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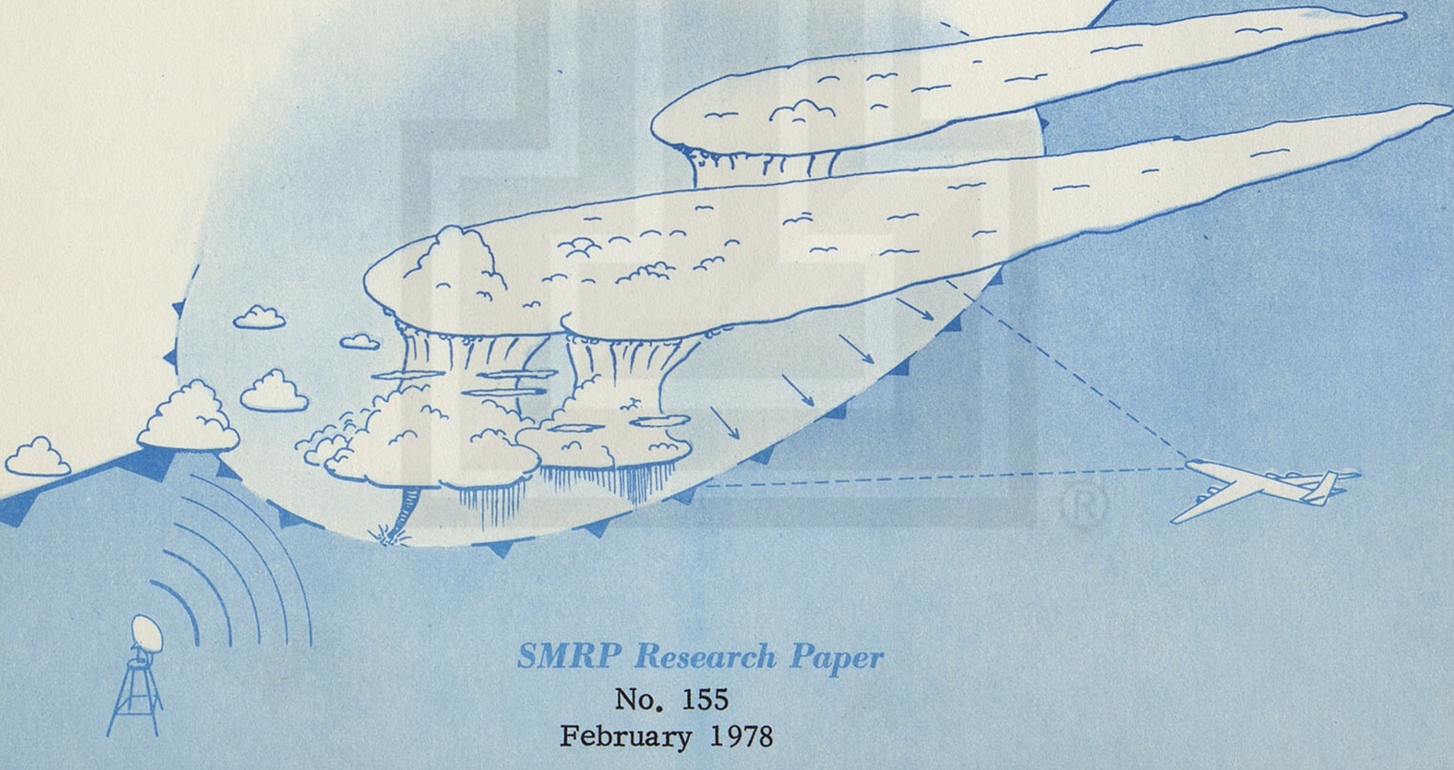
SATELLITE & MESOMETEOROLOGY RESEARCH PROJECT

Department of the Geophysical Sciences
The University of Chicago

A SITE-SPECIFIC STUDY OF WIND AND TORNADO PROBABILITIES AT THE WIPP SITE IN SOUTHEAST NEW MEXICO

by

T. Theodore Fujita



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T. Theodore Fujita

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EXECUTIVE SUMMARY

Introduction

The Waste Isolation Pilot Plant (WIPP) will be the first facility designed and constructed to gather data and demonstrate, on a large scale, the feasibility of disposal of radioactive waste in bedded salt. This study was undertaken to determine the characteristics of the most severe tornado which is credible at the WIPP site. The study is based upon the reported tornado history of the Pecos River Valley watershed and the adjacent areas of west Texas and central New Mexico.

WIPP Site Location and Surrounding Areas

The proposed site for the WIPP facility lies approximately 26 miles east of the city of Carlsbad, New Mexico, in an area known as Los Medanos -- "the dunes". The surrounding area considered is the Pecos River Valley watershed extending from 30.0° N latitude to 35.5° N latitude (see Figure I).

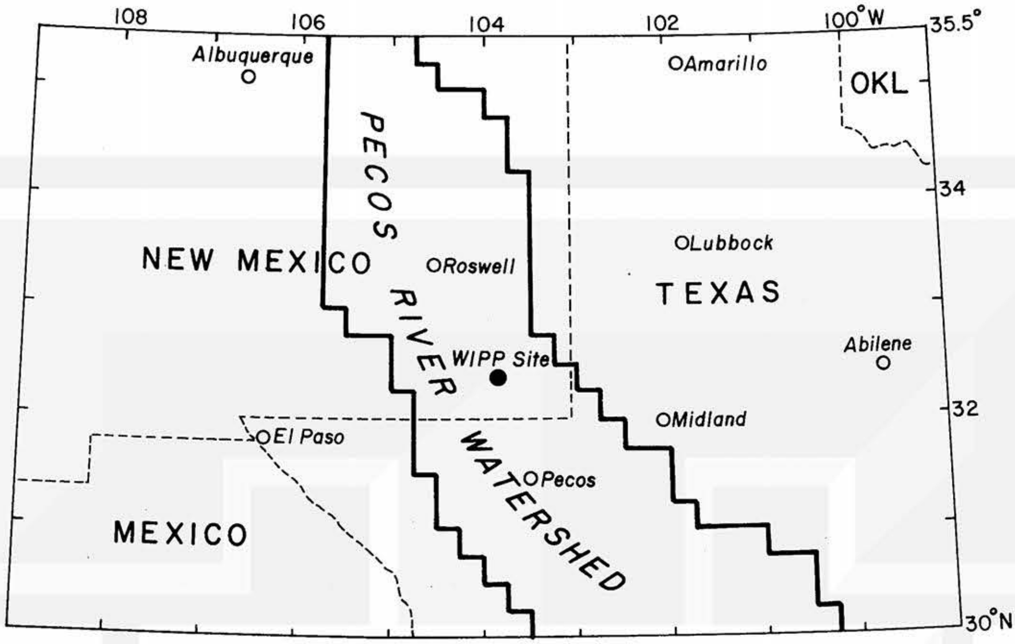

Figure I. WIPP site in Pecos River Valley watershed and surrounding areas.

Significant Assumptions

Two major difficulties were involved in assessing the tornado hazard at the site. They are: (1) the low population density within the statistical area, and (2) the rapid decrease in tornado activity as one proceeds west across eastern New Mexico. These difficulties were overcome by the adoption of following assumptions, which are believed to be conservative:

(a) The path lengths of all reported tornadoes were corrected based upon the population of the reporting location; i.e., the path length was increased for low population areas.

(b) The overall probabilities of tornado occurrences within the Pecos Valley have been applied to the WIPP site.

Site-specific Wind and Tornado Probabilities

The site-specific straight-line wind and tornado probabilities which are applicable for use in risk assessment studies relating to the WIPP operations are shown in Figure II. The straight-line wind probabilities were derived from climatological station data recorded at Roswell, New Mexico, Lubbock, Midland, and El Paso, Texas.

The site-specific tornado probabilities were derived using the Pecos Valley method developed by the author for this study and the DAPPLE (Damage Area Per Path LEngth) method devised by Abbey and Fujita (1975).

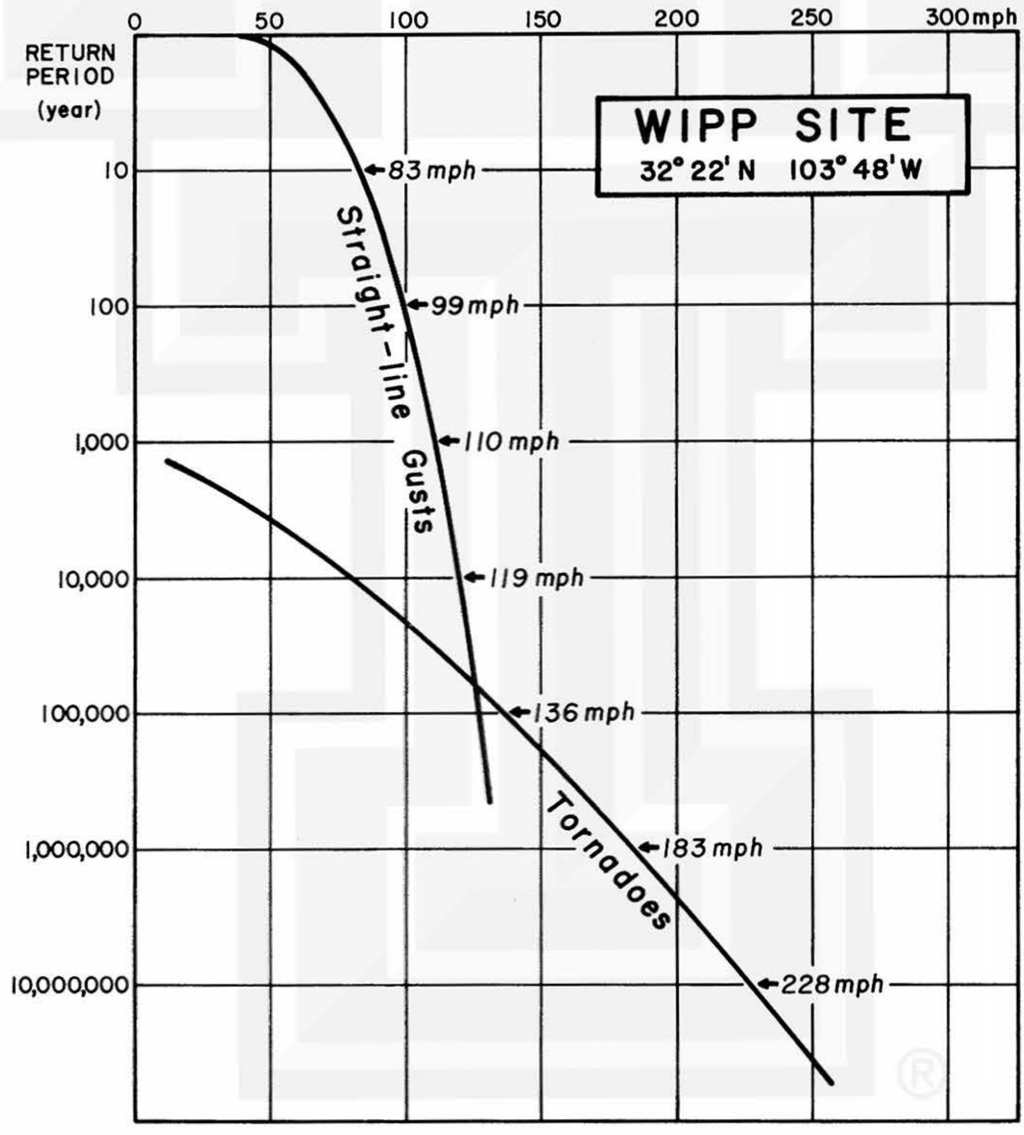

Figure II. Probabilities of straight-line winds and tornadoes at the WIPP site.

Most Severe Credible Tornado (One in one-million-year tornado)

Based upon the results of this study, the most severe credible tornado which could be expected to occur at the WIPP site can be characterized by:

Maximum Wind Speed --------- 183 mph
Translational Velocity --------- 37 mph
Tangential Velocity ----------- 146 mph
Pressure Drop -------------- 0.69 psi
Rate of Pressure Drop ---------- 0.08 psi/sec
Return Period ------------- One million years

TECHNICAL REPORT

Introduction

The Waste Isolation Pilot Plant (WIPP) site in southeast New Mexico is located at 32°22'30" N and 103°48'W with an elevation of 3,414 ft MSL.

The environmental topography of the site is shown in Figure 1 where elevations are contoured at 100' intervals. The western side of the site slopes down to the Pecos River, southeast of Carlsbad, N.M. There is a 3,800 ft hill on the east side of the site. The area under a site-specific study is hilly, but it is by no means mountainous.

Tornado risk of the southernmost Rockies was studied by Fujita (1972), who reached a conclusion that the tornado risk decreases rapidly toward the west from the Texas plains and plateau.

