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Ozone Air Quality Trends in the Lake Michigan Region

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INTRODUCTION

Monitoring programs operated by the States of Illinois, Indiana, Michigan, and Wisconsin are an essential component of the on-going regulatory efforts to deal with the ozone nonattainment problem in the Lake Michigan region. These monitoring programs provide information on compliance with the National Ambient Air Quality Standard (NAAQS) for ozone and on progress toward attainment. Progress can be assessed by performing trends analyses, which examine the change in ozone concentrations over time. Because ozone levels are strongly influenced by meteorology, ozone trends analyses should account for the year-to-year variability in meteorological conditions.[1]

The Lake Michigan region experienced one of the hottest summers on record during 1995. In July alone, there were 12 days above 90°F. A severe heat wave in mid-July saw temperatures exceed 100°F for several days. Even though such high temperatures are conducive to elevated ozone concentrations, the summer of 1995 ozone values were not as bad as those in other recent hot summers. This suggests that recent State and Federal emission control programs have been effective in lowering ozone levels in the region.

The purpose of this paper is to review the ozone and ozone precursor levels in the Lake Michigan region over the past 15 years (1981 - 1995). A preliminary adjustment is made for the effect of meteorology in order to assess better the effect of various emission control programs. This review indicates that the region has made considerable progress towards attainment. Data for the most recent 3-year period (1993 - 1995) indicate that there are only eight monitoring sites with a design value above the current 1-hour ozone NAAQS.

AMBIENT DATA BASE

The Lake Michigan States have historically operated a number of ozone monitoring sites, which are classified as either National Aerometric Monitoring Stations (NAMS), State and Local Aerometric Monitoring Stations (SLAMS), or Special Purpose Monitoring Stations (SPMS). To better understand the ozone problem in the region, two enhancements of State monitoring programs have been implemented in recent years: a regional network of Photochemical Assessment Monitoring Stations (PAMS), and boundary aircraft flights. The PAMS network was initiated in 1993 pursuant to the requirements of the Clean Air Act Amendments of 1990 and subsequent regulations promulgated by the United States Environmental Protection Agency (USEPA).

Within the Lake Michigan region, the States currently operate a total of 70 ozone monitors as part of their approved NAMS/SLAMS/SPMS/PAMS networks. The locations of these sites are shown in Figure 1. The breakdown of site types by State is as follows:

STATE	NAMS	SLAMS	SPMS	PAMS	TOTAL
Illinois	7	14	0	3	24
Indiana	2	4	2	1	9
Michigan	2	4	2	1	9
Wisconsin	3	21	1	3	28
REGIONAL TOTAL	14	43	5	8	70

There are also two industrial sites providing ozone data near Kalamazoo, Michigan. Thus, the total number of ozone monitoring sites in the region during 1995 was 72.

All ozone data collected in the region during the past 15 years (1981 - 1995) were considered in this analysis. Not all of the current 70 monitoring sites, however, operated for all 15 years. Although only 24 of these sites operated for all 15 years (see Figure 1), the trends based on data from all sites are qualitatively similar to those based on data from the 24 long-term sites. Thus, use of all data in this analysis is considerable acceptable.

Data for ozone precursors (non-methane hydrocarbons [NMHC] and oxides of nitrogen [NOx]) are relatively sparse. Between 1981 and 1995, NHMC data were collected at only a handful of sites (e.g., the PAMS sites in 1995); no site with data for all 15 years. Between 1981 and 1995, NOx data were collected at several sites (e.g., 20 sites in 1995); only a few sites with data for all 15 years.

Boundary aircraft flights were performed on select high ozone days during 1990, 1991, 1994, and 1995 along the southern and western (upwind) boundaries of the region. These data provide information on incoming (transported) concentration levels and on the change in incoming concentration levels over time.

LOCAL SURFACE OZONE TRENDS

Ozone Exceedances by Month

Most ozone exceedances in the Lake Michigan region over the past 15 years occurred during the months of June, July, and August (see Table 1). The earliest measured exceedance was April 18 (1987) at the Lisle monitor located southwest of Chicago. The latest measured exceedance was September 13 (1990) at the Newport Beach monitor in Door County, Wisconsin.

