A NOTE ON VISIBILITY AT SACRAMENTO, CALIF.

GEORGE C. HOLZWORTH

Weather Bureau Research Station, Berkeley, Calif.

[Manuscript received January 13, 1959]

ABSTRACT

Daylight visibility observations at the Sacramento Municipal Airport were used to investigate the possibility that visibility in the area has been declining due to rising levels of air pollution. Those visibility observations made with naturally occurring fog (defined as relative humidity greater than 90 percent) and/or precipitation were eliminated from the data. Observations for July, a warm, dry month with relatively slight climatic differences from year to year, and November, a cool month that often exhibits a considerable annual variation of climate, were tabulated for the three 4-year periods, 1935–38, 1945–48, and 1953–56. The results show that for July the percent frequency of poor visibilities steadily increased, and of good visibilities steadily decreased over the last 20-odd years. Such a trend is consistent with the Sacramento population increase. For November the trend was irregular. This is believed to be due to variations in the occurrence of meteorological factors important to atmospheric dispersion. It is likely that such irregularities are characteristic of other months and areas where there are large annual climatic variations.

From concurrent surface wind observations, the preferred wind conditions for various visibility ranges were determined. These data indicate that poor visibilities at the airport, on the southern edge of the city, occurred most frequently with light winds from over the nearby Sacramento urban area. Good visibilities were favored by moderate winds from rural directions. Visibilities were reduced when the wind speed became strong enough for loose materials to be picked up from the ground.

1. INTRODUCTION

Residents of Sacramento and other cities in California's Central Valley, as well as aircraft pilots in the vicinity, have stated that over the years they have observed a general decrease in visibility. These individuals have attributed such a trend to increasing levels of air pollution. Because air pollution measurements have not been made in the Central Valley until recently, studies of trends in the concentrations of specific pollutants are not possible. However, the solid and liquid particulate matter suspended in the atmosphere, which represents air pollution, reduces visibility [1], and therefore a measure of visibility may be interpreted as a measure of air pollution. Hence, changes in visibility not attributable to naturally occurring aerosols may be indicative of manmade trends in air pollution. This study was undertaken in order to assess the possibility that there has been a general deterioration of visibility in the Sacramento area due to human activity.

2. DATA AND TREATMENT

From the hourly weather observations made by the U.S. Weather Bureau at Sacramento Municipal Airport, the July and November data for the three 4-year periods 1935–38, 1945–48, and 1953–56 were selected and punched on cards for machine tabulation. Only daytime observations, 0730–1730 PST,[1] were considered since visibility at night depends upon different factors and the observations are generally less reliable [1]. All observations, 1935–56, were made from the same location.

Prior to 1943 visibility to be reported by Weather Bureau observers was defined as "the greatest distance toward the horizon that known objects can be identified." This was later revised to "the lowest visibility over the half of the horizon with the greatest visibility." Summaries for this study do not suggest that this change in definition had any noticeable effect on Sacramento observations.

July and November visibility trend analyses were considered with respect to the three 4-year periods. The data were lumped into 4-year groups in an attempt to smooth out year-to-year variations in meteorological conditions such as factors affecting the dispersion of pollutants.

The natural aerosols which limit visibility are fog and precipitation. Precipitation may occur at various relative

[1] Actual observation times are about 28 minutes past the hour for 1945–56 and about 41 minutes past the hour for 1935–38. At Sacramento in November the latest sunrise is about 0700 PST and the earliest sunset is near 1700 PST.

