reformulated gasoline (RFG), which has reduced benzene and aromatic content, was required in “severe” and “extreme” ozone nonattainment areas beginning in 1995. (Note that additional areas were allowed to “opt-in”

Table 3-3. Summary of Mean Concentration Changes for Selected VOCs, 1994–1995

Parameter	Summer Data (1- and 3-hr samples)								Annual Data (24-hr samples)		
	All Sites				Type 2 Sites				All Sites		
	Number of Sites		Median	Change	Number of Sites		Median	Change	Number of Sites		
	Total	#Up	#Down	Change	Total	#Up	#Down	Change	Total	#Up	#Down
Total NMOC	19	4	13	-18%	13	3	10	-18%	4	1	2
2,2,4-Trimethylpentane	17	4	11	-23%	11	3	6	-24%	4	1	2
Acetaldehyde	6	1	3	-14%	5	0	3	-14%	1	0	1
Benzene	19	2	17	-38%	12	1	11	-41%	7	0	5
Ethylbenzene	17	2	12	-23%	11	2	6	-22%	8	0	3
Ethylene	17	2	11	-16%	11	1	6	-13%	4	1	2
Formaldehyde	6	2	2	+4%	5	1	2	+3%	1	0	0
Isoprene	17	6	4	-2%	11	3	4	-5%	4	2	2
M/P Xylene	14	2	8	-21%	10	2	5	-6%	8	0	3
N-hexane	17	6	9	-8%	11	3	6	-8%	4	2	1
O-xylene	17	2	13	-18%	11	2	7	-11%	7	0	2
Propylene	17	3	10	-15%	11	1	8	-15%	4	0	3
Styrene	17	4	8	-17%	11	3	4	-8%	8	0	3
Toluene	17	2	11	-23%	11	2	6	-23%	8	0	4

Note: “#Up” and “#Down” refer to the number of sites with a 1994–1995 mean concentration that was statistically significant. Thus, the total number of sites may not equal the sum of the numbers in the columns labeled “#Up” and “#Down”.

