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First Progress Report

METEOROLOGICAL INSTALLATION AND ANALYSIS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (CONCLUDED)

LIST OF FIGURES

LIST OF FIGURES (CONCLUDED)

ABSTRACT

The program of meteorological observations described in this progress report was undertaken to measure the significant variables at the plant site, where valley influences are likely to be a dominating factor.

The following meteorological instrumentation has been installed on a 100-ft steel tower about 1/2 mile south of the plant: one Bendix-Friez Aerovane for wind speed and direction measurements: three thermographs and three maximum-minimum thermometers for measurement of temperature lapse rate; and a Hewson-Gill gust accelerometer for measurement of atmospheric turbulence.

Wind data at Standiford Field are compared with the averages observed there during the five-year period 1951 to 1955 to determine the extent that the current year may be considered normal. The winds at New Albany are then compared with those at Standiford Field for the fall (12 October to 30 November 1956), winter (1 December 1956 to 28 February 1957), and spring season (1 March 1957 to 31 May 1957). Atmospheric turbulence is analyzed by direction and wind speed for the entire period independent of season.

The report concludes with five recommendations: that the present program of observations be continued; that differential thermocouples be installed; that concentration values of SO_2 in the Silver Hill area be calculated for a hypothetical smoke plume; that background SO_2 values be analyzed in relation to meteorological conditions; and that wind characteristics at the top of the stacks be compared with those at the top of the meteorological tower.

OBJECTIVE

This project was undertaken to evaluate the possibilities of atmospheric pollution of the Silver Hill residential area by stack gases from the proposed plant of the Public Service Company of Indiana near New Albany, Indiana. One of the major aims of the project is to determine the frequency of winds in various directions, especially towards Silver Hill. A second objective is to obtain diffusion patterns appropriate for the terrain in the vicinity of the plant. Study of the frequency of inversion breakup concentrations and of the role of local winds in modifying the pollution pattern under inversion conditions are also objectives.

The following sections of this report outline the progress made in attaining these goals and present further recommendations based on the information gained thus far.

TOPOGRAPHY OF AREA

1. GENERAL

The area immediately surrounding the plant site is the flat land bordering the Ohio River in the vicinity of Louisville, Kentucky. This area is characterized by a moderately broad river valley with hilly regions running more or less parallel to the western edge of the river. The eastern side has some hilly areas but they are more broken up by small valleys.

The river upstream from Louisville runs from the NE to the SW but bends sharply on the northeastern outskirts of the city so as to run west, then northwest, west again, south southwest, south and finally southwest (see Fig. 1).

A small valley runs from the Portland section of the City of Louisville to the southeast for nearly 20 miles or so. This valley is marked by higher land to the NE and SW running 150-200 ft higher than the valley floor.

2. PLANT SITE

The plant site is located along the western bank of the Ohio River in Floyd County, Indiana (see Fig. 1). Immediately across the river is the City of Louisville, Kentucky. Two miles to the NNE lies the center of New Albany, Indiana.

Bordering the western edge of the river is a small plain 1/2 mile in width with a gentle rise to the west. The hills begin to rise rapidly to the west after the first 1/2 mile so as to become 400 ft higher than the plant site within a distance of 2 miles. These hills have creeks and small river valleys draining into the Ohio River. The hills follow the contour of the river generally so as to form a topographic barrier to the west of the plant. This chain of hills curves slightly to the east about 6 miles north of the plant so as to continue this barrier to the north. Thus the plant is shielded from SSW through NW to NNE winds by hilly country. The other sectors surrounding the plant are relatively flat; the nearest hills are 6 miles to the SSE. The hills to the SSE do cause a channel to be formed SSW of the plant and this topographic feature will influence the winds. Another channel exists from the NNE to ENE. This too will influence the winds.

3. STANDIFORD FIELD AREA

Standiford Field is located in the extreme SE section of Louisville between the Highland Park area and Edgewood (see Fig. 1). This airfield is in the small valley mentioned above which runs SE out of Louisville. There are hills 3 miles

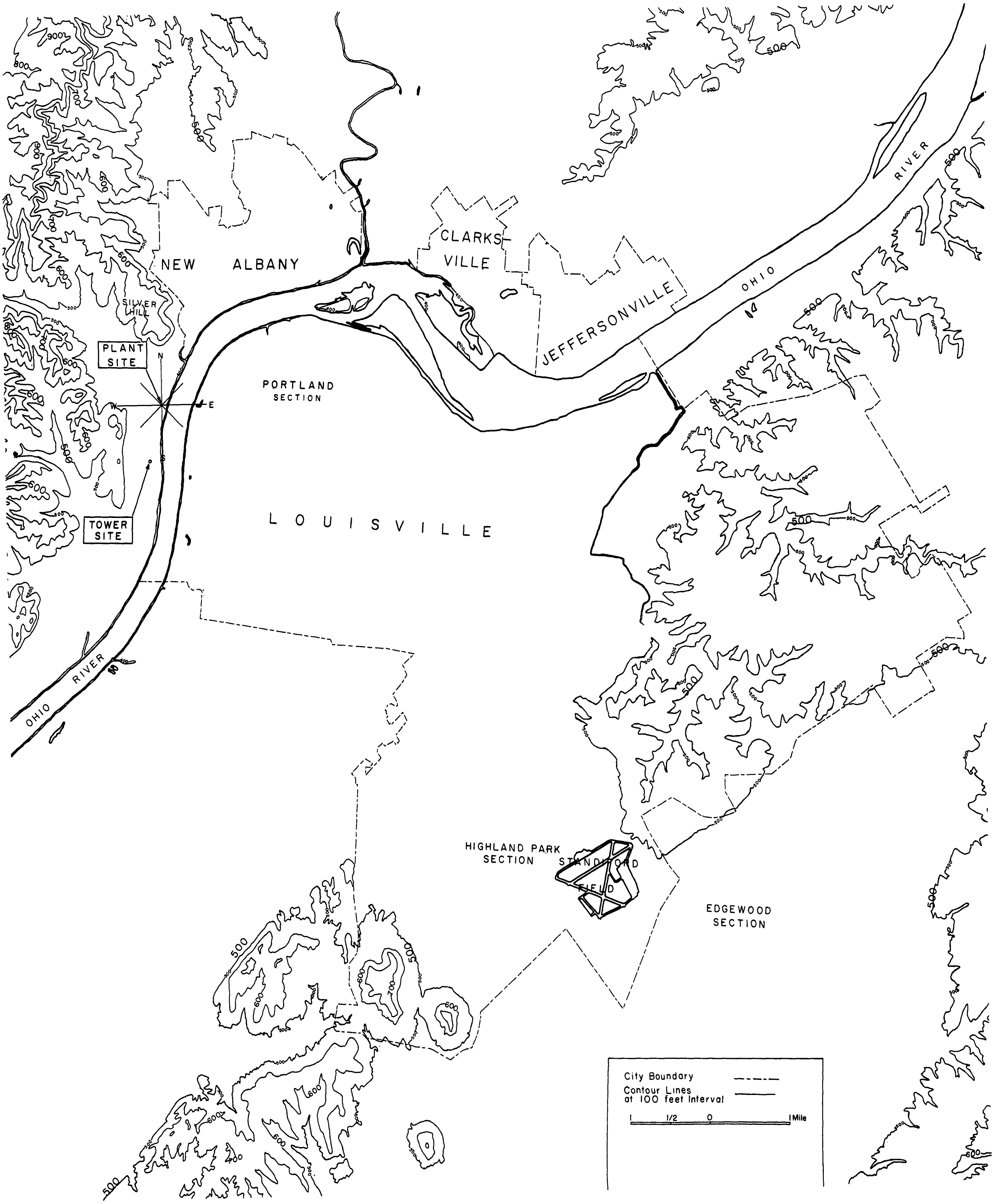


Fig. 1. Topographic map of site and surroundings.

to the SW of the field and rising ground within 2 miles to the NE. The result is that the field has a natural protection from the SSE to W on one side and from the NNE to SE on the other side. There is a channel or valley to the SE and another to the north. These topographic features will influence the frequency of wind directions.

Since the topography of the two areas where wind data are taken is so different, we can expect to find differences when comparing them.

EXPERIMENTAL INSTALLATION

The site selected for the meteorological installation was made after considering the location of the power plant with its extensive coal storage and residue pits and the desirability of obtaining truly representative wind speed and wind-direction records at the plant site for winds from the southeast through south to southwest. The site selected (see Fig. 1) was a point about 0.7 mile SSW of the future plant stacks, just outside the construction area, and about 0.1 mile from the river bank. The valley here is quite flat, sloping gently toward the Ohio River and likewise gently toward a creek near the base of the hills to the west of the tower. The land is devoted to farming and there are no trees in the immediate neighborhood of the tower to the south or to the north. The closest trees of significant height are located adjacent to the river bank. Figures 2 and 3 are photographs taken from the top of the tower. Figure 2 looks due north showing the plant site, the Ohio River, and Silver Hill in the background. Figure 3 looks almost due south. It shows the flat, broad valley of the Ohio River. The single stack to the left of the five stacks of the Louisville Gas and Electric Company's Paddy Run Plant is due south in the picture. All these stacks are on the south side of the river.

The elevation of the base of the tower is about 435 ft (M.S.L.) and the wind instruments about 539 ft. This compares with the following approximate elevations: the river - 385 ft, plant yard - 460 ft, highest land on Silver Hill - 650 ft, and the top of the stacks - 1010 ft. The tower is three-legged and has an outside ladder with guard. Its overall height above the concrete foundations is 97 ft. Figure 4 is a photograph of the tower showing the instrument details. It was taken from the instrument hut which is located about 50 ft west of the tower base.

1. WIND AND TURBULENCE EQUIPMENT

The wind-measuring equipment consists of a wind-speed and wind-direction transmitter with dual-channel recorder. The wind-speed and wind-direction equipment is a standard Bendix-Friez "Aerovane." The transmitter of this unit

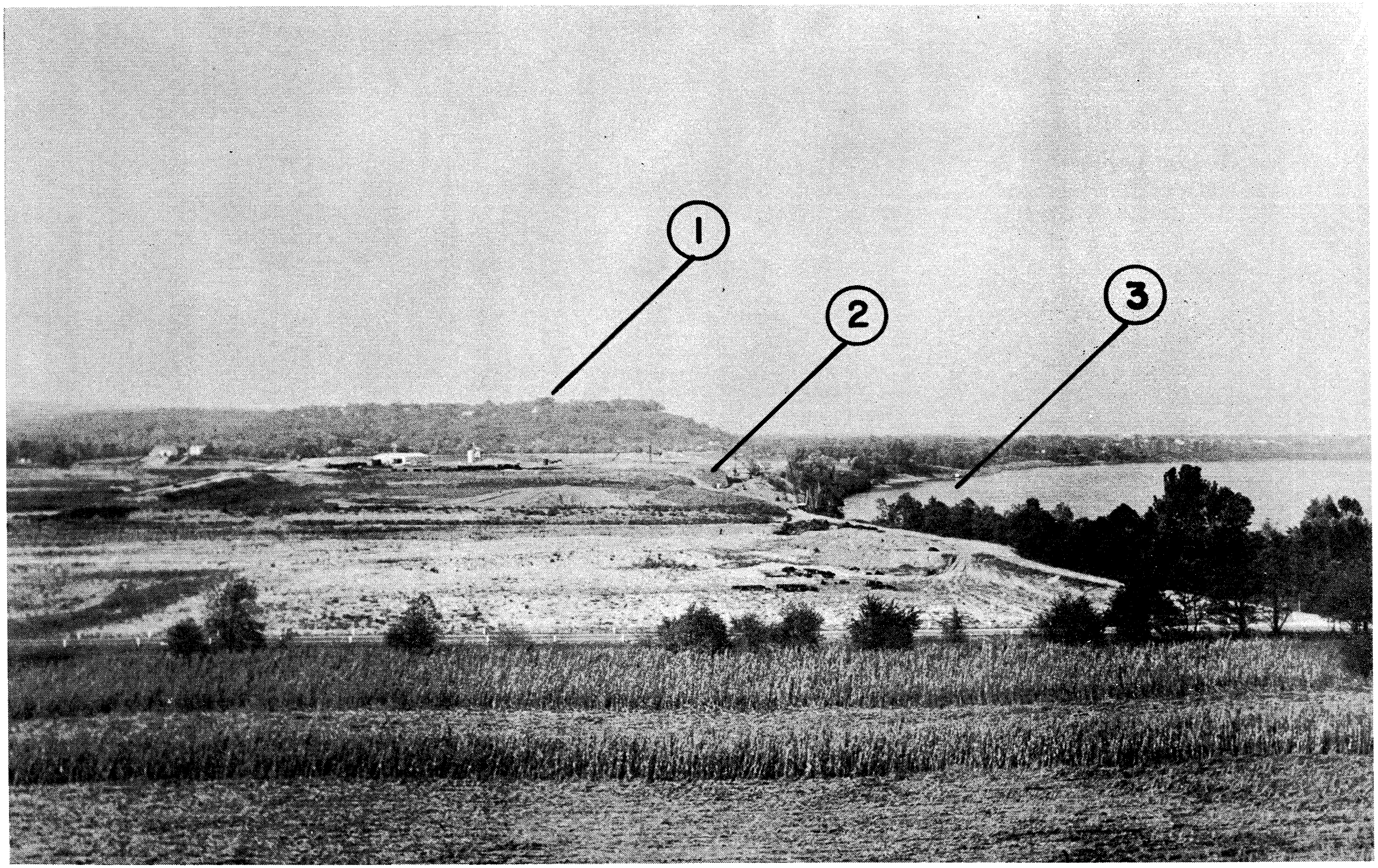


Fig. 2. View from top of tower looking north towards Silver Hill: (1) Silver Hill; (2) approximate location of future stacks; (3) Ohio River.