This seasonal relationship in ozone concentrations reflects the importance of summertime meteorological conditions (e.g., warm temperatures, high solar radiation, and slow-moving high pressure systems) in producing elevated ozone conditions in the region. These conditions accelerate photochemical reactions and increase anthropogenic evaporative and biogenic volatile organic compound (VOC) emissions, which enhance the build-up of ozone concentrations. (It is because of the strong seasonal dependence that the USEPA-approved ozone monitoring season for the four Lake Michigan States is April through September.)

Ozone Exceedances by Day of the Week

In addition to meteorology, local emissions also contribute to elevated ozone concentrations. The effect of local emissions is evident in the frequency of exceedances by day of the week. Figure 2a shows the exceedance frequency for the period 1981-1995 and the year 1995. The effect of emissions is exemplified by the day with the least anthropogenic emissions (Sunday) also being the day with one of the lowest exceedance rates for the period 1981-1995. In addition, the relatively low exceedance rates on Monday and Tuesday may be due to the lower emissions on preceding (weekend) days, while the relatively high exceedance rates on Wednesday and Thursday may be due to the higher emissions on these and preceding (weekday) days.

Figure 2a indicates a decrease in the frequency of weekday exceedances and an increase in the frequency of weekend exceedances in 1995 compared to the period 1981-1995. The total number of weekday and weekend exceedances for each of the past 15 years is presented in Figure 2b. This figure shows that up until 1991, there were many more weekday exceedances than weekend exceedances. Since then, the number of weekday exceedances seems to have declined, while the number of weekend exceedances has remained relatively steady. This may be because existing control programs have focused on industrial sources and on-highway mobile sources, which tend to have higher weekday emissions than weekend emissions. Controls on other sources, which may have higher emissions on weekends (e.g., off-road mobile sources), may be needed to reduce the number of weekend exceedances. The weekday/weekend trend may further suggest that VOC control is the preferred control path in this region.

A recent study in northern California also identified a noticeable difference in weekday/weekend exceedances.[2] The researchers attributed this effect to the difference in the weekday and weekend emission patterns. Based on the emissions and ozone concentration differences (and consideration of the relationship between VOC, NOx, and ozone, as represented by a standard EKMA diagram), the researchers concluded that VOC controls will be more effective than NOx controls in lowering ambient ozone levels in northern California. Similar weekday/weekend emission differences in the Lake Michigan region (in conjunction with a standard EKMA ozone isopleth diagram) suggests that VOC controls will also be more effective than NOx controls in lowering ambient ozone levels in the Lake Michigan region.

Ozone Exceedances

The number of ozone exceedance days over the past 15 years, based on all data and based on data from just the 24 long-term monitoring sites, is presented in Figure 3. During this period, the worst ozone years were 1983, 1987, 1988, 1991, and 1995. These were the same years with most number of "hot" days. Two observations on Figure 3 are worth noting. First, during the early 1980s, there were more exceedance da,s than hot days, while during the early 1990s, there were fewer exceedance days than hot days. Second, unlike the previous hot summers (1983, 1987, 1988, and 1991) when the number of exceedance days were comparable to the number of hot days, there were many fewer exceedance days than hot days during 1995.

The year-to-year variability in meteorology makes it difficult to ascertain the exact trend in regional ozone air quality. A simple adjustment for meteorology can be made, however, by dividing the number of exceedance days by the number of hot days. The resulting "normalized" exceedance rate shows a clear downward trend since 1989 (see solid line in Figure 3). It should be noted, however, that the complexity of meteorological effects in ozone formation and transport in the Lake Michigan region may necessitate the use of more sophisticated adjustment techniques, and it may be premature to base any conclusions on just a few years of data. Continued monitoring is needed to confirm the apparent trend. Nevertheless, this result is encouraging and may suggest that the significant amount of recent VOC emission reductions from stationary sources (due to Reasonably Available Control Technology [RACT] regulations) and motor vehicles (due to the Federal Motor Vehicle Control Program [FMVCP] and lower Reid Vapor Pressure [RVP] gasoline) have been effective in lowering ozone levels in the region.

Additional trends-related information in presented in Table 2. The table identifies the following air quality indicators in each State over the past 15 years: sites with the top three peak ozone concentration ($\geq$ 140 ppb), design value concentration ($\geq$ 140 ppb), and number of exceedance days ($\geq$ 3). This information indicates:

(1) The generally lower peak ozone concentrations, lower design value concentrations, fewer number of sites with high peak and design value concentrations, and fewer number of sites with more than three exceedances in recent years all support the finding that there has been a significant improvement in regional ozone air quality.

