Maximum Snow Loads along the Western Slopes of the Wasatch Mountains of Utah

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ABSTRACT

For the Salt Lake Valley and adjacent western slopes of the Wasatch Mountains 25-, 50-, and 100-year snow loads were determined, using the theory of extreme probability. Maximum seasonal snow depths were used to estimate the maximum water equivalent at stations where the latter was not measured. Snow loads, in turn, were computed from maximum water equivalents. A high correlation between elevation and maximum snow load was found.

1. Introduction

Many requests are received by the Weather Bureau relative to snow loads in the Salt Lake Valley and adjacent western slopes of the Wasatch Mountains of northwest Utah. Information of this type is of particular importance in the design of buildings and other structures to be erected along the mountain slopes as well as in the valley.

Annual snowfall increases from about fifty inches in the valley floor at an elevation of 4200 ft, to about 375 inches at Silver Lake Brighton at an elevation of 8700 ft in the Wasatch Mountains. Maximum snow depths also vary greatly with elevation, as snow in the valley frequently melts quite rapidly after it has fallen, while in the higher mountains, snow does not melt appreciably in the winter, but accumulates from the early storms up to the time of maximum water equivalent, around 1 April. The maximum water equivalent of the snowpack in any given year at Salt Lake City airport, elevation 4200 ft, is frequently the result of a single snowstorm. Only in colder winters does snow remain on the ground continuously for an appreciable length of time.

2. Methods

In computing snow loads, what is desired, of course, is not merely the maximum snow depth, but the maximum water equivalent of snow on the ground. This is a function of several things, including the total seasonal snowfall (where snow accumulates throughout the winter), evaporation, rainfall trapped in the snowpack, and the rate of snow melt. Rate of snow melt, in turn, is highly dependent on temperature. Since winter precipitation and temperature are both well correlated with elevation in northern Utah, it is reasonable to expect that there would be a very high correlation between maximum water equivalent of snow on the ground and elevation. Maximum snow loads in pounds per square foot may be computed by multiplying the maximum water equivalent in inches by 5.2.

Water equivalents were measured at four stations for periods of 25–30 years. These stations were Silver Lake Brighton (8700 ft), Parleys Canyon Summit (7500 ft), Mill D South Fork (7400 ft) and Lambs Canyon (6600 ft). Fig. 1 shows the location of the stations and the general topography of the area. Water equivalents have been measured daily at Salt Lake City airport since 1952. Estimates were made for Mt. Dell (5500 ft), Highline City Creek (5300 ft). Lower Mill Creek (5000 ft), and also for the earlier years at Salt Lake City. Salt Lake airport records were used from 1936 to 1960, and city office records for earlier years, back to 1895. The difference in elevation between airport and city offices is less than 50 ft, and although winter precipitation averages slightly higher at the downtown office, the years with overlapping record, 1936–1952, showed no appreciable differences in snowfall accumulation.

For Salt Lake City, the annual maximum water equivalents were estimated for years prior to 1952 as follows. Since daily snow depths were available for most of the 66-year record, it was comparatively easy to determine the annual maximum snow depth. If the maximum depth was due to a single storm, the total precipitation associated with the snowfall was used as the maximum water equivalent. If the weather was cold and mostly below freezing, with persistent accumulating snow cover, daily precipitation amounts during the cold period were totalled, and this figure was used as the maximum water equivalent. If the weather was partially below and partially above freezing, subjective estimates were made of the water equivalent of the snow on the ground (nearly always quite small), and any precipitation from new snowfall was added to this to give the total water equivalent.

At the three foothill stations, 5000 to 5500 ft in elevation, snow accumulates on the ground during most of the winter, but occasionally a single storm will produce a maximum snow cover. A ratio of 5 to 1 was used for the water equivalent of snow on the ground for stations

FIG. 1. Location of stations and general topography of Salt Lake City, Utah, area.

in this elevation range. This ratio seemed to be a reasonable compromise between computed ratios at the times of maximum snow depth at Salt Lake airport and the higher level stations. At Salt Lake City (4200 ft), where snow depths and water equivalents have both been

measured for the past nine years, the ratio averaged 6.7 to 1, although it varied from 4.0 to 12.5 to 1. At the higher stations, 6600 to 8700 ft, the ratios averaged between 2.5 and 3.0 to 1. Undoubtedly the actual ratio for the 5000 to 5500 ft stations varied somewhat at

times from the average ratio used. However, if a single heavy storm fell on an old snow pack to produce the maximum depth, the water equivalent of the old snow was estimated at 5 to 1, and then the total precipitation of the new storm was added to that figure to estimate the maximum water equivalent.

3. Analysis of data

The method of extreme probability analysis, as described by Lieblein (1954), is used for this paper to estimate the 25-, 50-, and 100-year snow loads. The theory of extreme probability was first applied to hydrologic data by Gumbel (1941), and since the publication of his work, others have used the technique with various hydrologic data. Linsley, Kohler and Paulhus (1958) give a discussion of the Gumbel method and illustrate its application by estimating food-frequency for the Clearwater River at Kamiah, Idaho. Magnuson (1958) uses the theory in the estimation of snow depths for various return periods for several locations in Oregon, and the same general technique has also been applied to other meteorological data.