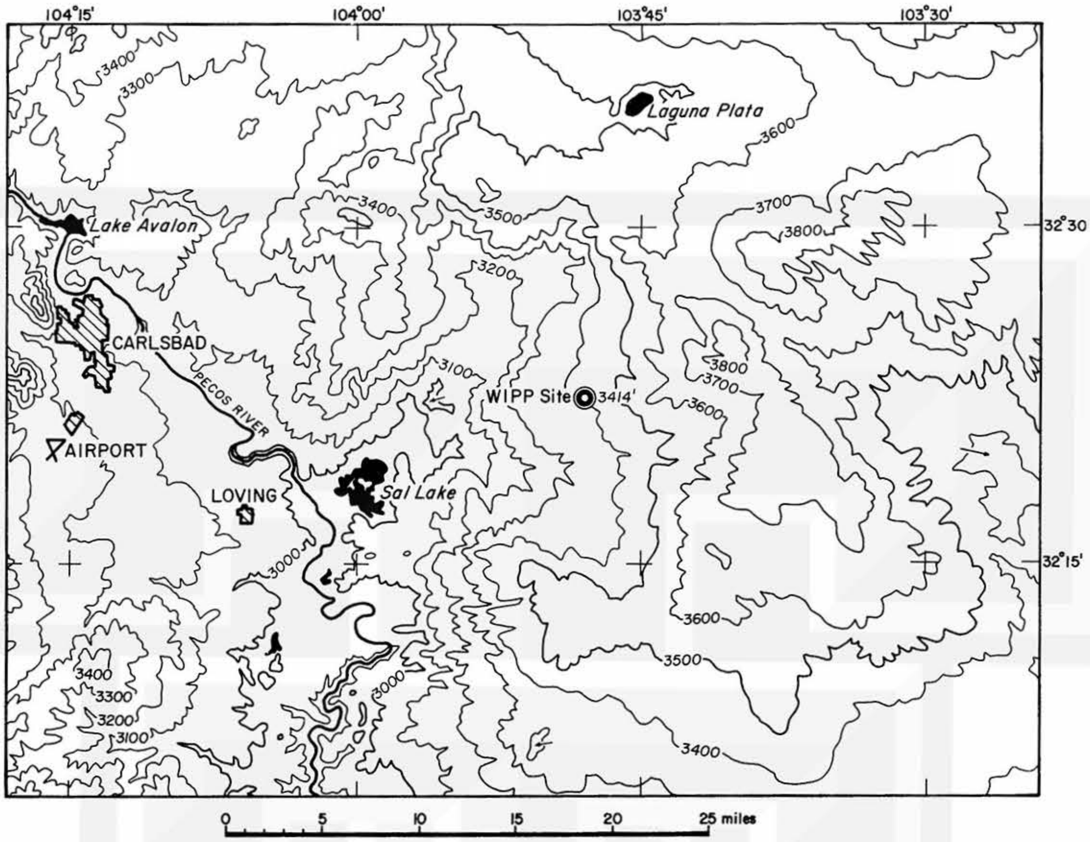

Figure 1. Location of the waste isolation pilot plant (WIPP) site, 25 miles east-southeast of Carlsbad, New Mexico. Its geographic coordinates are 32°22' 30" N and 103°48'W with elevation, 3,414ft MSL.

The WIPP site is located in a transition zone in which tornado frequency, as well as intensity, undergoes significant changes, especially with respect to elevation and longitude.

The site-specific study presented in this analysis was performed based on the DAPPLE Method of risk computations devised by Abbey and Fujita (1975). Since the environmental areas of this site are sparsely populated, the original path lengths of the tornadoes were prorated by using "correction factors" which vary with population within a 15-minute square sub-box of longitudes and latitudes.

Semi-square areas bounded by latitudes and longitudes of a specific interval are called "Marsden squares". 10°, 5°, and 1° are used to show the distribution of meteorological data, especially over the oceans. The 15-minute square used in the DAPPLE Method is called the "Sub-box".

Probabilities of straight-line winds were also computed in an attempt to estimate the maximum windspeeds corresponding to shorter return periods or high-risk probabilities.

Results of these analyses revealed that the probabilities of straight-line winds at the WIPP site are higher than those of tornadoes when the design-basis windspeed is lower than about 125 mph or when the probabilities of interest is greater than 2×10^{-5}.

Non-tornado Wind Analysis

● Straight-line Winds

Statistics of severe local storm occurrences by Pautz (1969) revealed that the frequencies of windstorms 50 kts and greater by 2-degree square during the 13-year period, 1955 - 67, decrease westward across the state of New Mexico, from about 40 to less than 5. His statistics are based on the SELS (SEvere Local Storms) Log collected operationally at the National Severe Storms Forecast Center (NSSFC) at Kansas City, Missouri.

There are four climatological stations within a 160-mile range of the WIPP site. These stations are Roswell, N.M., Lubbock, Midland, and El Paso, Texas. According to Pautz' statistics mentioned above, it is likely that the risk of 50 kts or greater winds will decrease in the order, Lubbock (highest) to Midland to Roswell to El Paso (lowest).

The mean values of fastest-mile windspeeds, given in Table 1, from these four stations decrease, however, from El Paso (fastest) to Roswell to Lubbock to Midland (slowest). This order is entirely different from that expected from Pautz' statistics.

It is suspected that this unexpected variation of mean windspeeds is the result of anemometer environment, such as height, exposure, etc. at each climatological station.

Since the WIPP site is located near the geographic center of these four stations, an attempt was made to normalize the windspeeds from each station with

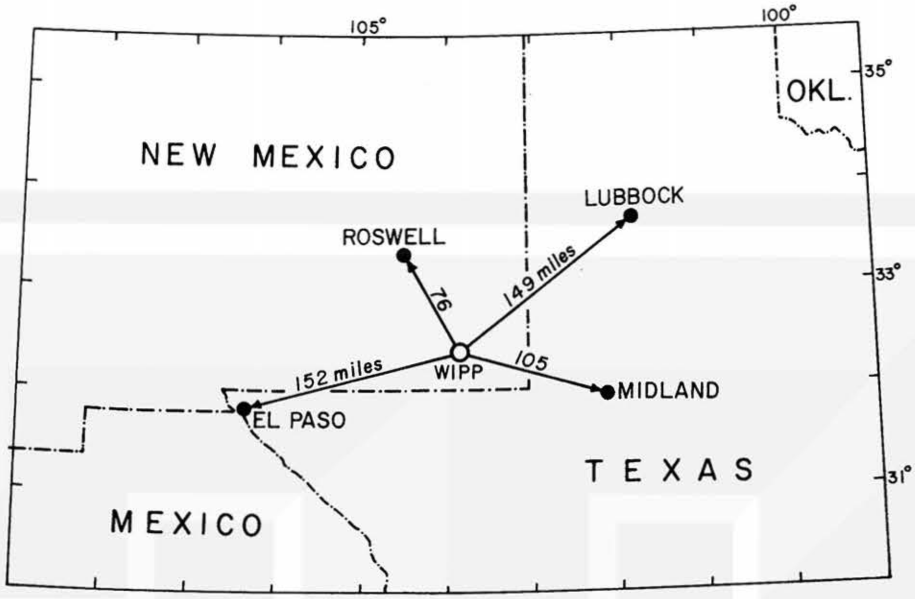

Figure 2. Distribution of four climatological stations around the WIPP site in southeastern New Mexico.

Table 1. Fastest-mile windspeed of the year at El Paso, Tex., Lubbock, Tex., Midland, Tex., and Roswell, N.M. From Climatological Data, 1950-76.

Stations	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
El Paso	70	66	59	61	66	56	57	61	66	56 mph
Lubbock	64	60	70	50	50	63	58	69	50	58
Midland	--	--	--	--	45	40	40	58	52	44
Roswell	59	61	65	75	61	73	65	72	69	68

Stations	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
El Paso	69	57	61	57	56	56	68	61	61	53 mph
Lubbock	58	52	58	52	58	59	46	44	51	44
Midland	67	44	46	49	38	41	58	44	48	41
Roswell	70	45	50	59	43	42	48	45	41	36

Stations	1970	1971	1972	1973	1974	1975	1976	Mean speeds
El Paso	66	59	57	54	59	48	42 mph	59.3 mph
Lubbock	43	40	44	51	53	53	48	53.6
Midland	39	36	41	45	44	41	40	45.3
Roswell	50	47	--	52	46	73	44	56.1

respect to the mean speed of all four stations. Thus, the windspeeds in Table 1 were normalized by multiplying the following ratio or normalization factor applicable to each station. This normalization increases data points for statistics by the factor of 4, under the assumption that the distribution of windspeeds at these stations are more or less uniform. If not, we have to use Roswell only, because it is closest to WIPP.

$$\frac{\text{Mean of 4 stations}}{\text{Mean of El Paso}} = \frac{53.9}{59.3} = 0.91 \quad \text{(for El Paso)} \tag{1}$$

$$\frac{\text{Mean of 4 stations}}{\text{Mean of Lubbock}} = \frac{53.9}{53.6} = 1.01 \quad \text{(for Lubbock)} \tag{2}$$

$$\frac{\text{Mean of 4 stations}}{\text{Mean of Midland}} = \frac{53.9}{45.3} = 1.19 \quad \text{(for Midland)} \tag{3}$$

and

$$\frac{\text{Mean of 4 stations}}{\text{Mean of Roswell}} = \frac{53.9}{56.1} = 0.96 \quad \text{(for Roswell)} \tag{4}$$

These normalization factors along with other parameters are given in Table 2.

Windspeeds computed by multiplying each of these ratios by the fastest-mile speeds from each station are called the "normalized fastest-mile windspeeds".

Table 2. Mean windspeeds and normalization factors applicable to climatological stations in Table 1.

Stations	Distance from WIPP	Mean windspeeds	Normalization factors
El Paso	152 miles	59.3 mph	0.91
Lubbock	149	53.6	1.01
Midland	105	45.3	1.19
Roswell	76	56.1	0.96

The probabilities of the occurrence of maximum windspeeds at climatological stations should be defined differently from those of tornadoes, because windspeeds at each station are measured in time domain at a fixed point. Their spatial variations around the anemometer are usually unknown.

For tornadoes, the National Weather Service lists all reported storms based on the best possible information. Tornadoes are listed separately, even if they occur on the same day or even one hour later, hitting the same spot again.

The maximum fastest-mile speeds are listed in "Climatological Data" by month and by year. There is no mention as to how often the maximum speed occurred within one month or one year. The period of straight-line winds, especially the ones caused by continental cyclones, are long, lasting for hours or even days. There will be numerous maxima during such a long period. We should, therefore, define the following terms:

Fastest-mile day -- the day on which the speed occurred

Fastest-mile month -- the month in which the speed occurred

Fastest-mile year -- the year in which the speed occurred

These are similar to the term

Tornado Day -- the day on which one or more tornadoes occurred.

In all of these cases, the number of occurrences of a specific event is not important.

The probability of the fastest-mile year can be computed from

$$P_s = \frac{\text{Number of fastest-mile years with specific speed and larger}}{\text{Total number of years used in statistics}} \qquad (5)$$

where P_s denotes the probability of fastest-mile years with a specific windspeed or larger.

● Probabilities of Straight-line Winds

If the causes of straight-line winds affecting the WIPP site are identical throughout the entire year, we could estimate the probability by combining all normalized wind speeds into a data set.

The number of occurrences by month, shown in Figure 3, reveals, however, that there are significant seasonal variations. The entire year was divided into two 6-month periods: April - September (warm months) and October - March (cold months). The former period is characterized by convective activities, spawning 93% of the annual tornadoes, while the latter, by continental cyclones with gusty winds.

Wind-direction distribution in Figure 4 show clearly a concentration of wind directions in cold months in westerly directions. During warm months, directions of strong winds spread out on both sides of the maximum frequency.

Probabilities of fastest-mile years were computed from Eq. (5) as a function of wind speeds normalized by Eqs. (1) through (4). The results in Table 3 and Figure 5 show that the maximum speeds were 72 mph in warm months and 80 mph in cold months, with the occurrence probability of 0.01 year^{-1} (return period of 100 years).

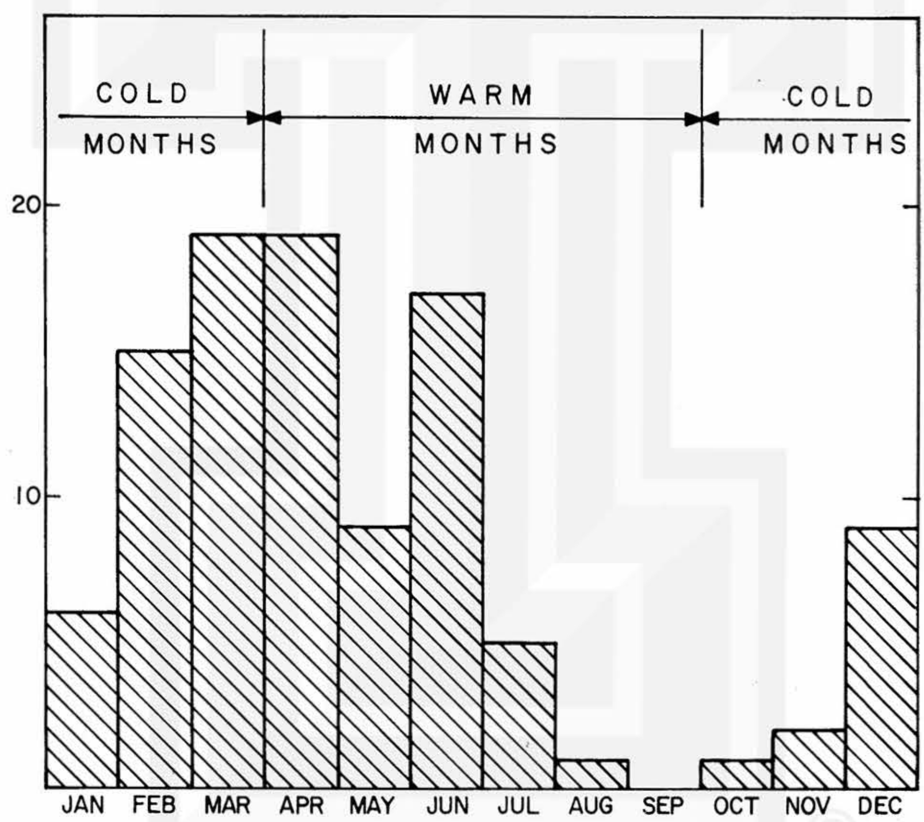

Figure 3. Frequencies of maximum fastest-mile windspeed of the year by month. For statistical purposes, one year is divided into two 6-month periods. Based on 1950-76 data from El Paso, Lubbock, Midland, and Roswell.

