Snow Engineering: Recent Advances, Izumi, Nakamura & Sack (eds) © 1997 Balkema, Rotterdam. ISBN 90 5410 865 7

Database and methodology for conducting site specific snow load case studies for the United States

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ABSTRACT: We have developed data and a methodology for determining the ground snow load at locations not covered in our ground snow load map of the United States due to extreme local snow load variations in the area. The elevation, the years of record available, the maximum observed value and the "50-year" ground snow load at a number of nearby sites are considered. A plot of elevation vs. load is often helpful.

1 DATABASE AND STATISTICS

Measurements collected by the National Weather Service (NWS) are the largest source of information on snow on the ground in the United States. At 266 "first-order" NWS stations across the nation, both the depth of the snow on the ground and its load (i.e., its "water equivalent") have been measured frequently each winter. At about 11,000 other NWS "co-op" stations only the depth of the snow on the ground has been measured.

At each NWS station we determined the maximum depth of the snow on the ground each winter. At each NWS first-order station we also determined the maximum water equivalent for each concurrent winter. Log-normal extreme value statistics (Ellingwood and Redfield 1983) were then used to estimate the depth of snow on the ground and, where available, the ground snow load (i.e., the water equivalent) having a 2% annual probability of being exceeded (i.e., the 50-year mean recurrence interval value). We did not do statistics for locations having less than 10 years of data or locations with 10 or more years of data but less than 5 years in which snow was observed.

The nonlinear equation of best fit between the 50-year depths and 50-year loads at the 204 first-order stations in the continental United States which met our criteria for analysis was as follows:

$$L = 0.279\, D^{1.36} \tag{1}$$

where L = 50-year load in lb/ft^2 and D = 50-year depth in inches. In SI units with the load in kN/m^2 and the depth in meters, the equation becomes $L = 1.97\, D^{1.36}$.

A separate equation was developed for Alaska from the 20 first-order stations located there.

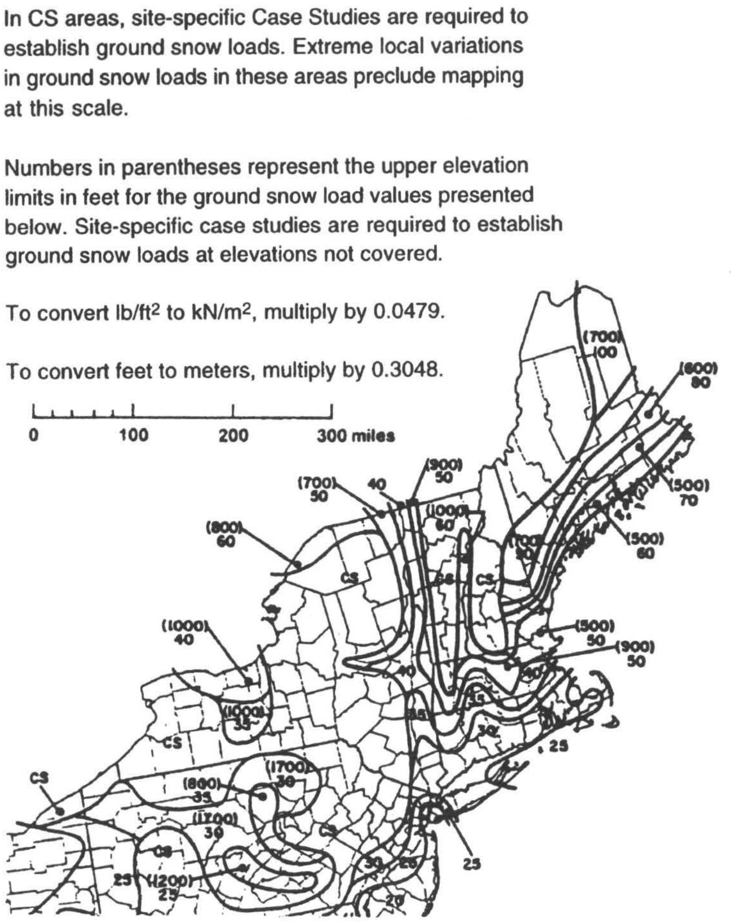
Our database also contains information from about 3300 additional locations where the water equivalent of snow on the ground is measured several times each winter. Some of those measurements are by companies that generate hydroelectric power, others are by the Corps of Engineers for flood forecasting, but most have been collected by the Natural Resource Conservation Service (NRCS) for similar purposes and for monitoring water supplies. Until recently NRCS was known as the Soil Conservation Service (SCS). Most of these "non-NWS" locations are in high mountain watersheds, not in populated areas.