(2) The location of the worst ozone site, as characterized by these parameters, does not seem to have changed appreciably over the years. In eastern Wisconsin, in particular, the worst sites are consistently in the Kenosha/Racine/Milwaukee area. Thus, the local VOC emission reductions in recent years do not appear to have "shifted" the ozone problem farther downwind in the region. This suggests that the reductions in VOC emissions in the VOC-limited area around Chicago/Gary/Milwaukee has reduced the amount of locally generated ozone and, in turn, locally transported ozone. (It also possible that ozone concentrations farther downwind have decreased due to local NOx emission reductions in the major urban areas or in these

downwind (NOx-limited) areas. Separate analyses, however, indicate that local VOC emissions from the major source regions of Chicago/Gary/Milwaukee are the more likely cause of high ozone farther downwind within the region.[3])

LOCAL SURFACE OZONE PRECURSOR TRENDS

As noted above, ozone precursor data over the past 15 years are relatively sparse. NMHC measurements are available for the most number of years at only two urban sites: one in Chicago and one in Milwaukee. NMHC data were mostly collected for the 0600-0900 CDT time period. NOx measurements are available for the most number of years at a few urban monitoring sites in Chicago and Milwaukee. Although hourly NOx data were collected, only the 0600-0900 CDT average values are reported here for consistency with the NMHC data. A summary of the ozone precursor data for high ozone days (i.e., days with peak ozone concentrations greater than 100 ppb), along with the associated NMHC:NOx ratios, is provided below. Due to the limited nature of these data, any analysis and interpretation is less complete than that for ozone.

Total NMHC Concentrations

The average 0600-0900 CDT total NMHC concentration levels in Chicago and Milwaukee in 1994 were about 580 and 180 ppbC, respectively. These levels are considerably less than those from the mid- to late-1980s. The average 0600-0900 CDT total NMHC concentrations in Chicago in 1986 and 1987 ranged from 900 to 1300 ppbC (peak values exceeded 2000 ppbC). The average 0600-0900 CDT total NMHC concentrations in Milwaukee in 1987 and 1988 ranged from 330 to 550 ppbC (peak values exceeded 1500 ppbC). The reduction in total NMHC concentrations can be attributed to numerous emission control programs, and helps to explain the improvement in ozone concentrations in recent years.

NOx Concentrations

The average 0600-0900 CDT NOx concentration levels in Chicago and Milwaukee in 1994 were about 145 and 30 ppb, respectively. These levels are less than those from the mid- to late-1980s. The average 0600-0900 CDT NOx concentrations in Chicago in 1986 and 1987 were on the order of 180 ppb. The average 0600-0900 CDT NOx concentrations in Milwaukee in 1987 and 1988 were on the order of 35 ppb. The reduction in NOx concentrations (about 15 - 20%) is much less than the reduction in NMHC concentrations (about 35 - 70%).

NMOC:NOx Ratios

The ratio of the morning concentrations of NMOC and NOx is a simple parameter which may be useful in assessing the relative effectiveness of VOC v. NOx control. At low ratios (e.g., less than 10), VOC emission reductions will be most effective in lowering local ozone concentrations, while NOx emission reductions will be counterproductive. At higher ratios (e.g., greater than 10), NOx emission reductions will be most effective, and VOC emission reductions will be generally ineffective.

The average 0600-0900 CDT NMHC:NOx ratios in Chicago and Milwaukee in 1994 were about 5 and 6, respectively. These levels are considerably less than those from the mid- to late-1980s. The average 0600-0900 CDT NMHC:NOx ratios in Chicago in 1986 and 1987 were on the order of 8.[4] The average 0600-0900 CDT NMHC:NOx ratios in Milwaukee in 1987 and 1988 were on the order of 15 ppb.[5] The reduction in NMHC:NOx ratios can be explained by the much greater reduction in NMHC concentrations than in NOx concentrations. This decrease in NMHC:NOx ratios over time is consistent with the trend reported in other areas in the eastern United States.[6] The lower ratio indicates that the chemical composition of the local urban air has changed somewhat since the mid- to late-1980s. The current NMHC:NOx ratios clearly indicate VOC-limited conditions.