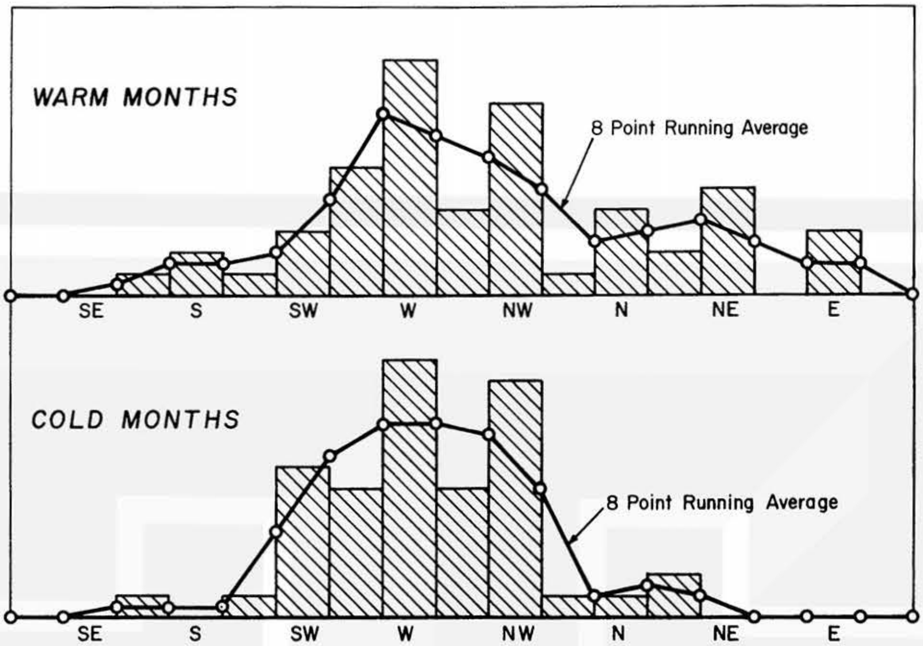

Figure 4. Distribution of the directions of fastest-mile winds of the year from El Paso, Lubbock, Midland, and Roswell, 1950-76. Since 8-point (every 45°) directions are reported more frequently than 16-point (every 22.5°) directions, curves of the 8-point running average were added in this figure.

These data points with 0.01 year^{-1} probability may not always be reliable because they represent the maximum values in 100 statistical years generated by combining four climatological stations. The normalized windspeeds are accurate, but the occurrences of windspeeds in future years are uncertain. Namely, we do not know how many years we have to wait before experiencing the same or a larger maximum windspeed. During these "waiting" years, the probability of the maximum speed decreases continuously.

As it turned out, the trends of windspeed with probability in warm and cold months are not too different from each other. It should be noted that trends are significantly different in other parts of the U.S., especially those in the Midwest.

The probabilities for two periods were combined into the all-year probability in Figure 5. The smoothed curve of the all-year probability gives 60 mph (10-year), 79 mph (100-year), and 88 mph (1,000-year return period).

It is recommended that the design-basis straight-line winds,

$$\text{Design-basis speed} = 1.25 \times \text{Fastest-mile speed} \qquad (6)$$

be used at the WIPP site.

Table 3. Probabilities of fastest-mile windspeeds of the year obtained by combining the corrected windspeeds from four stations in Table 1.

Corrected windspeeds	Warm months (Apr - Sep)	Cold months (Oct - Mar)	All year (Jan - Dec)
35 mph	0.505	0.495	1.000
38	0.505	0.485	0.990
39	0.505	0.476	0.981
40	0.505	0.466	0.971
41	0.495	0.456	0.951
42	0.495	0.447	0.942
43	0.485	0.447	0.932
44	0.466	0.427	0.893
45	0.437	0.408	0.845
46	0.427	0.398	0.825
48	0.417	0.379	0.767
49	0.388	0.340	0.728
50	0.379	0.301	0.680
51	0.359	0.282	0.641
52	0.350	0.233	0.583
53	0.272	0.214	0.486
54	0.262	0.204	0.466
55	0.252	0.165	0.417
57	0.214	0.146	0.360
58	0.184	0.146	0.330
59	0.146	0.126	0.272
60	0.136	0.106	0.242
62	0.126	0.068	0.194
63	0.097	0.058	0.155
64	0.087	0.048	0.135
65	0.068	0.048	0.116
66	0.068	0.038	0.106
67	0.058	0.038	0.096
69	0.058	0.029	0.087
70	0.038	0.010	0.048
72	0.010	0.010	0.020
80	---	0.010	0.010

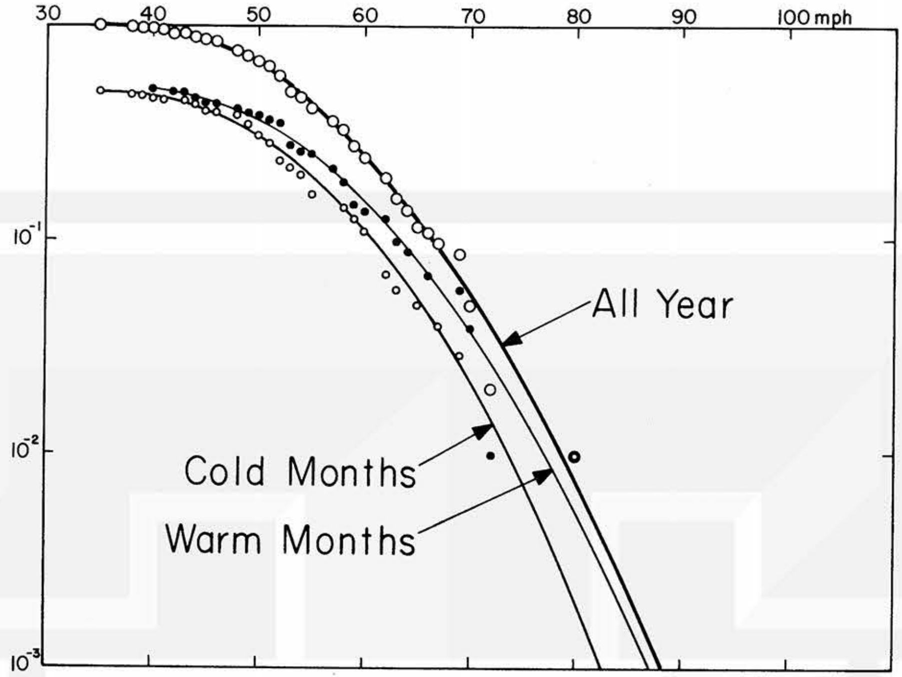

Figure 5 Probabilities of fastest-mile wind of the year obtained by combining the data from four climatological stations in Figure 2. Note that speeds in warm months increase slightly more than those in cold months.

Data Base for Tornado Study

● Reported Tornadoes in Study Area

Two major difficulties involved in assessing the tornado risk at this site are (1) low population density within statistical areas and (2) rapid decrease in tornado activities across eastern New Mexico.

It is necessary, therefore, to investigate the statistical relationship between tornado data and population before obtaining a best possible answer to this question.

As pointed out by Fujita (1972), tornado frequencies and intensities in the southernmost Rockies are influenced by topographic factors as well. Topographic factors investigated are mean height of the terrain and height variations. Since the study of the southernmost Rockies was aimed at the site-specific evaluation of the Los Alamos facilities, the statistical areas are high in elevation and large in height variations. Most of the statistical results at the Los Alamos site cannot be used for the WIPP site located over the terrain with low elevation and small height variations.

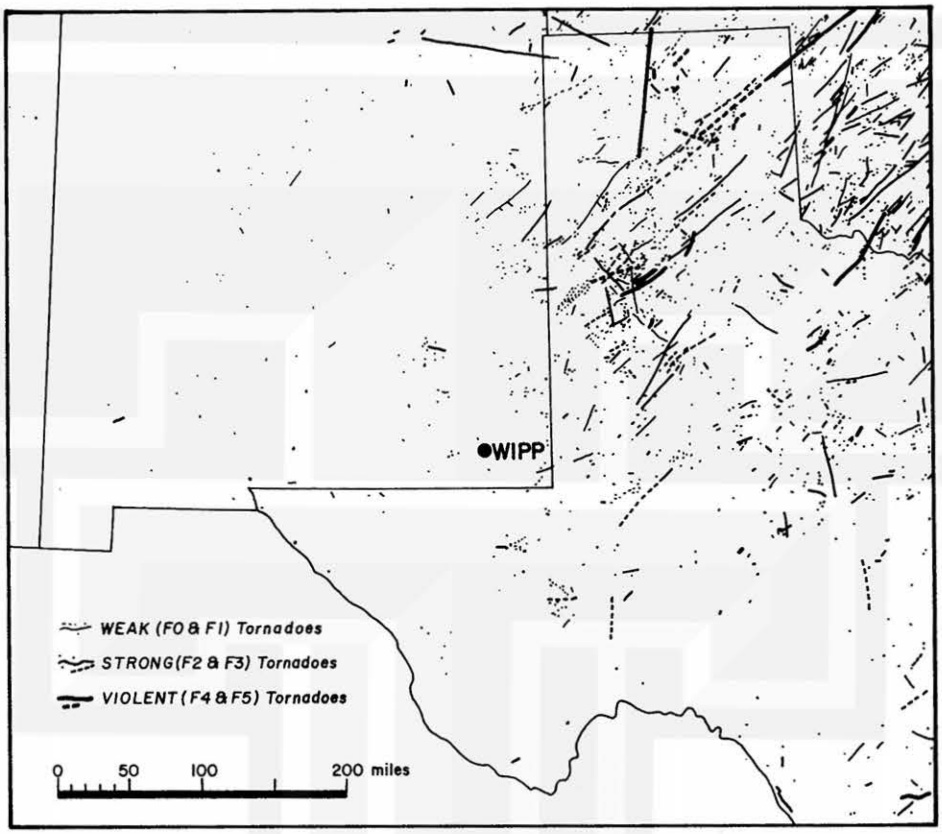

Figure 6. Distribution of tornadoes in three categories within about 300-mile range of the WIPP site. From Fujita and Pearson (1976).

● Annual and Diurnal Variations

The peak months of tornado activities within 144-mile range of the WIPP site are May and June when moist-air inflow from the Gulf generates frequent thunderstorms.

As the season progresses, moisture passes over the area, moving deep into the Rio Grande Valley and mountains. Upon the onset of the rainy season in these areas, tornado activities around the site decrease rapidly (see Figure 6).

The bi-monthly distribution of the 363 tornadoes in Figure 7 reveals a rapid decrease in the tornado frequencies during the month of June. Table 4 shows that a total of 101 tornadoes in 1950-75 occurred in June. However, 74 occurred during the first half of the month while only 27 occurred during the second half.

Strong straight-line winds occur frequently during December through March. Occurrences of tornadoes during these months are rare, however. High winds in early spring are characterized by dust storms but rarely by tornadic storms.

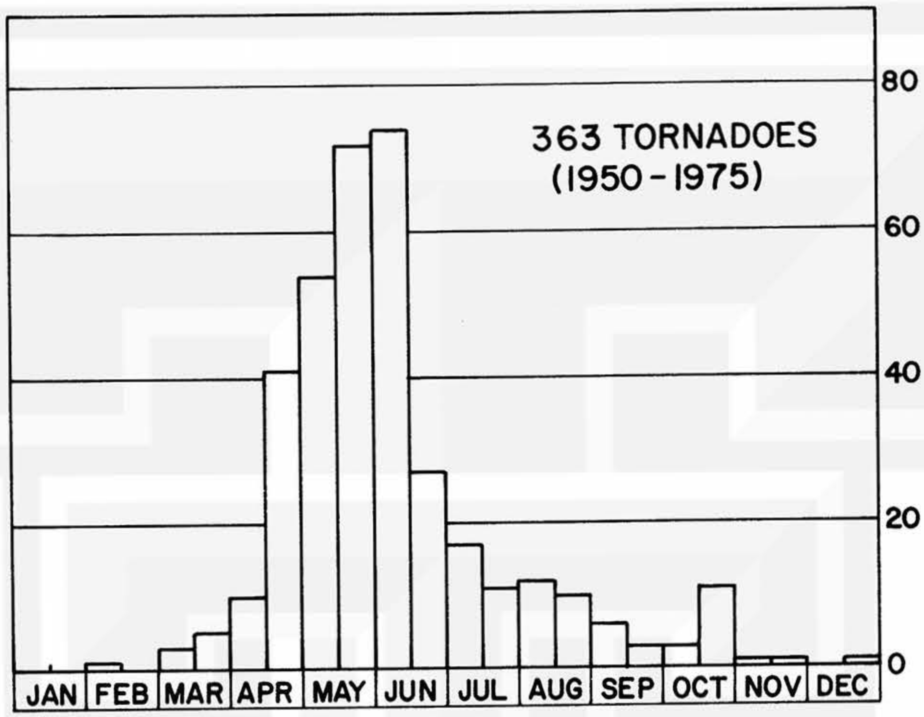

Figure 7. Frequencies of tornadoes within 144-mile range of the WIPP site by bi-month. Based on the NSSFC Tornado Tape (1977).