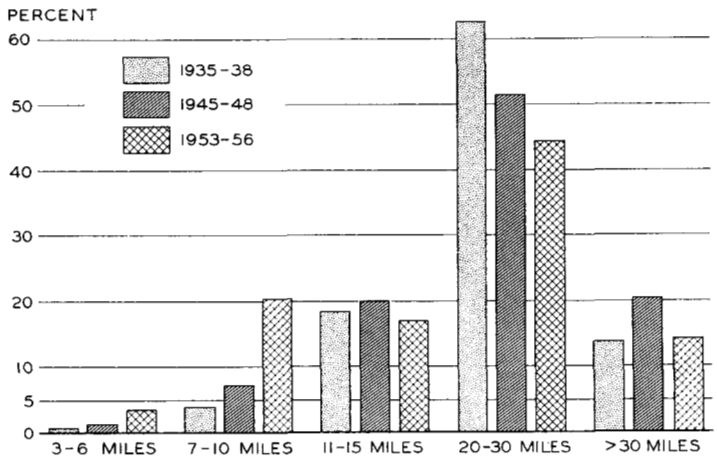

FIGURE 1.—July visibilities at Sacramento Municipal Airport, 0730–1730 PST. Percent frequencies when relative humidity less than 91 percent and no precipitation occurring.

humidities, but natural fog is unlikely below about 91 percent. Those visibility observations with precipitation and/or relative humidity greater than 90 percent were tabulated separately, and remaining visibility observations were originally broken down according to various other relative humidity ranges. Although the visibilities tended to be lower with higher humidities, the trends between 4-year periods for various humidity ranges were all similar. For this reason, and because it is desirable to deal with large samples, all visibilities recorded with humidities below 91 percent (and no precipitation) were considered together. In 96.7 percent of the July visibility cases, humidities were less than 71 percent. In November, humidities were below 71 percent in 60.2 percent of the cases and below 91 percent in 83.9 percent of the cases.

3. RESULTS

In the following discussions visibility observations with precipitation and/or relative humidity greater than 90 percent are excluded. This provision is intended to eliminate visibility restrictions that might be attributed to naturally occurring fog and precipitation particles.

JULY

July was chosen as typical of the warm, arid summers when there are seldom marked variations in Central Valley weather. The percent frequencies of visibilities in given ranges for each of the three 4-year periods are shown in figure 1. This bar diagram indicates that the frequency of visibility reports in the ranges 3–6 and 7–10 miles steadily increased over the years studied. The percentage frequency of the combined 3–10-mile range increased by a factor of almost 5 from 1935–38 to 1953–56, apparently at the expense of the 20–30-mile range whose frequency

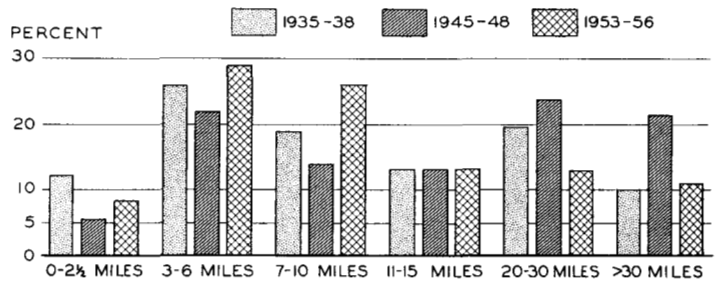

FIGURE 2.—November visibilities at Sacramento Municipal Airport, 0730–1730 PST. Percent frequencies when relative humidity less than 91 percent and no precipitation occurring.

steadily declined from 62.8 percent in 1935–38 to 44.5 percent in 1953–56. The frequency of visibilities of 11–15 miles changed only slightly and inconsistently with time. In the range exceeding 30 miles, there was no regular trend. There were no July visibilities of 0–2½ miles. Considering all visibilities, a deteriorating trend is clearly indicated for July.

The most striking visibility trends were in the 3–10- and 20–30-mile ranges. By the chi-square test [2], differences between the three 4-year periods for both these visibility ranges are significant at the 1-percent level. It should be mentioned that such tests of significance assume independence of samples, and hourly weather observations do not fully satisfy this assumption. However, each of the 4-year groups was considered to more clearly approach the property of independence.

NOVEMBER

Climatologically, November is a relatively cool month and was chosen to represent early winter conditions as opposed to summer. The weather is often quite variable within this month and considerable differences may occur from year to year. Some Novembers are rainy and foggy while others are relatively dry and fog free.

