PROBABILITIES OF EXTREME SNOWFALLS AND SNOW DEPTHS

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The economic effects of severe snowstorms and of deep snow cover are felt by rural and urban areas alike. In 1963 the author made a study of extreme snowfalls over New Jersey, using records which varied in length from 6 to 78 years. This work has been expanded to cover approximately 120 stations in 12 northeastern States, and in the Province of New Brunswick.

In addition to snowfall, a similar coverage of extreme snow depth has been calculated for most of those stations. A standard period of 15 seasons, from the winter of 1949-50 through that of 1963-64, has been selected in order to provide compatibility for the analyses.

It is recognized that since the completion of the work presented here, some stations have received record snowfalls beyond the figures used for this study. The purpose of this paper is to show a technique of statistical analysis for determining the return period in years of a snowfall or snow depth of a particular magnitude.

The maximum snow load which might be expected to occur is important in the design of both urban and rural buildings. The construction of dwellings and shelters must provide for sufficient stability to withstand such meteorological elements as wind force on all external surfaces, and snow load which acts primarily on horizontal or sloping surfaces, such as roofs.

The fact that snow load poses a serious problem has been discussed by Landsberg(1), concerning the collapse of the roof of the Knickerbocker Theater in Washington, D. C., in January 1922, following a 28-inch snowfall; and by C. E. P. Brooks(2), concerning the same disaster, and with reference to building practices in New York State. The Housing and Home Finance Agency issued a paper entitled "Snow Load Studies"(3) in 1952, and recent work on this subject has been published by Brown and Williams(4), and by Hahn, Thom, and Bond(5), both in 1962.

In most cases in the New Jersey study, the maximum snow load was the result of a single storm, and the majority of these storms received the bulk of snowfall within a 24-hour period. The decision was made to evaluate maximum 24-hour snowfalls over a network of stations in New Jersey and immediately adjacent weather stations in neighboring States, using the extreme probability theory.

The Lieblein method of handling extreme distributions was published in 1953(6) and 1954(7), and has been discussed by Thom(8) and Vestal(9). An earlier method of analyzing extreme-value data was developed by Gumbel(10) in the 1930's. The Lieblein method was chosen for these studies as it permits the utilization of all available data, instead of rendering some useless, as other methods might.

Vestal(9) points out that 'order statistics' deal with extreme values and near-extreme values, and that extreme-value distributions present a special case of order statistics. The Lieblein fitting procedure, which is the special interest of this paper, concerns itself with the Fisher-Tippett(11) Type I distribution. The graphical solution of a double exponential equztion uses certain weights which are dependent upon sample size. Lieblein calculated the weights up to size six. Recent work on more modern computers has expanded the tables of weighted values considerably. Mann(12) has developed tables to sample size 25. McCool(13) has developed an alternative method of handling samples larger than 25, and Johns and Lieberman(14) have derived tables of weights which are good approximations to the best linear invariant estimates for sample size equal to 10, 15, 20, 30, 50 and 100.

In the original New Jersey study, records from four of the stations used extend over a period of from 74 to 78 seasons, one station record covers only six seasons, and the remaining stations have records of from 10 to 34 seasons. Analyses for the complete periods of record were made for all stations. For purposes of comparison, however, compatible short periods of 12 seasons (1949/50-1960/61) were evaluated for 14 stations.

Both the Lieblein and Gumbel methods were used on the 32-season record for Newark and on the 75-season record for Trenton. Maximum values for return periods were tabulated in both the New Jersey and the 12-State studies.

There were only six storms in the New Jersey study in which the 24-hour snowfall exceeded the 100-year return value among all the data analyzed. They were the blizzard of March 1888 in Trenton, the February 1902 storm in Atlantic City, the storms of December 1909 and April 1915 in Philadelphia, the December 1947 storm in Long Branch and Newark, and the February 1958 storm in Hawley, Pennsylvania. In none of these snowstorms did the water equivalent precipitation exceed 15 pounds per square foot.

With regard to water equivalent precipitation, two outstanding snowstorms have occurred since the autumn of 1884. In the blizzard of March 11-13, 1888, Trenton reported 2.22 inches of rain, with temperatures mostly near or below the freezing point, followed by a 21-inch snowfall which had a water equivalent of 2.70 inches. The combination of rain and snow produced a record total of 4.92 inches, equivalent to 25.6 pounds per square foot. As the rain preceded the snow, however, not all of the total weight could be considered as contributing to roof loads.

During the ice storm of February 4-7, 1920, New York City measured 4.46 inches of water equavalent from a fall of 17.5 inches of snow, sleet, and rain, while at the same time Trenton reported 3.60 inches of water equivalent precipitation in a 6.0-inch fall of snow, sleet, and rain. The load in pounds per square foot was 23.2 in New York City and 18.7 in Trenton, and again, not all of the total weight could be considered in roof loads.

