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Final Report

AIR-POLLUTION CLIMATOLOGY NEAR MONROE, MICHIGAN

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ABSTRACT

The topography and geography of the area near the plant site are described. The average wind conditions as measured at the Toledo Airport are discussed in relation to winds near the plant site, and the importance of local lake effects at the latter is emphasized. The maximum hazard to various population centers as a result of this wind pattern is outlined. The occurrence of precipitation would reduce the hazard to the more distant communities. The occurrence of inversions at Toledo Airport is analyzed and their significance indicated. The results of a study of atmospheric visibility at Toledo Airport are presented and discussed. Sutton's equations are then employed to examine in detail the hazard to communities.

The conclusions regarding hazards are outlined and recommendations made for a program of measurements and analyses of meteorological quantities and of concentrations of a tracer substance over the lake in order to reduce the uncertainty concerning the hazards involved.

OBJECTIVE

The object of the study is to assess the hazard to the communities around the western end of Lake Erie if an accidental release of radioactive materials from the projected plant near Monroe, Michigan, should occur.

TOPOGRAPHY AND GEOGRAPHY

The plant site is located on the western shore of Lake Erie about 7 miles ENE of Monroe. The shoreline in the immediate neighborhood of the site is cut by a series of inlets. The general terrain is very flat in all directions and only a few feet above the level of the lake. The vegetation consists mostly of tall grass, low bushes, and occasional clumps of trees about 40 feet high. Although the shoreline is quite irregular, in general the west shore of Lake Erie lies in a NE-SW direction.

Figure 1 illustrates the topography of the area and the location of important population centers. In addition to Monroe, mentioned above, there are the cities along the Detroit River from Trenton, about 12 miles NNE of the site, through Wyandotte, Ecorse, River Rouge, to Detroit, about 22 miles to the NNE. Directly to the NE, about 10 miles away, lies Canada. The city of Toledo is about 22 miles SSW of the site. But perhaps the closest population center is the group of beaches along the lakeshore from 2 to 5 miles SW of the site. Thousands crowd these beaches every weekend during the summer. At other seasons they are virtually deserted. The topographical contours on the map illustrate the flatness of the terrain with only a gentle rise from the lakeshore.

WINDS

Two sets of data were considered for this report. One was for Willow Run Airport, about 24 miles NW of the site, and the other was for Toledo Airport, about 29 miles to the SSW. Willow Run data for the period January, 1948, to December, 1950, had been analyzed in connection with an earlier report[1] and will be discussed later. However, for the present report it was decided to rely mainly on the Toledo data since they were more likely to reflect the influence of Lake Erie. In addition, Toledo had been the site of a vertical temperature sounding station for a number of years and these important data were also available for study. Accordingly, wind observations from January, 1950, to December, 1954, were analyzed.

The weather station at Toledo was located about 10 miles SW of Lake Erie. Winds were observed at a height of 47 feet above the ground. In view

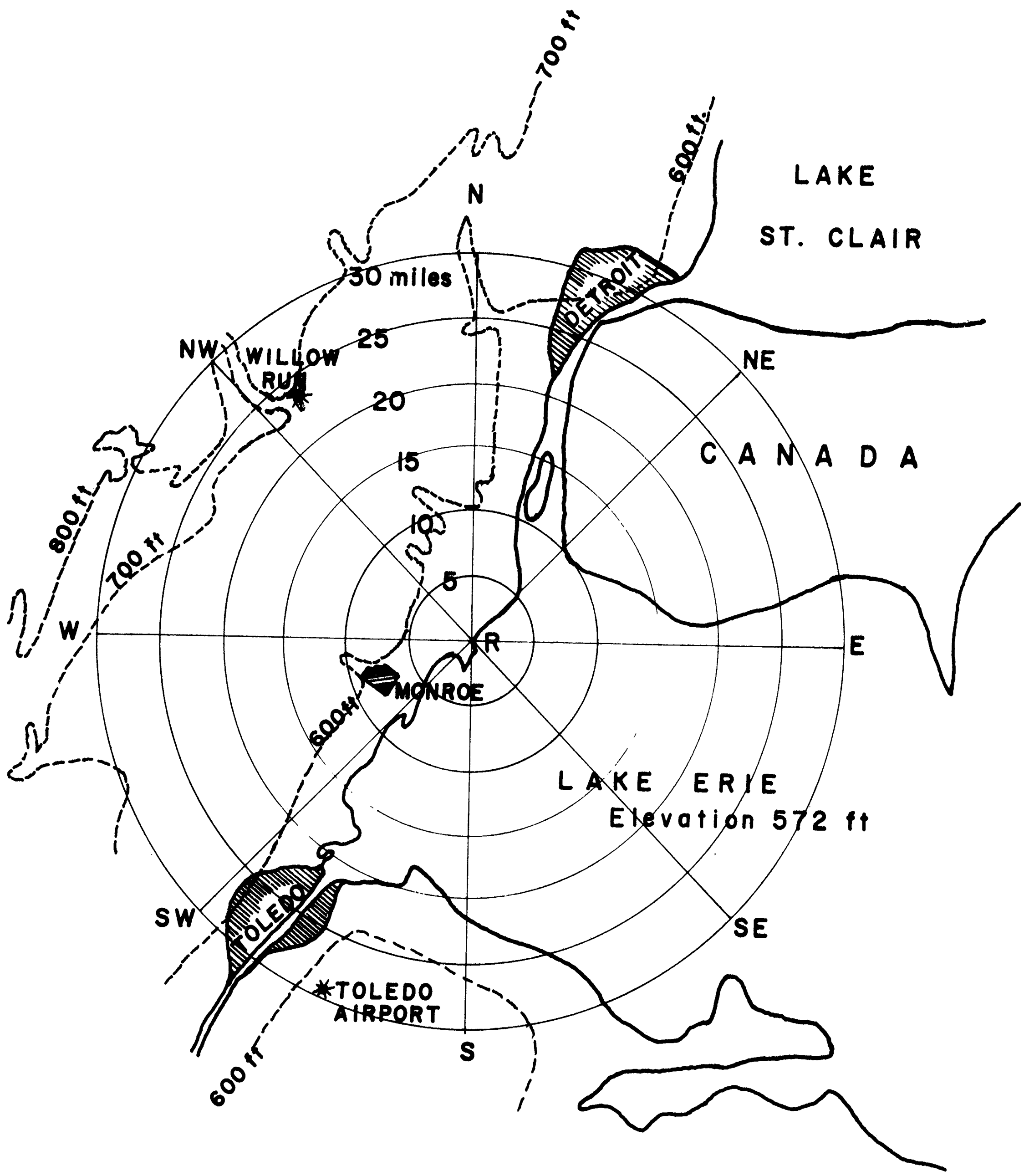

FIG. I–TOPOGRAPHIC MAP OF PROPOSED SITE AND SURROUNDINGS of the flat terrain, the observed winds at Toledo generally would be representative of those at the plant site. However, the influence of the lake undoubtedly would be much stronger at the plant site. Some discussion on the possible nature of lake effects on winds will be given later.

The frequency of occurrence of winds at Toledo from various directions, grouped according to wind speed, is shown for the seasons and the whole year in Tables I through V. The increased frequency of ENE and E winds in spring is the only important seasonal departure from the yearly picture. Figures 2 and 3 also illustrate the frequency of occurrence of winds from various directions, and the mean wind speed for each direction.

In discussing the significance of Tables I through V and Figs. 2 and 3, some grouping of wind directions is possible. For instance, winds from the NE and ENE would carry contaminants to the nearby beaches. Winds from the ENE would also carry contaminants towards Monroe. Winds from the E, ESE, SE, SSE, and S would carry 20 or more miles before reaching any large population center. Winds from the SSW would carry contaminants to the Detroit River communities, the nearest of which is 12 miles from the site. Winds from the SW and WSW would carry 10 to 15 miles across Lake Erie to Canada. Winds from W, WNW, NW, NNW, N, and NNE would carry across Lake Erie 20 or more miles from the site before reaching land.

The two groups of directions which provide dispersal without serious hazard may be considered first. Winds from the E through SE to S occur 21.7 percent of the time in an average year, and with nearly the same frequency in each season. Winds from the W through NW to NNE occur 29.9 percent of the time in an average year, and with nearly the same seasonal frequency. Combining the two, it is seen that 51.6 percent of the time any contaminants released at the plant site would be carried 20 or more miles before reaching large population centers. Even under adverse diffusion conditions a considerable dilution would result in this distance. However, Toledo might be affected under special circumstances described later.