Table 4. Frequencies of tornadoes within 144 miles (125 n.m.) from the WIPP site. Based on 363 tornadoes in NSSFC Tape (1950-75).

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Frequencies	0	1	8	51	126	101	28	22	9	14	2	1

Diurnal variations of tornado time (touchdown) was computed based on the NSSFC Tornado Tape (1977). The results are shown in Table 5 and Figure 8.

The peak occurrence time between 2 and 4 PM MST is apparently earlier than that experienced in the Midwest. Recently, Kelly et al. (1977) obtained the peak time averaged over the entire Midwest of between 4 and 5 PM, which is one to two hours later than that around the WIPP site.

Physical meanings of these early peak occurrences have not been fully understood. It is likely, however, that the parent clouds which spawn tornadoes near this site are, on the average, younger than those of other tornado-spawning thunderstorms. Statistics show, nonetheless, the following facts:

a. 345 tornadoes (95%) occur during the 12-hour period, 10 AM to 11 PM

b. 249 tornadoes (68%) occur during the 6-hour period, 1 PM to 7 PM

c. 153 tornadoes (42%) occur during the 3-hour period, 2 PM to 5 PM

Table 5. Frequencies of tornadoes by touch-down hour in MST. Based on 365 tornadoes with known time in NSSFC Tape (1950-76).

						A M							
Hours	12	1	2	3	4	5	6	7	8	9	10	11	12
Frequencies	2	1	1	0	1	2	1	0	0	3	5	8	13

						P M							
Hours	12	1	2	3	4	5	6	7	8	9	10	11	12
Frequencies	13	26	54	54	45	38	32	23	31	13	18	2	2

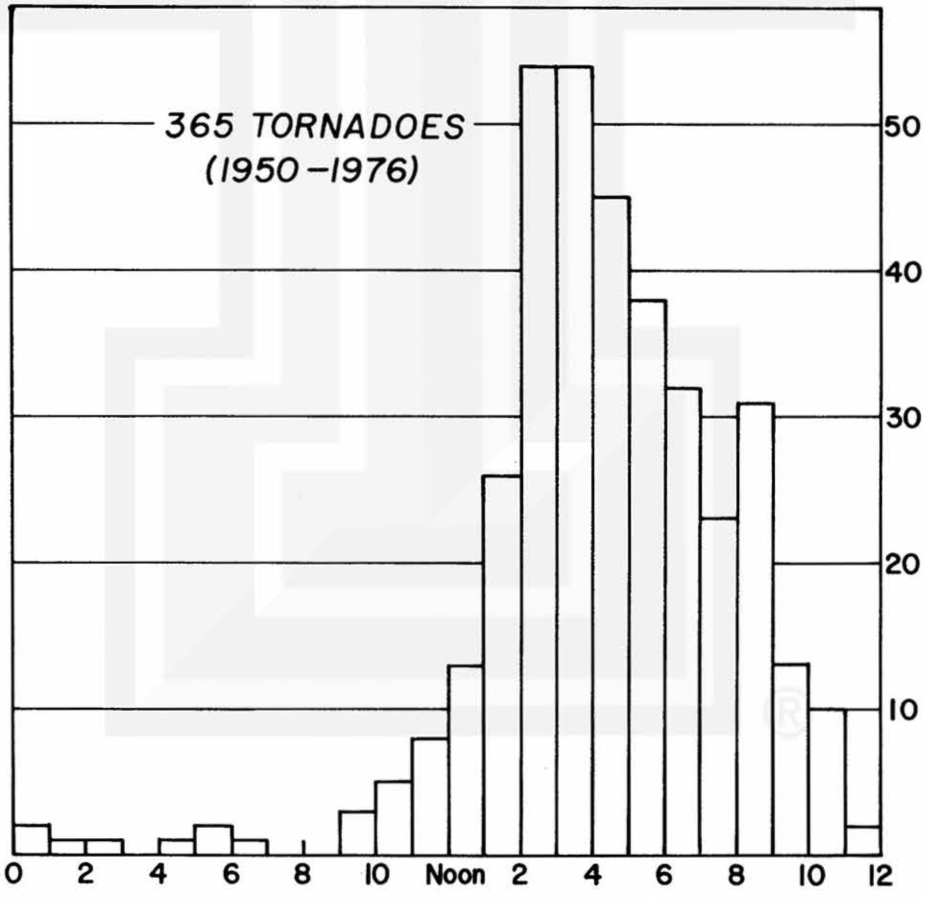

Figure 8. Diurnal variation of tornadoes within 144-mile range of the WIPP site. Note the peak occurrences between 2 and 4 PM. Time in MST.

● Path Lengths in 15 x 15 - minute Sub-boxes

The NSSFC Tornado Tape has been made and is being updated at the National Severe Storms Forecast Center (NSSFC) under the direction of Allen D. Pearson. The tape includes:

* Year, month, date, time, weather event
* Longitudes and latitudes of beginning and ending point
* Type of paths, per cent on the ground, storm types and rotational sense
* Path length and mean path width
* Fatalities, injuries, and damage class
* Affected states and counties
* FPP scale

A copy of the up-to-date tape may be obtained from Pearson.

The DAPPLE (Damage Area Per Path LEngth) tape has been made and is being updated now at the University of Chicago under the direction of T. Theodore Fujita under NRC Contract No. AT(49-24)-0239. The tape includes

* Year, month, date and time
* F scale
* Fatalities and injuries
* Affected boxes identified by 1 x 1 degree of longitude and latitude boxes, each subdivided into 15-minute sub-boxes
* Path length, path types, and direction within each sub-box

A copy of the up-to-date tape may be obtained from Fujita.

For this site-specific study, a semi-rectangular area in Figure 9 was selected. There are 22 x 40 = 880 sub-boxes (less those in Mexico) in this rectangular area.

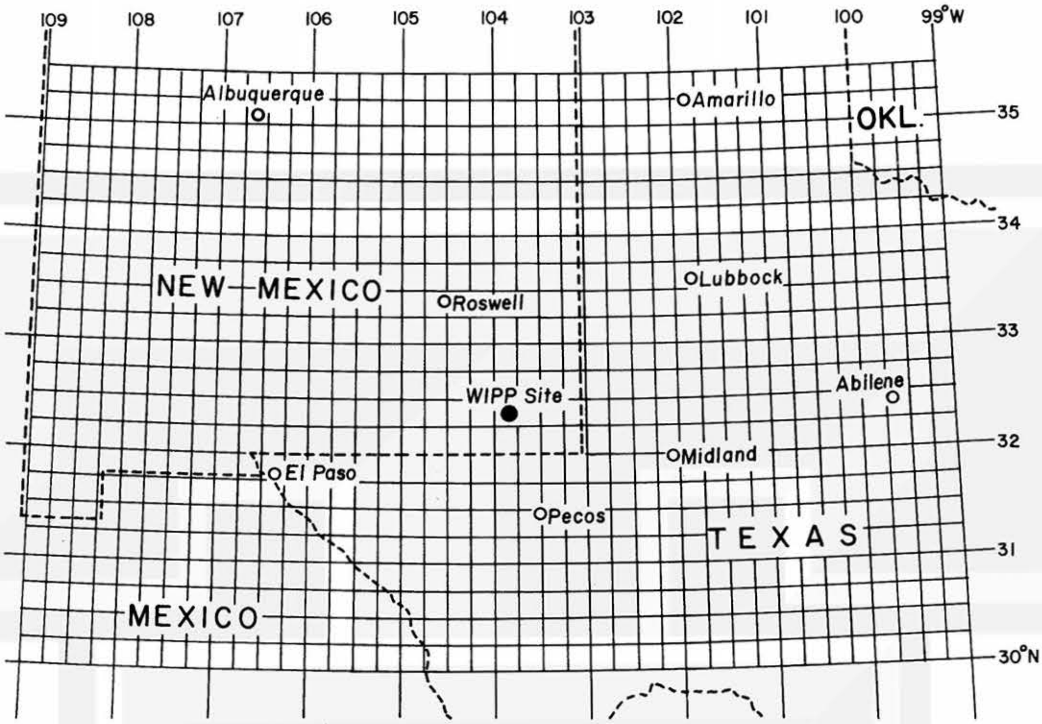

Figure 9. An area bounded by 99° and 109°W longitudes and 30° and 35.5°N latitudes which was sub-divided into 15' x 15' sub-boxes. The DAPPLE Tape lists the path length of tornadoes in each sub-box by F scale.

The DAPPLE tape was used to determine the path lengths of tornadoes in three categories within each sub-box. The three categories are

Weak tornadoes	(F0 and F1),
Strong tornadoes	(F2 and F3), and
Violent tornadoes	(F4 and F5).

The path lengths of tornadoes in three categories are given in Tables 6, 7, and 8, the area of which covers a 5 x 5 degree square which is less than that of Figure 9.

Table 6. Path lengths of weak (F0+F1) tornadoes within 15-min sub-boxes. Longitudes and latitudes are subdivided by A(60'-45'), B(45'-30'), C(30'-15'), and D(15'-00').

(unit in miles)

		105°W				104°W				103°W				102°W				101°W			
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
35°	A	0	0	0	0	1	1	0	1	12	18	17	4	0	7	24	7	6	1	5	1
	B	0	0	0	0	0	0	0	1	6	5	0	13	4	23	4	6	21	2	0	4
	C	1	1	0	0	0	0	0	0	0	3	1	4	12	10	1	4	22	1	2	2
	D	0	0	1	0	2	0	0	0	0	4	7	1	1	15	10	29	9	7	5	0
34°	A	1	0	0	0	0	0	0	0	0	0	0	3	71	22	8	37	5	5	1	1
	B	0	0	0	0	0	0	0	0	0	0	0	0	7	6	5	14	20	0	6	4
	C	0	5	0	0	0	4	2	0	0	2	1	1	2	3	4	4	7	24	2	1
	D	0	0	0	0	1	0	0	0	0	1	7	0	4	1	7	11	2	10	6	1
33°	A	0	0	0	0	0	1	4	0	0	1	3	1	0	7	1	0	1	0	1	0
	B	0	0	0	0	0	1	0	0	1	0	0	2	1	14	0	8	13	0	1	5
	C	0	0	0	0	0	1	1	1	●	0	0	2	6	12	1	1	9	3	1	0
	D	0	0	0	0	0	1	0	0	1	0	7	13	0	1	1	4	0	3	4	0
32°	A	0	3	0	3	0	0	0	0	1	0	4	1	1	0	3	1	2	0	0	0
	B	0	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	1
	C	0	0	0	0	0	0	0	0	1	7	4	2	0	0	2	0	0	0	1	0
	D	M	1	0	0	0	0	0	0	0	1	0	12	2	0	2	11	0	1	1	0
31°	A	M	M	0	0	0	0	0	0	0	0	0	6	3	0	0	0	0	0	0	0
	B	M	M	M	M	0	1	1	1	0	0	1	1	9	0	0	0	0	0	0	0
	C	Mexico			M	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	M	M	M	M	M	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

New Mexico — Texas — Pecos Valley

● denotes the WIPP site and M, the sub-box in Mexico.

Table 7. Path lengths of strong (F2+F3) tornadoes within 15-min sub-boxes. Longitudes and latitudes are subdivided by A(60'-45'), B(45'-30'), C(30'-15'), and D(15'-00')

(unit in miles)

		105°W				104°W				103°W				102°W				101°W			
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
35°	A	0	0	0	0	0	1	0	0	0	0	0	11	0	0	8	2	7	0	8	17
	B	0	0	0	0	0	0	0	0	0	0	7	14	0	2	16	0	1	4	11	17
	C	0	0	0	0	0	0	0	0	0	0	8	10	8	38	12	19	9	15	28	0
	D	0	0	0	0	0	0	0	0	0	0	1	4	0	1	45	30	38	7	0	0
34°	A	0	0	0	0	0	0	0	0	0	0	0	12	0	1	19	11	1	4	1	3
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	9	25	1	6	8	10	0
	C	0	0	0	0	0	0	0	0	0	0	0	0	2	0	15	7	3	23	4	3
	D	0	0	0	0	0	1	0	0	0	0	0	1	1	0	3	7	8	7	1	4
33°	A	1	0	0	0	0	0	0	0	0	0	2	0	0	2	0	1	0	0	0	1
	B	0	0	0	0	0	0	0	0	0	0	0	1	1	4	1	1	0	0	0	0
	C	0	0	0	0	0	0	0	0	●	0	0	0	0	0	0	0	0	1	0	1
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
32°	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	0	0	0	2	9	3	0	0	1	0	0	0	0	0	0
	D	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31°	A	M	M	0	0	0	0	0	0	0	0	0	2	3	0	4	5	0	0	0	0
	B	M	M	M	M	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	2
	C	Mexico			M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	M	M	M	M	M	0	0	0	0	0	0	0	0	0	1	10	0	0	0	0

● denotes the WIPP site and M, the sub-box in Mexico.