INCOMING (TRANSPORTED) OZONE AND OZONE PRECURSOR TRENDS

The Lake Michigan Ozone Study (LMOS) field programs demonstrated that aloft measurements are necessary to provide a reliable estimate of the incoming (transported) ozone and ozone precursor concentrations. Although continuous ozone data are available at a few surface stations along the upwind boundary, these data are limited in their representativeness of the horizontal and vertical concentration patterns. For example, aloft ozone measurements from the field programs were about 60 ppb higher than corresponding surface measurements at night, and about 10 ppb higher during the day. Thus, the use of surface stations do not provide a reliable measure of the incoming transported ozone concentrations.

Unfortunately, aloft measurements (in the form of aircraft sampling) are available for only a few days from the 1990 and 1991 LMOS field programs, and recent supplemental sampling conducted in 1994 and 1995. These data do not represent a very long timeframe and do not include a lot of sampling days. Nevertheless, the data do indicate that incoming ozone concentrations during the worst episodes have remained relatively steady over the past 6 years; 70 - 110 ppb during two 1991 episodes, 60 - 90 ppb during one 1994 episode, and 60 - 120 ppb during three 1995 episodes. Thus, while local ozone concentrations seem to be declining (in response to local emission control programs), incoming (transported) ozone levels remain very high. Unless these elevated incoming ozone levels are reduced, it will be difficult for the region to attain the ozone NAAQS.

CONCLUSIONS

Based on this preliminary examination of the local ozone and ozone concentrations, and the incoming (transported) ozone concentrations over the past 15 years, three important conclusions can be made:

* There has been significant improvement in ozone levels in recent years due to local VOC emission control programs and favorable meteorological conditions. Although the unseasonably warmer and drier weather conditions during the summer of 1995 produced higher ozone levels than those during the other recent summers, the 1995 ozone levels were less than those observed during other past hot summers.

* Several indicators (e.g., downward trends in the number of meteorologically adjusted ozone exceedances, weekend/weekday emission and ozone concentration differences, and NMHC:NOx ratios) suggest that VOC control is more effective than NOx control in reducing the impact of local urban emissions on local ozone concentrations.

* Transport of ozone and ozone precursors **into** the Lake Michigan region remains a significant problem.

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3. "Characteristics of VOC-Limited and NOx-Limited Areas Within the Lake Michigan Air Quality Region", Technical Memorandum, May 1995, Sonoma Technology, Inc., Santa Rosa, CA.

4. "Application of the OZIPM4/EKMA Ozone Model for Chicago Area Federal Implementation Plan (FIP)", Draft Report, June 1989R, U.S. Environmental Protection Agency, Region V, Chicago, IL.

5. M.K. Allen, "Milwaukee VOC monitoring results for 1990", January 25, 1991, Wisconsin Department of Natural Resources, Madison, WI.

6. G.T. Wolff, "On a NOx-Focused Control Strategy to Reduce O3", Journal of Air & Waste Management, December 1993, Vol. 43, pp. 1593 - 1596.

Table 1. Ozone Exceedance Days by Month in the Lake Michigan Area

Year	April	May	June	July	Aug	Sept	TOTAL
1981	0	0	5	9	5	0	19
1982	0	3	2	6	5	1	17
1983	0	0	10	16	8	5	39
1984	0	0	3	7	12	0	22
1985	0	2	4	6	1	1	14
1986	1	0	5	7	2	1	16
1987	1	4	9	11	3	1	29
1988	0	4	7	13	12	1	37
1989	0	0	5	6	3	0	14
1990	1	0	2	2	3	2	10
1991	0	6	9	7	7	1	30
1992	0	1	1	1	1	0	4
1993	0	0	0	0	5	0	5
1994	0	1	3	1	0	0	5
1995	0	0	5	6	3	0	14
TOTAL	3	21	70	98	70	13	275