Some examples of computed return periods are shown below. A 100-year storm, for example, is defined as one that happens, on the average, once every 100 years; therefore it has a 100-year return period. There are some pecularities about the distribution of the extreme value. The median, which is much smaller than the mean, is 0.69T, where T is the return period. This means that there is a fifty-fifty chance of the 100-year storm occuring within 69 years. Conversely, the probability of the event happening within its return period is only 63 percent, which means that there is only a 63 percent chance of the 100-year storm occuring at all within the 100 years, although on the average it does occur every 100 years.

SNOWFALL

Return Period

STATION	Years 2	10	25	50	100	1949-1964 Maximum
Mt. Carmel, Conn.	5.7	10.0	12.1	13.7	15.3	12.0
Norfolk, Conn.	10.3	15.4	18.0	19.9	21.9	16.5
Wilmington, Del.	4.5	9.2	11.5	13.2	15.0	10.3
Eastport, Maine	8.6	12.8	14.9	16.4	18.0	13.0
Greenville, Maine	12.3	21.3	25.8	29.1	32.4	25.0
Royal Oak, Md.	3.9	7.3	9.0	10.2	11.5	9.0
Westminster, Md.	7.0	14.2	17.8	20.4	23.1	20.0
Blue Hill, Mass.	12.8	20.4	24.3	27.1	29.9	27.2
East Wareham, Mass.	6.7	11.4	13.7	15.5	17.2	11.5
Fredericton, N. B.	12.4	15.7	16.3	18.7	20.2	23.5
Pinkham Notch, N.H.	14.4	23.1	27.4	30.7	33.9	33.5
Surry Mtn. Dam, N.H.	8.9	11.4	12.7	13.6	14.6	14.0
Flemington, N. J.	8.8	16.7	20.7	23.6	26.6	24.0
Millville, N. J.	4.8	10.4	13.2	15.2	17.3	12.0
Bennetts Bridge, N.Y.	15.2	27.9	34.3	39.0	43.7	30.0
Massena, N. Y.	6.4	8.9	10.2	11.1	12.0	14.0
Montrose, Pa.	9.7	16.4	19.8	22.2	24.7	20.0
Uniontown, Pa.	5.2	9.2	11.2	12.7	14.2	12.0
Block Island, R.I.	5.1	10.4	13.1	15.1	17.0	16.7
Kingston, R.I.	7.6	13.9	17.1	19.5	21.9	16.2
Cavendish, Vt.	10.5	14.9	17.1	18.7	20.3	19.2
St. Johnsbury, Vt.	8.6	12.5	14.5	16.0	17.4	16.5
Bayard, W. Va.	10.5	16.5	19.5	21.7	23.9	23.0
Parkersburg, W. Va.	4.0	7.6	9.3	10.7	12.0	15.7

SNOW DEPTH

Mt. Carmel, Conn.	7.9	15.1	18.8	21.5	24.1	21
Norfolk, Conn.	26.0	45.2	54.8	61.9	69.0	55
Wilmington, Del.	4.9	10.1	12.7	14.7	16.6	13
Eastport, Maine	14.2	26.1	32.1	36.6	41.0	39
Greenville, Maine	37.1	63.3	76.5	86.3	96.0	56
Royal Oak, Md.	4.1	8.1	10.1	11.5	13.0	10
Westminster, Md.	8.8	18.7	23.7	27.4	31.1	28
Blue Hill, Mass.	15.3	26.6	32.3	36.5	40.7	30
East Wareham, Mass.	10.0	19.7	24.5	28.1	31.7	21
Pinkham Notch, N. H.	52.6	74.4	85.3	93.4	101.5	76
Surry Mtn. Dam, N. H.	19.3	30.5	36.1	40.3	44.4	32
Flemington, N. J.	10.2	18.5	22.6	25.7	28.8	24
Millville, N. J.	5.2	11.2	14.3	16.5	18.7	14
Bennetts Bridge, N.Y.	31.0	44.8	51.8	56.9	62.1	60
Massena, N.Y.	16.2	29.0	35.4	40.2	45.0	29
Montrose, Pa.	16.3	27.7	33.4	37.6	41.8	35
Uniontown, Pa.	7.1	11.9	14.3	16.1	17.8	21
Block Island, R. I.	4.7	10.8	13.9	16.2	18.5	12
Kingston, R. I.	9.9	20.7	26.1	30.1	34.1	30
Cavendish, Vt.	29.4	45.1	53.0	58.9	64.7	49
St. Johnsbury, Vt.	19.0	31.7	38.0	42.7	47.4	34
Bayard, W. Va.	16.3	23.9	27.7	30.5	33.4	31
Parkersburg, W. Va.	5.7	12.2	15.5	18.0	20.4	28

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