Table 8. Path lengths of violent (F4+F5) tornadoes within 15-min sub-boxes. Longitudes and latitudes are subdivided by A(60'-45'), B(45'-30'), C(30'-15'), and D(15'-00').

(unit in miles)

			105°W				104°W				103°W				102°W				101°W		
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
35°	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	14	14	0	0
				New		Mexico															
34°	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	4	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
																		Texas			
33°	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	0	0	0	●	0	0	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32°	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
										Pecos				Valley							
31°	A	M	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	M	M	M	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C	Mexico			M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	M	M	M	M	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

● denotes the WIPP site and M, the sub-box in Mexico.

Because of the small number of violent tornadoes compared with the occurrence of strong and weak tornadoes, the stronger the tornadoes the shorter the total path mileage. The total path length of weak tornadoes in Table 6 is 914 miles, while that of strong tornadoes in Table 7 is 668 miles. The total path mileage of violent tornadoes in Table 8 turned out to be only 67 miles.

Although Tables 6, 7 and 8 include only 400 sub-boxes, tornado statistics in this paper were performed over the area of Figure 9 which is much larger than that shown in these tables.

● Population Corrections

The path lengths of tornadoes by F scale in each sub-box are available in the DAPPLE tape. However, the actual population for each sub-box is not available.

A breakdown of the population into 15-minute sub-boxes was performed by

a. Obtaining county and town (city) population from the 1970 census
b. Drawing 15-minute grid on 250,000 scale U.S.G.S. map which covers the area of 1° latitude and 2° longitude
c. Placing the known population of cities and towns on the map and subtracting them from the county population
d. Distributing the balance of the population into 15-minute squares within the county, taking into consideration the distribution of communities, farm roads, and ranch houses.

This is a rather difficult and time-consuming method. However, the author found no other way except to use the original census data from the Census Bureau. This attempt, nevertheless, generated the sub-box population with estimated 50% accuracy over sparsely populated areas and with 90% accuracy in city areas.

After completing the sub-box population, the path length of all tornadoes in each sub-box was sorted against the population to compute the mean path length within sub-boxes of various population ranges.

The results, thus obtained, are presented in Figure 10. Since the population categories were selected to be (0-200), (200-500), (500-1,000), (1,000-2,000), (2,000-3,000) ..., (10,000-20,000), (20,000-30,000) etc., both linear and log scales were used in this figure.

It is seen that the mean path length is extremely short when the population in a sub-box is less than 200. Then it increases rapidly to become more or less constant after 3,000 to 10,000 population per sub-box.

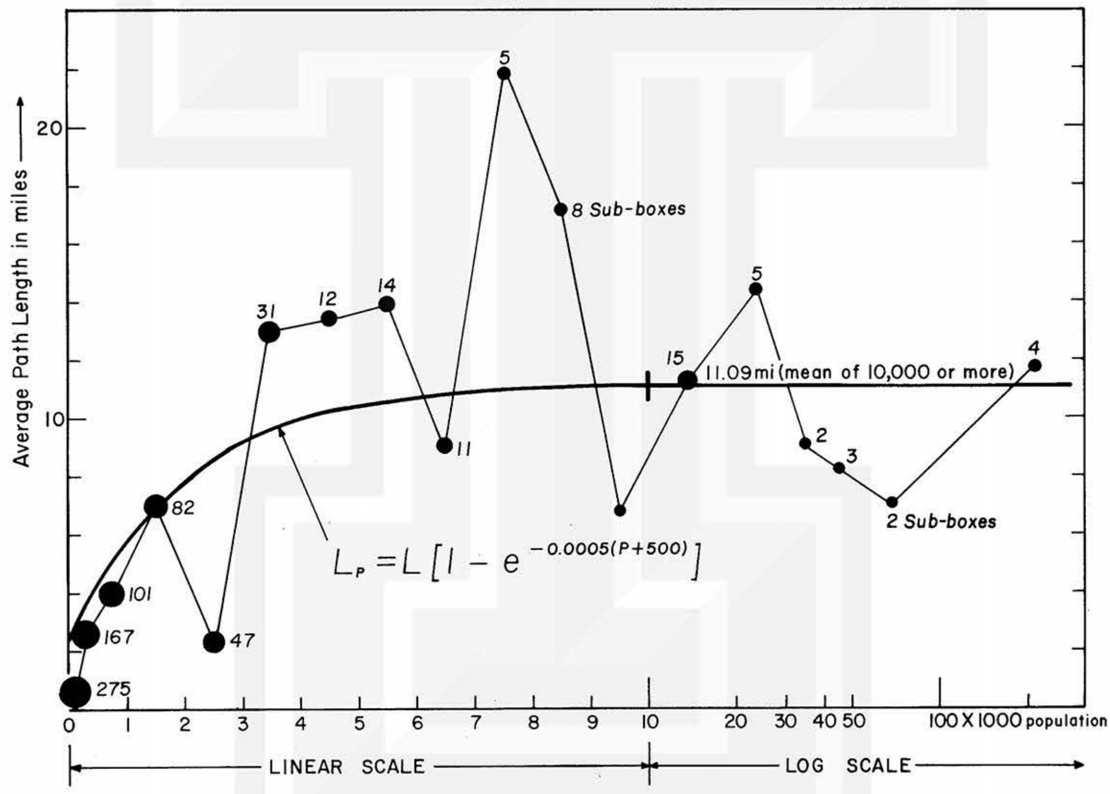

Figure 10. Average path lengths of all tornadoes plotted as a function of the population within 15-min sub-boxes. The numbers by each painted circle denote the number of sub-boxes used in compiling the statistics.

A curve fitting was attempted, keeping in mind the ultimate use of the fitted curve for gross population correction of the path length. This is why the curve was not brought down to zero path length when the sub-box population approaches zero. The analytical equation obtained is

$$L_p = L\,[\,1 - e^{-0.0005\,(P + 500)}\,] \tag{7}$$

where L_p denotes the "original path length" reported by the existing population; L, the "population corrected path length" reported if there were infinite population; and P, in parenthesis, the population within the sub-box. Eq. (7) shows that

$$L_p = L \text{ when } P \text{ is infinity}$$

and

$$L_p = 0.221\,L \text{ when } P = 0\ , \tag{8}$$

indicating that 22% of the path length is mapped if there were no population within a sub-box. This means that tornadoes in the zero-population sub-box are assumed to be observed from outside the box and/or reported by someone who enters the sub-box later. This result suggests that the original path length must be multiplied by a correction factor in order to obtain the population corrected path length (path length which would be reported if there were infinite population).

The correction factor which is defined as the ratio, true path length divided by apparent path length, can be expressed by

$$C_p = \frac{L}{L_p} = \frac{1}{1 - e^{-0.0005(P+500)}} \tag{9}$$

where C_p is "population correction factor" which varies with P, the population. Special values of the correction factor are

$$C_p = 1 \quad \text{when } P \text{ is infinity}$$

$$C_p = 4.52 \text{ when } P = 0\ . \tag{10}$$

Shown in Figure 11 is the variation of C_p as a function of sub-box population. In view of a possibly large error in path length when the sub-box population is low, the correction factors were chosen to be coarse when population is low.

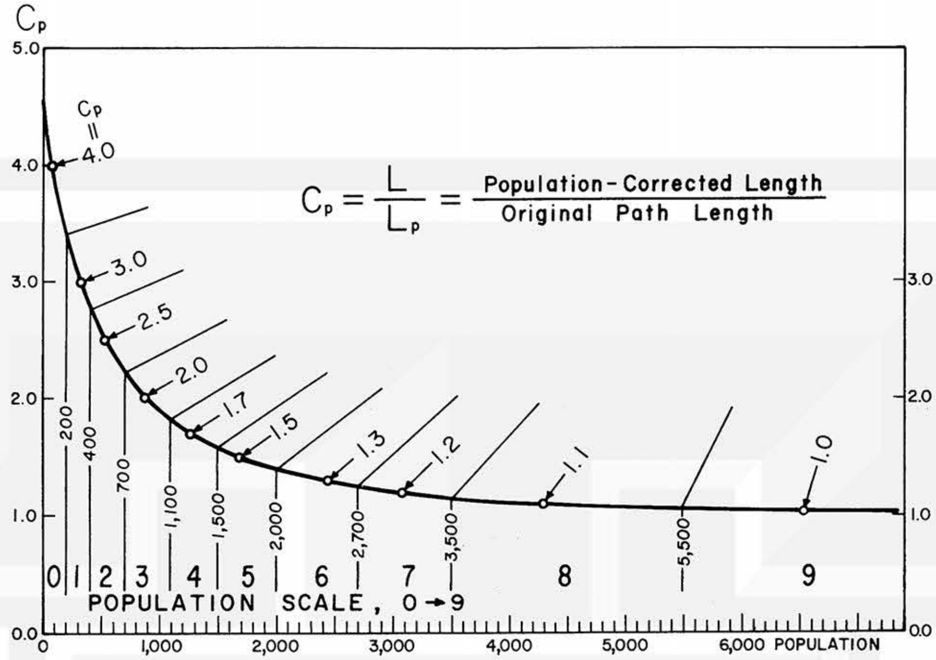

Figure 11. Variation of C_p, the population correction factor with the population scale which varies between 0 and 9.

The population scale in Table 9 was produced to result in such a variation in the correction factor. For instance, $C_p = 4.0$ is chosen when the sub-box population is less than 200 (population scale 0) while $C_p = 3.0$ applies to population scale 1 (200 to 399 population). The correction factor is designed to decrease by one-tenth when the sub-box population exceeds 2,000. Naturally, the minimum value of C_p is 1.0 which is reached when the sub-box population is 5,500 or greater.

The population scale (PS), applicable to each sub-box, is plotted in Figure 12. It should be noted that there are a large number of PS-0 sub-boxes in New Mexico and southwestern Texas. Scattered PS-0 also are found near the Oklahoma border where tornado frequencies in Figure 6 are apparently low.

Table 9. Range of population and population correction for each population scale. Population-corrected path length is obtained as a product of original path length and C_p, the population-correction factor.

Population scale	Range of population	Population Correction factor C_p
0	0 - 199	4.0
1	200 - 399	3.0
2	400 - 699	2.5
3	700 - 1,099	2.0
4	1,100 - 1,499	1.7
5	1,500 - 1,999	1.5
6	2,000 - 2,699	1.3
7	2,700 - 3,499	1.2
8	3,500 - 5,499	1.1
9	5,500 or more	1.0

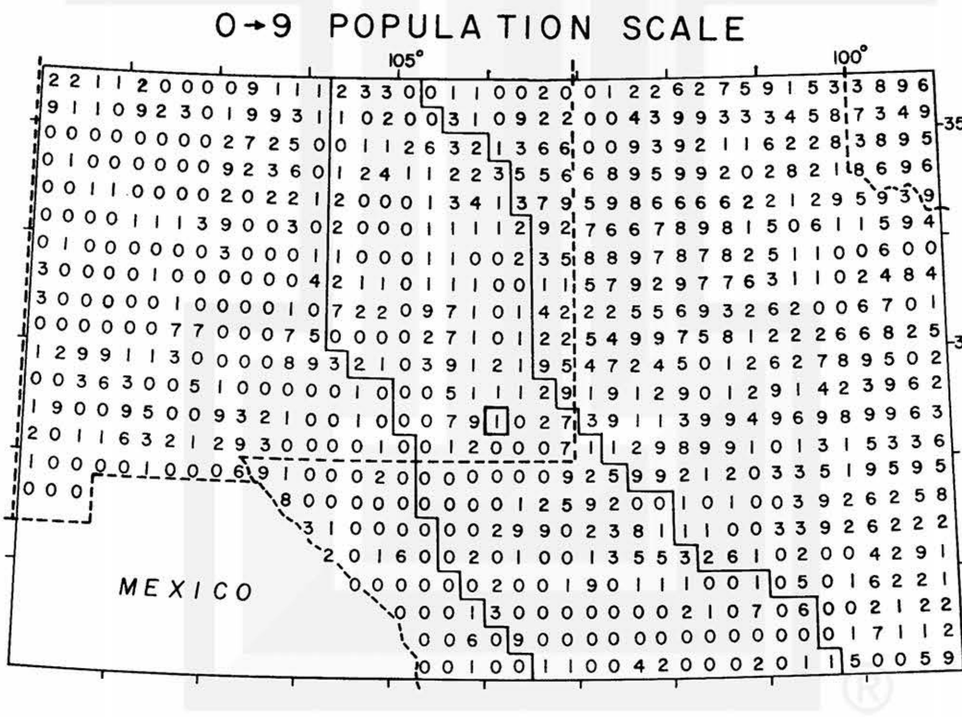

Figure 12. Distribution of population scale for 15-min. sub-boxes. No estimate of population in Mexico was attempted because no tornado reports, if any, could be obtained.