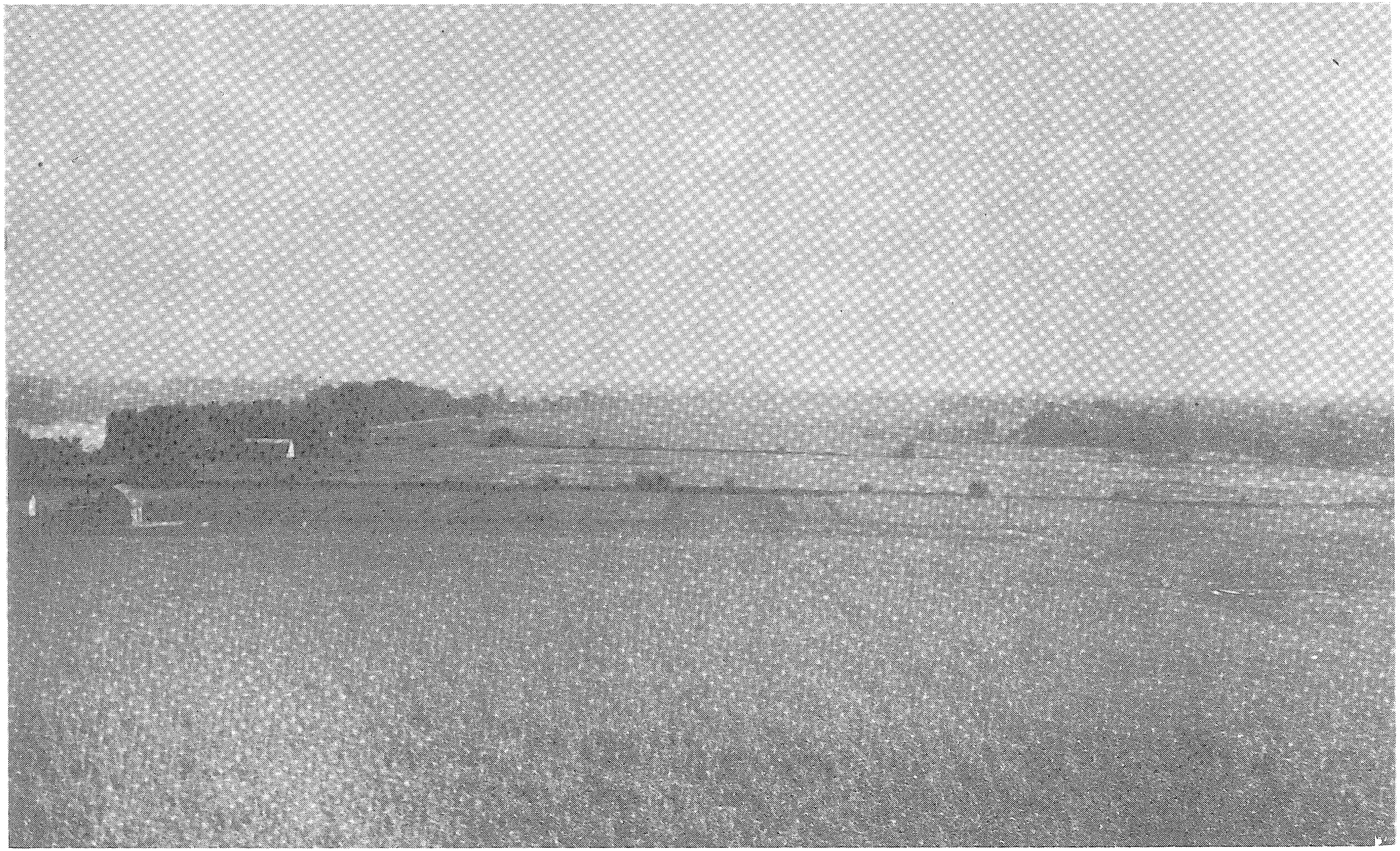


Fig. 3. View from top of tower looking south towards the Paddy Run Plant of the Louisville Gas and Electric Company.

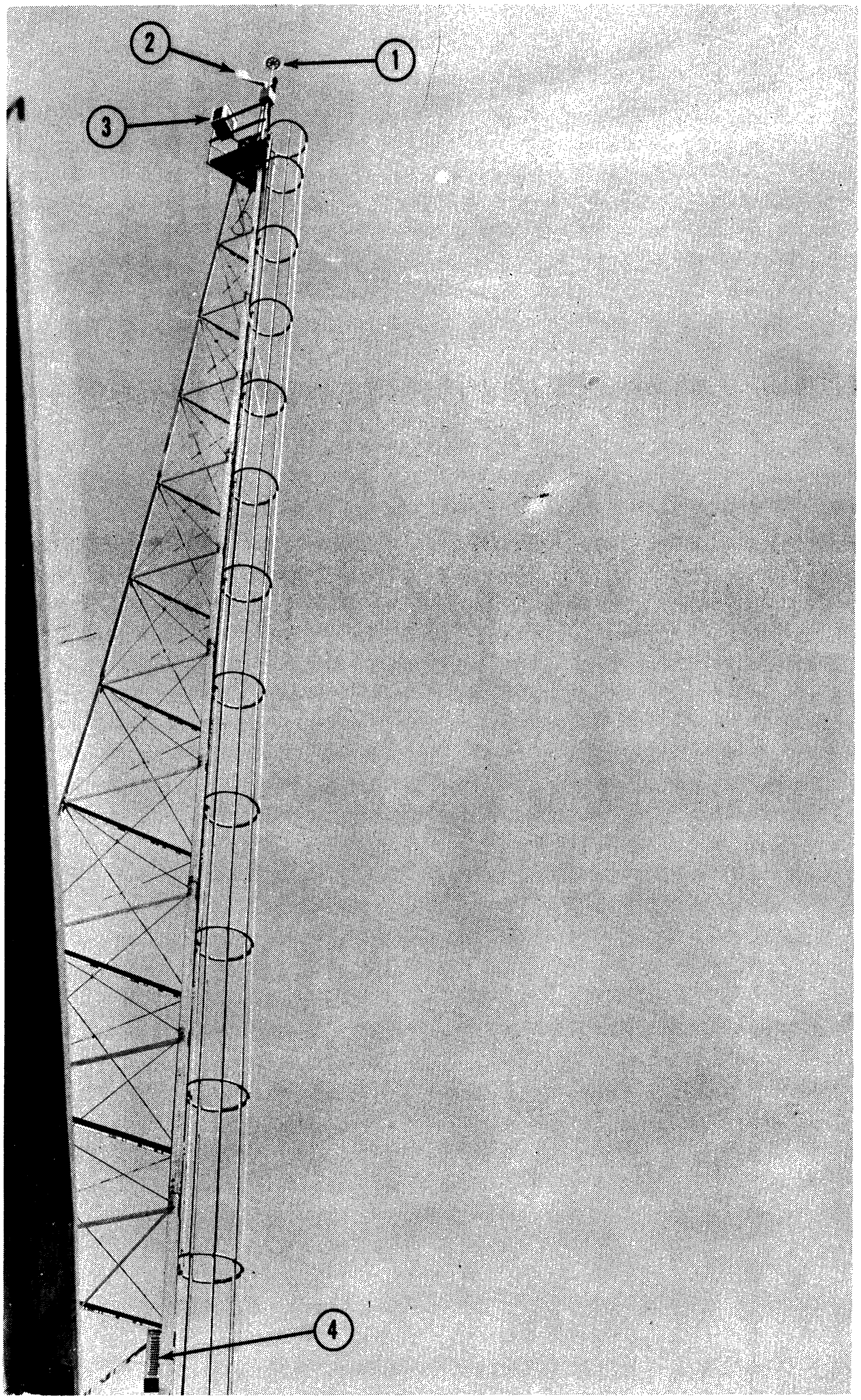


Fig. 4. Details of the meteorological tower installation: (1) turbulence measuring instrument; (2) wind-speed and wind-direction measuring instrument; (3) thermoscreen with maximum and minimum thermometers and thermograph at 97 ft; (4) thermoscreen with maximum and minimum thermometers and thermograph at 25 ft.

is shown in Fig. 5. A three-bladed molded propeller connected to a tachometer generator develops a d-c voltage proportional to the wind speed. The vane drives an a-c selsyn unit as well as orienting the propeller into the wind. The Aerovane recorder is a strip-chart recorder with two pens. One pen is attached to a d-c voltmeter to record wind speeds. The other is attached to a gear driven by the second selsyn unit to record the wind direction. Using a 9-to-1 reduction gear, 40 degrees of pen rotation corresponds to 360 degrees of wind-vane rotation.

The bridled-cup gust accelerometer shown in Figs. 6 and 7 is a further refinement of the instrument developed by Hewson and Gill* in 1939. The wind-sensitive element is a horizontal aluminum wheel around whose periphery are 22 equally spaced vertical curved surfaces each of the same size and shape. With increasing wind speed the horizontal chains seen in Fig. 7 wind up on the drum on the vertical shaft as the growing wind pressure on the curved blades of the wheel rotates the shaft. The two springs serve a double purpose: they bridle or restrain the rotation and they make the angular rotation of the shaft linearly proportional to the wind speed. A circular disc having a series of uniformly spaced, rectangularly shaped teeth of soft iron is concentrically mounted on the vertical shaft. As the disc rotates under the action of the wind, the soft iron rectangles pass in succession between a small U-shaped magnet and the switch it operates. The passage of each of the soft iron rectangles causes the switch to open and close an electric circuit which is connected to an electromagnetic counter in the instrument hut. Two pens register on the recorder the addition of each 10 and each 100 impulses from the instrument. The drum size and the spring tension are adjusted so that there is one make and break for each change in the wind speed of 2 mph. Thus the total number of makes and breaks in an hour is numerically equal to one-half the horizontal gust acceleration in mph. Hence 600 pen recordings in an hour denote a mean gust acceleration of 1200 mph. Thus this instrument has the merit of giving the turbulence as a specific number.

The mechanism in the lower central portion of Fig. 7 is a magnetic damper. This dampens out any tendency of the coil springs to keep the cup wheel oscillating back and forth more than it should. Wind-tunnel studies show that the instrument is properly damped in the 10- to 20-mph range, somewhat underdamped for the winds above 20 mph, and correspondingly overdamped for wind speeds below 10 mph. This means that in general the indicated gustiness count is somewhat too low for wind speeds below 10 mph, correct for wind speeds of 10 to 20 mph, and somewhat too high for speeds above 20 mph. However, the instrument is equally sensitive to winds from all directions. Accordingly, the gust-count comparisons made subsequently in this report for winds from different

*Hewson, E. W., and Gill, G. C., 1944: "Meteorological Investigations in Columbia River Valley near Trail," in "Report Submitted to the Trail Smelter Arbitral Tribunal." U. S. Bureau of Mines Bull. No. 453.

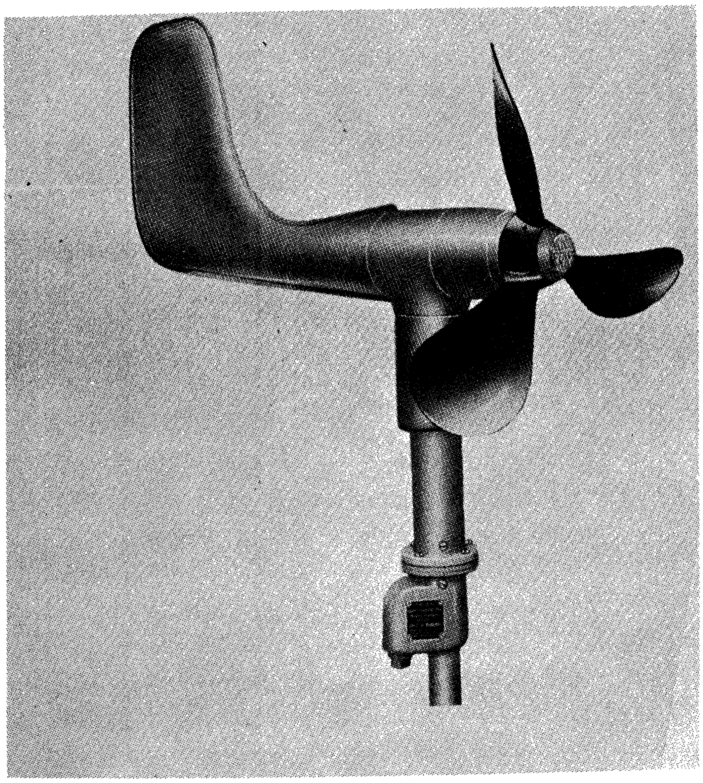


Fig. 5. View of the Bendix-Friez Aerovane Transmitter.

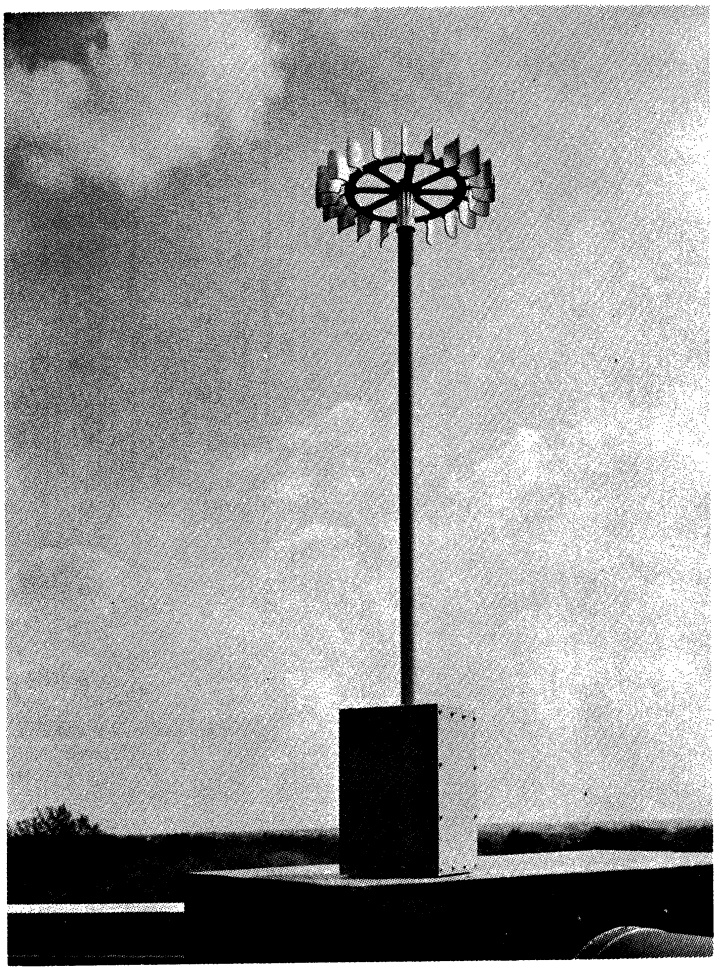


Fig. 6. View of the Hewson-Gill Gust Accelerometer.

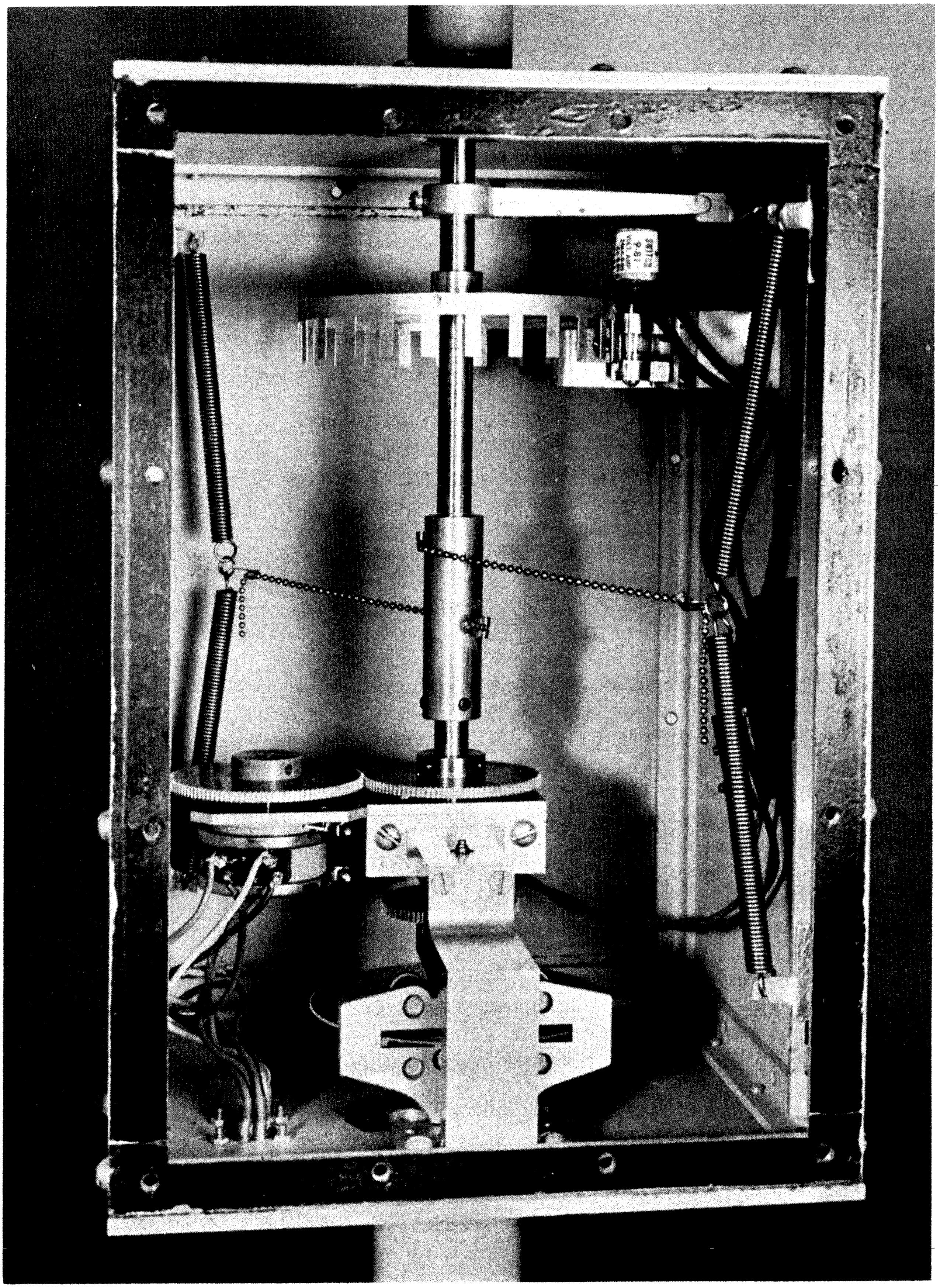


Fig. 7. Interior of Gust Accelerometer showing moving parts.

directions and for various speed intervals are entirely valid.