Considering possible hazards to the beaches, winds from the NE and ENE occur 13.3 percent of the time in an average summer. The average wind speed at Toledo for these directions is 9.5 mph. However, along the lake shore some lake-breeze effect[2] would be felt. During the summer afternoon, when air temperatures are higher over land than over water, this would tend to reduce wind speeds somewhat and impart a small component across the shoreline from water to land. The rate of dilution is small in this influx of stable stratified air from the lake. During summer nights, when air temperatures are higher over water than over land, the lake effect would increase the winds and impart a small component from land towards water.

The beach hazard is primarily a summer concern. However, Monroe is a permanent population center subject to ENE winds throughout the year. The frequency

TABLE I

RELATIVE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS
GROUPED ACCORDING TO WIND SPEEDS

Toledo Municipal Airport
January, 1950 — December, 1954
Winter (Dec., Jan., Feb.)

Dir. \ Speed	1-3 mph	4-12 mph	13-24 mph	25-31 mph	32 and Over mph	Total 4 and Over mph	Total Obs. %	Total Obs. No.	Mean Speed mph
N	0.3	2.3	1.0			3.4	3.6	395	10.1
NNE	0.1	1.8	1.6	0.1		3.4	3.6	385	12.4
NE	0.2	1.9	1.8	0.1		3.8	4.0	432	12.3
ENE	0.2	2.1	2.8	0.4		5.3	5.5	591	14.3
E	0.3	2.6	1.4			4.0	4.3	467	10.1
ESE	0.2	2.0	0.6			2.5	2.8	301	9.1
SE	0.3	2.3	0.7			3.0	3.3	352	8.9
SSE	0.2	2.2	1.3			3.6	3.8	411	11.1
S	0.4	3.2	3.4	0.2		6.8	7.2	777	12.9
SSW	0.2	4.8	6.5	0.6	0.2	12.1	12.3	1330	14.5
SW	0.3	5.7	7.1	0.8	0.2	13.8	14.1	1524	14.1
WSW	0.3	5.4	6.6	0.7	0.3	12.9	13.2	1429	14.0
W	0.3	3.6	2.9	0.2		6.8	7.2	774	12.1
WNW	0.1	2.6	3.5	0.4	0.1	6.7	6.8	732	14.3
NW	0.2	2.1	2.7	0.2		5.0	5.3	570	13.5
NNW	0.1	1.2	2.2	0.1		2.6	2.7	295	12.5
Calm							0.5	59	0
Totals 0.5	3.9	45.8	45.1	3.8	0.9	95.6	100.0	10824	12.9

TABLE II

RELATIVE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS
GROUPED ACCORDING TO WIND SPEEDS

Toledo Municipal Airport
January, 1950 — December, 1954
Spring (Mar., Apr., May)

Speed / Dir.	1-3 mph	4-12 mph	13-24 mph	25-31 mph	32 and Over mph	Total 4 and Over mph	Total Obs. %	Total Obs. No.	Mean Speed mph
N	0.3	2.9	1.0			3.9	4.2	468	9.1
NNE	0.1	1.9	1.2			3.1	3.2	351	11.1
NE	0.2	3.0	2.7			5.8	6.0	667	11.8
ENE	0.2	4.1	6.5	0.6	0.1	11.2	11.4	1258	14.6
E	0.4	3.8	3.0	0.1		6.9	7.3	811	11.4
ESE	0.2	2.2	0.7			3.0	3.2	350	9.4
SE	0.3	2.3	0.5			2.7	3.0	332	8.4
SSE	0.2	1.8	0.9	0.1		2.7	2.9	323	11.0
S	0.3	2.9	1.8	0.2		4.9	5.3	582	11.7
SSW	0.2	3.1	3.5	0.3	0.1	7.0	7.2	796	13.7
SW	0.4	4.8	4.4	0.5	0.2	9.8	10.2	1127	13.3
WSW	0.3	4.2	5.4	0.7	0.2	10.4	10.8	1189	14.3
W	0.2	3.6	3.7	0.4		7.7	8.0	881	13.4
WNW	0.3	2.4	4.7	0.4		7.6	7.8	865	14.9
NW	0.1	2.2	3.1	0.3		5.6	5.8	636	14.0
NNW	0.2	1.7	0.8	0.1		2.6	2.8	307	10.6
Calm							0.9	97	0
Totals 0.9	3.9	46.9	43.9	3.7	0.8	95.2	100.0	11040	12.7

TABLE III

RELATIVE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS
GROUPED ACCORDING TO WIND SPEEDS

Toledo Municipal Airport
January, 1950 — December, 1954
Summer (June, July, Aug.)

Dir. \ Speed	1-3 mph	4-12 mph	13-24 mph	25-31 mph	32 and Over mph	Total 4 and Over mph	Total Obs. %	Total Obs. No.	Mean Speed mph
N	0.7	3.3	0.6			3.9	4.6	509	7.8
NNE	0.3	2.4	0.8			3.2	3.5	391	9.1
NE	0.6	3.7	1.3			5.0	5.6	619	9.1
ENE	0.6	4.9	2.2			7.1	7.7	849	9.9
E	0.7	4.1	0 6			4.8	5.5	604	7.7
ESE	0.4	2.5	0.1			2.5	3.0	330	6.4
SE	0.7	3.3	0.1			3.4	4.1	456	6.0
SSE	0.6	2.9	0.3			3.2	3.8	416	6.7
S	0.7	5.2	0.7			5.8	6.6	727	7.6
SSW	0.7	6.6	2.4	0.1		9.1	9.8	1086	9.7
SW	1.1	9.0	3.1	0.1		12.1	13.3	1463	9.1
WSW	0.7	5.5	2.6	0.1		8.2	8.8	973	9.7
W	0.8	4.1	1.4			5.6	6.4	705	8.8
WNW	0.5	3.8	2.1			6.0	6.5	721	10.5
NW	0.7	2.9	1.3			4.2	4.9	545	9.3
NNW	0.5	2.2	0.8			3.1	3.6	394	8.8
Calm							2.3	252	0
Totals 2.3	10.4	66.4	20.4	0.4	0.1	87.3	100.0	11040	8.6

TABLE IV

RELATIVE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS
GROUPED ACCORDING TO WIND SPEEDS

Toledo Municipal Airport
January, 1950 — December, 1954
Fall (Sept., Oct., Nov.)

Dir. \ Speed	1-3 mph	4-12 mph	13-24 mph	25-31 mph	32 and Over mph	Total 4 and Over mph	Total Obs. %	Total Obs. No.	Mean Speed mph
N	0.6	3.0	0.9			3.9	4.5	493	8.7
NNE	0.2	1.7	1.3			3.0	3.2	347	11.3
NE	0.4	2.4	1.5			4.0	4.4	478	10.4
ENE	0.4	2.1	1.2			3.3	3.7	403	10.0
E	0.6	2.6	0.5			3.1	3.7	405	7.5
ESE	0.2	1.6	0.1			1.8	2.0	221	7.1
SE	0.6	2.5	0.1			2.6	3.2	355	6.3
SSE	0.5	2.5	0.5	0.1		3.2	3.6	395	8.6
S	0.7	5.8	2.0	0.1		7.9	8.6	940	9.8
SSW	0.6	7.9	5.4	0.2		13.6	14.2	1556	11.4
SW	0.9	9.4	5.2	0.4	0.2	15.1	16.0	1745	11.3
WSW	0.8	5.5	3.7	0.3		9.5	10.3	1122	11.2
W	0.5	3.6	1.6	0.1		5.3	5.8	630	10.0
WNW	0.3	3.2	2.8	0.1		6.1	6.4	703	12.1
NW	0.6	2.3	2.6	0.1		5.0	5.6	606	12.1
NNW	0.2	1.7	1.3			3.1	3.3	362	11.2
Calm							1.5	159	
Totals 1.5	8.1	57.8	30.7	1.6	0.4	90.5	100.0	10920	10.3