Table 2. Air Quality Indicators

YEAR	Peak Concentration (>140 ppb) IL	IN	MI	WI	Design Value (>140 ppb) IL	IN	MI	WI	Number of Exceedances (>3) IL	IN	MI	WI
1981	172 Waukegan 163 Libertyv. 161 Deerfield	173 Hammond	140 Muskegon	208 UWM 200 Racine 198 Kenosha	N/A	N/A	N/A	N/A	4 Waukegan			10 Racine 8 UWM 7 Kenosha
1982	144 Evanston	170 Hammond	157 Muskegon	148 Sheboygan	N/A	N/A	N/A	N/A				4 Waukesha
1983	180 Waukegan 175 Chi(Sci.) 164 Libertyv.	181 Hammond 166 Porter 162 Gary	170 Muskegon	245 Racine 228 UWM 226 Sheboygan	151 Evanston 142 Waukegan 141 Deerfield	165 Hammond 146 Gary	141 Muskegon	200 Racine 179 UWM 165 Sheboygan	7 Chi(SEPol) 6 Evanston 5 Waukegan	5 Hammond 5 Gary	6 Muskegon	13 Racine 11 Sheboygan 10 UWM
1984	172 Evanston	155 Porter 151 Gary 142 Hammond		195 Racine 174 Milw. 173 UWM	157 Evanston 148 Waukegan	151 Gary	140 Muskegon	195 Racine 173 UWM 170 Sheboygan	4 Evanston 4 Waukegan	5 Gary 4 Hammond 4 Porter		6 Manitowoc 5 Racine 4 UWM
1985	148 Waukegan 148 Taft 145 Deerfield		154 Muskegon 140 G.Rapids	165 Milw. 160 UWM 153 Blakewood	157 Evanston 148 Waukegan 145 Deerfield	155 Valpo 151 Gary 142 Hammond	143 Muskegon	195 Racine 173 UWM 170 Sheboygan	4 Evanston 3 Waukegan		3 Muskegon	4 Racine 4 UWM 3 Milw. 3 Kensoha
1986		142 Porter		142 Waukesha 141 UWM	146 Waukegan			172 Racine 147 UWM 144 Kenosha		3 Porter	4 Muskegon	5 UWM 4 Racine
1987	178 Waukegan 177 Deerfield 173 Libertyv.	160 IndDunes 154 Porter	181 Muskegon 141 G.Rapids	250 Sheboygan 234 Bayside 200 Grafton	146 Waukegan 140 Edgewatr	142 Porter	154 Muskegon	167 Racine 165 Sheboygan 160 UWM	7 Waukegan 6 Evanston 5 Taft	5 Porter 4 IndDunes	8 Muskegon 3 G.Rapids	11 Racine 11 Manitowoc 11 Sheboygan
1988	223 Chi(SWFP) 215 Evanston 212 Edgewatr	192 Porter 186 Hammond 164 IndDunes	203 Muskegon 154 G.Rapids	222 Chiwaukee 211 UWM 200 Racine	170 Evanston 162 Edgewatr 162 Waukegan	158 Porter	154 Muskegon 141 G.Rapids	193 Chiwaukee* 183 UWM 178 Racine	16 Evanston 11 Chi(SWFP) 11 Waukegan	10 Porter 6 IndDunes 5 Hammond	12 Muskegon 7 G.Rapids	18 Chiwaukee 17 Kenosha 16 Racine 15 Sheboygan
1989			191 Muskegon 151 Ottawa 144 G.Rapids	176 Chiwaukee 174 Racine 170 Kenosha	170 Evanston 162 Edgewatr 162 Waukegan	158 Porter	180 Muskegon 143 G.Rapids	190 Chiwaukee* 183 UWM 178 Racine			5 Muskegon 3 G.Rapids	6 UWM 5 Bayside 4 Kenosha 4 Chiwaukee 3 Newport
1990			140 Muskegon		170 Evanston 147 Edgewatr 145 Waukegan	148 Porter	152 Muskegon 143 G.Rapids	187 Chiwaukee 174 Racine 173 UWM			3 Muskegon	
1991	152 Cary 152 Lemont		170 Borculo 170 SlpgBear 161 Holland	189 Bayside 178 Grafton 175 Sheboygan 175 Manitowoc				151 Bayside 150 UWM 143 Chiwaukee			5 Muskegon 5 Holland 4 MasonCty	10 Chiwaukee 10 Bayside 6 Sheboygan 6 UWM
1992	149 Waukegan			179 Chiwaukee 156 Racine 150 Kenosha				148 Bayside 143 Chiwaukee				
1993			156 G. Rapids 141 Muskegon	145 Chiwaukee			141 Muskegon	148 Bayside 146 Chiwaukee				
1994	169 Lemont		149 G.Rapids 146 Muskegon	175 Harr.Beach 166 Chiwaukee 163 Manitowoc								3 Bayside
1995	166 Chi(SE) 150 Cal.City 149 Evanston	157 Hammond 154 MichCity	178 Holland 171 Muskegon 163 G.Rapids	146 Slinger 143 Harr.Beach 142 Collins						6 MichCity	4 Muskegon 4 Holland	4 Chiwaukee