An excellent discussion of the Lieblein fitting procedure is given by Thom (1960). This procedure, which requires that the original time order of the climatological series be maintained, provides a simple means of estimating quantiles with minimum variance.

As an example of the application of the extreme probability theory, data for one of the stations used in this study, Lambs Canyon, are given in Table 1, and the actual plotting of these data is shown in Fig. 2. The ordinate (x -scale) of the plotting is the annual maximum snow load in pounds per square foot. The abscissa values are probabilities, which are calculated as follows:

$$\text{Probability} = 1 - (m/N + 1),$$

where N is the number of x values and m is the rank of an x value (see Table 1). The annual maximum snow loads are plotted against the probability values on extreme probability paper and, according to the theory of extreme values, these points should approximate a straight line. The line of best fit to the plotted data for each station was determined as described by Lieblein, and this line was used in estimating snow load values for the 25-, 50-, and 100-year return periods.

It was found that plottings of annual maximum snow loads against probability values for the various stations approximated straight lines, although plotted points of the unusually heavy snow loads in the middle elevations along the Wasatch Front during the winter of 1951-1952 deviated markedly from the lines of best fit. One of the advantages of the extreme probability theory is in the analysis of data such as these heavy snow loads. At Lambs Canyon, for example, the plotted points of snow loads show relatively small deviations from the line of best fit for all years except the winter of 1951-1952

(Fig. 2). According to the plotted data, the snow load for that winter at Lambs Canyon would occur on an average of once in about 28 years. The extreme probability theory, however, indicates that over a long period of time such a heavy snow load at that location might be expected to occur on an average of once in 180 years. The latter figure is considered much more realistic since the extreme probability theory makes maximum use of an entire set of data, i.e., each year of record contributes to the estimation of snow loads for various return periods.

TABLE 1. Maximum snow load data for Lambs Canyon, Utah, elev. 6600 ft. (See text for explanation of probability.)

Max. annual snow load lb per sq ft x	Rank m	Probability
153.9	1	0.963
118.0	2	0.926
101.9	3	0.889
100.9	4	0.852
99.8	5	0.815
94.6	6	0.778
86.3	7	0.741
86.3	8	0.704
84.2	9	0.667
83.2	10	0.630
82.7	11	0.593
80.1	12	0.556
78.0	13	0.519
78.0	14	0.481
73.3	15	0.444
73.3	16	0.407
72.3	17	0.370
70.7	18	0.321
67.6	19	0.296
66.6	20	0.259
66.6	21	0.222
60.3	22	0.185
59.8	23	0.148
59.3	24	0.111
58.2	25	0.074
55.1	26	0.037

FIG. 2. Return periods of annual maximum snow loads at Lambs Canyon, Utah (elevation 6600 ft.).

The line of best fit for Salt Lake City return periods of maximum snow loads is shown in Fig. 3.

4. Results

Fig. 4 shows a plot of 25-, 50-, and 100-year snow loads with elevation. The lines are terminated at the valley floor, elevation 4200 ft. The lines are fitted by the method of least squares, and it can be seen that a straight line fits the data rather well. In fact, the correlation of snow load with elevation is 0.996 for all three periods. From this chart it would be possible to estimate

FIG. 3. Return periods of annual maximum snow loads at Salt Lake City, Utah (elevation 4200 ft.).

FIG. 4. Relationship between elevation and 25-, 50-, and 100-year snow loads along western slopes of Wasatch Mountains of Utah.

the maximum snow loads reasonably closely at any elevation along the Wasatch Front.

A comparison has been made with some earlier computations of snow loads (Housing and Home Finance Agency, 1952). This earlier paper gives the maximum snow pack of record at Salt Lake City as 40 lb per sq ft. The 66-year record data used in this study give the maximum as only 20 lb per sq ft. Also the earlier paper gives 30 lb per sq ft as the maximum snow load to be expected once in 10 years at Salt Lake City, whereas Fig. 3 of this study indicates about 11 lb per sq ft for this period. The earlier figures seem to be very high in view of the measurements and estimates used in the current study. One possible source of discrepancy in the referenced paper is the tendency to calculate snow pack at Salt Lake City on the basis of accumulation through the winter, which is just not the case in most winters. In the unusually cold winters when this does occur, as in 1948-49, the year of the greatest snow depth by several inches in 66 years of record, the maximum possible water equivalent was a little less than 4 inches, totalling all the precipitation that fell during the winter, from the date of the first snowfall accumulation to the time of melting of the snowpack. This would give a snow load of only about 20 lb per sq ft.

5. Conclusions

Using the method of extreme probability, return periods of 25-, 50-, and 100-years are calculated for snow loads in the Salt Lake Valley and adjacent western slopes of the Wasatch Mountains to the east of Salt Lake City. Possible errors arise from the necessity of estimating annual maximum water equivalents of snow on the ground at foothill stations, 5000 to 5500 ft in elevation. A high correlation was found to exist between elevation and 25-, 50-, and 100-year snow loads.

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