TABLE V

RELATIVE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS
GROUPED ACCORDING TO WIND SPEEDS

Toledo Municipal Airport
January, 1950 — December, 1954

Dir. \ Speed	1-3 mph	4-12 mph	13-24 mph	25-31 mph	32 and Over mph	Total 4 and Over mph	Total Obs. %	Total Obs. No.	Mean Speed mph
N	0.5	2.9	0.9			3.8	4.3	1865	8.8
NNE	0.2	2.0	1.2			3.2	3.4	1474	10.9
NE	0.4	2.8	1.8			4.6	5.0	2196	10.8
ENE	0.3	3.3	3.2	0.2		6.7	7.1	3101	12.6
E	0.5	3.3	1.4			4.7	5.2	2287	9.5
ESE	0.3	2.1	0.4			2.5	2.7	1202	8.1
SE	0.5	2.6	0.3			2.9	3.4	1495	7.3
SSE	0.3	2.4	0.7	0.1		3.2	3.5	1545	9.2
S	0.5	4.2	2.0	0.1		6.4	6.9	3026	10.4
SSW	0.4	5.6	4.5	0.3	0.1	10.4	10.9	4768	12.3
SW	0.7	7.2	4.9	0.4	0.1	12.7	13.4	5859	11.9
WSW	0.5	5.1	4.6	0.4	0.1	10.2	10.8	4713	12.5
W	0.5	3.7	2.4	0.2		6.4	6.8	2990	11.3
WNW	0.3	3.0	3.3	0.2		6.6	6.9	3021	13.1
NW	0.4	2.4	2.4	0.1		5.0	5.4	2357	12.3
NNW	0.3	1.7	1.1			2.8	3.1	1358	10.6
Calm							1.3	567	0
Totals 1.3	6.6	54.2	35.0	2.4	0.5	92.1	100.0	43824	11.1

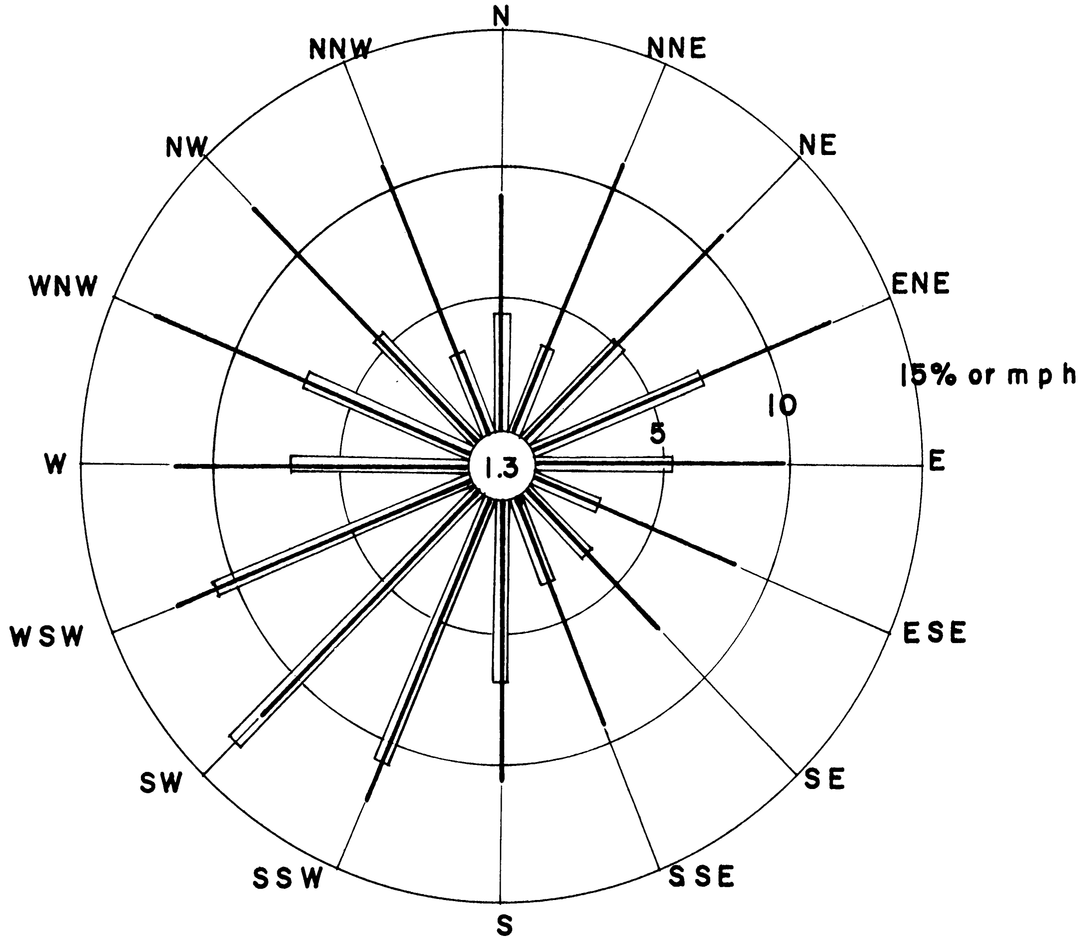

FIG. 2– PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS (rectangles) AND WIND SPEED IN MPH (heavy lines) FROM DIRECTIONS SHOWN. NUMBER IN CENTER GIVES PERCENTAGE OF CALMS. TOLEDO MUNICIPAL AIRPORT JANUARY 1950—DECEMBER 1954 INCLUSIVE.

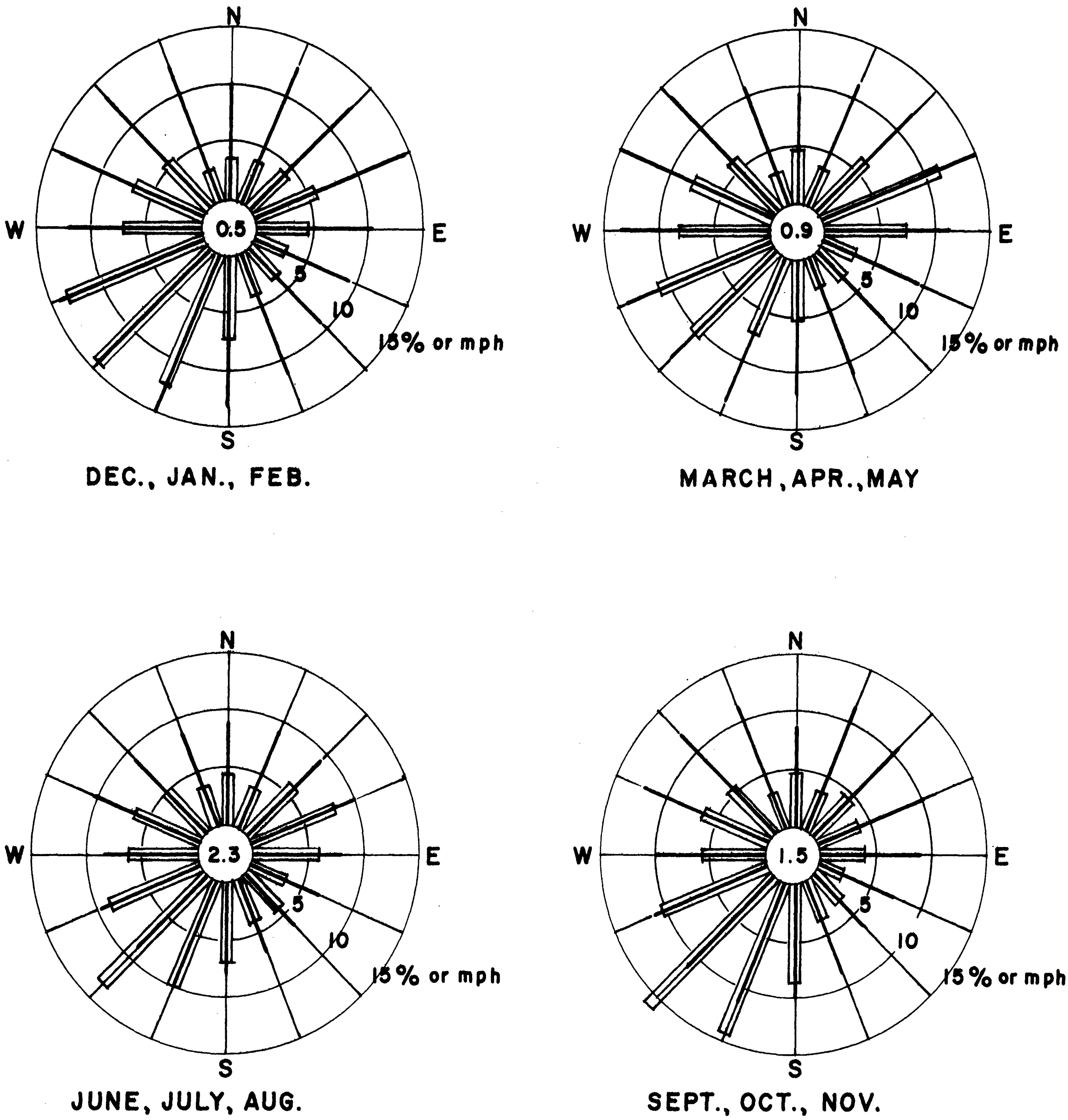

FIG. 3 – PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS (rectangles) AND WIND SPEED IN M P H. (heavy lines) FROM DIRECTIONS SHOWN. NUMBER IN CENTER GIVES PERCENTAGE OF CALMS. TOLEDO AIRPORT BY SEASONS. JAN. 1950 – DECEMBER 1954 INCLUSIVE