*=based on less than 3 yrs data

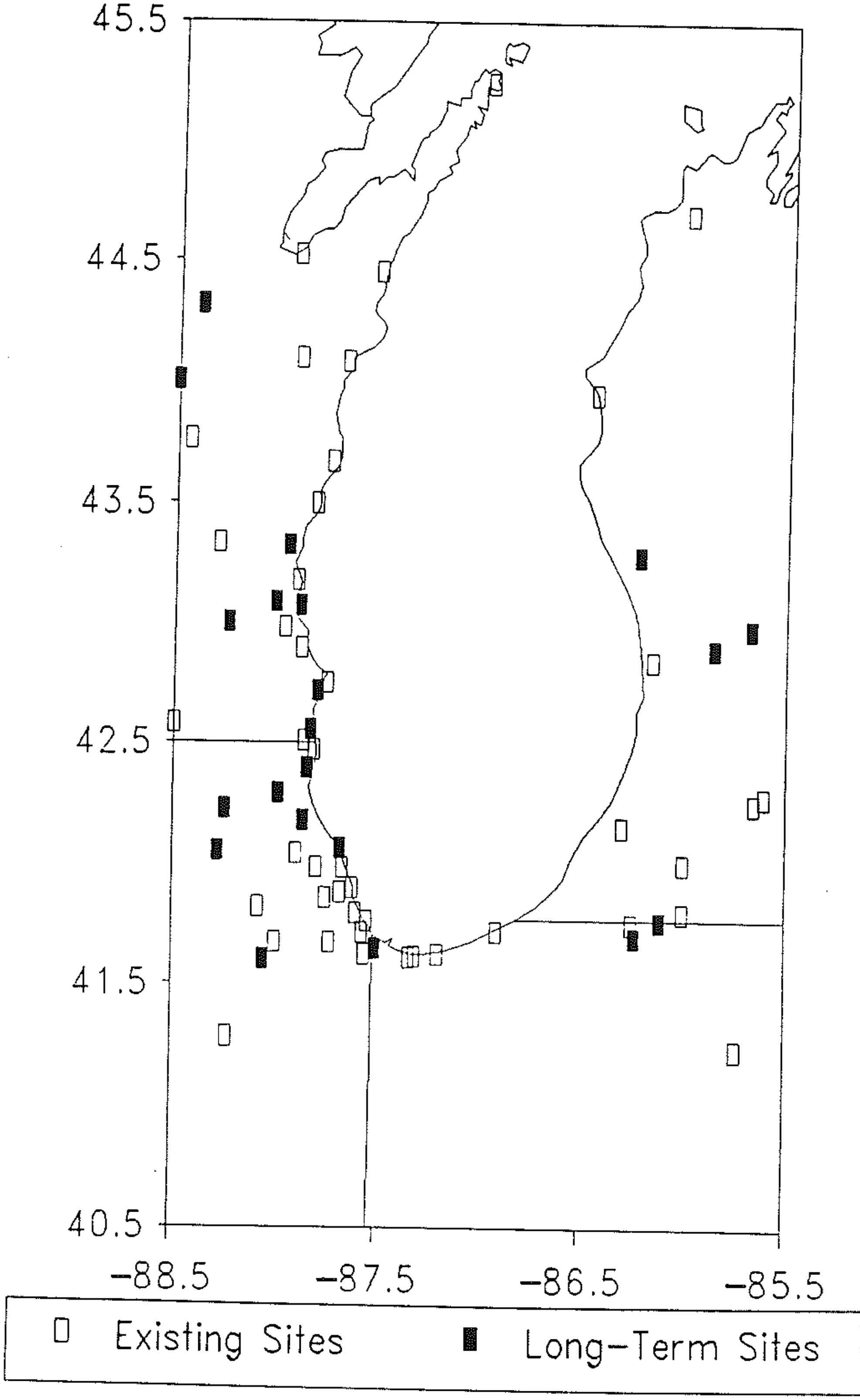

Figure 1. Ozone Monitoring Sites in the Lake Michigan Region