The percentage frequencies of visibilities in given ranges for each of the three 4-year periods, as shown in figure 2, indicate that November visibilities followed an irregular trend. As a whole, poor visibilities (0–10 miles) were least frequent, and good visibilities (20 miles or greater) were most frequent in the middle period, 1945–48. In the later period, 1953–56, the picture was reversed with 0–10-mile visibilities most frequent and visibilities of 20 miles or greater least frequent. In the early period, 1935–38, poor and good visibilities occurred with frequencies intermediate between those of the other two periods. The frequency of visibilities of 11–15 miles differed between periods by only 0.2 percent. Considering all visibilities for November, they may be described as having been intermediate in 1935–38, good in 1945–48, and poor in 1953–56.

This irregular variation stands in sharp contrast to the steady trend shown for July. As mentioned above, data for 4-year periods were lumped together in the hope that important weather variations would be smoothed out. This result is more probable for July than for November when conditions may be quite variable. November average 4-year precipitation amounts were 1.09, 1.41, and 1.59 inches for the earliest to latest periods, respectively; for any one November in these 12 years, precipitation ranged from 0.03 to 3.35 inches. These are cited to indicate to some extent the degree of weather variability in these 12 Novembers. It is thought that such variations in important meteorological factors, affecting both dispersion and emission of visibility-reducing pollutants, have resulted in the irregular November trend shown in figure 2.

With respect to pollutant sources, the burning of crop residues after harvesting should be mentioned. It is thought that this practice, which has been common in the rich agricultural area of Sacramento and other parts of the Central Valley, is partly responsible for the irregular trend of November visibilities. Smoke from what agricultural burning occurs in July is likely to be more rapidly dispersed by the usual summer conditions of windiness and instability. However, because the desired facts on agricultural burning are nonexistent, such remarks must be regarded as speculation.

4. FURTHER CONSIDERATION

It is generally recognized that as urban areas expand, pollutant emissions from such sources also increase (in the absence of emission controls). It is logical then that, other things being the same, visibility should show a general decline with increasing urbanization. The Sacramento Municipal Airport is on the southern edge of the city, about 4½ miles from the downtown area. Because Sacramento is the only large city in the county and because much of the total metropolitan population lies beyond the official city limits, Sacramento County population figures have been used. From decennial population data [3] and others [4], the following population estimates were made for Sacramento County for 1 year within each of the three periods studied:

1937	160,000
1947	230,000
1955	380,000

Thus the trend of deteriorating July visibilities was associated with a rapidly increasing population. In November this same trend held true for 1945–48 to 1953–56, but improving visibilities from 1935–38 to 1945–48 were also associated with a population increase. As pointed out, this latter irregularity is believed to have been due to variations of important meteorological factors.

That the Sacramento metropolitan area was indeed a source of visibility-reducing pollutants may be shown from a consideration of surface winds. For each visibility observation the concurrent wind observation was tabulated in wind rose form for each visibility range. Wind directions were divided into two groups, northwest clockwise through east-southeast (NW–ESE) and southeast through west-northwest (SE–WNW). As shown in figure 3, most of the Sacramento metropolitan population lies in the sector NW–ESE from the airport. The other sector, SE–WNW, may be described as relatively rural. The relationship of poor visibilities (0–10 miles) to winds was considered first. This was done by summarizing the percent frequency of occurrence of wind in each of the two direction sectors, NW–ESE and SE–WNW, by 5-m.p.h. speed intervals for 0–10-mile visibilities and for all visibilities. The ratio of the former to the latter was then determined and these values for July and November are given in table 1. Each number in this table is the ratio of percent frequency of given wind conditions for low visibility to the percent frequency of such wind conditions for all visibilities. Thus, the higher the ratio, the greater the "preference" of low visibilities for such wind conditions.[2] For example, table 1 shows that in July the most preferred wind condition for 0–10-mile visibilities was from NW–ESE at 1–5 m.p.h. It should be made clear that these wind conditions are not necessarily those with which the visibility was most often 0–10 miles. The preference is relative to what is expected from a consideration of all visibilities.