of these winds ranges from 3.7 percent in the fall to 11.4 percent in the spring. The spring is thus seen to be the season of chief concern. The average speed of ENE winds in spring at Toledo is 14.6 mph, which would normally assure rapid dilution by mechanical turbulence. However, the lake effects again must be considered. Lake effects are most pronounced when the difference in air and water temperatures is greatest. During the spring, when the lake temperature lags behind the air temperature, the lake-breeze effect can be quite pronounced, particularly on a warm afternoon. The result will be an influx of stable lake air and reduction of wind speeds along the lake shore. Therefore, it is likely that with ENE winds the intensity of mechanical turbulence and, hence, mixing will be less near the plant site than at Toledo.

It should be noted that an abstract discussion such as this does not reveal the magnitude of these conflicting influences. An analysis of on-the-spot wind observations is the most satisfactory way of evaluating land- and lake-breeze effects. It would be desirable to conduct such an investigation at the proposed site. The lake-breeze effect is pertinent not only to possible hazards to Monroe, but also to the Detroit River area, as will be pointed out in the next paragraph.

When winds are SSW, the Detroit River communities are downwind from the plant site. The frequency of SSW winds ranges from 7.2 percent in the spring to 14.2 percent in the fall. The mean speed at Toledo ranges from 9.7 mph in summer to 14.5 mph in winter. However, there is a possibility of lake effects producing significant wind changes in the area of the plant site. When the temperature over the land is higher than the water temperature, there will be a tendency for these winds to increase in speed, and there will also be an influx of stably stratified lake air. These two conflicting influences on turbulence would tend to cancel one another. However, when the temperature over the land is lower than the water temperature, there will be a tendency for these winds to decrease and there will be a slight flow of air out over the lake. Conditions of this sort may be expected at night during the three fall months when western Lake Erie temperatures average 65°, 54°, and 45°F,[3] compared to average overnight minima of 54°, 43°, and 32°F[4] at Toledo. Thus, in the fall the influence of the lake will be to act as a brake on SSW winds, producing more occurrences of light winds near the plant site and along the lake and river shore than the Toledo statistics would indicate. Evidently, then, the greatest hazard to Detroit River communities will be during the fall months.

When winds are from the SW and WSW, contaminants from the plant site would be carried across Lake Erie to Ontario. Although this section of Ontario is mainly farming country with a few small towns, the high frequency of these winds (24.2 percent) and the possibility of international complications make it worthy of some consideration. The mean speed of SW and WSW winds is above the average for all directions at Toledo, and probably at the plant site too, suggesting that mechanical turbulence will be considerable. Although the winds will be influenced by the lake in much the same manner as were the SSW winds, the lake's effect on vertical temperature gradients will be more important.

When the lake is warmer than the air moving across it, the flow will become more turbulent as it moves out over the lake. This will be the situation throughout much of the fall and winter. Thus, during the fall and winter, contaminants carried towards Canada would be dispersed rapidly in the turbulent flow over the lake. On the other hand, when the lake is colder than the land, the flow will tend to become laminar over the lake. This will often be the case during the spring and summer. The persistence of smoke plumes from vessels over Lake Erie is quite noticeable during warm summer days. Thus, during the spring and summer, contaminants might reach the Canadian shore in considerable concentration. They would begin to disperse more rapidly on moving over the land.

The possibility of contaminants reaching Toledo is somewhat analogous to the case just discussed. Contaminants carried by NNE winds from the site to Toledo would travel over water most of the way. Thus, during the fall and winter, turbulence induced by the relatively warm lake would provide effective dilution in the 22-mile distance. However, during spring and summer, stable stratification of the air induced by the cool lake surface might prevent adequate dilution of contaminants before reaching Toledo. It should be noted that effluents were observed to cross Lake St. Clair from Sarnia to Detroit, a distance of more than 30 miles, during May, 1952.[5]

The essence of the forgoing discussion of winds is summarized in Table VI.

As mentioned earlier, weather data are available for Willow Run Airport which is 5 miles closer to the site than Toledo but considerably farther from the lake. Analyses similar to the foregoing have been performed on Willow Run observations for the period January, 1948, to December, 1950. From these analyses, a portion of which is reproduced in Table VII, it is evident that data from either of the two stations would give essentially the same picture.

PRECIPITATION

The amount of precipitation occurring, and its correlation with wind direction, is of significance in an air-pollution survey. Although precise details are lacking, it is clear that contaminants are washed out to some extent by precipitation. For a discussion of washout, see Reference 6. The variation of precipitation with wind direction for each of the seasons and for the year is given in Table VIII through XII and depicted by wind roses in Figs. 4 and 5. These data are computed for Toledo Airport based on the period January, 1950, to December, 1954.

TABLE VI

SEASON OF MAXIMUM HAZARD FOR VARIOUS POPULATION CENTERS AFFECTED BY DIFFERENT WINDS

Wind Direction	Affected Area	Distance to Affected Area (miles)	Season of Maximum Hazard	Frequency of Wind During Season of Maximum Hazard (percent)
N	Nil within 20 miles			
NNE	Toledo	22	Spring and summer	3.2 and 3.5
NE ENE	Beaches	2-5	Summer	13.3
ENE	Monroe	7.5	Spring	11.4
E ESE SE SSE S	Nil within 20 miles			
SSW	Detroit River	12-25	Fall	14.2
SW WSW	Canada	10	Spring and summer	21.0 and 22.1

With this analysis it is possible to consider how precipitation may modify the conclusions summarized in Table VI. For instance, Toledo is most susceptible to the influence of NNE winds in spring and summer. Tables IX and X and Fig. 4 indicate that rainfall is very infrequent with these winds. Hence, there is only a small probability of contaminants being washed out before they might reach Toledo. Therefore, the vulnerability of Toledo to NNE winds is essentially unaltered by precipitation in spring and summer. During the fall and winter, when turbulence alone is considered sufficient to disperse contaminants before they might reach Toledo, rainfall would also tend to remove contaminants, thus providing an additional margin of safety.