The mechanism to the left of the control axis of Fig. 7 and connected by gears to the vertical shaft is a potentiometer. This permits recording of the wind speed as well as the gustiness count on an Esterline-Angus milliampere recorder fitted with two chronometric pens.

Figures 8 and 9 are illustrations of a section of the Aerovane and gust-accelerometer records for the same period of time. Note that as the wind speed falls off, the gust-accelerometer count diminishes too. Also note that the speed traces of both instruments are very similar as to magnitude and time of occurrence of individual gusts.

2. TEMPERATURE LAPSE-RATE EQUIPMENT

During periods of light winds, the turbulence or gustiness of the air is closely associated with the lapse rate. If there is an inversion in the lowest few hundred feet of the atmosphere (temperature increasing with height), the gustiness is likely to be very low and any pollution in the air is likely to be dispersed very slowly. This is a common condition in the early morning hours during clear weather. Conversely, if the lapse rate is adiabatic or superadiabatic (a condition usually found around midday on clear days) the gustiness is likely to be high with plenty of eddies to break up or disperse any pollution in the atmosphere.

To correlate gustiness measurements with lapse rates, temperature-measuring instruments were installed in thermometer shelters located at 5, 25, and 98 ft above the ground. The latter two shelters are visible in Fig. 4. Within each shelter were mounted a Casella thermograph, a maximum thermometer, and a minimum thermometer. These thermographs employ bimetal strips for their sensing elements. Chart records were changed weekly, at which time the maximum and minimum thermometers were read to the nearest 0.1°F and reset.

In subsequent abstraction of data from these records, it was planned to read the temperatures at each of the three levels at 2 hourly intervals and to record these temperatures to the nearest 0.2°F. Then temperature differences between the 5- and 25-ft levels, and the 25- to 100-ft levels would be obtained. It was hoped that these temperature differences would be obtained with an accuracy of ±0.3°F. Unfortunately the accuracy of recording the data and the compressed time scales on these charts do not generally permit abstracting the temperatures to closer than ±1.0°F Thus temperature differences between any two levels are not generally reliable to better than ±1 0°F and often to ±2.0°F. But for these small differences in elevation (5 to 25 ft, and 25 to 100 ft), an error of ±0.3°F in measuring the temperature difference can change the lapse rate from an inversion to a superadiabatic condition. Thus the use of these thermographs for lapse-rate measurements is quite inadequate.

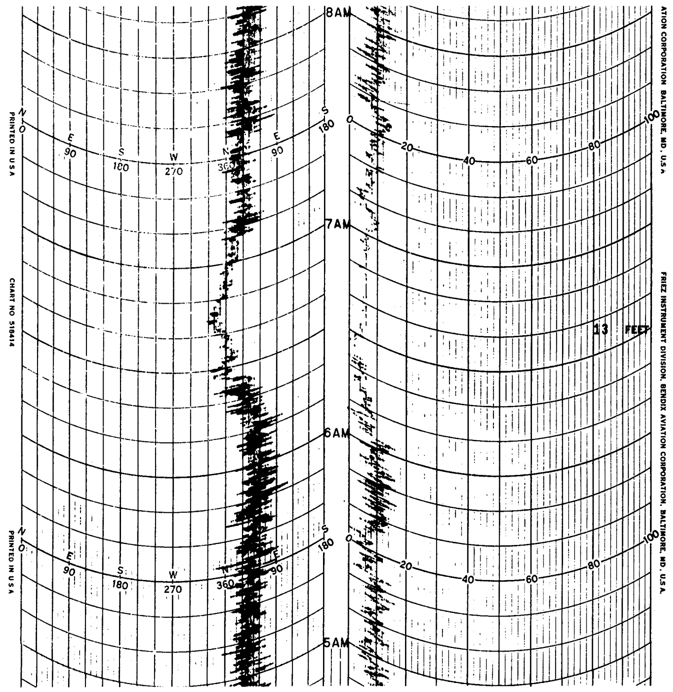


Fig. 8. Section of Aerovane chart 25 March 1957, 0500 to 0800. Left is direction trace 0° through 360° to 180°, right is speed trace 0 to 100 mph.

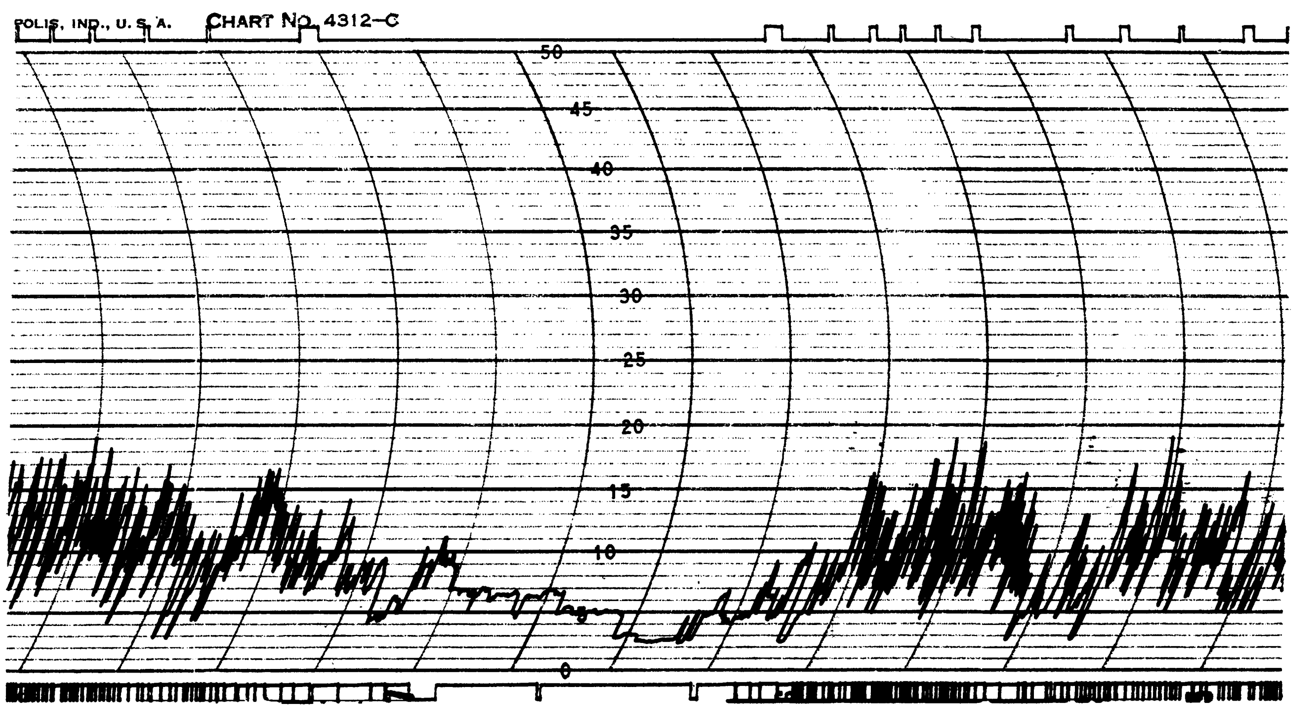


Fig. 9. Section of Gust Accelerometer chart 25 March 1957, 0500 to 0800. Trace to left is the tens count, center trace is the wind speed, 0 to 50 mph, trace to right is hundreds count.

In view of these findings, the more expensive temperature lapse-rate measuring equipment that was originally recommended has now been ordered, and will be installed as soon as delivered. With this equipment, temperature differences will be measured directly instead of trying to measure actual temperatures at two levels and subtracting one from the other. Differential thermocouples will be employed. This system has been used successfully by the writers on two other similar towers during the past year. With this equipment, temperature differences will be measured routinely with an accuracy of ±0.2°F or better.

ANALYSIS OF WIND SPEED AND DIRECTION DATA

Since 12 October 1956, winds have been observed at a height of 104 ft at the plant site near New Albany, Indiana. Winds are also observed routinely by the U. S. Weather Bureau at a height of 71 ft at Standiford Field, Louisville, Kentucky. Although the two instruments are only about 8 miles apart, Fig. 1 indicates that there are important differences in the topography at the two sites. Specifically, the anemometer at the plant site is located in the Ohio River valley at a point where the river lies along a NNE-SSW axis, whereas Standiford Field is separated from the river valley by higher ground, and is itself situated in a different, broad valley. This valley lies along a NW-SE axis and extends for a considerable distance SE of Louisville. The importance of these differences will become evident in the analysis that follows.

The general plan of analysis is to compare the winds at Standiford Field with the average observed there during the 5 years 1951 to 1955 to determine to what extent the current year may be considered typical. Then the winds at New Albany will be compared with those at Standiford Field.

The data to be analyzed are presented in Tables I-IX. Preliminary inspection of the tabulated frequencies for Standiford Field, both for the past year and the 5-year period, revealed a bias in the records. Although nominally 16-compass-point frequencies are presented, it is evident that the Observers have a personal preference for reporting winds to only 8 points. Thus it is seen (Tables I, II, IV,V,VII, VIII) that N winds are more frequent than NNW or NNE, NE winds are more frequent than NNE or ENE, E winds are more frequent than ENE or ESE, and so on, almost without exception, around the compass. Clearly nature has no such preference for the 8 cardinal compass points, yet this biased picture complicates the problem of comparing the records at the New Albany site and Standiford Field. Therefore, before attempting any comparisons, the reported frequencies at Standiford Field were first subjected to a change to eliminate the bias. The method of eliminating the bias is described in the Appendix. It must be emphasized that tabulated wind frequencies with the bias

TABLE I

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

Louisville, Kentucky (Standiford Field)
(Wind instrument at height of 71 ft)

1 January 1951 - 31 December 1955
(Fall)

Direction	Speed, mph						Total Obs.		Mean Speed, mph
	0-3	4-12	13-24	25-31	32 and over	Total 4 and over	%	No.	
N	1.3	7.1	1.2			8.3	9.6	1043	8.5
NNE	0.2	2.4	0.5			2.9	3.2	348	9.2
NE	1.2	3.6	0.6			4.2	5.4	585	7.8
ENE	0.2	0.9	0.1			1.0	1.2	133	7.7
E	0.9	1.2	0.1			1.3	2.2	235	5.8
ESE	0.4	0.8				0.8	1.2	129	6.2
SE	3.7	6.8	0.2			7.0	10.8	1178	6.2
SSE	1.6	5.0	0.7			5.7	7.4	804	7.8
S	2.4	7.3	3.0	0.1		10.4	12.8	1393	9.5
SSW	0.3	3.0	2.1	0.1		5.2	5.5	601	11.9
SW	0.9	5.1	2.7	0.1		7.9	8.8	959	10.7
WSW	0.2	2.4	1.0			3.4	3.6	392	10.5
W	0.7	3.1	1.0			4.1	4.7	515	9.3
WNW	0.4	3.0	1.2			4.2	4.6	506	10.5
NW	1.0	5.7	2.5			8.2	9.2	1004	10.2
NNW	0.3	2.5	1.0	0.1		3.6	3.9	425	10.7
Calm	6.0						6.0	652	0.0
Totals	21.7	59.9	17.9	0.4	0.0	78.2	100.0	10902	8.5

TABLE II

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

Louisville, Kentucky (Standiford Field)
(Wind instrument at height of 71 ft)

1 October 1956 - 30 November 1956
(Fall)

Direction	Speed, mph						Total Obs.		Mean Speed, mph
	0-3	4-12	13-24	25-31	32 and over	Total 4 and over	%	No.	
N	1.2	7.4	0.7			8.1	9.3	136	6.7
NNE	0.5	3.0	0.3			3.3	3.9	57	7.9
NE	1.9	5.5	0.5			6.0	7.9	115	6.4
ENE	0.5	2.2	0.3			2.5	3.0	44	6.0
E	1.6	2.0				2.0	3.7	54	4.9
ESE	0.3	1.0				1.0	1.3	19	5.3
SE	4.0	8.7	0.3			9.0	13.0	191	6.1
SSE	1.8	4.3	1.6			5.9	7.8	114	8.1
S	1.6	3.5	3.8	0.2		7.5	9.1	133	9.5
SSW	0.2	1.8	2.4	0.1		4.3	4.5	66	11.9
SW	0.6	3.2	3.1			6.3	6.9	101	11.5
WSW	0.2	2.6	1.9			4.5	4.7	69	11.0
W	0.8	2.1	1.2			3.3	4.1	60	7.8
WNW	0.1	2.7	2.9	0.1		5.7	5.7	83	11.1
NW	1.4	5.4	2.9	0.1		8.4	9.8	143	9.1
NNW	0.1	1.5	0.5	0.1		2.1	2.2	32	11.5
Calm	3.2						3.2	47	0.0
Totals	20.0	56.9	22.4	0.6	0.0	79.9	100.0	1464	8.1

TABLE III

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

Public Service Company of Indiana
New Albany, Indiana
(Aerovane at height of 104 ft)

12 October 1956 - 30 November 1956
(Fall)

Direction	Speed, mph						Total Obs.		Mean Speed, mph
	0-3	4-12	13-24	25-31	32 and over	Total 4 and over	%	No.	
N	4.9	3.8				3.8	8.7	103	4.6
NNE	6.5	10.0				10.0	16.5	195	5.6
NE	1.0	2.1				2.1	3.1	37	6.1
ENE	0.1	0.7				0.7	0.8	9	7.3
E	0.3	0.3				0.3	0.5	6	5.0
ESE	0.7	0.8				0.8	1.4	17	5.2
SE	1.1	1.9				1.9	3.0	35	5.8
SSE	1.2	2.2				2.2	3.4	40	5.9
S	2.0	4.4	2.3	0.1	0.1	6.8	8.8	105	9.7
SSW	2.5	10.2	4.3			14.5	17.0	202	9.8
SW	0.6	3.4	0.2			3.5	4.1	49	7.6
WSW	1.4	3.8	0.5			4.3	5.7	67	7.5
W	0.4	2.4	0.3			2.7	3.1	37	8.0
WNW	0.6	4.8	1.1			5.9	6.5	77	9.2
NW	0.3	3.3	0.8			4.1	4.4	52	9.4
NNW	1.3	0.7				0.7	1.9	23	4.1
Calm	11.1						11.1	131	0.0
Totals	36.0	54.8	9.5	0.1	0.1	64.3	100.0	1185	6.6