Within the 880 sub-boxes in Figure 9, 783 are in the U.S., allowing us to make reasonable estimates of the sub-box population. Of these, 271 sub-boxes (35%) are characterized by PS-0, resulting in a serious problem in assessing the tornado risk at the WIPP site (see Table 10 and Figure 13). There are only 75 sub-boxes (less than 10%) with PS-9 (5,500 or more population). This number is considerably smaller than that in the Midwest plains where over 70% of sub-boxes are regarded as PS-9.

It should be noted, however, that the sub-boxes located both east and west of the WIPP site have significant populations. The sub-boxes to the north of the WIPP site and the sub-box containing the WIPP site are populated. The large number of zero population sub-boxes have been introduced in this model by the inclusion of southwestern Texas and the western two-thirds of New Mexico.

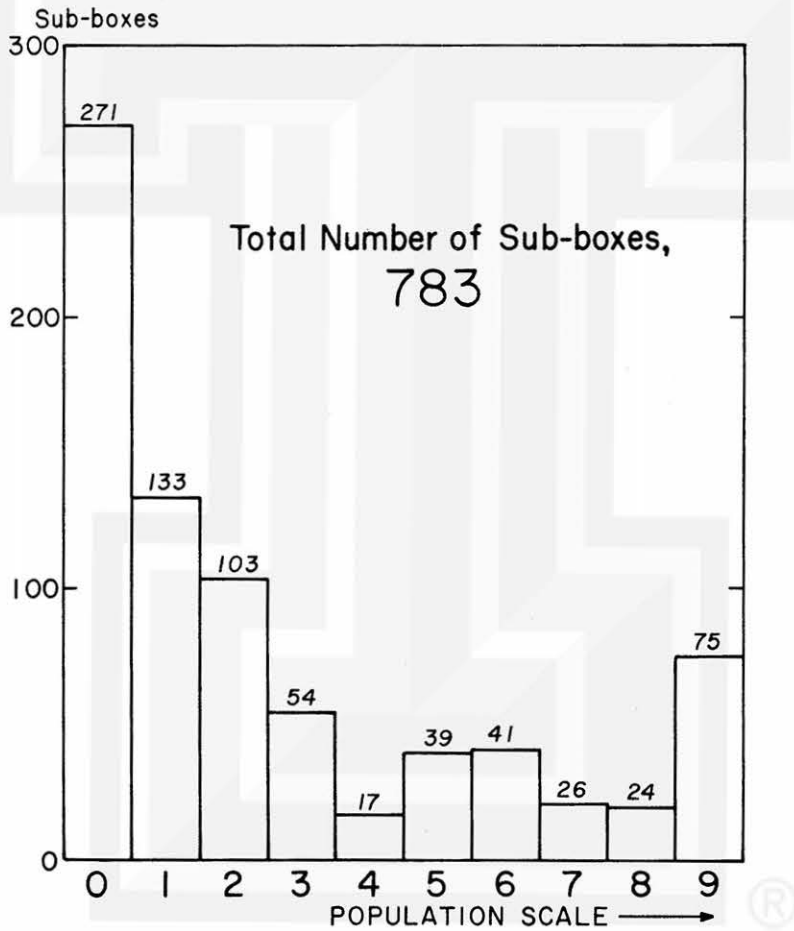

Figure 13. Number of sub-boxes shown as a function of population scale. Only 205 sub-boxes (26%) are PS-5 (1.5 population correction factor) or more.

Table 10. Distribution of population scale within 10 x $5\frac{1}{2}$ degrees of longitudes and latitudes around the WIPP site.

	Population scale (0-9)									
	0	1	2	3	4	5	6	7	8	9
Population range in each scale	200	200	300	400	400	500	700	800	2,000	infinity
Number of Sub-boxes (in %)	271 (35)	133 (17)	103 (13)	54 (7)	17 (2)	39 (5)	41 (5)	26 (3)	24 (3)	75 (10)

● Population-corrected Path Lengths

According to above derivations, population corrections can be obtained simply through a multiplication process:

$$L = C_p L_p$$

where C_p, the correction factor is obtained from Table 9 as a function of the population scale for each sub-box.

When population-corrected lengths were plotted (Figure 14) it turned out that there were a large number of sub-boxes which would have to be left "blank" because no tornado was reported from these sub-boxes.

Can we use these blank sub-boxes as evidence of no tornado? The answer is either "yes" or "no", depending upon the population in each sub-box. If the sub-box includes sufficient population to observe tornadoes, we should use the "yes" category. If not, the answer should be the "no" category because tornadoes in a sparsely populated area may never be reported, unless meteorological methods can be advanced for identifying tornadoes at remote locations. Based on these considerations, a sub-box with "zero" path length was categorized as:

Category 1 -- Zero Path Length category if the population scale is 5 or larger. Shown with • in Figure 14, 15 and 16.

Category 2 -- Unknown Path Length category if the population scale is 4 or smaller. Sub-boxes in Figure 14, 15, and 16 are left blank.

The " zero path length" can be used as evidence of no tornado, but the "unknown path length" should be treated as if there were no data at all. The areas of the sub-box with unknown path length are thus eliminated entirely, thus regarding them as water areas or Mexican territory.

Figures 14 through 16 include concentric circles and zigzag boundaries. They are later used in assessing tornado probabilities at the WIPP site indicated by "+" symbol in these figures.

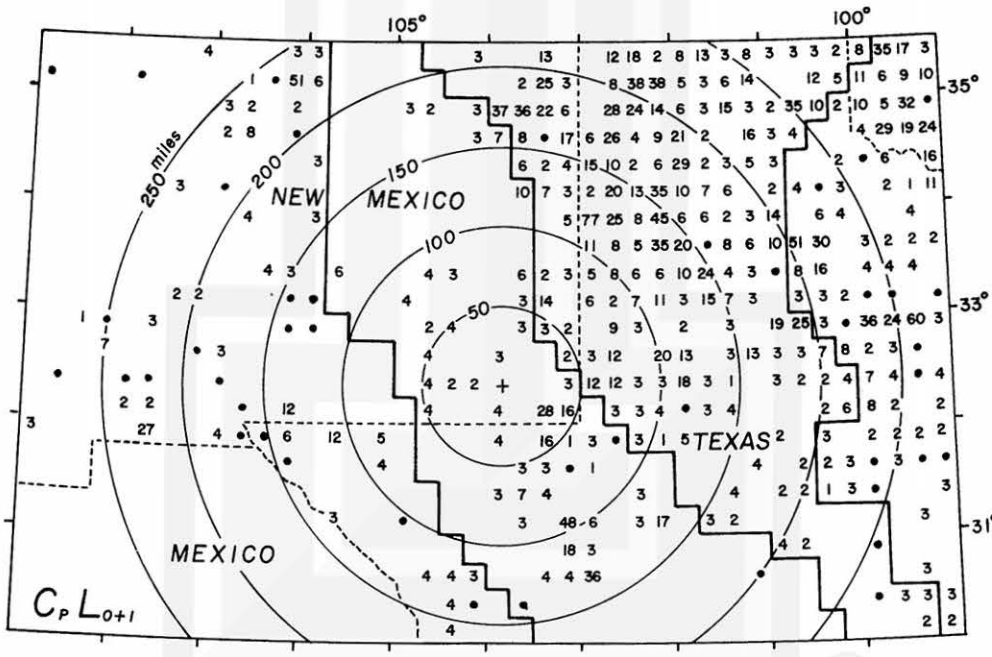

Figure 14. Population-corrected path length of Weak (F0+F1) tornadoes in miles. Sub-boxes with • are regarded as those of no tornadoes during 1950-75.

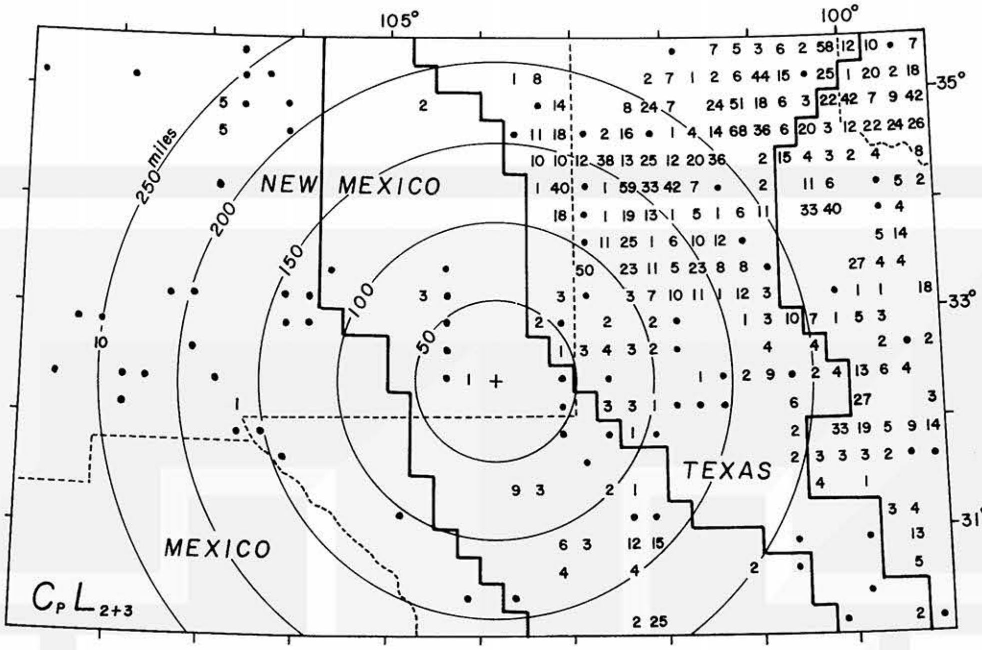

Figure 15. Population-corrected path length of Strong (F2+F3) tornadoes in miles. Sub-boxes with ● are regarded as those of no tornadoes during 1950-75.

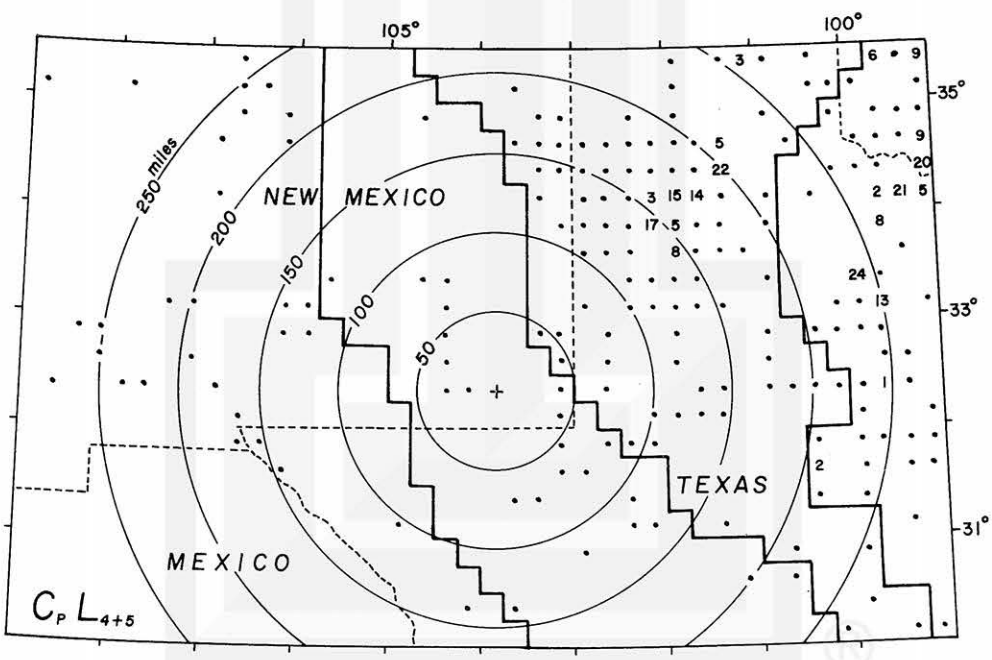

Figure 16. Population-corrected path length of Violent (F4+F5) tornadoes in miles. Sub-boxes with ● are regarded as those of no tornadoes during 1950-75.

● Computation of Probabilities by DAPPLE Method

In general, tornado probability, P_T, at a given site can be computed as the ratio,

$$P_T = \frac{\Sigma A}{B \times Y} = \frac{\text{tornado area}}{\text{land area x years}} \tag{11}$$

where ΣA denotes the total area of tornadoes inside B, the land area during Y, the number of statistical years.

Since sub-boxes in category 2 are regarded as equivalent to water areas, Eq. (11) can be modified into

$$P_T = \frac{\Sigma A}{Y \, \Sigma b} \tag{12}$$

where Σb is the total area of sub-boxes excluding those of category 2.