TABLE VII

RELATIVE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS
GROUPED ACCORDING TO WIND SPEEDS

Willow Run Airport
January, 1948 — December, 1950

Dir. \ Speed	1-3 mph	4-12 mph	13-24 mph	25-31 mph	32 and Over mph	Total 4 and Over mph	Total Obs. %	Total Obs. No.	Mean Speed mph
N	0.2	2.1	0.7			2.9	3.1	803	9.9
NNE	0.3	2.8	0.9			3.8	4.0	1056	9.7
NE	0.4	5.6	2.2	0.1		7.9	8.2	2168	10.3
ENE	0.3	2.5	1.6	0.2		4.3	4.5	1195	11.8
E	0.3	2.8	2.1	0.1		5.1	5.4	1414	11.9
ESE	0.2	2.2	1.1			3.3	3.6	942	10.5
SE	0.2	2.3	0.7			2.9	3.2	835	9.3
SSE	0.3	2.5	0.5			3.1	3.4	894	8.4
S	0.4	2.9	0.7			3.6	3.9	1031	8.4
SSW	0.6	4.7	2.2	0.1		7.1	7.6	2000	10.2
SW	0.9	8.9	3.5	0.2		12.6	13.5	3550	9.9
WSW	0.8	6.5	3.1	0.4		10.0	10.8	2835	10.7
W	0.6	5.1	3.3	0.3	0.1	8.7	9.3	2440	11.7
WNW	0.2	4.6	2.8	0.1		7.5	7.7	2033	11.3
NW	0.4	4.1	1.9			6.1	6.4	1691	10.3
NNW	0.2	2.4	0.8			3.2	3.4	883	9.5
Calm							2.0	528	
Totals 2.0	6.1	61.9	28.1	1.6	0.2	91.9	100.0	26298	10.2

TABLE VIII

THE ASSOCIATION OF PRECIPITATION WITH WIND AT TOLEDO AIRPORT

January 1950 - December 1954
Winter (Dec., Jan., Feb)

Wind Direction	Average Wind Speed (mph)	Average Precipitation (in.)	No. Observations	Hours of Precipitation as Percentage of	
				Total Hours of Precipitation	Total Hours
N	12.1	.03	78	7.1	0.7
NNE	15.9	.04	81	7.4	0.7
NE	13.6	.04	75	6.8	0.7
ENE	16.7	.05	136	12.4	1.3
E	12.0	.04	73	6.7	0.7
ESE	11.9	.04	46	4.2	0.4
SE	11.1	.05	57	5.2	0.5
SSE	13.9	.04	60	5.5	0.6
S	14.6	.04	116	10.6	1.1
SSW	15.2	.04	114	10.4	1.1
SW	16.9	.03	77	7.0	0.7
WSW	15.7	.03	47	4.3	0.4
W	12.4	.02	26	2.4	0.2
WNW	14.5	.02	32	2.9	0.3
NW	14.3	.02	47	4.3	0.4
NNW	13.5	.03	29	2.6	0.3
Calm	0.0	.01	2	0.2	0.0
Total	14.3	.04	1096	100.0	10.1

TABLE IX

THE ASSOCIATION OF PRECIPITATION WITH WIND AT TOLEDO AIRPORT

January 1950 - December 1954
Spring (Mar., Apr., May)

Wind Direction	Average Wind Speed (mph)	Average Precipitation (in.)	No. Observations	Hours of Precipitation as Percentage of Total Hours of Precipitation	Hours of Precipitation as Percentage of Total Hours
N	13.3	.04	26	2.7	0.2
NNE	14.0	.05	34	3.5	0.3
NE	13.9	.05	69	7.1	0.6
ENE	16.3	.05	193	19.8	1.7
E	13.4	.06	98	10.1	0.9
ESE	14.5	.06	44	4.5	0.4
SE	11.6	.05	40	4.1	0.4
SSE	14.0	.04	49	5.0	0.4
S	14.6	.05	49	5.0	0.4
SSW	15.4	.05	73	7.5	0.7
SW	14.8	.04	84	8.6	0.8
WSW	16.4	.05	46	4.7	0.4
W	14.3	.03	45	4.6	0.4
WNW	15.5	.04	57	5.9	0.5
NW	16.6	.04	40	4.1	0.4
NNW	11.5	.02	23	2.4	0.2
Calm	0.0	.01	4	0.4	0.0
Total	14.7	.05	974	100.0	8.8

TABLE X

THE ASSOCIATION OF PRECIPITATION WITH WIND AT TOLEDO AIRPORT

January 1950 - December 1954
Summer (June, July, Aug.)

Wind Direction	Average Wind Speed (mph)	Average Precipitation (in.)	No. Observations	Hours of Precipitation as Percentage of Total Hours of Precipitation	Hours of Precipitation as Percentage of Total Hours
N	11.2	.08	18	3.8	0.2
NNE	11.5	.09	24	5.0	0.2
NE	11.0	.05	42	8.8	0.4
ENE	10.2	.06	25	5.2	0.2
E	11.3	.10	28	5.9	0.3
ESE	7.6	.23	8	1.7	0.1
SE	7.3	.07	18	3.8	0.2
SSE	8.2	.05	17	3.6	0.2
S	8.2	.05	27	5.7	0.2
SSW	12.4	.08	62	13.0	0.6
SW	10.8	.08	82	17.2	0.7
WSW	11.4	.09	38	8.0	0.3
W	9.8	.16	21	4.4	0.2
WNW	12.0	.10	24	5.0	0.2
NW	10.9	.06	13	2.7	0.1
NNW	13.0	.14	21	4.4	0.2
Calm	.0	.07	9	1.9	0.1
Total	10.6	.08	477	100.0	4.3

TABLE XI

THE ASSOCIATION OF PRECIPITATION WITH WIND AT TOLEDO AIRPORT

January 1950 - December 1954
Fall (Sept., Oct., Nov.)

Wind Direction	Average Wind Speed (mph)	Average Precipitation (in.)	No. Observations	Hours of Precipitation as Percentage of: Total Hours of Precipitation	Total Hours
N	14.6	.06	36	5.7	0.3
NNE	15.2	.06	40	6.3	0.4
NE	11.5	.14	27	4.3	0.2
ENE	14.3	.07	35	5.5	0.3
E	10.8	.06	53	8.4	0.5
ESE	10.0	.07	15	2.4	0.1
SE	9.4	.06	14	2.2	0.1
SSE	13.6	.05	35	5.5	0.3
S	14.3	.06	69	10.9	0.6
SSW	13.6	.05	77	12.1	0.7
SW	12.4	.06	79	12.5	0.7
WSW	12.2	.04	48	7.6	0.4
W	9.7	.03	23	3.6	0.2
WNW	12.9	.05	27	4.3	0.2
NW	17.1	.04	33	5.2	0.3
NNW	19.2	.08	18	2.8	0.2
Calm	0.0	.02	5	0.8	0.0
Total	13.2	.06	634	100.0	5.8

TABLE XII

THE ASSOCIATION OF PRECIPITATION WITH WIND AT TOLEDO AIRPORT

January 1950 - December 1954
Annual

Wind Direction	Average Wind Speed (mph)	Average Precipitation (in.)	No. Observations	Hours of Precipitation as Percentage of: Total Hours of Precipitation	Hours of Precipitation as Percentage of: Total Hours
N	12.7	.04	158	5.0	0.4
NNE	14.8	.05	179	5.6	0.4
NE	13.0	.06	213	6.7	0.5
ENE	15.9	.05	389	12.2	0.9
E	12.2	.06	252	7.9	0.6
ESE	12.3	.07	113	3.6	0.3
SE	10.6	.05	129	4.1	0.3
SSE	13.2	.04	161	5.1	0.4
S	13.8	.05	261	8.2	0.6
SSW	14.3	.05	326	10.2	0.7
SW	13.7	.05	322	10.1	0.7
WSW	14.0	.05	179	5.6	0.4
W	12.1	.05	115	3.6	0.3
WNW	14.1	.05	140	4.4	0.3
NW	15.4	.03	133	4.2	0.3
NNW	14.0	.06	91	2.9	0.2
Calm	0.0	.04	20	0.6	0.0
Total	13.7	.05	3181	100.0	7.3