TABLE IV

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

Louisville, Kentucky, (Standiford Field)
(Wind instrument at height of 71 ft)

1 January 1951 - 31 December 1955
(Winter)

Direction	Speed, mph						Total Obs.		Mean Speed, mph
	0-3	4-12	13-24	25-31	32 and over	Total 4 and over	%	No.	
N	0.6	4.7	1.8			6.5	7.1	772	10.1
NNE	0.2	2.1	0.8			2.9	3.0	327	10.4
NE	0.8	4.1	0.8			4.9	5.7	621	8.7
ENE	0.2	1.1	0.1			1.2	1.4	153	8.2
E	0.5	1.7	0.1			1.8	2.4	258	6.6
ESE	0.2	1.1	0.1			1.2	1.3	142	7.6
SE	1.6	7.5	0.4			7.9	9.5	1024	7.4
SSE	0.7	5.6	1.4			7.0	7.6	827	9.4
S	0.8	7.6	5.1	0.2	0.1	13.0	13.8	1472	11.9
SSW	0.3	3.4	3.6	0.2		7.2	7.5	816	13.3
SW	0.5	5.1	3.4	0.1		8.6	9.1	985	11.9
WSW	0.1	2.6	1.3	0.1		4.0	4.1	446	11.5
W	0.2	3.2	1.4	0.1		4.7	4.9	531	10.9
WNW	0.1	3.4	2.6	0.1		6.1	6.1	661	12.5
NW	0.4	6.3	4.0			10.3	10.8	1163	11.7
NNW	0.1	2.3	1.6			3.9	4.0	432	12.2
Calm	1.7						1.7	184	0.0
Totals	9.0	61.8	28.5	0.8	0.1	91.2	100.0	10814	10.6

TABLE V

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

Louisville, Kentucky (Standiford Field)
(Wind instrument at height of 71 ft)

1 December 1956 - 28 February 1957
(Winter)

Direction	Speed, mph						Total Obs.		Mean Speed, mph
	0-3	4-12	13-24	25-31	32 and over	Total 4 and over	%	No.	
N	1.2	6.3	3.7			10.0	11.2	242	10.0
NNE	0.4	2.3	1.9			4.2	4.6	99	10.3
NE	1.7	6.2	1.4			7.6	9.3	201	7.9
ENE	0.3	1.5	0.3			1.8	2.2	47	7.7
E	0.9	1.7	0.1			1.8	2.7	59	6.1
ESE	0.3	0.9				0.9	1.2	25	5.8
SE	2.0	7.1	0.7			7.8	9.8	212	6.8
SSE	0.4	2.7	0.6			3.3	3.8	81	8.2
S	0.6	3.5	3.9	0.2		7.6	8.1	176	11.5
SSW	0.1	1.9	3.6			5.5	5.6	122	13.5
SW	0.4	4.7	4.3			9.0	9.4	202	12.0
WSW	0.1	2.9	2.4			5.3	5.4	117	11.4
W	0.4	3.3	2.1			5.4	5.8	125	10.8
WNW	0.1	2.7	2.4			5.1	5.2	113	12.5
NW	0.8	4.7	4.5			9.2	10.1	219	11.8
NNW	0.1	2.2	2.3			4.5	4.7	101	12.5
Calm	0.9						0.9	19	0.0
Totals	10.7	54.6	34.2	0.2	0.0	89.0	100.0	2160	10.2

TABLE VI

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

Public Service Company of Indiana
New Albany, Indiana
(Aerovane at height of 104 ft)

1 December 1956 - 28 February 1957
(Winter)

Direction	Speed, mph						Total Obs.		Mean Speed, mph
	0-3	4-12	13-24	25-31	32 and over	Total 4 and over	%	No.	
N	3.3	3.4	0.8			4.1	7.4	156	6.4
NNE	5.6	11.7	1.6			13.3	18.9	396	7.1
NE	1.5	3.3				3.3	4.9	102	6.1
ENE	0.3	0.7				0.7	1.0	21	6.3
E	0.3	0.4				0.4	0.7	15	5.2
ESE	0.7	1.0				1.0	1.7	35	5.6
SE	0.6	0.9				0.9	1.5	31	5.7
SSE	1.0	0.7				0.7	1.6	34	4.5
S	1.2	2.3	1.3			3.6	4.8	100	9.3
SSW	2.9	10.2	3.3			13.5	16.3	343	9.1
SW	1.2	6.0	0.6			6.6	7.8	164	7.9
WSW	1.0	3.8	0.1			3.9	5.0	104	7.0
W	1.6	3.4	0.3			3.7	5.3	111	6.7
WNW	1.5	2.8	0.5			3.3	4.8	100	7.3
NW	0.7	4.9	0.7			5.5	6.2	130	8.5
NNW	0.8	4.0	1.1			5.1	6.0	125	9.2
Calm	6.2						6.2	131	0.0
Totals	30.4	59.5	10.3	0.0	0.0	69.6	100.0	2098	7.1

TABLE VII

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

ouisville, Kentucky (Standiford Field)
(Wind instrument at height of 71 ft)

1 January 1951 - 31 December 1955
(Spring)

Direction	Speed, mph						Total Obs.		Mean Speed, mph
	0-3	4-12	13-24	25-31	32 and over	Total 4 and over	%	No.	
N	0.8	6.0	2.1			8.1	8.9	986	10.0
NNE	0.3	2.4	0.3			2.7	3.0	335	8.6
NE	0.8	4.6	0.9			5.5	6.3	693	8.7
ENE	0.2	1.4	0.2			1.6	1.9	210	8.5
E	0.8	2.2	0.2			2.4	3.2	356	7.2
ESE	0.2	1.5	0.2			1.7	2.0	216	8.6
SE	2.0	7.1	0.7			7.9	9.8	1085	7.5
SSE	1.0	4.0	1.0		0.1	5.0	6.0	668	8.9
S	1.2	5.6	3.3	0.1		9.0	10.3	1135	10.9
SSW	0.3	2.3	3.1	0.3	0.1	5.8	6.1	670	14.1
SW	0.7	4.9	4.2	0.2	0.1	9.4	10.0	1110	12.5
WSW	0.1	2.7	1.9	0.1		4.7	4.7	524	12.6
W	0.3	3.4	1.6	0.1		5.1	5.3	589	11.0
WNW	0.2	3.4	2.8	0.1	0.1	6.4	6.5	719	12.7
NW	0.5	5.2	3.7	0.1		9.0	9.5	1052	11.9
NNW	0.2	2.1	1.2			3.3	3.6	395	11.2
Calm	2.8						2.8	308	0.0
Totals	12.4	58.8	27.4	1.0	0.4	87.6	100.0	11051	10.3

TABLE VIII

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

Louisville, Kentucky (Standiford Field)
(Wind instrument at height of 71 ft)

1 March 1957 - 31 May 1957
(Spring)

Direction	Speed, mph						Total Obs.		Mean Speed, mph
	0-3	4-12	13-24	25-31	32 and over	Total 4 and over	%	No.	
N	0.4	3.9	1.6			5.5	5.9	131	10.0
NNE	0.2	2.1	1.5			3.6	3.8	83	10.9
NE	0.4	5.9	2.9			8.8	9.2	203	10.3
ENE	0.2	2.2	1.4			3.6	3.7	82	10.7
E	0.5	2.4	0.7			3.1	3.6	80	8.2
ESE	0.5	1.9	0.3			2.2	2.7	59	7.8
SE	1.8	9.7	1.6			11.3	13.2	291	8.1
SSE	0.6	4.6	1.7	0.1		6.4	7.0	155	9.7
S	0.7	4.3	2.4			6.7	7.5	165	10.0
SSW		2.6	2.3	0.1		5.0	5.1	112	13.8
SW	0.6	3.8	3.2			7.0	7.7	171	11.9
WSW	0.3	3.5	3.1	0.1		6.7	7.0	154	12.5
W	0.5	3.0	2.2			5.2	5.8	127	11.2
WNW	0.2	2.6	3.1			5.7	5.9	131	11.2
NW	0.4	3.4	3.4			6.8	7.2	160	11.4
NNW	0.2	2.2	1.7			3.9	4.1	90	11.4
Calm	0.6						0.6	14	0.0
Totals	8.1	58.1	33.1	0.3	0.0	91.5	100.0	2208	10.4

TABLE IX

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

Public Service Company of Indiana
New Albany, Indiana
(Aerovane at height of 104 ft)

1 March 1957 - 31 May 1957
(Spring)

Direction	Speed, mph						Total Obs.		Mean Speed, mph
	0-3	4-12	13-24	25-31	32 and over	Total 4 and over	%	No.	
N	2.3	5.9	1.5			7.3	9.6	195	8.2
NNE	2.4	9.6	2.6			12.2	14.6	296	8.9
NE	1.1	4.0	0.6			4.6	5.7	115	8.0
ENE	0.2	1.5				1.5	1.8	36	7.2
E	0.4	0.2				0.2	0.6	13	4.3
ESE	0.3	1.0				1.0	1.3	27	6.7
SE	0.5	1.5				1.5	2.1	42	6.4
SSE	0.7	2.1	0.2			2.3	3.0	61	7.3
S	1.3	4.3	1.4			5.7	7.0	141	9.0
SSW	2.8	10.0	3.6			13.6	16.4	332	9.3
SW	1.7	3.3	0.9			4.2	5.9	120	7.9
WSW	0.8	4.2	1.2			5.4	6.3	127	9.2
W	1.1	3.1	0.2			3.3	4.4	89	7.1
WNW	0.5	3.3	0.2			3.5	4.0	82	7.9
NW	0.5	3.3	0.4			3.7	4.2	85	8.4
NNW	0.4	3.4	0.9			4.3	4.7	96	9.5
Calm	8.4						8.4	170	0.0
Totals	25.4	60.7	13.7	0.0	0.0	74.3	100.0	2027	7.8

removed can never be as satisfactory as carefully taken, unbiased observations. The technique used to remove the bias is basically a smoothing operation and cannot reproduce all the details of the truth. Nevertheless, in cases where the evidence of observer bias is so conclusive, removing the bias from the tabulated frequencies does yield greater accuracy. Wind frequencies with the bias eliminated from the tabulation are listed in Tables X and XI for Standiford Field during the fall, winter, and spring seasons. These are the frequencies that are used in the analysis.

1. WIND DIRECTION

Seasonal comparisons of wind direction at New Albany and Standiford Field are presented in Figs. 10, 11, and 12 by means of conventional wind roses. They are presented in a somewhat different form in Figs. 13, 14, and 15. Referring first to the upper graph in Figs. 13, 14, and 15, it is evident that the three seasons studied to date were in general quite typical of the long-term average for the area. However, reference to the lower graph in the same figures indicates a marked difference between New Albany and Standiford Field. The striking features are a shift in one of the modes from SSE at Standiford Field to SSW at New Albany and a pronounced increase in the size of the NNE mode at New Albany. Figures 10, 11, and 12 emphasize that the two modes at New Albany form a couple which coincides with the orientation of the Ohio River valley at the plant site. Less pronounced, but still evident, is the tendency for winds at Standiford Field to favor a NNW-SSE axis which coincides with another broad valley, referred to earlier, and depicted in Fig. 1. There can be little doubt that the striking difference in the wind directions at New Albany and Standiford Field results from the funnelling and drainage influences of these two valleys.

The subsequent discussion in this report assumes that the wind characteristics as measured at the top of the tower are the same as those at the height of the smoke plume from the stack. However, the tops of the stacks are 470 ft above the meteorological instruments, and well above any of the nearby terrains, and these winds may be less subject to valley influences than those measured below. The validity of this assumption should be determined.

2. WIND SPEED

Data obtained during the period 12 October 1956 to 31 May 1957 indicate that winds are lighter at New Albany than at Standiford Field. A comparison of mean wind speeds as given in Tables II, III, V, VI, VIII, and IX shows that wind speeds at New Albany average 75% of those at Standiford Field. Consistent with this, the percentage of calms is greater at New Albany than at Standiford Field.

TABLE X

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS, ALL SPEEDS, BIAS REMOVED

Louisville, Kentucky (Standiford Field)
1 October 1956 - 31 May 1957

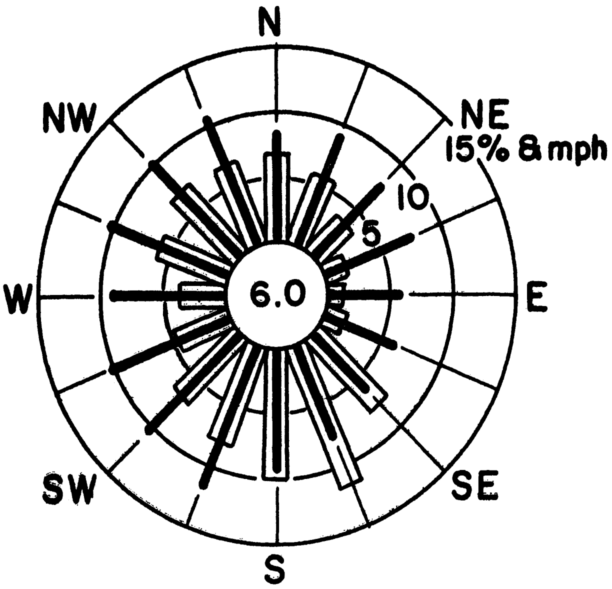
Direction	Fall	Winter	Spring
N	6.2	8.1	4.7
NNE	7.1	8.2	5.6
NE	5.9	6.5	7.1
ENE	4.5	3.5	5.2
E	2.5	1.8	2.6
ESE	2.1	2.2	3.8
SE	9.3	6.4	9.9
SSE	12.4	7.2	10.5
S	7.4	6.2	6.2
SSW	5.6	7.7	5.7
SW	5.9	7.9	7.1
WSW	5.1	6.5	7.3
W	3.8	4.9	5.7
WNW	7.5	6.7	6.4
NW	7.4	7.9	6.4
NNW	4.1	7.5	5.1
Calm	3.2	0.9	0.6

TABLE XI

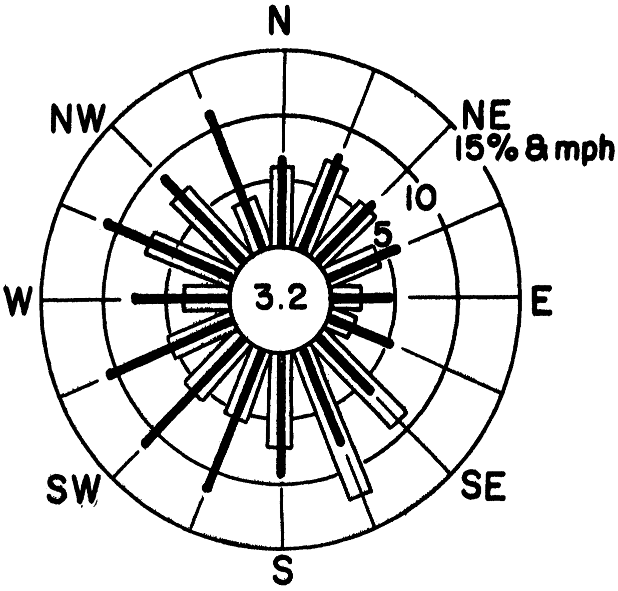
PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS, ALL SPEEDS, BIAS REMOVED