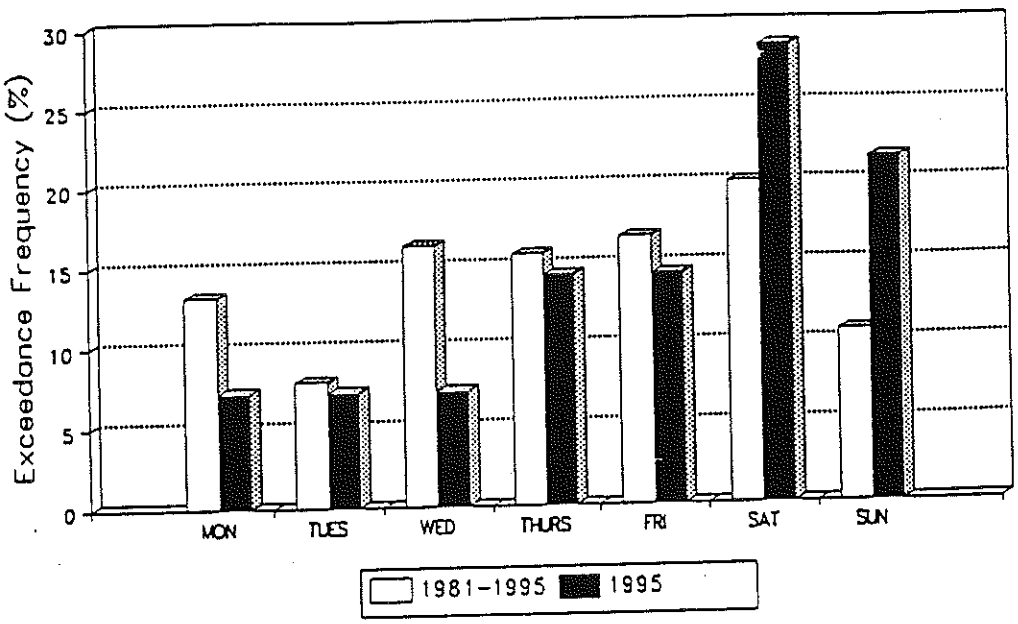

Figure 2a. Exceedance Frequency by Day of the Week

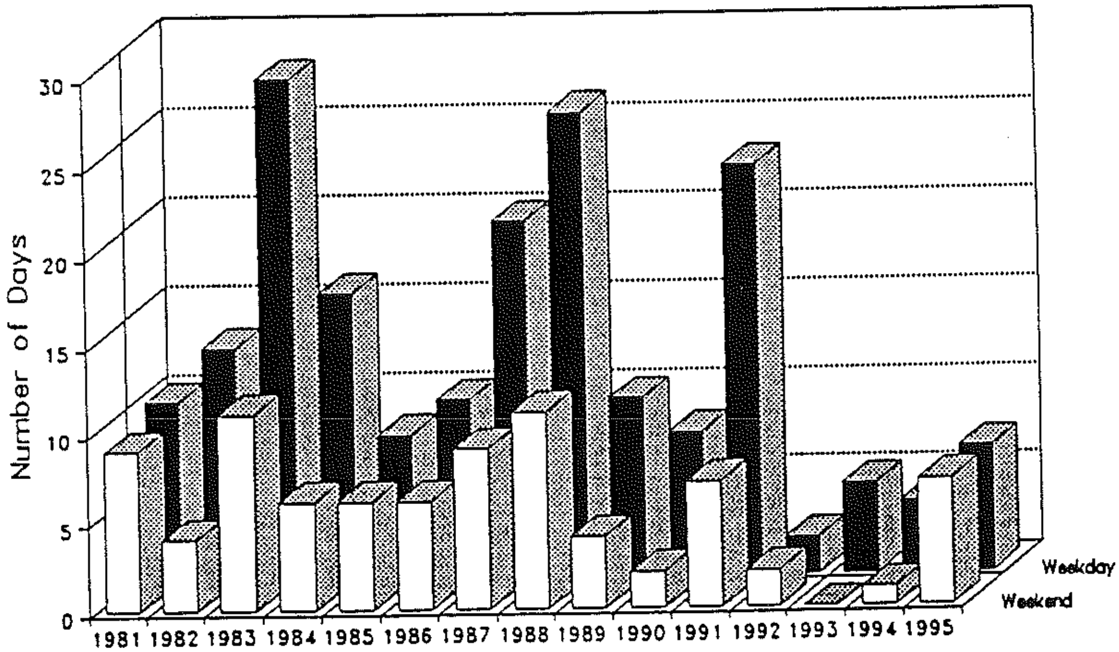