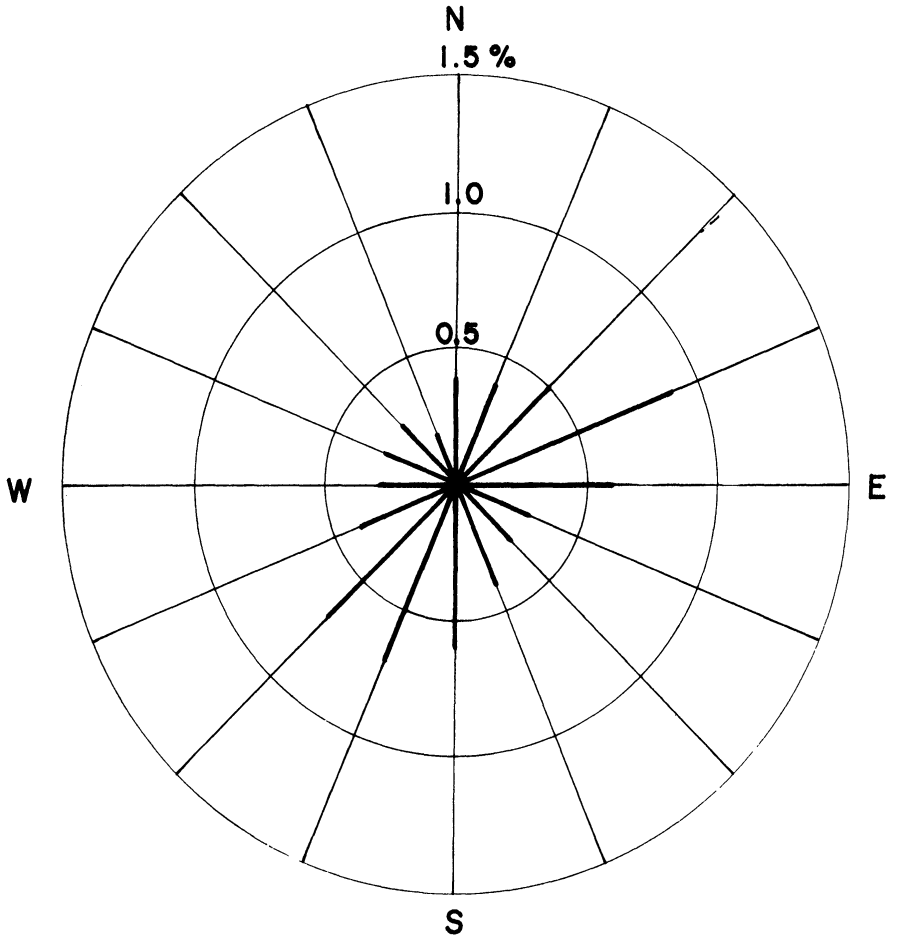

FIG. 4- PERCENTAGE OF TOTAL WINDS WHICH BROUGHT PRECIPITATION FROM EACH DIRECTION AT TOLEDO.
JANUARY 1950- DECEMBER 1954 INCLUSIVE

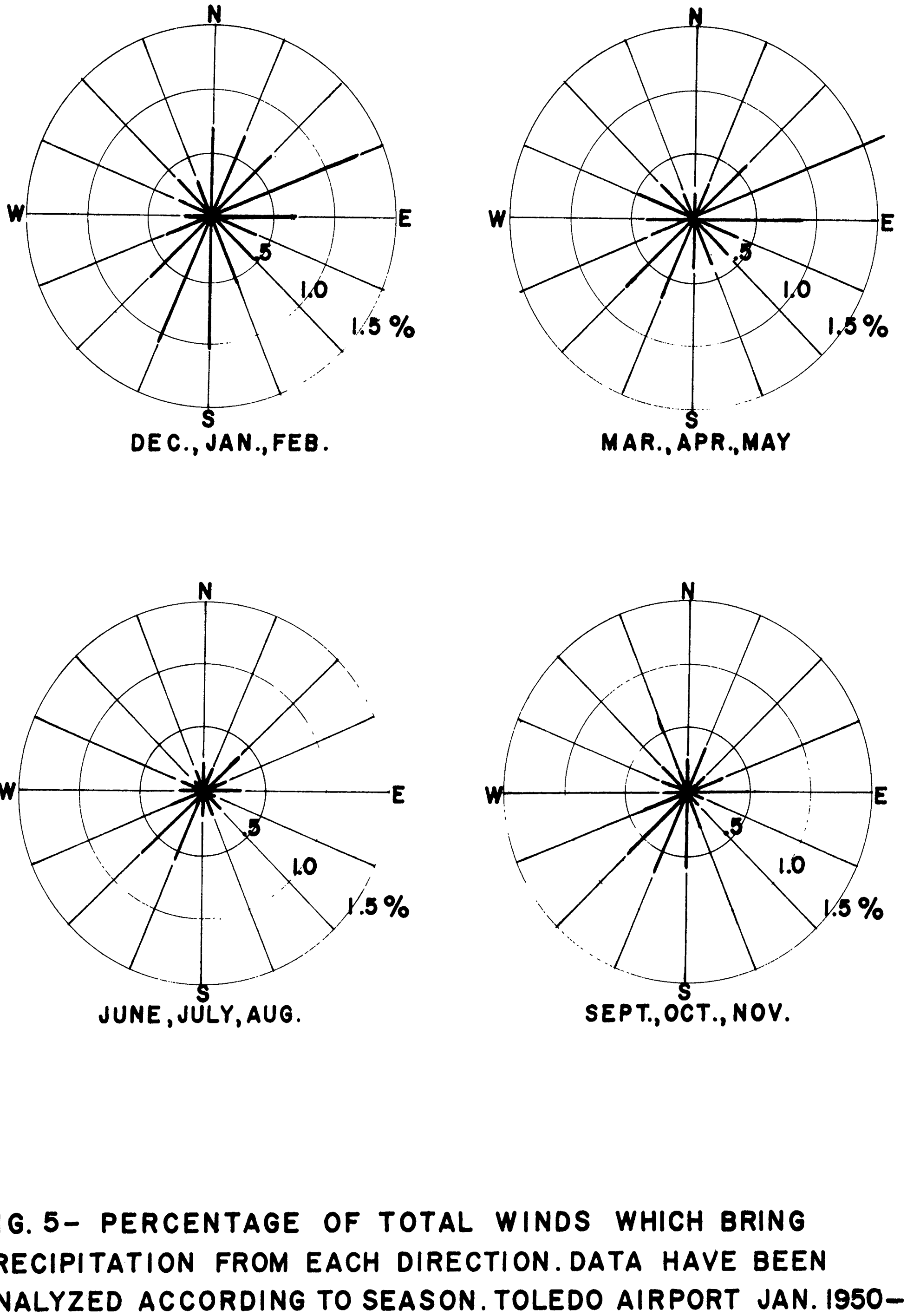

FIG. 5- PERCENTAGE OF TOTAL WINDS WHICH BRING PRECIPITATION FROM EACH DIRECTION. DATA HAVE BEEN ANALYZED ACCORDING TO SEASON. TOLEDO AIRPORT JAN. 1950– DECEMBER 1954 INCLUSIVE.

The occurrence of precipitation will reduce the hazard to Monroe. The important wind direction is ENE. Since Monroe is about 7.5 miles from the site, rainfall probably would wash out most of the contaminants before they could reach Monroe. During the spring, ENE winds occur 11.4 percent of the time. However, precipitation occurs with ENE winds 1.7 percent of the time. The difference, 9.7 percent, represents the portion of the time when contaminants would reach Monroe, diluted by diffusion processes only. Similar computations give 4.2 percent as the frequency of vulnerability to contaminants from the plant during winter, 7.5 percent during summer, and only 3.4 percent during the fall. Even after considering precipitation, spring remains the season of greatest hazard.

Similarly, the occurrence of precipitation will reduce slightly the hazard to such remote centers as the Detroit River communities and Canada. On the average, precipitation occurs 7 percent of the time that the wind is SSW and 5.5 percent of the time that the wind is SW. This will not materially alter the conclusions of Table VI.

In the cases discussed thus far, precipitation is considered an agency to reduce the hazard. Only in the unlikely event that the precipitation commenced at the exact time that a cloud of contaminants reached a population center, or just before, would precipitation increase the hazard. However if the area being considered is close to the source, the washout produced by rainfall would increase the hazard. It is this type of effect that must be considered with reference to the beaches, which are 2 to 5 miles from the plant site. During the summer, the beaches will be downwind from the site 13.3 percent of the time. Rain together with NE and ENE winds occurs only 0.5 percent of the time. Hence the hazard to the beaches will be increased by the occurrence of rain only about 4.5 times out of every 100 times that the beaches are downwind from the site.

TEMPERATURE INVERSIONS

Temperature inversions in which temperature increases with height are important because they tend to suppress turbulent air motion and, hence, turbulent diffusion. With inversions, concentrations downwind from a source will be relatively high.

Radiosonde observations provide one of the most satisfactory sources of data on vertical temperature gradients. Such observations are not available for the plant site, but were taken at Toledo for a number of years. The incidence and intensity of inversions may differ between Toledo Airport and the plant site as a direct result of lake influences, some of which were discussed in relation to possible hazards to Canada and Toledo. Nevertheless, the observations at Toledo will provide a measure of the seasonal trends for the plant site.