In order to obtain the probability as a function of windspeed, we have to estimate tornado areas as a function of windspeed. This can be done by applying the DAPPLE method devised by Abbey and Fujita (1975).

In their method, it is assumed that Damage Area Per Path LEngth (DAPPLE) varies with the F scale intensity of tornadoes. A set of DAPPLE curves for each F scale tornado can be obtained analytically as a function of windspeed. DAPPLE values have been computed for tornadoes divided into three categories, Weak(F0+F1), Strong(F2+F3), and Violent (F4+F5).

Available DAPPLE values, so far, are those computed from the April 3 - 4, 1974 super-outbreak. These DAPPLE values will, nevertheless, result in conservative values when applied to probability computations at most sites outside the highest tornado-risk areas.

By applying these DAPPLE values, we replace vague tornado areas with those given as functions of windspeed. For details of computation steps, see Abbey (1976). Now we express the tornado probability by

$$P_T = \frac{1}{Y}\left(D_w \frac{\Sigma L_w}{\Sigma b_w} + D_s \frac{\Sigma L_s}{\Sigma b_s} + D_v \frac{\Sigma L_v}{\Sigma b_v} \right) \tag{13}$$

where D denotes DAPPLE value and L, path length. Suffixes, w, s, and v indicate weak, strong, and violent tornadoes, respectively. It should be noted that the DAPPLE value, D, varies with windspeed as well as three-categories of tornadoes.

The ratio of total area of one-category tornado and that of sub-boxes can be approximated by

$$PLD = \frac{\Sigma L}{\Sigma b} = \frac{\Sigma L}{n \times b} \tag{14}$$

where PLD is called the path-length density; n, the number of sub-boxes; and b, the area of each sub-box which may be assumed constant. The sub-box area, without water area in it, varies only with latitude.

At 32° 22' 30", the latitude of WIPP, b is 252 sq. mi. Between extreme latitudes of 30° N and 35.5° N, b decreases from 258 to 243 sq. mi or between +2.4% and -3.6% of the value at the WIPP latitude. In view of possible errors in tornado path lengths which, in most cases, exceed variations in b, Eq. (14) can be used unless the range of latitudes is excessive.

The path-length density in Eq. (14) is characterized by the dimension,

$$(PLD)_{\text{dimension}} = \left(\frac{\text{mile}}{\text{mile}^2}\right) = (\text{mile}^{-1}). \tag{15}$$

Now we combine Eqs. (13) and (14) into

$$P_T = (\text{DAPPLE}) \times \frac{(PLD)}{Y}, \tag{16}$$

the dimension of which is

$$(P_T)_{\text{dimension}} = \left(\frac{\text{mi}^2}{\text{mi}}\right) \times \frac{(\text{mile}^{-1})}{(\text{year})} = (\text{Year}^{-1}). \tag{17}$$

Probability Calculations

● Probabilities by Circular-area Method

The accuracy of probability computations is dependent upon that of PLD, the path-length density. If we select a small area around the site to obtain tornado data, we will end up with a small value of ΣL divided by a small value of n. This would result in a situation to compute a value, "zero over zero" which is quite often indeterminate.

By selecting a large area around the site we definitely increase the accuracy of PLD, but the area could extend into that of non-representative tornadoes. Table 11 was prepared to show the effects of ranges upon three parameters: ΣL, the total path length; n, the number of sub-boxes; and PLD, the path-length density.

PLD of weak tornadoes increases gradually from about 20 mi^{-1} to over 30 mi^{-1} as the range increases to 250 miles. Both strong and violent tornadoes are characterized by zero PLD at the WIPP site but the values begin showing up at about 50 and 100 miles, respectively.

Table 11. Population-corrected path lengths within various ranges of the WIPP site, during the 26-year period, 1950-75. Path-length density represents the value for 26 years.

	Ranges (in miles)				
	50	100	150	200	250
WEAK (F0+F1) TORNADOES					
Total path length	94	317	948	1,570	2,203 miles
Number of sub-boxes	15	55	124	202	292 boxes
Path-length density	24.7	22.8	30.4	30.8	29.9×10^{-3} mi^{-1}
STRONG (F2+F3) TORNADOES					
Total path length	4	94	435	856	1,455 miles
Number of sub-boxes	8	31	85	144	207 boxes
Path-length density	2.0	12.1	20.3	23.6	27.9×10^{-3} mi^{-1}
VIOLENT (F4+F5) TORNADOES					
Total path length	0	0	25	62	129 miles
Number of sub-boxes	8	23	68	109	152 boxes
Path-length density	0	0	1.46	2.26	3.37×10^{-3} mi^{-1}

Path-length densities in Table 11 were plotted as functions of the range from the WIPP site. Results in Figure 17 indicate that violent tornadoes were not reported inside the 100-mile range of the WIPP site.

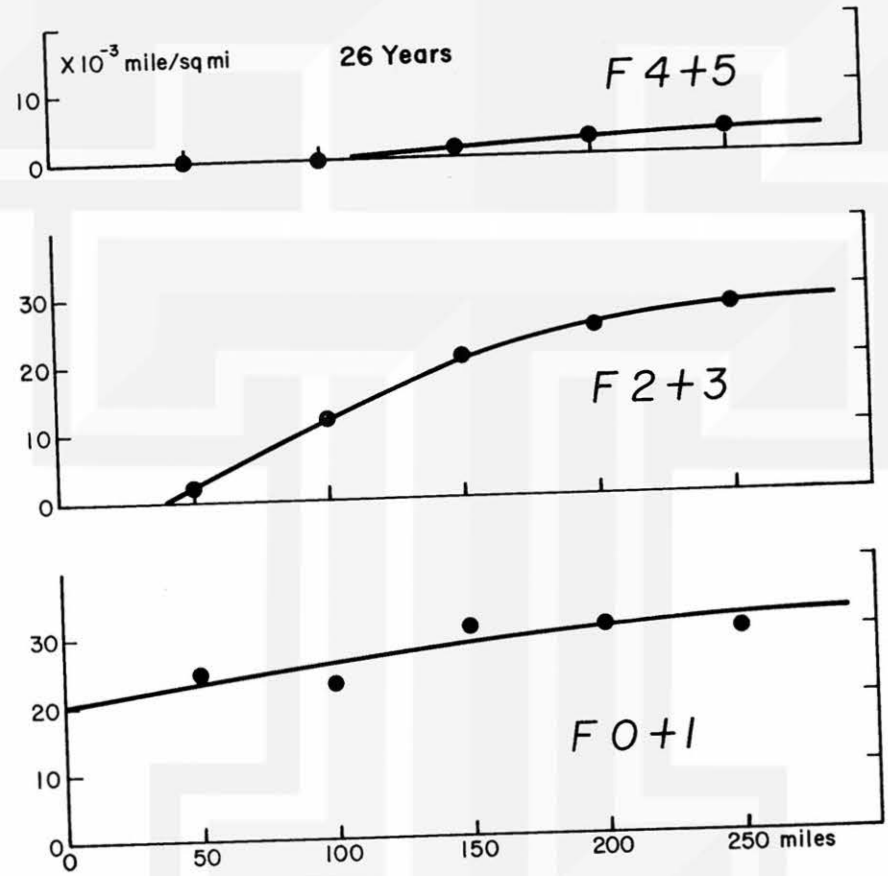

Figure 17. Variation of path-length density, PLD as a function of the ranges from the WIPP site. PLD were computed for 3-category tornadoes by varing ranges between 50 and 250 miles.

Table 12. Path-length density within 100-mile range of the WIPP site. Smoothed value from Figure 17.

Tornado categories	Path-length densities (100 mile range) 26yrs(1950-75)	(per year)
WEAK (F0+F1)	25.6×10^{-3} mile^{-1}	0.98×10^{-3} mile^{-1} yr^{-1}
STRONG (F2+F3)	12.1×10^{-3}	0.47×10^{-3}
VIOLENT (F4+5)	0.0	0.00

Figures 14 through 16 reveal that the 50 mile range is too small to include reliable tornado data. A 150-mile range is certainly too large, thus including high-risk areas around Lubbock, Texas, which should not be extrapolated to the WIPP site based on meteorological grounds.

It is customary to use a 100-mile range of given site in computing site-specific probabilities. Because of a large gradient of PLD across the WIPP site, it is very difficult to justify the 100-mile range as the most representative range for probability computations.

Under these circumstances an attempt was made to compute probabilities within the customary 100-mile range. Path-length densities and their per-year values, thus computed, are given in Table 12.

From these figures, the tornado probabilities were computed from Eq. (16) by using DAPPLE values for every 50 mph increment of windspeed. Note that there are no violent tornadoes within the 100-mile range of the WIPP site (see Table 13).

Table 13. Probabilities of tornadoes within 100-mile range of the WIPP site. Values were computed from the path-length densities per year in Table 12.

Windspeed	WEAK TORNADOES		STRONG TORNADOES		ALL TORNADOES
(mph)	DAPPLE	Probabilities	DAPPLE	Probabilities	Probabilities
50	0.074	7.25×10^{-5} yr^{-1}	0.43	2.02×10^{-4} yr^{-1}	2.75×10^{-4} yr^{-1}
100	0.0028	2.74×10^{-6}	0.062	2.91×10^{-5}	3.18×10^{-5}
150	0.000052	5.10×10^{-8}	0.0098	4.61×10^{-6}	4.66×10^{-6}
200	0.000000	0.00	0.0012	5.64×10^{-7}	5.64×10^{-7}
250	0.000000	0.00	0.000087	4.09×10^{-8}	4.09×10^{-8}

● Probabilities by Pecos Valley Method

An arbitrary selection of the 100-mile range discussed in the previous section resulted in a set of probabilities as a function of windspeeds. Until another method is tested these values are not justifiable because of the large PLD variations across the WIPP site.

To overcome this difficulty an independent method was devised. The statistical area was divided into four regions:

Rio Grande Valley --- Rio Grande watershed and west

Pecos Valley --- Pecos Valley watershed

Plateau --- west of the 2,000 ft contour line

Plains --- east of the 2,000 ft contour line

The boundaries of these four regions are shown in Figure 18.

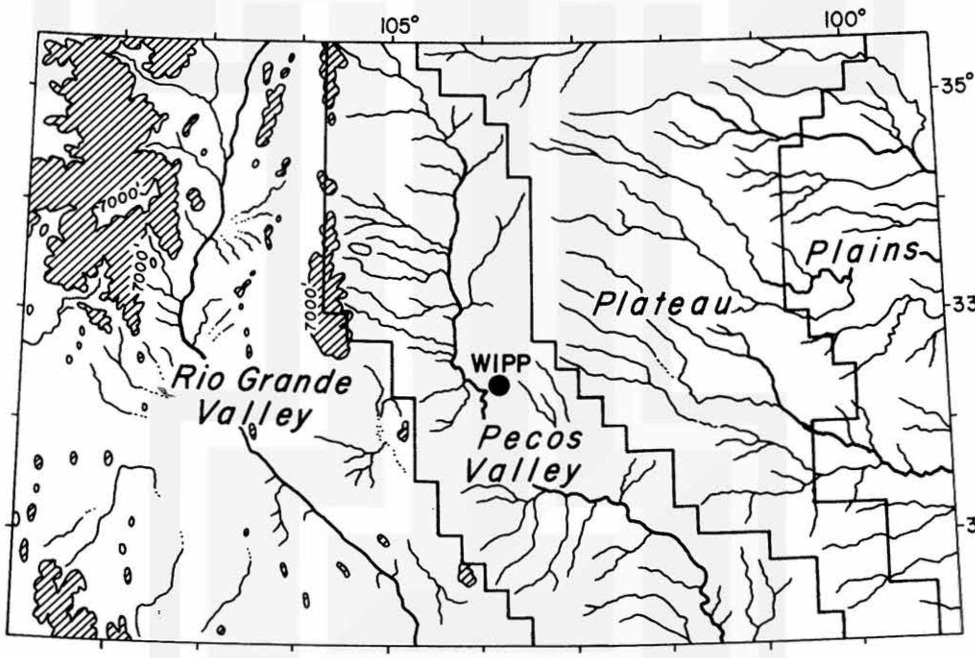

Figure 18. Four regions of different tornado characteristics. Boundaries are chosen as those of watersheds except the 2,000ft height contour was used to separate "Plateau" from "Plains".

Normalized paths of the three-category tornadoes in Figures 14 through 16 are divided into four regions. It is seen that tornado distributions are separated by three boundaries reasonably well.

After determining the sub-boxes belonging to each region, path-length densities of the three-category tornadoes within each region were computed and plotted in Figure 19. From this figure the path length density at the WIPP site was estimated for each category of tornadoes (see Table 14).