Louisville, Kentucky (Standiford Field)
1 January 1951 - 31 December 1955

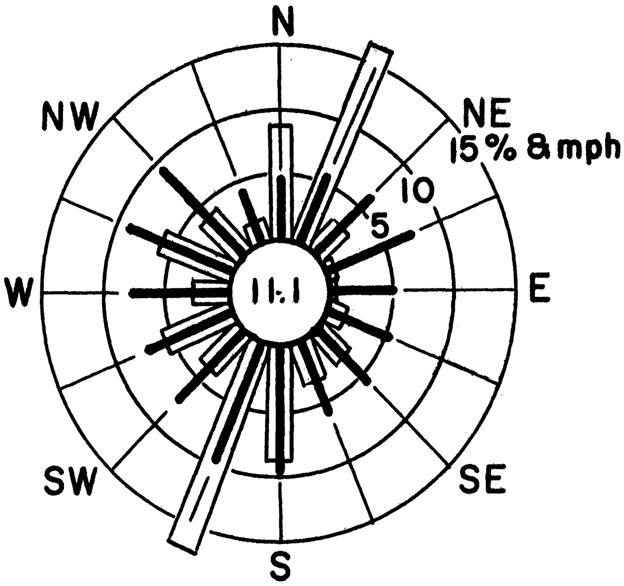
Direction	Fall	Winter	Spring
N	6.8	5.2	6.2
NNE	5.7	5.1	5.5
NE	3.7	4.0	4.4
ENE	1.9	2.2	2.9
E	1.3	1.5	2.2
ESE	1.9	1.9	3.0
SE	7.6	6.8	7.1
SSE	12.0	11.3	9.3
S	10.0	11.3	8.2
SSW	8.1	10.1	8.4
SW	6.7	7.4	8.1
WSW	4.6	4.7	6.0
W	3.8	4.1	4.6
WNW	6.1	7.8	7.9
NW	7.1	8.7	7.8
NNW	6.7	6.1	5.9
Calm	6.0	1.7	2.8



STANDIFORD FIELD
LOUISVILLE , KENTUCKY
Wind Instrument at Height of 71 ft.
Fall (Sept., Oct., Nov.) 1951–1955

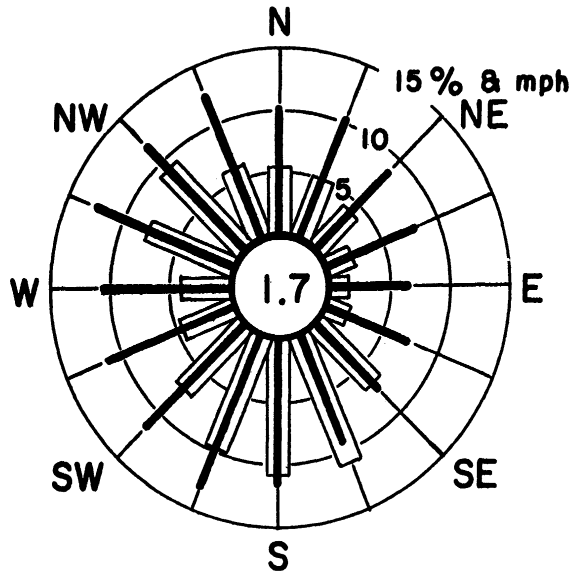


STANDIFORD FIELD
LOUISVILLE , KENTUCKY
Wind Instrument at Height of 71 ft.
Fall (Sept., Oct., Nov.,) 1956

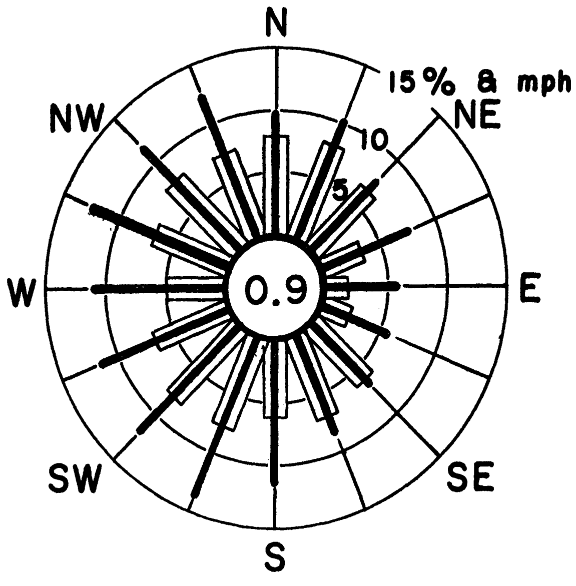


PUBLIC SERVICE COMPANY OF INDIANA
NEW ALBANY , INDIANA
Aerovane at Height of 104 ft.
Fall (Oct., Nov.) 1956

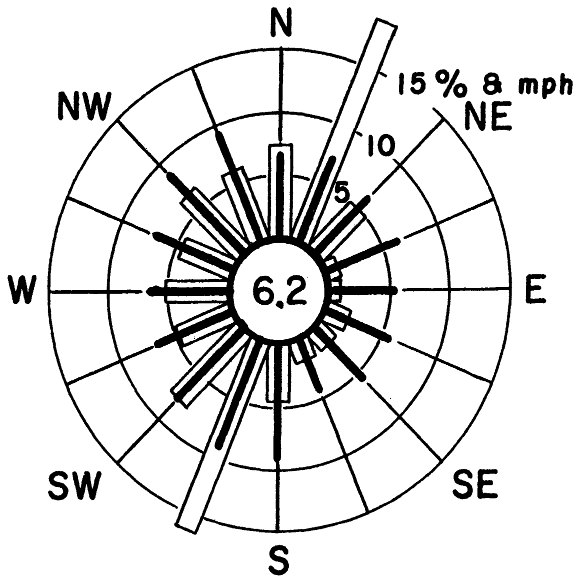
Fig. 10. Percentage frequency of occurrence of winds from 16 directions (rectangles) and corresponding wind speed in mph (heavy lines) at Standiford Field, 1951-1955; Standiford Field, 1956; and New Albany Plant Site, 1956; Fall. Percent of calms in center.



STANDIFORD FIELD
LOUISVILLE KENTUCKY
Wind Instrument at Height of 71 ft.
WINTER (Dec., Jan., Feb.) 1951-1955

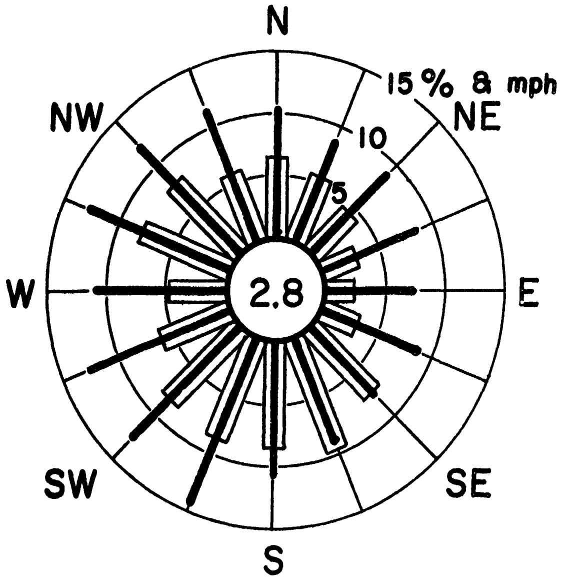


STANDIFORD FIELD
LOUISVILLE KENTUCKY
Wind Instrument at Height of 71 ft.
WINTER (Dec., Jan., Feb.) 1956-57

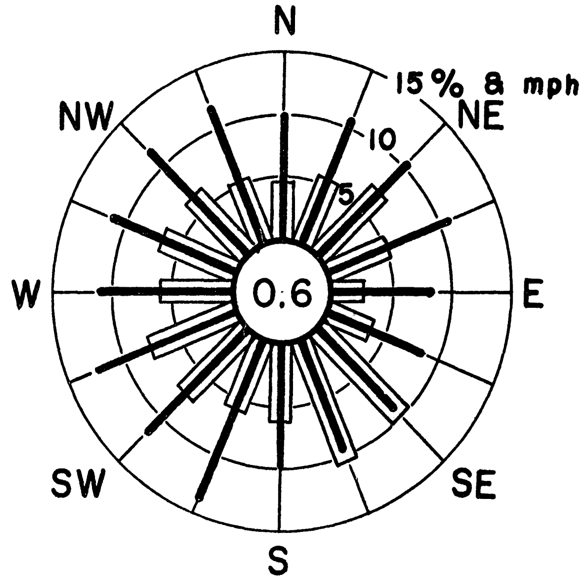


PUBLIC SERVICE COMPANY OF INDIANA
NEW ALBANY, INDIANA
Aerovane at Height of 104 ft.
WINTER (Dec., Jan., Feb.) 1956-57

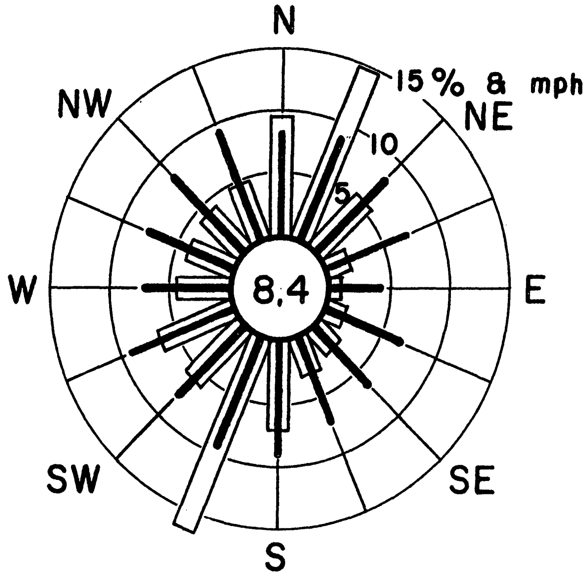
Fig. 11. Percentage frequency of occurrence of winds from 16 directions (rectangles) and corresponding wind speed in mph (heavy lines) at Standiford Field, 1951 - 1955; Standiford Field, 1956 - 1957; and New Albany Plant Site, 1956 - 1957: Winter. Percent of calms in center.



STANDIFORD FIELD
LOUISVILLE KENTUCKY
Wind Instrument at Height of 71 ft.
SPRING (Mar., Apr., May) 1951-1955

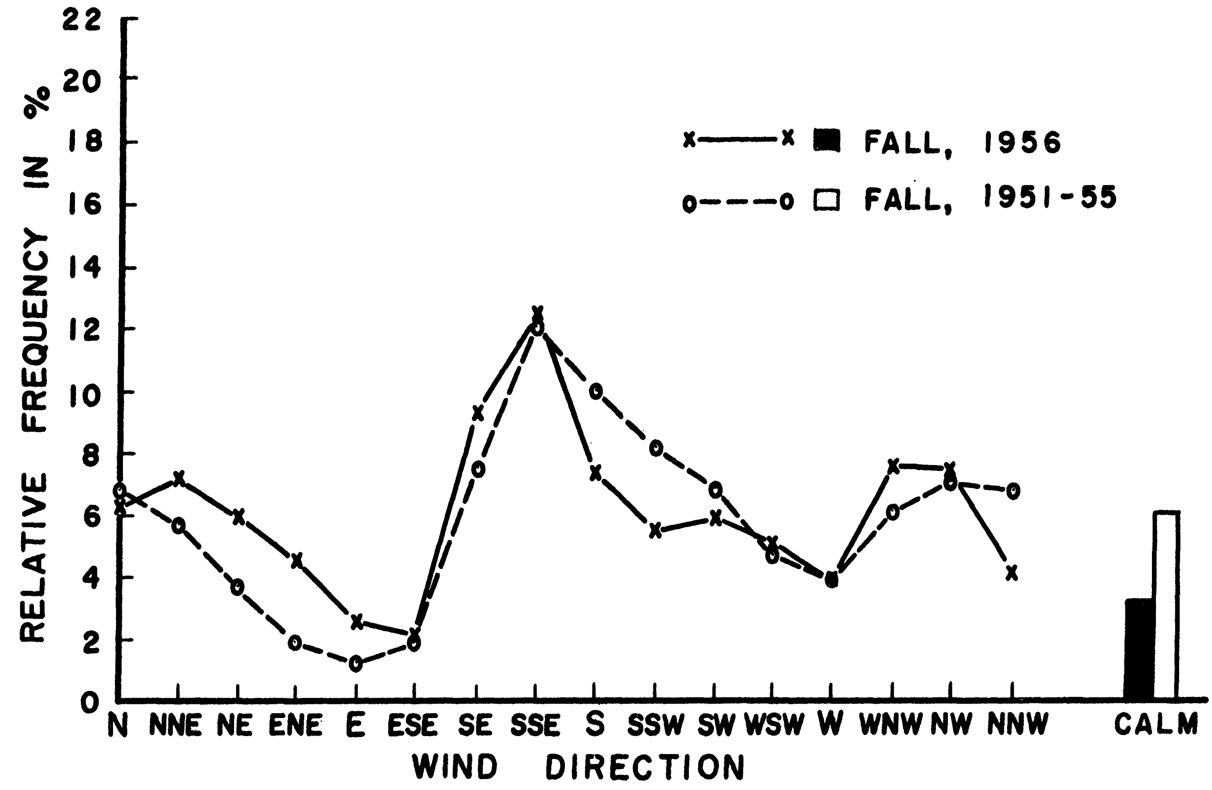


STANDIFORD FIELD
LOUISVILLE KENTUCKY
Wind Instrument at Height of 71 ft.
SPRING (Mar., Apr., May) 1957

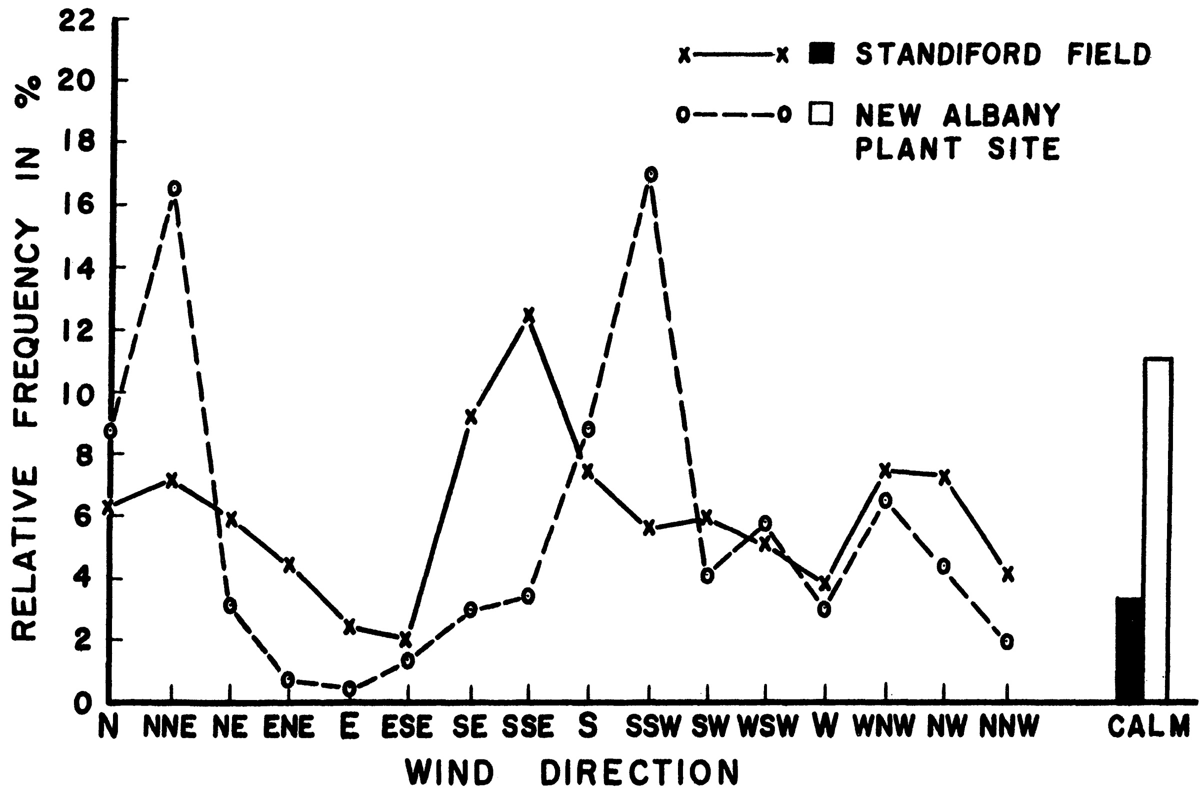


PUBLIC SERVICE COMPANY OF INDIANA
NEW ALBANY, INDIANA
Aerovane at Height of 104 ft.
SPRING (Mar., Apr., May) 1957

Fig. 12. Percentage frequency of occurrence of winds from 16 directions (rectangles) and corresponding wind speed in mph (heavy lines) at Standiford Field, 1951 - 1955; Standiford Field, 1957; and New Albany Plant Site, 1957: Spring. Percent of calms in center.