The distributions of inversion and noninversion conditions in relation to wind direction at Toledo are given in Table XIII. The data cover the period January, 1946, to December, 1950. A wind rose giving percentage frequency of occurrence of winds associated with inversions with bases below 1000 feet and corresponding mean wind speeds for 2200 EST is presented in Fig. 6.

Table XIII shows clearly that the low-level inversion is primarily a nighttime phenomenon. In fact, inversions over land are usually the result of surface cooling produced by long-wave radiation to outer space. They were observed on 61 percent of the nighttime temperature soundings but only on 19 percent of the daytime soundings. The association of light winds with low-level inversions is quite evident at nighttime from a comparison of mean winds, but is apparent only to a lesser extent in the daytime. This suggests that the hazard due to any contaminants will in general be greater at night than during the day.

Inversions are also seen to be a relatively common occurrence with winds from the sector S through SW. Thus, a transport of contaminants towards the Detroit River or Canada under conditions of poor diffusion is likely to be rather common. However, it has been noted earlier that the relatively warm lake surface may improve the diffusion conditions somewhat in SW winds during fall and winter.

VISIBILITY

The object of a survey such as this is to define as accurately as possible the diffusion climatology of an area without measuring the concentrations of contaminants over a period of months or years. There is another source of information, involving observations over a number of years, which helps to reveal the seasons in which poor diffusion conditions are most prevalent. The monthly climatological summaries for first-order Weather Bureau stations include occurrences of restricted visibility when ceilings are higher than 9500 feet. For this group of observations, the 9500-foot ceiling precludes the possibility of precipitation; hence, the visibility restriction must be smoke, haze, or fog, whose occurrence is mainly associated with poor diffusion.

A tabulation was made of occurrences of visibilities equal to or less than 6 miles with ceilings greater than 9500 feet at Toledo Airport for the period January, 1950, to December, 1954. The mean number of hourly occurrences for each month was computed and the results expressed as the relative

TABLE XIII

PRESENCE OR ABSENCE OF INVERSIONS BASED BELOW 1000 FEET
IN RELATION TO WIND SPEED AND DIRECTION

Toledo Municipal Airport
January, 1946 — December, 1950

Wind Direction	2200 EST				1000 EST			
	Inversion Occurrences	Mean Wind Speed mph	Noninversion Occurrences	Mean Wind Speed mph	Inversion Occurrences	Mean Wind Speed mph	Noninversion Occurrences	Mean Wind Speed mph
N	23	5.7	44	10.0	8	6.9	75	10.8
NNE	16	10.2	25	13.9	5	12.6	70	11.0
NE	49	7.4	66	10.9	13	11.8	105	12.3
ENE	40	9.2	56	11.7	20	12.0	92	14.5
E	56	6.3	28	8.3	26	10.8	57	11.5
ESE	49	5.9	16	6.8	12	11.1	39	9.3
SE	101	5.5	12	6.7	16	7.6	44	7.3
SSE	56	6.4	12	9.7	20	11.1	29	8.7
S	152	9.0	30	10.9	51	13.5	74	10.6
SSW	133	10.8	41	13.2	59	13.0	123	13.7
SW	161	8.6	78	13.6	67	12.0	248	13.8
WSW	59	7.7	78	14.2	27	10.0	188	14.8
W	39	6.3	61	12.3	7	6.7	101	11.3
WNW	32	7.8	68	13.0	5	11.6	102	13.4
NW	30	8.6	50	13.7	5	15.4	88	13.8
NNW	8	10.3	36	11.1	2	6.0	33	12.0
Calm	30		4		4		12	
Total or Average	1108	7.8	705	12.0	347	11.5	1480	12.6

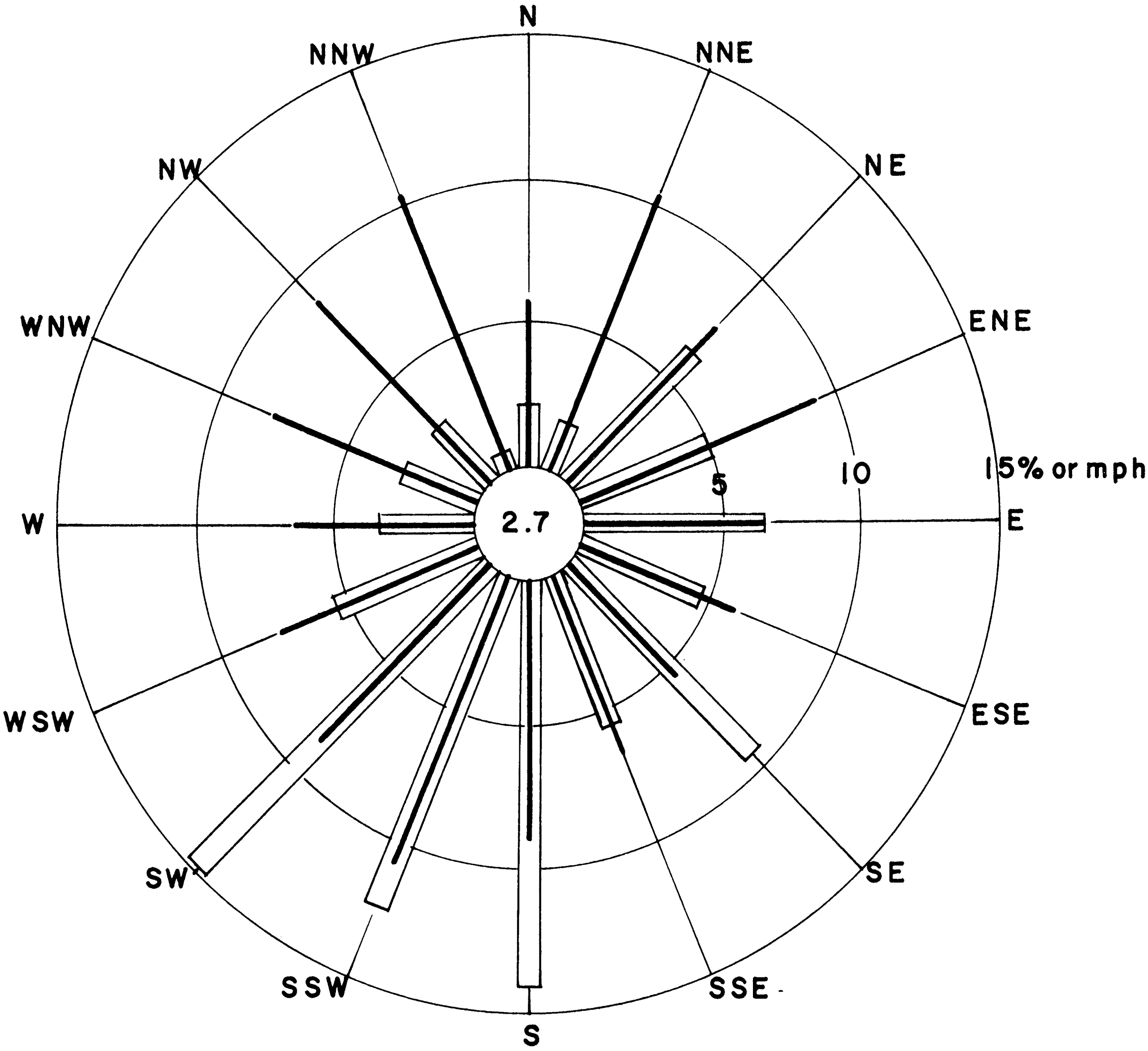

FIG. 6 – PERCENTAGE FREQUENCY OF OCCURRENCE AT 2200 EST OF WINDS ASSOCIATED WITH INVERSIONS BASED BELOW 1000 FT (rectangular areas) AND CORRESPONDING MEAN WIND SPEEDS WITH SAME INVERSIONS (mph – heavy lines) FROM DIRECTIONS SHOWN. NUMBER IN CENTER GIVES PERCENTAGE OF CALMS. TOLEDO, OHIO JANUARY 1946 TO DECEMBER 1950 INCLUSIVE.

frequency of restricted visibility. These data are presented in line 1 of Table XIV. Line 2 is obtained by smoothing the data of line 1 [by the formula (A + 2B + C)/4 = smoothed B], a standard procedure for climatological data computed for a short period of years.