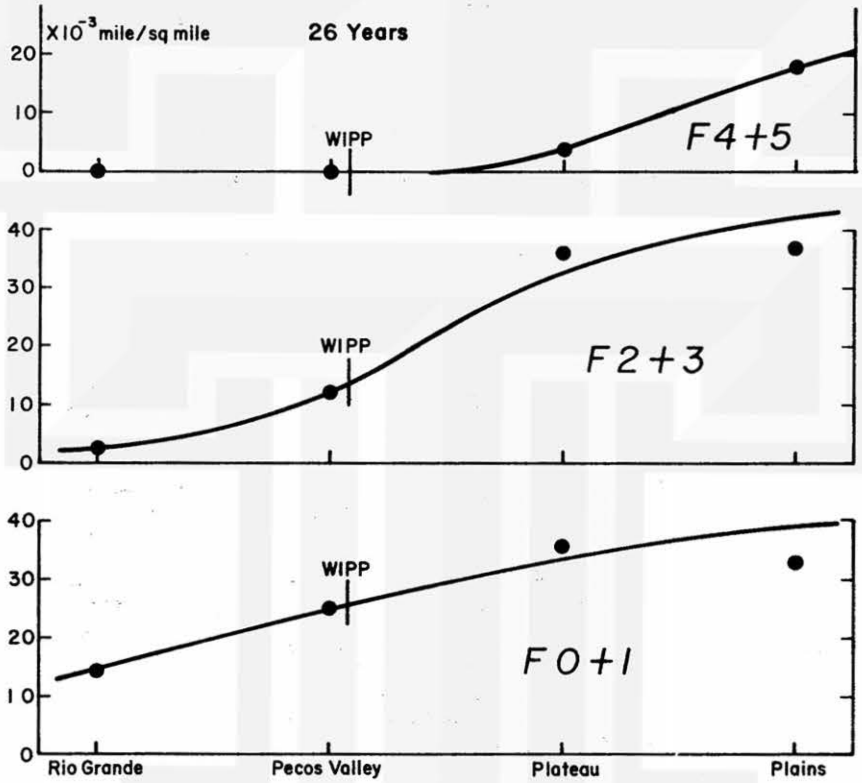

Figure 19. East-west variations of path-length densities of three-category tornadoes. The WIPP site is located to the east of the center line of Pecos Valley.

Table 14. Path-length density at the WIPP site obtained by Pecos Valley method. Values were estimated from Figure 19 by placing the site on the east side of the valley.

Tornado categories	Path-length densities at WIPP site 26yrs (1950-75)	(per year)
WEAK (F0+F1)	26.8×10^{-3} mile^{-1}	1.03×10^{-3} mile^{-1} yr^{-1}
STRONG (F2+F3)	14.3×10^{-3}	0.55×10^{-3}
VIOLENT (F4+F5)	0.0	0.00

Then the probabilities of various windspeeds were computed from Eq. (16), using Table 14 as input data. As shown in Table 15, probabilities computed by this method (Pecos Valley method) are slightly larger than those of the 100-mile range values. If we choose either the 110- or 120-mile range, the probabilities will become very close to those obtained by the Pecos Valley method.

Table 15. Probabilities of tornadoes at the WIPP site. Values were computed from the path-length densities per year in Table 14.

Windspeed (mph)	WEAK TORNADOES DAPPLE	Probabilities	STRONG TORNADOES DAPPLE	Probabilities	ALL TORNADOES Probabilities
50	0.074	7.62×10^{-5} yr^{-1}	0.43	2.37×10^{-4} yr^{-1}	3.13×10^{-4} yr^{-1}
100	0.0028	2.88×10^{-6}	0.062	3.41×10^{-5}	3.70×10^{-5}
150	0.000052	5.36×10^{-8}	0.0098	5.39×10^{-6}	5.44×10^{-6}
200	0.000000	0.00	0.0012	6.60×10^{-7}	6.60×10^{-7}
250	0.000000	0.00	0.000087	4.79×10^{-8}	4.79×10^{-8}

CONCLUSIONS

Probabilistic Wind Storm Model for WIPP Site

Probabilities of straight-line winds were computed by multiplying the fastest-mile winds in Table 3 by the factor of 1.25 as recommended in Eq. (6). The probability curve, thus obtained, was combined with the tornado probabilities in Table 15 obtained by the Pecos Valley method.

Two probability curves in a semi-log diagram (see Figure 20) represent the probable windspeeds at the WIPP site as a function of probabilities ranging between 10^{-1} and 10^{-7} per year.

The combined results in Table 16 reveal that the speeds of straight-line gusts are higher than those of tornadoes when probabilities are higher than about 2×10^{-5} year^{-1} (return period, 50,000 years). The maximum wind speeds of tornadoes are computed to be 136, 183, and 228 mph, corresponding to 10^{-5}, 10^{-6}, and 10^{-7} year^{-1} probabilities.

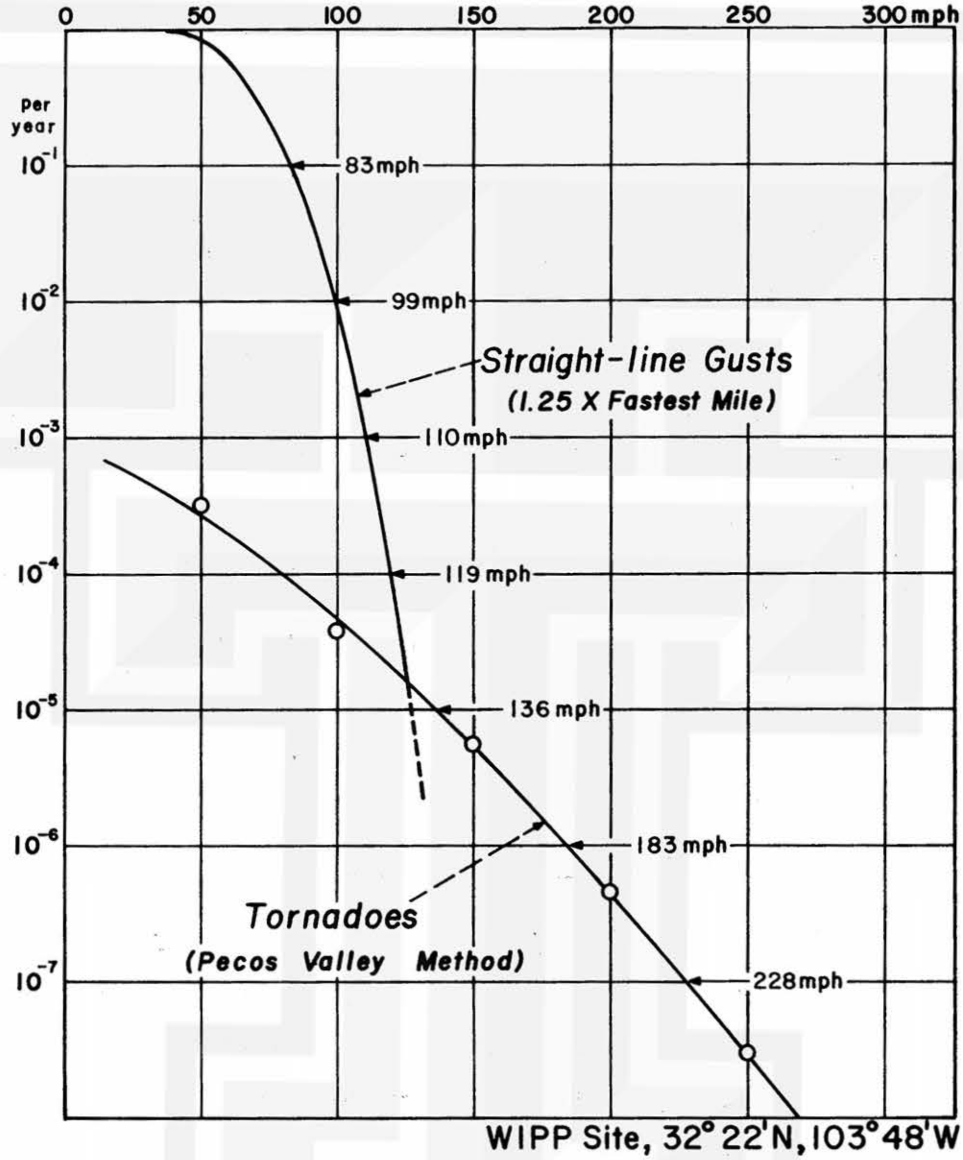

Figure 20. Probabilities of straight-line winds and tornadoes at the WIPP site located 25 miles east-southeast of Carlsbad, New Mexico.

Table 16. Characteristics of storms corresponding to seven probabilities. Air density of the standard atmosphere at 3,414ft is 1.108 kg/m³. The radius of maximum wind was assumed 150m for computational purposes. SLG---Straight-line gust. TOR---Tornado.

	Probabilities (year^{-1})						
	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
Wind storms	SLG	SLG	SLG	SLG	TOR	TOR	TOR
Maximum windspeeds (mph)	83	99	110	119	136	183	228
Translational vel. (mph)	--	--	--	--	27	37	46
Max. tangential vel. (mph)	--	--	--	--	109	146	182
Pressure drop (mb)	--	--	--	--	26.3	47.3	73.4
(psi)	--	--	--	--	0.38	0.69	1.06
Rate of pr. drop (mb/sec)	--	--	--	--	2.12	5.22	10.06
(psi/sec)	--	--	--	--	0.03	0.08	0.15

The maximum windspeeds of tornadoes are assumed to be the sum,

$$T_m = V_m + C \tag{18}$$

where T_m denotes the maximum total velocity (maximum windspeed); V_m, the maximum tangential velocity; and C, the translational velocity. For convenience both vertical velocity and environmental flow velocity are neglected.

For design-basis tornadoes, C is regarded as 20% of the maximum windspeed or

$$C = 0.2\ T_m \tag{19}$$

thus we have

$$V_m = 0.8\ T_m. \tag{20}$$

By assuming the radius of maximum wind to be

$$R_o = 150\ \text{m}, \tag{21}$$

we are able to estimate both the total pressure drop and the rate of pressure drop from

$$\Delta P = \rho\ V_m^2 \tag{22}$$

and

$$\frac{d}{dt}\Delta P = \frac{C}{R_o}\rho\ V_m^2 \tag{23}$$

where ΔP denotes the deficit pressure at the vortex center and ρ, the density of air. Eq. (23) is identical to Eq. (3) of WASH-1300 by Markee et al. (1974).

Parameters computed from these equations are given in Table 16. The author recommends that these parameters be used in evaluating risks of straight-line winds and tornadoes at the WIPP site.

As shown in this table, the design-basis windspeeds increase from 83 mph to 228 mph as the probability decreases from 10^{-1} to 10^{-7} per year. Meanwhile, the type of windstorms inducing damaging winds changes from straight-line wind to tornado.

It is recommended that the level of a proper probability be selected for each structure. Then the storm type and parameters corresponding to the specific probability be used as design criteria in assessing existing structures or those to be constructed at the WIPP site.

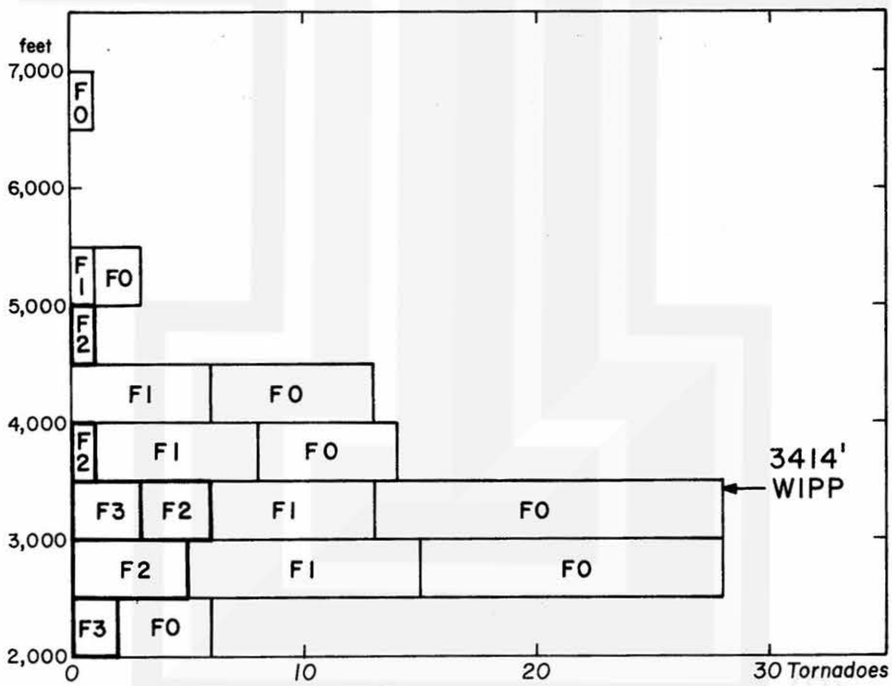

Figure 21. Frequency distribution of various F-scale tornadoes within Pecos Valley. The elevation of the WIPP site is not high enough to exclude the possibility of F3 tornado.

Most Severe Credible Tornado (One in one-million-year tornado)

Although the probabilities by the Pecos Valley method are reasonable, we must still consider the effects of elevation upon tornado intensities in order to determine the most severe storm which is credible at the WIPP site. For this purpose, the touch-down elevations within the Pecos Valley were obtained by plotting all reported tornadoes on 1:250,000 USGS topographic maps. Their distribution by F-scale and elevation at 500-ft intervals are presented in Figure 21.

The elevation of the WIPP site, 3,414 ft MSL, is apparently not high enough to eliminate the possibilities of F 3 tornadoes. It is reasonable to select the F 3 tornado as being the most severe credible tornado applicable to this site.

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