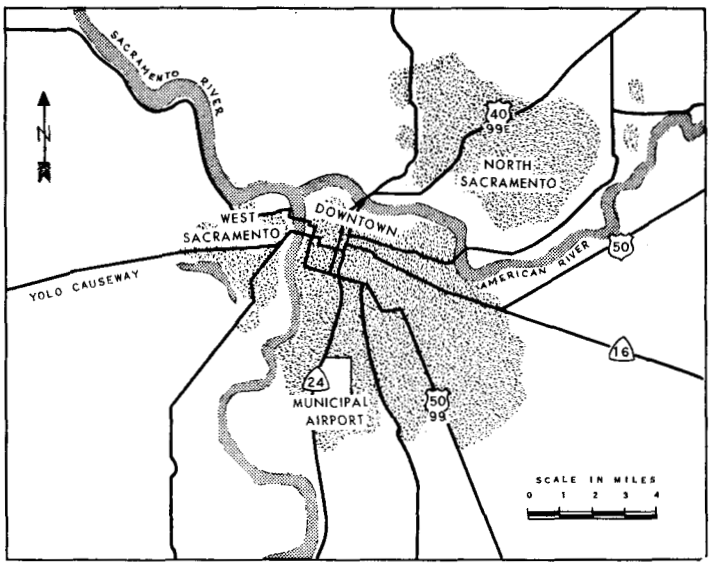

FIGURE 3.—Schematic map of Sacramento, Calif.

[2] Using tables B and F of *Local Climatological Data Supplement*, it is possible to compute the ratios of "percent of time the wind is from given directions for visibilities less than 7 miles with smoke or haze" to "percent of time the wind is from corresponding directions for all visibilities."

TABLE 1.—*Ratio of "percent of winds for visibility 0–10 miles" to "percent of winds for all visibilities." Data for Sacramento Municipal Airport when relative humidity less than 91 percent and no precipitation; 0730–1730 PST, 1935–38, 1945–48, 1953–56*

Wind speed m.p.h.	Wind direction			
	NW–ESE	SE–WNW	Calm	All
JULY				
(No visibility reported in 0-2½ miles range)				
Calm			2.57	2.75
1–5	3.03	1.82		2.12
6–10	1.49	.96		1.05
11–15	.80	.43		.45
16–20	2.23	.44		.50
>20	None	.77		.77
All	1.90	.83		
NOVEMBER				
Calm			1.49	1.49
1–5	1.36	1.16		1.27
6–10	1.04	.88		.98
11–15	.27	.52		.41
16–20	.18	.36		.25
>20	.47	.36		.44
All	.99	.89		

TABLE 2.—*Ratio of "percent of winds for visibility 20–30 miles" to "percent of winds for all visibilities". Data for Sacramento Municipal Airport when relative humidity less than 91 percent and no precipitation; 0730–1730 PST, 1935–38, 1945–48, 1953–56*

Wind speed m.p.h.	Wind direction			
	NW–ESE	SE–WNW	Calm	All
JULY				
Calm			0.75	0.75
1–5	0.68	0.79		.77
6–10	.86	.95		.94
11–15	1.33	1.14		1.15
16–20	1.50	1.14		1.14
>20	1.86	1.10		1.12
All	.89	1.02		
NOVEMBER				
Calm			0.34	0.34
1–5	0.51	0.88		.67
6–10	1.01	1.17		1.08
11–15	1.33	2.30		1.86
16–20	.84	2.92		1.67
>20	1.03	2.50		1.41
All	.83	1.39		