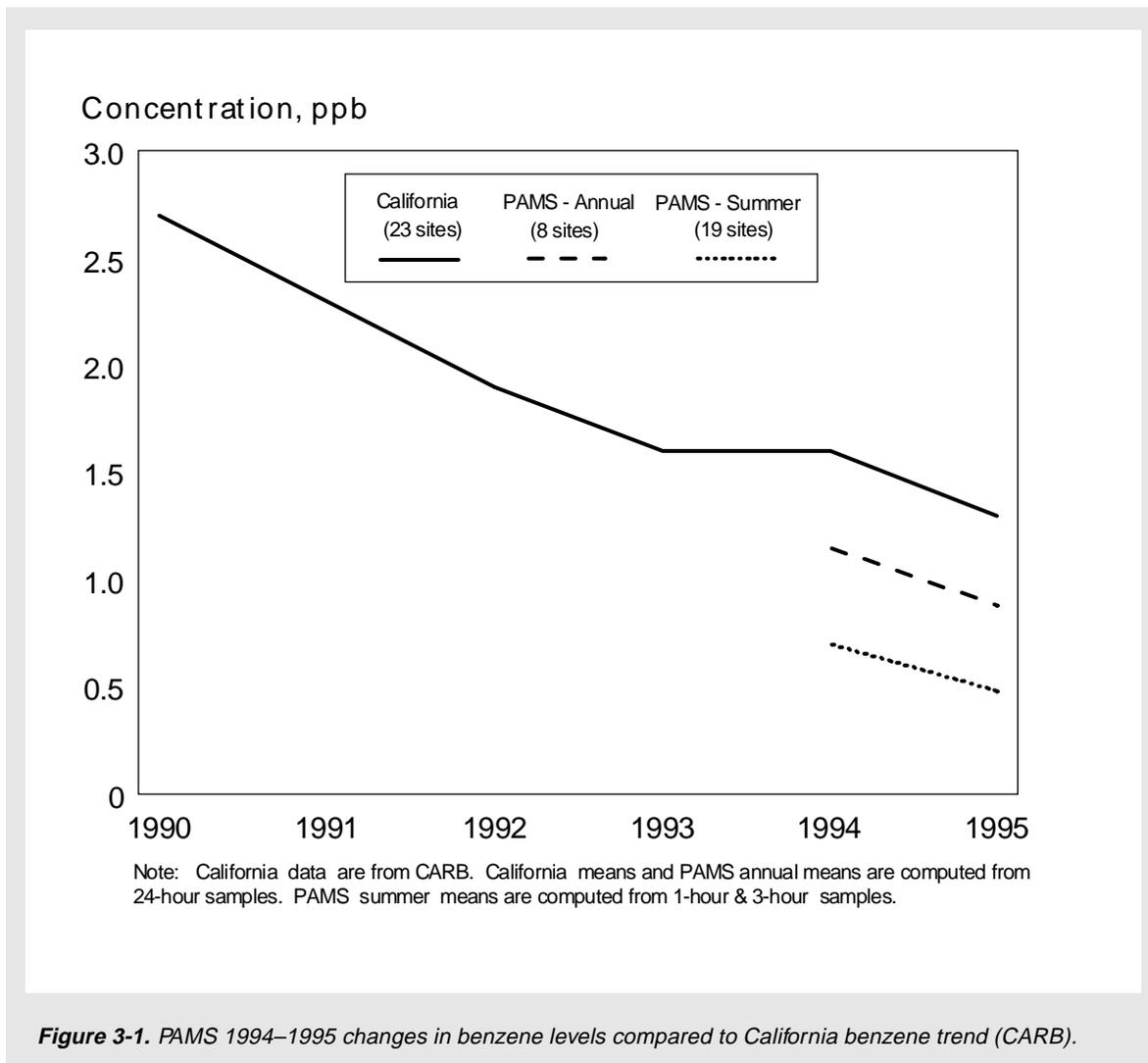


Figure 3-1. PAMS 1994–1995 changes in benzene levels compared to California benzene trend (CARB).

to the RFG program). Benzene emissions from motor vehicles were expected to drop an estimated 30 to 40 percent after the introduction of RFG; this decrease was predicted to be “detectable in ambient data as a relatively abrupt change occurring between the summers of 1994 and 1995.”³ Of the 19 PAMS sites that reported data in 1994 and 1995, the median reduction in benzene concentrations was 38 percent. A greater proportion of sites in RFG areas showed statistically significant decreases in average benzene and other highlighted mobile-related VOC concentrations than did sites in areas that did not use RFG. In Figure 3-1, PAMS

composite average annual and summer benzene means for 1994 and 1995 are plotted along with a recently released California benzene trend from the California Air Resources Board (CARB).⁴ Although there are notable differences in the mean levels, the relative changes between 1994 and 1995 are quite similar.

Of all the targeted VOC species, the seven most prevalent (in parts per billion Carbon, ppbC) at the Type 2 maximum precursor emissions PAMS sites, based on 1995 summer averages, are shown in Table 3-4. Although the compounds and rankings vary slightly from site to site, four compounds are present on most

lists: isopentane, toluene, propane, and ethane. Similar results have been found in earlier studies.⁵ On average, the top seven compounds at each Type 2 site accounted for about 50 percent of the total targeted ppbC. Though all the PAMS targeted VOCs (as well as additional reactive sources of carbon) contribute to the formation of ozone, some contribute more significantly than others. In 1994, William Carter of the University of California published a set of “ozone forming potential” factors known as the Maximum Incremental Reactivity (MIR) scale.⁶ The MIR technique was adapted by the State of California in setting automotive emissions standards. Applying the MIR factors to the means used in Table 3-4, a different set of compounds appears on top (see Table 3-5). The top seven reactivity-weighted compounds overall at the 17 Type 2 sites shown are formaldehyde, m&p-xylenes, ethylene, acetaldehyde, propylene, toluene, and isoprene. The targeted carbonyls formaldehyde and acetaldehyde ranked high overall in spite of the fact that they were not reported at several of the sites. Although applying the factors to

episode or period (e.g. morning) data may be more appropriate, the simple conversion illustrated does correspond favorably to prior studies. A 1994 analysis by the Ambient Monitoring and Assessment Committee of NESCAUM found comparable ranking results for the sites in just their region.⁷ The NESCAUM study found the five most active ozone-forming VOCs during studied ozone episodes to be formaldehyde, isoprene, acetaldehyde, m&p-xylene, and toluene. These five compounds accounted for more than 75 percent of the ozone-forming potential during the studied episodes. The top seven species at each site listed in Table 3-5 accounted for less (65 percent) of the total PAMS targeted ozone-forming potential, but that discrepancy can most likely be linked to the use of overall summer averages as opposed to episode averages. Because of their high overall rankings for ozone-forming potential at the Type 2 sites, summary statistics for the top seven compounds listed in Table 3-5 are included in the Appendix A. Additional parameters were selected because of their toxicity. (Notice the

Table 3-4. Most Abundant Targeted VOCs at Type 2 PAMS Sites—Summer 1995
(Numbers indicate ranking: 1=most prevalent)