STANDIFORD FIELD, FALL 1951-55
AND FALL 1956



NEW ALBANY & STANDIFORD FIELD
FALL 1956

Fig. 13. Relative frequency of occurrence of winds from 16 directions at Standiford Field, 1951 - 1955 and 1956; and at Standiford Field, 1956, and New Albany Plant Site, 1956: Fall. Percent of calms on the right.

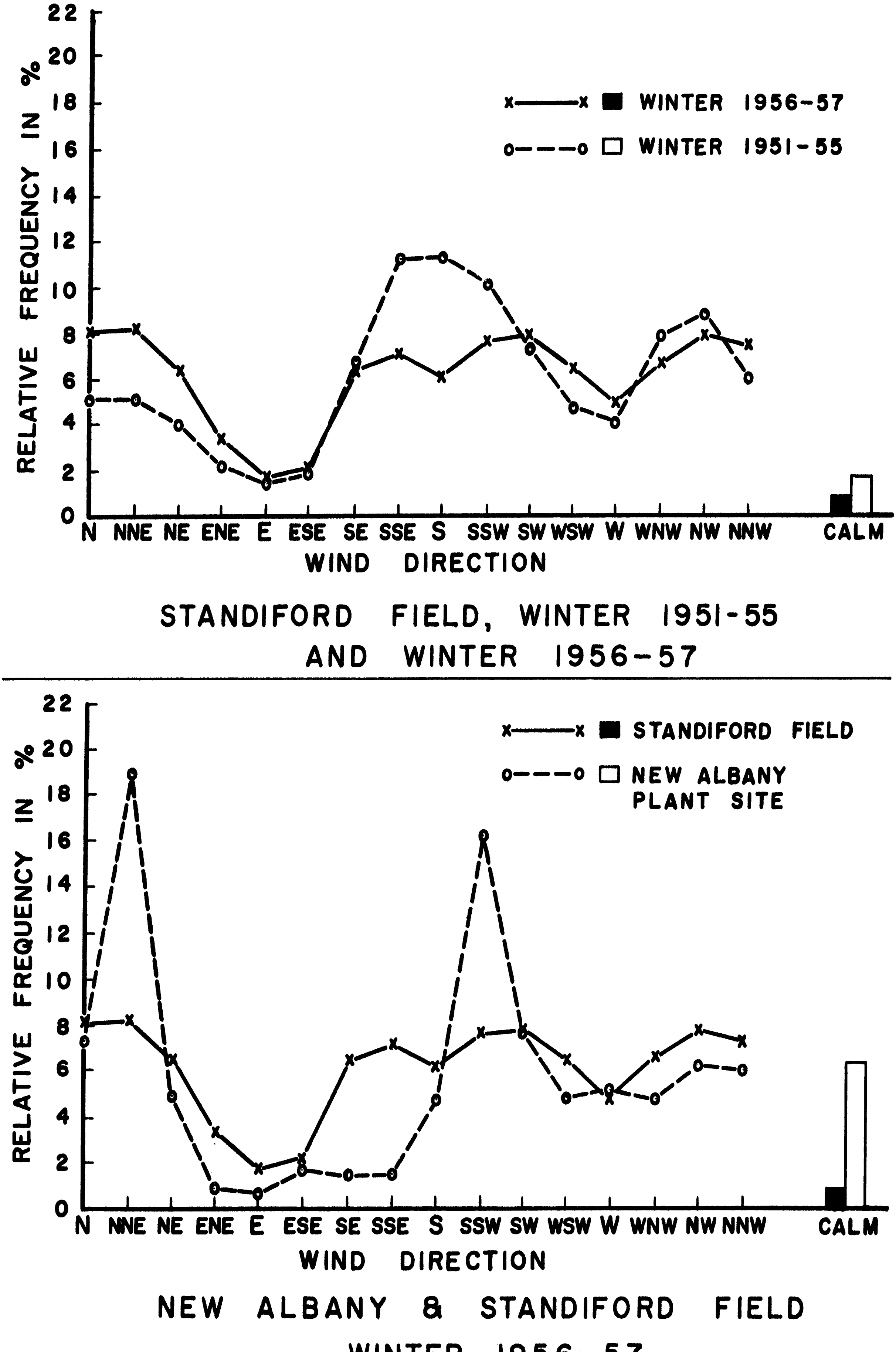


Fig. 14. Relative frequency of occurrence of winds from 16 directions at Standiford Field, 1951 - 1955 and 1956 - 1957; and at Standiford Field, 1956 - 1957, and New Albany Plant Site, 1956 - 1957: Winter. Percent of calms on the right.

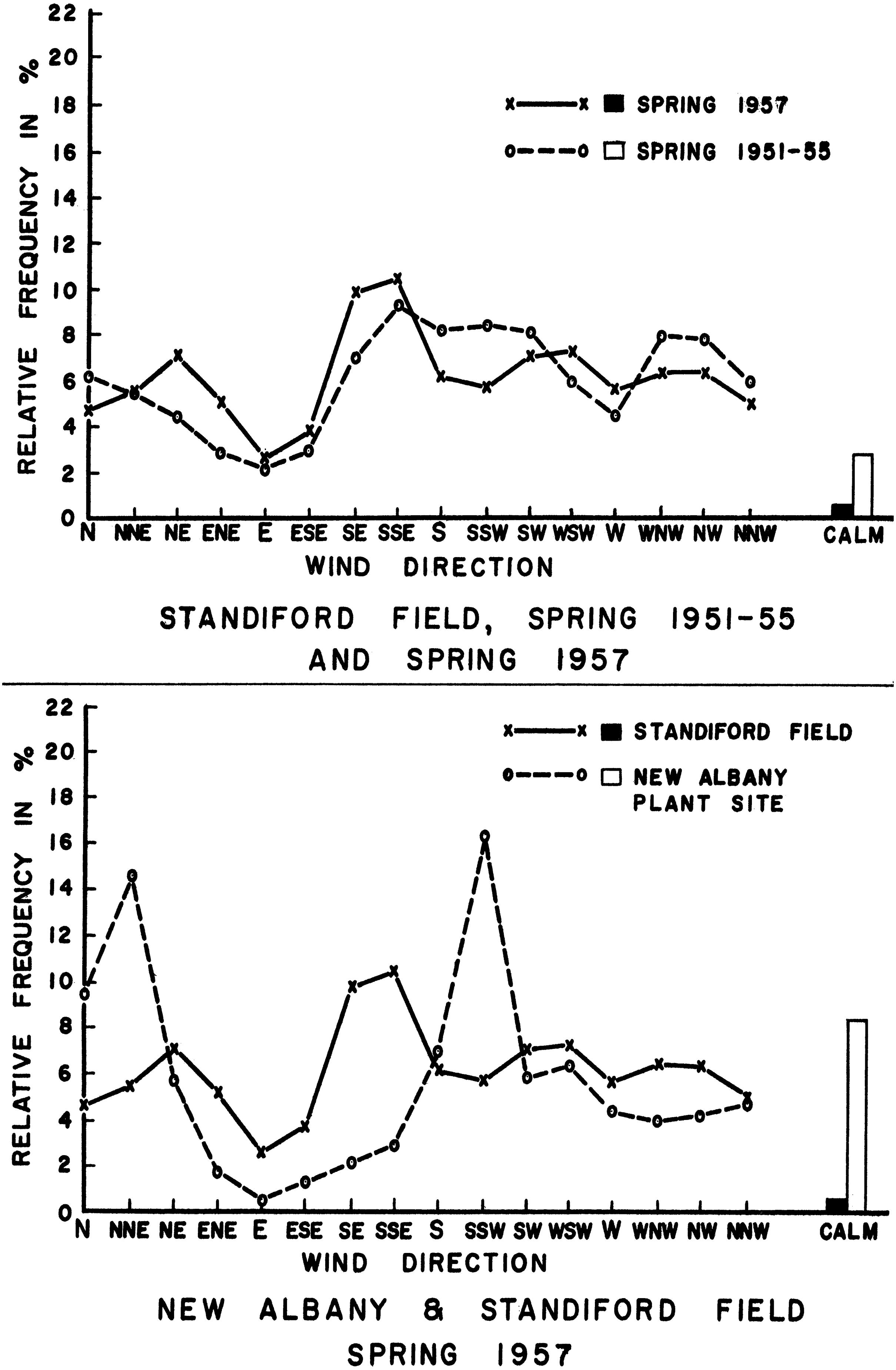


Fig. 15. Relative frequency of occurrence of winds from 16 directions at Standiford Field, 1951 - 1955 and 1957; and at Standiford Field, 1957, and New Albany Plant Site, 1957: Spring. Percent of calms on the right.

Differences in reported wind speeds at two stations can sometimes be accounted for by differences in anemometer sensitivity. However, it is unlikely that this is the explanation in this case since the Bendix-Friez Aerovane used at New Albany is, if anything, more sensitive than the cup anemometer in use at Standiford Field. At other times, differences in reported wind speed are explained by differences in the height of the anemometer above the ground, but in this case this would lead to stronger winds at New Albany. The indication of lighter winds at New Albany than at Standiford Field may therefore be accepted as valid.

Although winds from all directions at New Albany are lighter than the corresponding winds at Standiford Field, there is some evidence of selectivity. Winds from the sector SSW, SW through NW to NNE are lighter in relation to the corresponding winds at Standiford Field than winds from the other sector. This is probably due to the more rugged terrain to the west and north of the Ohio River as shown in Fig. 1.

ANALYSIS OF TURBULENCE DATA

The data from the gust accelerometer mounted on top of the tower give a measure of the turbulence. This turbulence can be caused by many factors. Some of the more important factors are the velocity of the wind, the roughness of the surrounding terrain, and the vertical temperature lapse rate. Since topography seems to be so important in the analysis of data from this plant site, it was decided to analyze the gust count in relation to the 16 compass directions and the wind speed. To do this, a breakdown of wind speed and direction was made as in the wind-analysis section. In each of these categories the average gust count was computed for the three seasons under discussion, but no seasonal differences were apparent. The analysis is therefore presented for the whole period only.

1. VARIATION OF TURBULENCE WITH WIND DIRECTION

The major variation in gust count seemed to be related to the different directions from which the wind was blowing. Table XII shows this very well. Figure 16 gives a visual representation of the gust count and a given wind direction for the three categories of wind speed, 0-3 mph, 4-12 mph, and 13-24 mph. To make the discussion easier to follow, it was decided to start with the northerly direction and continue around the compass in a clockwise motion, making groupings of directions where possible when the same comments could be made for several directions.

TABLE XII

COMPOSITE AVERAGE GUST COUNT PER HOUR

New Albany Plant Site
12 October 1956 - 31 May 1957
(Fall, Winter, Spring)

Direction	Speed, mph				
	0-3	4-12	13-24	25-32	32 +
N	2	99	1110		
NNE	5	208	1567		
NE	8	301	2035		
ENE	4	380	—		
E	9	248	—		
ESE	7	181	—		
SE	14	149	—		
SSE	6	170	1378		
S	8	205	1097	3740	5590
SSW	4	219	1210		
SW	3	329	1304		
WSW	10	446	2062		
W	28	444	1820		
WNW	41	431	1975		
NW	3	327	1321		
NNW	11	154	1159		
Avg	10	268	1503	3740	5590

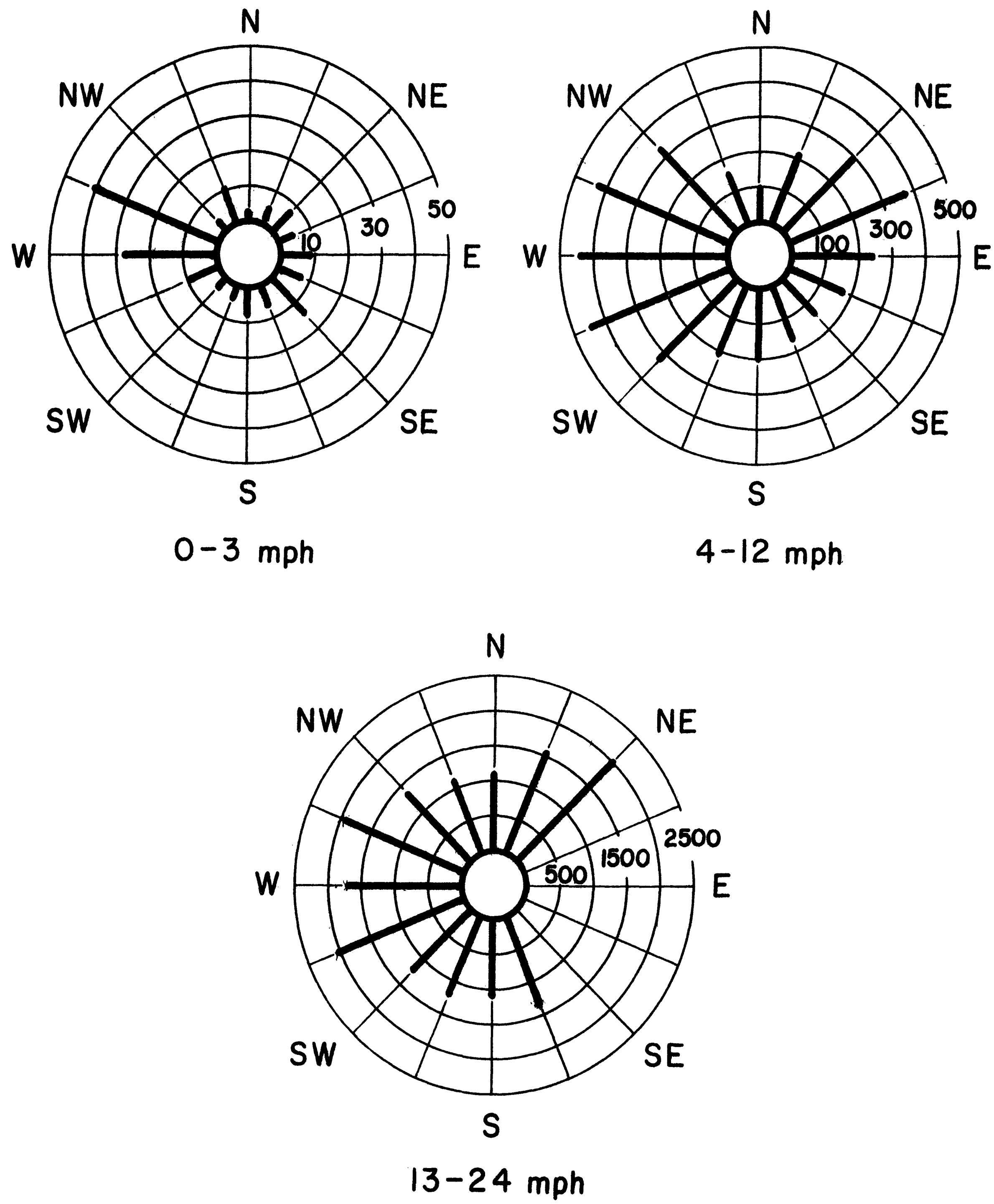


Fig. 16. Average gust count per hour by wind direction and wind speed categories. New Albany Plant Site: 12 October 1956 - 31 May 1957.