Figure 2b. Number of Weekday and Weekend Exceedances

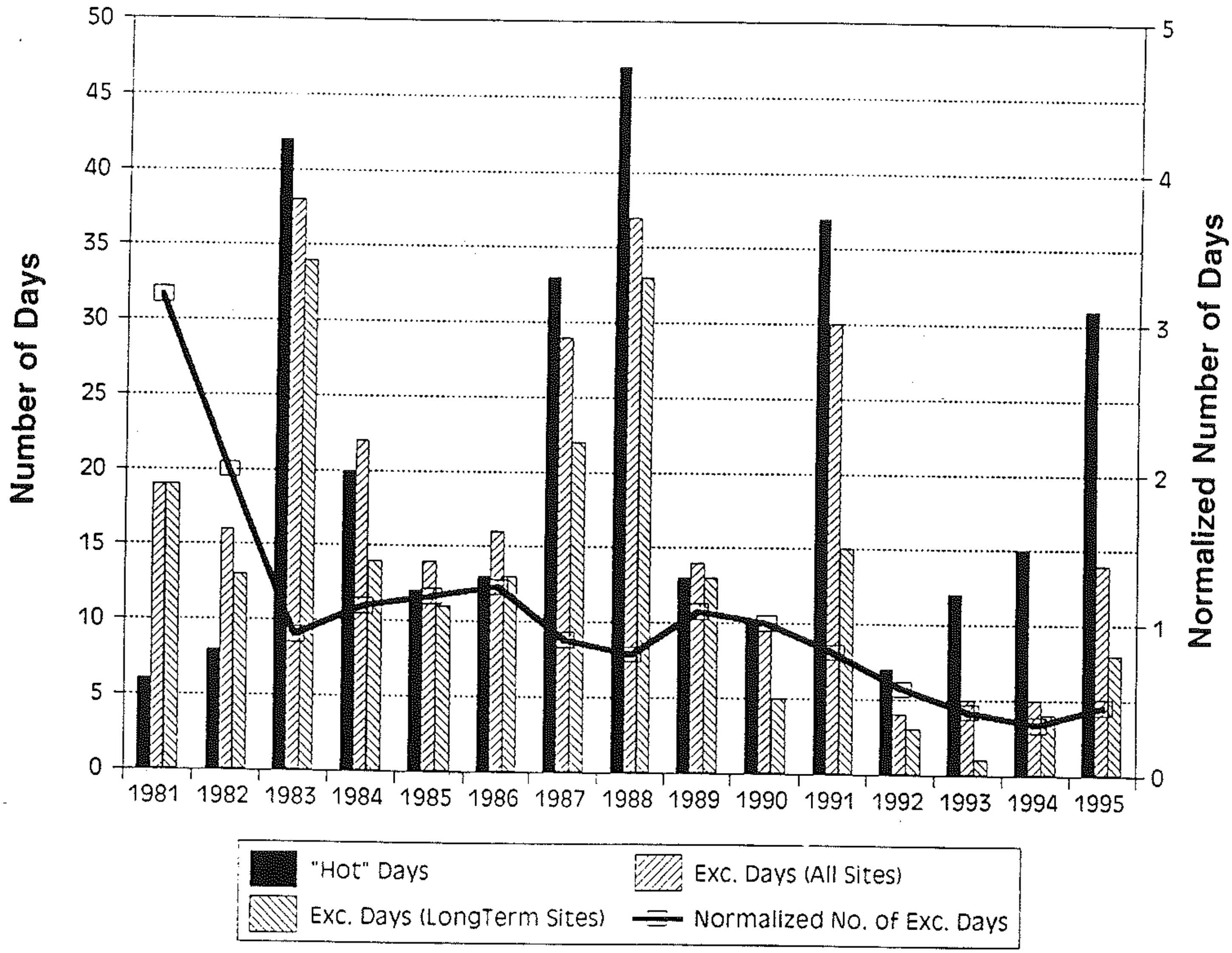

Figure 3. Number of Ozone Exceedance Days and "Hot" Days