TABLE XIV

RELATIVE MONTHLY FREQUENCY OF VISIBILITIES EQUAL TO OR LESS THAN 6 MILES, WITH CEILINGS GREATER THAN 9500 FEET, FOR TOLEDO, JANUARY, 1950, TO DECEMBER, 1954

	Percentages by Months											
	J	F	M	A	M	J	J	A	S	O	N	D
Observed frequency	6.7	8.3	6.1	6.6	9.1	8.8	10.1	15.5	9.6	16.8	12.2	8.3
Smoothed frequency	7.5	7.4	6.8	7.1	8.4	9.2	11.1	12.7	12.9	13.8	12.4	8.9

Table XIV represents the large-scale climatological trends, unaltered by the lake influence at the proposed site. It suggests that conditions predisposing to smog are most prevalent in the fall. This conclusion is borne out by the past occurrence in other areas of prolonged smogs in the fall months.

POSSIBLE HAZARDS TO POPULATION CENTERS

In considering the potential hazards to population groups, two possibilities must be considered: a slow leak of radioactive materials from the reactor, or an explosion which would instantaneously release radioactive materials. The former may be treated as a continuous point source, and the latter as an instantaneous point source. Sutton[7,8] gives expressions for downwind concentrations χ in mass of contaminant per unit volume of air as follows:

Instantaneous Point Source

$$\chi(x,y,z,t) = \frac{2Q}{\pi^{3/2} C_x C_y C_z (\bar{u}t)^{3(2-n)/2}} \exp\left[(\bar{u}t)^{n-2}\left(\frac{x^2}{C_x^2} + \frac{y^2}{C_y^2} + \frac{z^2}{C_z^2}\right)\right]$$

where x, y, and z are distances measured from an origin moving with the cloud at constant speed $\overline{u}$; t is the time interval from the instant of the explosion; Q is the total mass released by the explosion; C_x, C_y, and C_z are virtual diffusion coefficients; and n is a coefficient which varies with the turbulence and is obtained by fitting the theoretical profile $u = u_1 z^{n/(2-n)}$ to the observed variation of wind with height. The maximum concentration is found at the center of the puff, where x = y = z = 0, so that the expression for the maximum concentration is

$$\chi_{max} = \frac{2Q}{\pi^{3/2} C_x C_y C_z (\overline{u}t)^{3(2-n)/2}} \quad . \tag{1}$$

Continuous Point Source

$$\chi(x,y,z) = \frac{2Q}{\pi C_y C_z \overline{u} x^{2-n}} \exp\left[-x^{n-2}\left(\frac{y^2}{C_y^2} + \frac{z^2}{C_z^2}\right)\right]$$

where Q is now the mass of contaminant emitted per unit time. At a given distance x downwind from the source the maximum concentration occurs at y = z = 0 and is therefore given by

$$\chi_{max} = \frac{2Q}{\pi C_y C_z \overline{u} x^{2-n}} \quad . \tag{2}$$

The principal problem involved in the use of these equations is the choice of suitable values of the several coefficients. The values given below in Table XV represent the writers' choice on the basis of Sutton's earlier values,[9] Smith and Singer's recent values determined experimentally at Brookhaven National Laboratory from concentration measurements,[10] and Friedman's values obtained from wind-vane data at M.I.T.'s Round Hill Field Station.[11] The values are chosen so as to give mean concentrations at a point downwind from a continuous point source such as would be obtained by sampling continuously for a one-hour period.

Using these values of the coefficients, Equations 1 and 2 reduce to:

Instantaneous Point Source

Moderate lapse: $\chi/Q = 15.96/(\overline{u}t)^{2.64}$

Large inversion, land trajectory: $\chi/Q = 89.8/(\overline{u}t)^{2.0}$

Large inversion, water trajectory: $\chi/Q = 200/(\overline{u}t)^{1.8}$

TABLE XV

VALUES OF DIFFUSION COEFFICIENTS

Vertical Temperature Gradient	$\bar{u}$ (m sec^{-1})	n	C_x	C_y	C_z
Moderate lapse	6	.24	.30	.30	.25
Large inversion (land trajectory)	2	.65	.20	.20	.10
Large inversion (water trajectory)	2	.80	.16	.16	.04

Continuous Point Source

Moderate lapse: $\chi/Q = 1.414/x^{1.76}$

Large inversion, land trajectory: $\chi/Q = 15.91/x^{1.35}$

Large inversion, water trajectory: $\chi/Q = 49.74/x^{1.2}$

The calculated values of χ/Q at the centers of interest, using these equations, are given in Table XVI.

TABLE XVI

COMPUTED VALUES OF χ/Q

Type of Source	Center	Distance	Moderate Lapse	Large Inversion
Instantaneous point	Beaches	3200 m	$8.9 \times 10^{-9} m^{-3}$	$8.8 \times 10^{-6} m^{-3}$
	Monroe	11300	3.0×10^{-10}	7.0×10^{-7}
	Canada	16000	1.3×10^{-10}	5.4×10^{-6}
	Wyandotte	19500	7.5×10^{-11}	2.4×10^{-7}
	Toledo	35000	1.6×10^{-11}	1.4×10^{-6}
	Detroit	35000	1.6×10^{-11}	7.4×10^{-8}
Continuous point	Beaches	3200	9.6×10^{-7} sec m^{-3}	2.9×10^{-4} sec m^{-3}
	Monroe	11300	1.0×10^{-7}	5.3×10^{-5}
	Canada	16000	5.5×10^{-8}	4.1×10^{-4}
	Wyandotte	19500	3.9×10^{-8}	2.6×10^{-5}
	Toledo	35000	1.4×10^{-8}	1.8×10^{-4}
	Detroit	35000	1.4×10^{-8}	1.2×10^{-5}

CONCLUSIONS

The projected plant to be located on the west shore of Lake Erie, near Monroe, presents the greatest hazard to the nearby beaches and to that portion of Canada immediately across Lake Erie. There is also some hazard to Monroe and to Toledo. The hazard to the southern part of the densely populated strip along the Detroit River is less, decreasing to slight at Detroit.

The beaches may be affected in NE and ENE winds which occur 13.3 percent of the time in summer. However, the serious hazard associated with large inversions will occur only about 1/3 of the time, thus reducing the original 13.3 to about 4.5 percent.

The Canadian shore may be affected by SW and WSW winds during the spring and summer when large inversions may persist throughout day and night. These winds occur a little more than 20 percent of the time, but usually with a speed in excess of the 2 m sec^{-1} used in the computations of Table XVI.

The hazard to Monroe occurs when winds are ENE, and is therefore greatest in the spring. However, since persistent inversions are frequent in the fall, it is advisable to think of this season also as one of some hazard to Monroe, despite the relative infrequency (3.7 percent) of ENE winds.

The hazard to Toledo exists when winds are from the NNE and when the water temperature of the lake is generally colder than air temperatures over land. This limits the hazard to the spring and summer when NNE winds occur only a little more than 3 percent of the time. It should be noted that although Detroit and Toledo are equidistant from the source, the much closer approach to laminar flow that may be realized in a water trajectory may produce concentrations at Toledo that are 15 to 20 times those at Detroit.

RECOMMENDATIONS

The evaluation of the pollution hazard in the vicinity of the Monroe site is hampered by the absence of knowledge of the diffusion pattern over and near a lake surface. Thus, the values of coefficients used for this report, and given in Table XV, are estimates obtained by modifying values appropriate for land trajectories and may therefore be considerably in error.

A more adequate evaluation of the hazard can be made only by (1) an experimental program of appropriate measurements at and near the site and (2) an analysis of these measurements. The following recommendations are therefore made.

1. Meteorological Studies Recommended.—A program of meteorological observations should be undertaken at and near the plant site. For this purpose, the erection of a 100-foot self-supporting steel tower at the water's edge is recommended. The following instrumentation at each of three levels on the tower is proposed: anemometer and wind vane, bivane (for special periods), and temperature element, with necessary recording equipment.

Analyses of meteorological observations taken at the tower for evidences of special lake effects are an essential part of the program.

2. Diffusion Studies Recommended.—Studies of diffusion over the lake under various meteorological conditions are required. It is proposed to use a tracer substance emitted from a source near the plant site, with concentration measurements made at various locations offshore. A full program of meteorological measurements would be made at the same time.

Analyses of these measurements of concentration and of the meteorological variables provide the required knowledge of the diffusion pattern over the lake.

Such a program would reduce the uncertainty concerning the hazard from the projected plant to communities around the lake.

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