2 THE NEW SNOW LOAD MAP

The 50-year loads determined at the NWS first-order stations and the 50-year loads at the NWS co-op stations generated by use of Equation 1 were used to construct a new national snow load map, a portion of which is shown in Figure 1. Snow loads are presented as zones. Some zones contain elevation limits above which the zoned value should not be used. These elevation limits, in feet, are shown in parentheses above the zoned value.

In some areas extreme local variations in ground snow loads preclude mapping at this scale. In those areas the map contains the designation "CS" instead of a value. CS indicates that a *case study* is required to establish ground snow loads for locations in this area.

We examined the possibility of integrating the non-NWS information into the new map with the hope of being able to reduce the extent of areas needing case


In CS areas, site-specific Case Studies are required to establish ground snow loads. Extreme local variations in ground snow loads in these areas preclude mapping at this scale.

Numbers in parentheses represent the upper elevation limits in feet for the ground snow load values presented below. Site-specific case studies are required to establish ground snow loads at elevations not covered.

To convert lb/ft² to kN/m², multiply by 0.0479.

To convert feet to meters, multiply by 0.3048.

Figure 1. Northeast portion of the new ground snow load map of the United States. Loads are in lb/ft².

studies but determined that little could be gained by doing this. Thus our new map is based only on NWS data. However, all the non-NWS information has been incorporated into our database, making it available for case studies.

The new map was recently published in the 1995 version of the national design load standard, "Minimum Design Loads for Buildings and Other Structures" (ASCE 1995), which is known as ASCE 7-95.

That standard requires that all ground snow loads used in design "be based on an extreme value statistical analysis of data available in the vicinity of the site using a value with a 2% annual probability of being exceeded (50-year mean recurrence interval)." Our data and methodology make this possible anyplace in the United States.

3 "SNOW LOADS FOR THE UNITED STATES"

Our report with the above title (Tobiasson and Greatorex 1996) presents the new snow load map and explains in detail the many steps we took to consider missing and questionable data and to develop the equations used to convert 50-year depths to 50-year loads. That report contains numerous state maps on which all NWS first-order, NWS co-op and non-NWS stations are located. Figure 2 is one such map containing only NWS stations. Black dots indicate co-op stations and black triangles indicate first-order stations. The station number is presented adjacent to its dot or triangle. All non-NWS stations are presented on separate maps for the 24 states in which such stations exist.

The report also tabulates ground snow load data for all of these stations.

Table 1 shows a small portion of the NWS tabulation for Maine. Water equivalent information for first-order stations is presented in bold type. As with the maps, the NWS and non-NWS tabulations are presented separately.

The state maps contain a latitude and longitude reference grid and county boundaries. With this information a site of interest can be located on a state map. Using the scale shown on that map and a compass, we draw circles with radii of 25 and 50 miles (40 and 80 km) around the site of interest. The number of any NWS first-order station present within the 50-mile (80-km) outer circle is determined and noted on the case