N.—The first noticeable feature is that the gust count with a northerly wind is low relative to the other directions. To explain this, let us look to the north. A little over 3/4 of a mile from the plant site, Silver Hill starts to rise very rapidly (see Fig. 1). In a matter of 500 ft it rises 150 ft and then levels off. The northerly approach rises in the same manner. There are no other hills to the north of Silver Hill for a distance of several miles. Now let us consider a northerly wind. As it comes down from the north, it passes over hilly ground and becomes turbulent. For several miles north of Silver Hill it passes over a relatively flat area. Then it reaches Silver Hill. Because of the angle at which a north wind hits Silver Hill, the air must either move to the east to pass around the hill or rise and go up over the hill. Stable air has a greater probability of going around the hill than of rising over the hill. By going around the hill, the wind then becomes a NNE wind and will not be considered further here. The fact that a north wind at the plant has a small amount of turbulence is difficult to explain based upon present-day models, but it must be assumed that it is a particular result of the air passage in the vicinity of Silver Hill. In an effort to see if the cause might partly be diurnal in nature, the northerly wind data were separated into hourly occurrences. This analysis showed that when northerly winds occurred, they were prevalent only 26.4% of the time during daylight hours. That is to say, more than two-thirds of the northerly winds occurred during the darkness. Now we know that as soon as the sun begins to set, the earth begins to cool and the lower atmosphere tends to become more stable. This often results in an inversion which damps out practically all turbulent motion. This predominance of northerly winds at night, with associated inversions, suggests why the gust count should be so low. Perhaps analysis of more data will lead to a more complete explanation. Since the major concern is the Silver Hill area and not the area south of the plant, we will not consider this aspect further in this report.

NNE.—To the NNE there is a relatively flat area. The gust-accelerometer count is average to a little below average, indicating that there is some turbulence. This turbulence is undoubtedly due to the general roughness of the land even though there are no large rises in topography. As was pointed out in the preceding section, some NNE winds are probably really N winds that have come around Silver Hill. This effect would create some turbulence in an otherwise stable airstream.

NE.—Winds from the NE sector have a larger gust count even though the flow is directly off the Ohio River. The trajectory over the water is not more than three or four miles long. Before reaching the river, the flow is over relatively flat land. The stronger turbulence may be attributed to the influence of the relatively warm river water at this time of the year, which produces increased lapse rates, instability, and turbulence.

ENE and E.—Although the data are few, and entirely absent for winds above 12 mph, there is an average to moderate amount of turbulence in winds from this

sector. The air flow is over generally flat land; the turbulence present may be attributed to higher lapse rates caused by surface heating of the air as it passes over Louisville and the river.

ESE, SE, and SSE.—The gust counts in these sectors are among the lowest values recorded. The nearest hills are six to seven miles away so the trajectory of the airflow is over relatively flat land for some distance and mechanical turbulence is a minimum. Low turbulence, especially from the SSE, could be considered as important because winds from that direction pass near the western edge of Silver Hill. Low turbulence implies poor diffusion but in this case it is not very important because the records show that winds from these three directions occur only 6.3% of the time. In fact, in the three seasons studied, SSE winds occur only 2.7% of the time over that eight-month period. Another mitigating factor is the relatively low wind speeds from the SSE, which indicates the absence of aerodynamic downwash to bring stack gases to the surface over Silver Hill.

S.—Gust counts associated with southerly winds are below average; yet this cannot be construed to mean that diffusion will be poor. It signifies that there are other wind directions which give more turbulence owing to the roughness of the land. The low values of gust counts are due to the long flat path of the airstream up the river valley and over the plain along the river. This direction is probably the most important as far as pollution is concerned because the trajectory of the air stream after it leaves the plant is directly over Silver Hill. Air in the lower layers may be deflected around Silver Hill but the winds at the level of the top of the stacks will flow over Silver Hill, as suggested by earlier studies in the wind tunnel which indicate that the air does rise up over Silver Hill with a southerly wind. The wind-tunnel studies do not take into account the vertical temperature lapse rate, but it is known that the southerly winds in this area are usually warm moist winds characteristic of a tropical air mass. Since the ground at these seasons, especially in the late fall, winter, and early spring, tends to be cooler than the tropical air flowing over it, a stable stratification and limited diffusion are to be expected. Tables III, VI, and IX show a relatively high frequency of strong winds, suggesting that aerodynamic downwash may be a factor, although the stacks may be high enough to prevent the stack gases from reaching the surface on Silver Hill. Further analysis of this situation is required.

SSW.—The turbulence associated with SSW winds is also below average since the flow is along the flat river plain and in the river valley itself. Again the air mass is basically stable during these seasons. Even though there are SSW winds over 16% of the time, these winds will carry stack gases to the east of Silver Hill, and so the problem of pollution with these winds is minimized.

SW, WSW, W, and WNW.—These wind directions give the highest gust counts that are experienced at the plant site. The increase in the gust count and hence in the turbulence is due primarily to the topography. Figure 1 shows

that from the SW to the WNW there are hills rising 200 ft and more within a distance of 1 mile. In addition, the hills are rough in nature and therefore cause a good deal of mechanical turbulence. This large amount of turbulence lessens the possibility of a pollution problem towards Louisville or Clarksville since the turbulence will cause marked dilution of the pollutant.

<u>NW and NNW</u>.—The gust counts have fallen off as compared to the previous group of directions, especially in the NNW sector. Figure 1 shows that there is a slight indentation in the hills that runs for about 2 miles to the NW of the plant site. This feature permits relatively smooth air flow and therefore less turbulence is indicated at the tower. However, closer to the hills there will be more turbulence, so in reality the plant site may have more turbulence than the tower with these winds.

2. VARIATION OF TURBULENCE WITH WIND SPEED

The average values of the gust count for each of the wind-speed categories is also shown in Table XII. These values have been plotted against the mean wind speed for each of the five categories. The result is shown in Fig. 17. Surprisingly, the outcome is a straight line on log-log paper showing that the logarithm of the gust count varies as the logarithm of the wind speed. The equation of the line turns out to be:

$$G = 4.5 V^2,$$

where

G = gust count, and
V = wind speed.

As stated earlier, turbulence is a function of wind speed, roughness of the terrain, and vertical temperature lapse rate. With more data and the capability of separating stable from unstable conditions, as well as the use of trajectories that are known to be smooth, we will be able to interpret the above equation more fully. As a step in this direction, the gust counts with southerly winds are also plotted in Fig. 17. Winds from the south have a long, relatively smooth trajectory, and we have data from all five categories, but information on lapse rate is lacking. It is noted that the first three points of plotted southerly data all lie on a straight line with only the two high values deviating. Since both these high values represent only a few observations, more data might tend to relocate these points in such a manner as to clarify the interpretation of gust counts in relation to wind speed over level terrain.

An envelope about the mean line is also plotted in Fig. 17. This envelope was constructed by taking the maximum and minimum point in each category and plotting it. This envelope becomes smaller relative to the wind speed as the latter increases, suggesting that at low wind speeds there are other factors

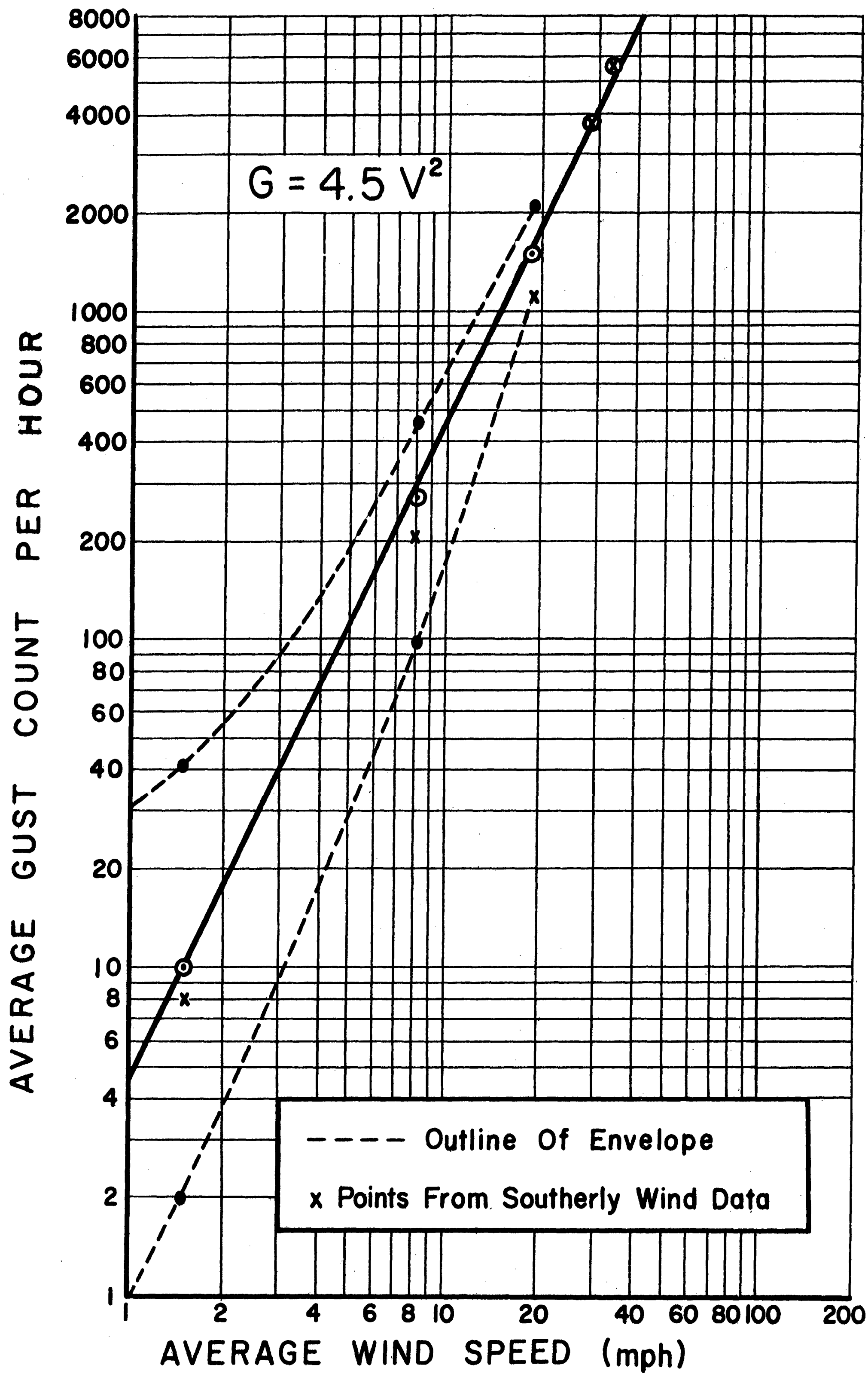


Fig. 17. Graph of average gust count per hour vs average wind speed.

besides the wind speed that cause turbulence. The range in gust counts in the 0-3 mph category represents 390% of the average value, whereas in the 13-24 mph category the range is only 63.6% of the average. Thus we can say that as the wind speed increases, roughness and lapse rate play a relatively smaller role in creating turbulence.

CONCLUSIONS

Analysis of the data shows that the valley effect is significant at the plant site. It causes the wind to flow either up or down the valley more than one-third of the time. The valley orientation is favorable when viewed from the specific potential air-pollution problem of this plant because it lessens the frequency of southerly winds which would tend to affect the Silver Hill area. The average wind speeds at the plant site are less than those at Standiford Field. These lighter winds are favorable when considering the air-pollution problem, for the number of hours of aerodynamic downwash will be reduced. The roughness of the topography in the area causes enough mechanical turbulence and associated mixing to ensure good dilution of stack gases except for a limited number of occasions. It has been assumed that wind characteristics above the tops of the stacks are similar to those at the top of the tower, but the validity of this assumption should be checked.

The presence of a significant difference in wind frequencies and wind speeds between the plant site and Standiford Field brings to light the fact that the establishment of a meteorological installation at the plant site was necessary to obtain more adequate knowledge of atmospheric phenomena, which, in turn, will enable appropriate action to be taken.

Finally, the effect of topography shows up strongly in the turbulence analysis. The nearer the hills in any direction, the higher the gust count and the greater the amount of turbulence in winds from that direction. Large values of gust count are indicative of good atmospheric diffusion conditions and of smaller chances of pollution. It is also shown that at higher wind speeds the influence of the roughness of the terrain and the magnitude of the lapse rate in producing turbulence and mixing is relatively less than at lower wind speeds.

RECOMMENDATIONS

The results obtained to date suggest five recommendations.

1. CONTINUATION OF THE PRESENT PROGRAM

The analysis of data from Standiford Field shows that the months under consideration have been quite normal. There will, however, be extreme conditions, and when these occur, there will be peculiarities in the air flow and properties that should be known to have a complete picture of the events that may be expected. The summer season remains to be analyzed and may show effects characteristic of the area that are not shown in the other seasons. Continuation of the observational program is therefore strongly recommended.

2. INSTALLATION OF DIFFERENTIAL THERMOCOUPLES

To help analyze diffusion patterns, the installation of two thermocouples on the 100-ft tower is advised. Accurate vertical temperature lapse rates will then be available and conclusions as to the stability and instability of the lower atmospheric layers can be made.

3. COMPUTATION OF CONCENTRATION VALUES

After observations for a full year have been made and analyzed, it is proposed to make preliminary calculations of SO_2 concentrations in the stack gases in the Silver Hill area for a variety of meteorological conditions. As more meteorological data become available, these preliminary calculations will be refined and improved. In particular, the influence of the plant itself on air flow and diffusion patterns will be studied.

4. DETERMINATION OF BACKGROUND SO_2 VALUES

It is important to know the SO_2 concentrations in the area under various meteorological conditions before the plant is actually operating to make a realistic assessment of later measured values in the Silver Hill area. It is therefore recommended that a study by made of existing and future SO_2 measurements in relation to the observed meteorological conditions.

5. COMPARISON OF WIND CHARACTERISTICS AT TOP OF STACKS WITH THOSE AT TOP OF TOWER

The wind speed, direction, and turbulence at the height and location of the tops of the stacks should be compared for a test period, by a mutually satisfactory method, with those at the top of the tower.