PAMS Area – Site Name	Isopentane	Toluene	Propane	Ethane	Acetone	Formaldehyde	n-Butane	Ethylene	m&p-Xylenes	Acetaldehyde	N-Pentane	Other
Baltimore – Morgan State	2	3	4	1				6				5,7 (n-Heptane, Acetylene)
Baton Rouge – Capitol	2	5	3	1			4	6			7	
Beaumont – Jeff. Co. Airport	2		4	1			6	3			5	7 (Isobutane)
Boston – Lynn	1	2	6	4	3	7						5 (Isoprene)
El Paso – Charizal	3	1	2				5	7	6		4	
Houston – Clinton Drive	1	4	3	2			6				7	5 (n-Hexane)
Lake Michigan – Chicago-Jardine	1	2	6	4	5	3						7 (Benzene)
Lake Michigan – Milwaukee	5	6	7	4	1	3				2		
New York – Bronx Botanical Gardens	3	1		2	7		6	5	4			
Philadelphia – East Lycoming	1	3	2	5	7		4					6 (2-methylpentane)
Providence – E. Providence	1	2	3	4	5	6	7					
San Diego – El Cajon	1	2	3	7				5	4		6	
San Diego – Overland	1	2	3	6				4	5		7	
South Coast/SEDAB – Pico Rivera	2	3	1	4			5		6			7 (n-Undecane)
Springfield – Chicopee	1	4		6	3	2					7	5 (Isoprene)
Ventura Co. – El Rio	7		4		1	2	6			3		5 (Isobutane)
Washington – McMillan Reservoir	1	2	5	3				7	4		6	

overlap between these two groups: formaldehyde, m&p-xylenes, acetaldehyde, and toluene are both HAPs and on the top seven reactivity-weighted list.)

Although the compounds shown in Table 3-5 have the highest ozone-forming potential overall at the Type 2 sites, a blanket reduction in these compounds may not necessarily reduce ozone levels. Sometimes NO_x reductions as opposed to VOC reductions will contribute more to reducing ozone concentrations. Because ozone concentrations are sensitive to shifts in the relative abundance of VOC and NO_x, the VOC to NO_x ratio is helpful in ozone control strategy planning.

The morning VOC to NO_x ratio is typically mentioned as a useful starting point for evaluating which type of controls (VOC and/or NO_x) to consider.⁷ A VOC to NO_x ratio less than about 6 implies that the area is “VOC-limited” and areas where the ratio is greater than about 10 are considered to be “NO_x-limited.” In a VOC-limited area, VOC reductions will be most effective in reducing

ozone concentrations, while NO_x reductions may actually increase them. In a NO_x-limited area, NO_x controls will be the most effective at reducing ozone concentrations. However, unlike NO_x controls, VOC reductions “always have benefits, or at worst no effect, and never have any adverse effect on air quality.”⁸ When VOC to NO_x ratios fall somewhere in between 6 and 10, ozone concentrations in the region may be sensitive to changes in VOC and/or NO_x.⁹ VOC to NO_x ratios computed from summer morning (6–9 a.m. DST) means are provided in Table 3-6. Although more intricate analyses should be utilized in actual strategic planning (such as evaluation of the entire distribution of daily/hourly ratios and absolute concentration levels, more emphasis on the ratios for episode days, consideration of aloft measurements, etc.), the ratios shown do evoke a sense of the heterogeneity of conditions across networks and the necessity of supplementary analysis. Note that many of the ratios fall between 6 and 10. Also, because over time an area may convert from one regime to another

Table 3-5. Top Reactivity-Weighted Targeted VOCs at Type 2 PAMS Sites–Summer 1995

PAMS Area – Site Name	Formaldehyde	m&p-Xylenes	Ethylene	Acetaldehyde	Toluene	Propylene	Isoprene	1,2,4-trimethylbenzene	Isopentane	Other	
Baltimore – Morgan State		3	1		4	2	5	6	7		
Baton Rouge – Capitol	1	6	2			3	5		7	4	(1,2,3-Trimethylbenzene)
Beaumont – Jeff. Co. Airport		5	1			2			3	4,6,7	(n-Pentane; n-Butane; Isobutane)
Boston – Lynn	1	3	5	4	6		2	7			
El Paso – Chamizal		1	2		3	4		5	7	6	(o-Xylene)
Houston – Clinton Drive		2			3	1		6	4	7	(o-Xylene)
Lake Michigan – Chicago-Jardine	1	2	4	5	6	7		3			
Lake Michigan – Milwaukee	1	4	3	2	5	6		7			
New York – Bronx Botanical Gardens	1	3	2		4	5	7	6			
Philadelphia – East Lycoming	1	5	2	4	7	3				6	(1-Pentene)
Providence – E. Providence	1	2	5	4	6		3		7		
San Diego – El Cajon	1	2	3	5	4	7		6			
San Diego – Overland	1	3	2	7	6	5				4	(o-Xylene)
South Coast/SEDAB – Pico Rivera		2	6		4					1,3,5,7	(1,3,5-Trimethylbenzene; 1,2,3-Trimethylbenzene; m-Diethylbenzene; o-Xylene)
Springfield – Chicopee	1	7	4	3	5		2		6		
Ventura Co. – El Rio	1	7		2				6		3,4,5	(Acetone; t-2-Butene; 1,2,3-Trimethylbenzene)
Washington – McMillan Reservoir		1	3		2	4	5	7	6		