Wind speeds exceeding 15 m.p.h. were infrequent, and so the ratios for such speeds had to be computed from small percentages. However, the computed ratios appear to exhibit reasonable trends as wind conditions vary. A likely exception is the value of 2.23 in table 1, July, which probably would be lower with more cases of such winds. This fault might be corrected by combining some of the higher wind speeds, but in so doing one of the features of the table would be lost. It is a reasonable hypothesis that, considering nearby community sources of visibility-reducing aerosols, improving visibility should be anticipated with increasing wind speed (more favorable dilution) up to the point where dust and other loose materials are picked up by the wind. This is borne out in table 1 where, considering all wind directions, there is a decrease in the ratios with increasing speeds up to the point where loose material is picked up. Here the ratios begin to increase. In July when precipitation averaged less than a trace and the ground was dry, this reversal began at 16–20 m.p.h. In November when precipitation averaged 1.36 inches, the ratios did not begin to increase until speeds exceeded 20 m.p.h.

From table 1 it is clear that wind directions occurring with low visibilities were most likely to be from the urban area. This was especially true for July when for every wind speed the ratios were greater for the sector NW–ESE than for the SE–WNW sector. For November, considering all wind speeds, the most preferred direction with low visibilities was also from the metropolitan area. However, the preference was not nearly so strong as in July. This may have been due in part to agricultural burning which provides pollutant sources to the south as well as to the north.

Table 2 is similar to table 1 except it is for good visibilities, 20–30 miles. This table indicates that for all directions there was an increase in the ratios, preference for good visibilities, with increasing speeds up to the point where loose materials are picked up, and then the trend reversed. Considering all wind speeds, the most preferred direction for good visibility was from the rural sector, SE–WNW.

Hygroscopic nuclei may be active in the humidity range 71–90 percent. If such relative humidities are related to wind directions, then the concurrent visibilities might be lower and tables 1 and 2 would be invalid. July daytime humidities above 70 percent are very rare. In November, humidities of 71–90 occurred 23.7 percent of the time. The November ratios in tables 1 and 2 were recomputed, using only data for relative humidities below 71 percent (and no precipitation). The recomputed ratios are almost identical with the original. It is concluded that any relationship between humidities of 71–90 percent and wind directions does not alter the ratios of tables 1 and 2.

5. CONCLUSIONS

The data for July indicate that Sacramento visibilities have been deteriorating over the last 20-odd years. This is most apparent in the 0–10-mile visibility range, which showed a steady increase in percent frequency, and in the 20–30-mile range, which showed a steady decrease. In November, visibilities went through an irregular trend from intermediate to good to poor, from the earliest to the latest periods, respectively. This may have been due

largely to variations in the occurrence of meteorological factors, especially those important to atmospheric dispersion of manmade pollutants. It is likely that such irregularities are characteristic of other seasons and areas where there are large variations in the weather.

From a consideration of wind data it is clear that poor visibilities were associated with wind directions from over the urban area and with light winds. Wind direction and speed factors were interdependent. Good visibilities were most likely with winds from rural directions and at moderate speeds. The data indicate that visibilities were reduced when winds became strong enough to pick up dust and other loose materials.

ACKNOWLEDGMENTS

This work was carried out in cooperation with the California State Department of Public Health as a part of the program of the Bureau of Air Sanitation. Various people in this Bureau made helpful suggestions and their contributions are gratefully acknowledged.

The raw data were kindly made available by the U.S. Weather Bureau at Sacramento. The encouragement of the Office of Meteorological Research and the Weather Bureau Research Station at the R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio, is also appreciated.

REFERENCES

1. H. G. Houghton, "Visibility," *Handbook of Meteorology*, McGraw-Hill Book Co., Inc., New York, 1945, pp. 242–251.
2. H. A. Panofsky and G. W. Brier, *Some Applications of Statistics to Meteorology*, Pennsylvania State University, University Park, Pa., 1958, see pp. 53–58.
3. U.S. Bureau of the Census, Census data for 1930, 1940, 1950.
4. California State Department of Finance, Population estimate for 1956.