APPENDIX

A METHOD FOR ELIMINATING THE BIAS FROM WIND DIRECTION FREQUENCY STATISTICS

INTRODUCTION

Although it is now standard procedure at first-order weather stations to report wind directions to 16 points of the compass, it is not uncommon to discover evidence of a bias in the records. This bias takes the form of an apparently greater frequency of winds from the eight primary points (N, NE, E, SE, S, SW, W, and NW) than of winds from the eight intermediate points (NNE, ENE, ESE, SSE, SSW, WSW, WNW, and NNW). For example, the record may indicate that N winds are more frequent than NNW or NNE, NE winds are more frequent than NNE or ENE, E winds are more frequent than ENE or ESE, and so on around the compass. Since nature clearly has no preference for the cardinal points unless there is an unusual arrangement of valleys intersecting precisely at the weather station, this improbable result must be attributed to observer bias, specifically a preference for reporting the wind direction as one of the eight primary points.

TESTING FOR PRESENCE OF BIAS

In the case of the Louisville records, there is scarcely any need for a rigorous check for bias since a casual observation shows that a bias exists. However, such a check can easily be made by measuring the compatibility of the observed and expected frequencies. This is known as the Chi-square test and is usually designated χ^2 where

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

O_i stands for the observed frequencies,
E_i stands for the expected frequencies, and
K is the number of pairs of frequencies to be compared.

This test should be made when the evidence of bias is not so strikingly evident.

Consider the eight cardinal compass directions. The reported frequency of each of these directions may be assigned to one of three categories as follows:

Category	Identification	Probability of Occurrence	Expected Occurrences
1	Reported frequency exceeds that of both adjacent intermediate compass points.	.25	2
II	Reported frequency exceeds that of one adjacent intermediate compass point.	.50	4
III	Reported frequency exceeds neither adjacent intermediate compass point.	.25	2

The right-hand column indicates the expected frequency of occurrence of this event among eight cardinal compass points. These occurrences are assumed to stem from a population of unbiased records.

The quantity

$$\sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

that we are interested in has a X^2 distribution with 2 degrees of freedom. This means that a number may be placed in either category I, II, or III, but if a value is assigned to any two of these categories, then the value of the third one is fixed since the total of categories I, II, and III must equal 8. The number of degrees of freedom is defined as k-1 where k is again the number of pairs of frequencies to be compared. In the case at hand there are three categories, so k = 3. Then k-1 = 2.

The wind frequency statistics for Louisville contained in Tables I, II, IV, V, VII, and VIII were subjected to a X^2 analysis. The results are tabulated in Table XIII. From tables of X^2 a value greater than 10.60 can be expected to occur with a frequency of less than one in two hundred where there is no bias. The large values of X^2 in Table XIII indicate that it is highly probable that the record has a bias.

REMOVING THE BIAS FROM THE RECORD

A satisfactory method of removing the bias from the wind record must itself be free of bias, and must involve the minimum amount of smoothing. In the light of these criteria, two tests may be applied to determine the best method of eliminating the bias. First, when a method for removing the bias is applied

TABLE XIII

COMPUTATIONS OF X^2 FROM LOUISVILLE, KENTUCKY (STANDIFORD FIELD) RECORDS

Season	No. of Occurrences Category I	II	III	X^2
Fall '56	7	0	1	17.00
Winter '56-'57	8	0	0	24.00
Spring '57	6	1	1	10.75
Fall '51-'55	8	0	0	24.00
Winter '51-'55	7	1	0	16.75
Spring '51-'55	7	1	0	16.75

to a record that is believed to be biased, the resulting table of wind frequencies must indicate no bias when subjected to the X^2 test. If two or more methods of removing the bias meet the test of being free of bias, the best method is that which effects the least smoothing to an unbiased record. Two simple methods of removing the bias will be described, and the best method will be selected on the basis of the two tests stated above.

FIRST METHOD*

The method will be demonstrated with the reported wind occurrences at Louisville, Kentucky (Standiford Field), for October and November, 1956. The logic behind the method is as follows. Reported occurrences for each of the cardinal points are considered to be too high (positive bias), whereas for each adjacent intermediate point, occurrences are too low (negative bias). If the average frequency of each compass point and the adjacent clockwise point is computed, an unbiased 16-point wind record is obtained. However, the computed frequencies will refer to 16 points which are rotated 12.25 degrees clockwise from the desired point. If frequencies are computed for 16 points which are rotated 12.25 degrees counterclockwise from the desired directions, by the same procedure, then the average of the two sets of frequencies will be an unbiased record for the desired 16 compass points.

As an illustration, consider the case of NE winds (Table XIV). The reported frequencies of NNE, NE, and ENE winds are 57, 115, and 44, respectively. The average frequency of the NE with the ENE wind is (115 + 44)/2; the average

*U.S. Atomic Energy Commission, A Meteorological Survey of the Oak Ridge Area, Final Report ORO-99, Technical Information Service, Oak Ridge, Tennessee, p. 70.

TABLE XIV

REPORTED WIND OCCURRENCES AND COMPUTED OCCURRENCES WITH BIAS REMOVED (METHOD 1)

Louisville, Kentucky (Standiford Field)
1 October 1956 - 30 November 1956

Direction	Column 1 Reported Occurrences	Column 2 $\left(\frac{f_{cc}}{2}\right)$	Column 3 $\left(\frac{f_c}{2}\right)$	1+2+3	Frequency with Bias Removed, $\frac{1+2+3}{2}$
N	136	16	28	180	90
NNE	57	68	58	183	92
NE	115	28	22	165	82
ENE	44	58	27	129	64
E	54	22	10	86	43
ESE	19	27	96	142	71
SE	191	10	57	258	129
SSE	114	96	66	276	138
S	133	57	33	223	112
SSW	66	66	50	182	91
SW	101	33	34	168	84
WSW	69	50	30	149	74
W	60	34	42	136	68
WNW	83	30	72	185	92
NW	143	42	16	201	100
NNW	32	72	68	172	86
Calm	47	→	→	→	47

frequency of the NE with the NNE wind is (115 + 57)/2. This gives the clockwise and counterclockwise displacement of 12.25 degrees. To get the frequency of the NE winds with the bias removed, we average these two displacements. Therefore the average frequency of NE winds is

$$\frac{\frac{115 + 44}{2} + \frac{115 + 57}{2}}{2} \quad \text{or simply} \quad \frac{115 + 44/2 + 57/2}{2} = \frac{165}{2} = 82.$$

This then gives us a general equation to compute the frequencies with the bias eliminated:

$$f_n = \frac{f_o + f_c/2 + f_{cc}/2}{2} ,$$

where

f_n = new computed frequency with the bias eliminated,

f_o = old frequency at the point under consideration,

f_c = old frequency next to the point under consideration in the clockwise direction, and

f_{cc} = old frequency next to the point under consideration in a counterclockwise direction.

The computed frequencies with bias eliminated appear as the last column of Table XIV. In Table XIII it was pointed out that the original record yielded a value of X^2 of 17.00. The new record gives $X^2 = 0.75$, indicating the effect of the smoothing process. In this case we assume, therefore, that most of the bias has been eliminated.

SECOND METHOD

The second method assumes that the positive bias of the cardinal points is constant and that valid comparison between cardinal points are offered by the reported frequencies. Similarly it assumes that the negative bias of the intermediate points is constant and that valid comparisons may be made between intermediate points. That is to say, if the reported frequency of NE winds is twice that of E winds, this may be accepted as their true relationship although both are actually less frequent than reported.

The computations, which are illustrated in Table XV, first effect a transformation into an unbiased 8-point record by apportioning the occurrences of the intermediate points to the adjacent cardinal points on the basis of the comparative frequencies of the two cardinal points. Having done this, half of the computed 8-point occurrences are attributed to the central 22.5 degrees of the whole 45-degree sector. The remaining half of the 8-point occurrences

TABLE XV

REPORTED WIND OCCURRENCES AND COMPUTED OCCURRENCES WITH BIAS REMOVED (METHOD 2)

Louisville, Kentucky (Standiford Field)
1 October 1956 - 30 November 1956

Direction	Reported Occurrences	Add to Cardinal Points	8-Point Occurrences: Bias Removed	Components of Intermediate Points	16-Point Occurrences: Bias Removed
N	136	15+31	182		91
NNE	57			58+48	106
NE	115	26+30	171		86
ENE	44			37+25	62
E	54	14+4	72		36
ESE	19			11+20	31
SE	191	15+67	273		136
SSE	114			117+69	186
S	133	47+38	218		109
SSW	66			40+42	82
SW	101	28+43	172		86
WSW	69			44+25	69
W	60	26+25	111		56
WNW	83			30+79	109
NW	143	58+17	218		109
NNW	32			33+30	63
Calm	47	→	→	→	47

are apportioned between the adjacent intermediate points on the basis of their comparative occurrences. The occurrences of the cardinal points with the bias removed are obtained by halving the 8-point occurrences. As an illustration, consider the reported frequencies of N, NNE, NE, ENE, and E winds which are 136, 57, 115, 44, and 54, respectively (Table XIV). Computing the occurrence of NE winds with the bias removed for an 8-point compass we get

$$115 + \left(\frac{115}{115 + 136}\right) 57 + \left(\frac{115}{115 + 54}\right) 44 = 115 + 26 + 30 = 171 .$$

By halving this number, the occurrence of NE winds with bias eliminated is obtained (171/2 = 86). The remaining 85 occurrences (171 - 86) are assigned to NNE and ENE as follows: to NNE, [57/(57 + 44)]85 = 48, and to ENE, (85 - 48 = 37). Thus each of the newly computed frequencies for the intermediate direction will have two components. The right-hand column in Table XV gives $\chi^2 = 2.00$ which falls within our assumed criterion for the elimination of the bias.

COMPARISON OF METHOD 1 AND METHOD 2

The two methods may be compared by applying each of them to the reported occurrences at New Albany, Indiana, for the period 12 October - 30 November, 1956. Table XVI contains reported occurrences at New Albany, and computed occurrences with the bias eliminated by use of both methods. Since the reported occurrences gives $\chi^2 = 2.75$, the record appears to be unbiased. Accordingly, the better method will be that which effects the least smoothing to the frequencies as reported. Figure 18 presents graphically this comparison between reported relative frequencies and relative frequencies computed by the two methods for removal of bias. Method 1 has a standard deviation of 2.4% from the reported relative frequencies, compared to 1.6% for method 2. Method 2 is therefore selected as the better of the two.

CONCLUSION

By means of a simple Chi-square test, bias may be detected in records of occurrences of winds by directions. Biased records may have the bias removed with a minimum of smoothing by the second of the two methods described in the foregoing. In the present report, all tables of wind occurrences for Louisville have had the bias removed in this way. Records with the bias eliminated are better than biased records, but can never be more than an approach to the true, unbiased record. Observers should be trained to observe winds without making the observations subject to personal preferences.

TABLE XVI

FREQUENCY OF OCCURRENCE OF WINDS FROM VARIOUS DIRECTIONS AS REPORTED, AND AS COMPUTED BY TWO METHODS FOR REMOVING THE BIAS

New Albany, Indiana
12 October 1956 - 30 November 1956

Direction	Occurrences			Relative Frequencies		
	Reported	Method 1	Method 2	Reported	Method 1	Method 2
N	103	106	130	8.7	8.9	11.0
NNE	195	132	162	16.5	11.1	13.7
NE	37	70	48	3.1	5.9	4.1
ENE	9	15	6	0.8	1.3	0.5
E	6	9	4	0.5	0.8	0.3
ESE	17	19	16	1.4	1.6	1.3
SE	35	32	30	3.0	2.7	2.5
SSE	40	55	41	3.4	4.6	3.5
S	105	113	136	8.8	9.5	11.5
SSW	202	139	164	17.0	11.7	13.8
SW	49	92	75	4.1	7.8	6.3
WSW	67	54	48	5.7	4.6	4.1
W	37	54	49	3.1	4.6	4.1
WNW	77	60	68	6.5	5.1	5.7
NW	52	51	52	4.4	4.3	4.4
NNW	23	50	22	1.9	4.2	1.9
Calm	131	131	131	11.1	11.1	11.1

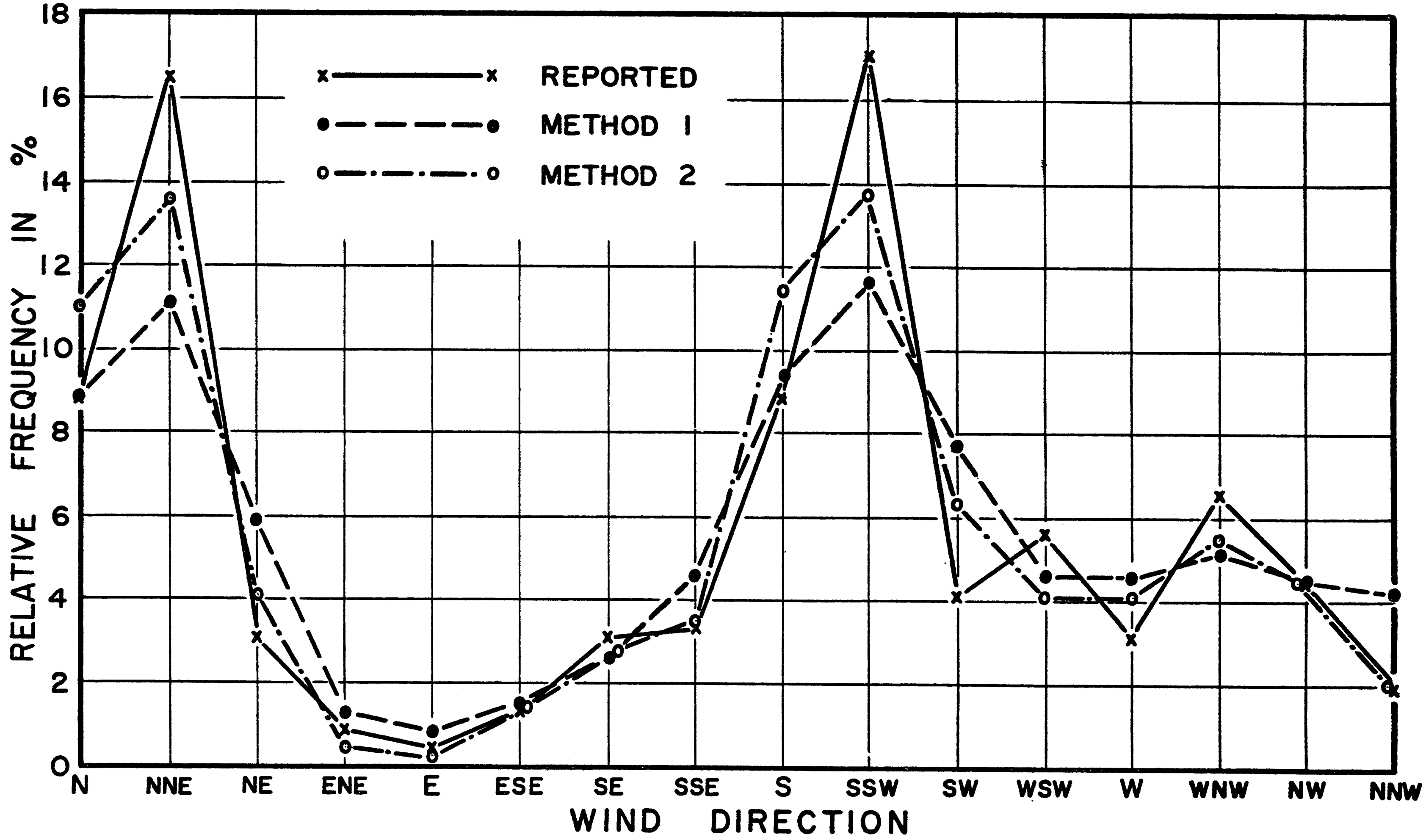


Fig. 18. Comparison of relative frequencies of wind at the New Albany Plant Site as reported and as computed by the two methods for removing the bias, 12 October 1956 - 30 November 1956.