Table 3-6. Summer 6–9 a.m. VOC:NO_x Ratios at Type 2 PAMS Sites, 1994–1995

Area – Site	1994	1995
Baltimore – Morgan State		6.3
Baton Rouge – Capitol	7.0	12.1
Boston – Lynn	4.7	4.0
Connecticut – E. Hartford	4.8	
Lake Michigan – Chicago–Jardine		7.0
Lake Michigan – Gary		3.3
Lake Michigan – Milwaukee	6.8	3.8
New York – Bronx Botanical Garden		2.8
Providence – E. Providence	9.5	7.8
Sacramento – Del Paso	20.5	13.9
San Diego – El Cajon	7.6	5.3
San Diego – Overland	5.4	3.6
San Joaquin - Clovis-Villa		8.6
San Joaquin – Golden St. Av.	7.8	7.0
South Coast/SEDAB – Pico Rivera	4.8	5.8
Springfield – Chicopee	6.8	4.0
Ventura Co. – El Rio	7.1	12.0
Washington – McMillan Reservoir	5.8	3.6

Notes

- VOC to NO_x ratios are computed from 6–9 a.m. DST summer site means;
- Data are only shown for years/sites that reported both parameters in at least two months of the summer ozone season. The summer ozone season is June–August for all states but CA; in CA the season is July–September.

(VOC-limited to NO_x-limited or vice versa), frequent reevaluation of the ratio as well as other factors is critical.

The VOC to NO_x ratio is just one example of the myriad of information produced by the PAMS networks invaluable to the development and evaluation of ozone control strategies and programs. A few other examples include: upper air and surface meteorological data capable of identifying transport trajectories, inter-species (benzene/toluene, xylene/toluene) components sufficient to quantify air mass aging, inputs to statistical models

(regression and neural network analysis) capable of forecasting high ozone concentrations and identifying vital VOC species, and continuous speciated detail useful for corroborating inventories and validating photochemical models. (For detailed discussion of these topics, see the previously noted *PAMS 1996 Data Analysis Results Report*). In addition, the networks will provide long-term perspectives on changes in atmospheric concentrations of ozone and its precursors (some of which are also hazardous air pollutants), provide information to evaluate population exposure, and most importantly, deliver a more complete understanding of the complex problem of ozone so that we may move toward the best solution.

References and Notes

1. Beaumont was recently reclassified on June 3, 1996 to "moderate" thus mitigating its PAMS requirements. St. Louis and Dallas are expected to be reclassified as "serious," thus requiring them to implement PAMS.
2. Contact Mark Schmidt at voice (919) 541-2416, or via Internet at 'mschmidt@epamail.epa.gov'.
3. Stoeckenius et al, *Recommendations for Analysis of PAMS Data*, Systems Application International, 1994
4. Donald Hammond, *Ambient Trends of Benzene in California from 1990 through 1995*, presented at the U.S. EPA / A&WMA International Symposium on Measurement of Toxics and Related Air Pollutants, RTP, NC, 5/7-9/96.
5. *National Air Quality and Emissions Trends Report, 1994*, EPA-454/R-95-014, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, November 1995.
6. W.P.L Carter (1994), Development of Ozone Reactivity Scales for Volatile Organic Compounds, *J. Air & Waste Manage. Assoc.* 44:881-899.
7. *Preview of 1994 Ozone Precursor Concentrations in the Northeastern United States*, The Ambient Monitoring and Assessment Committee, NESCAUM, 1995, R. Poirot, ed. Boston, MA.
8. Ralph E. Morris, *Review of Recent Ozone Measurement and Modeling Studies in the Eastern United States*, ENVIRON Corporation, 1995.
9. The VOC to NO_x ratio is insufficient in-and-of-itself to determine whether VOC and/or NO_x control will be most effective in reducing ozone levels. It must be tempered with some knowledge about the total emission reduction that will be necessary to achieve the standard as well as some knowledge regarding the cost and technical feasibility of implementing requisite control measures.