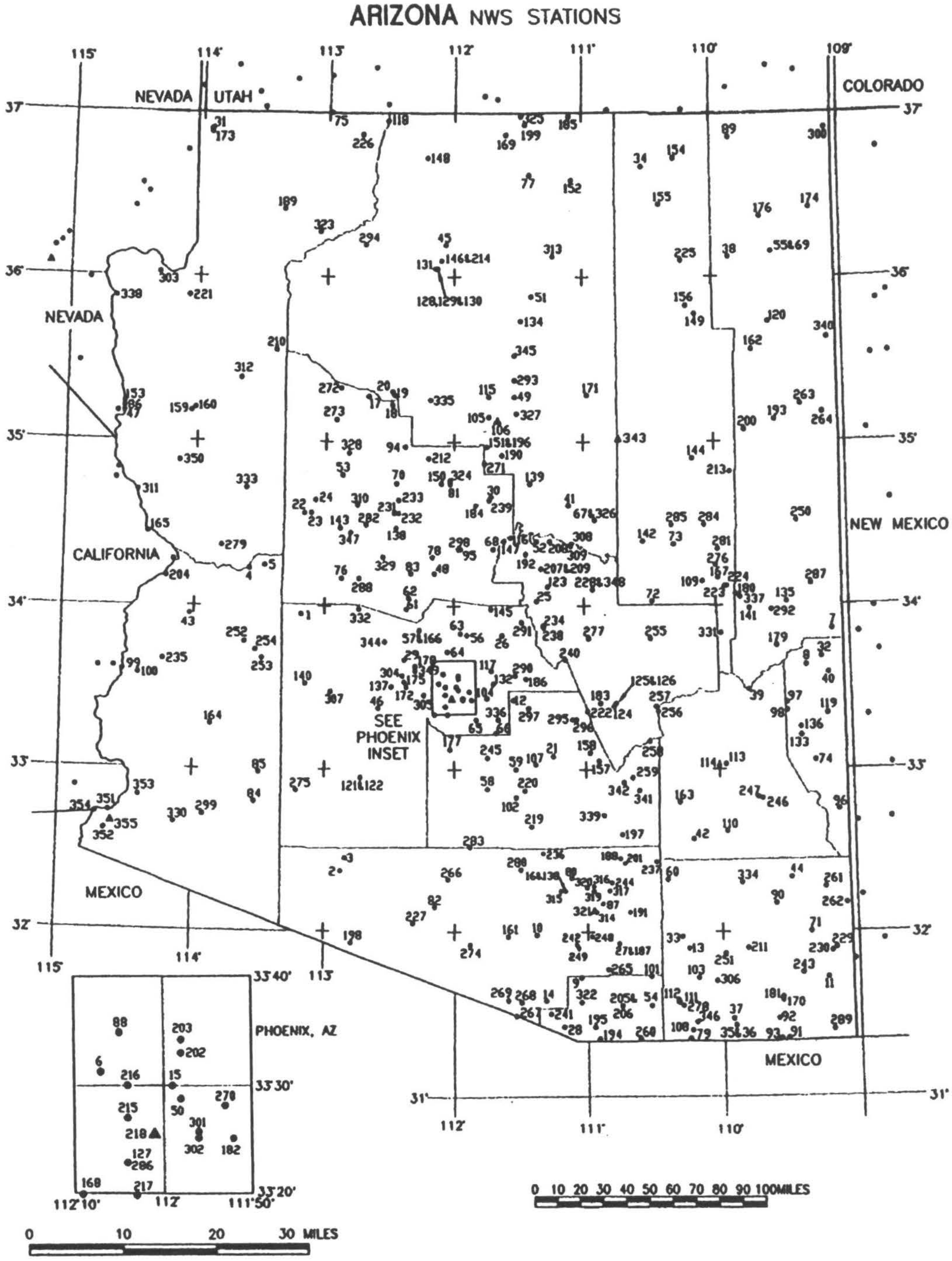


Figure 2. NWS stations in Arizona.

study form. If there is more than one first-order station, the closest is listed first. The scale on the map is used to determine the distance from each site of interest and those distances are noted on the case study form. An example case study form is shown in Figure 3. Space is provided for two lines of information for each first-order station. On the first line, the water equivalent (W.E.) values are presented. The second line presents loads generated by converting the 50-year and maximum observed *depths* measured during the same period to loads using Equation 1 (everywhere but Alaska, where a somewhat different equation is used). The first and second lines of first-order station information are labeled (W.E.) and (DEPTH EQ) to show that the first is based on water equivalent measurements and the second on snow depth measurements.

Next the numbers of all NWS co-op stations within the 25-mile (40-km) inner circle are listed on the case study form in order of increasing distance. Distances from the site of interest are determined and noted on the form.

If the circles enter an adjacent state, stations within that state are also needed. To facilitate that, the location of all adjacent-state stations within 25 miles (40 km) of a state's border are also shown on each state map as in Figure 2. Their numbers are not shown. They are obtained from the map of that adjacent state.

The state-by-state, station-by-station tabulation for NWS stations is then consulted for information on each station. That information is added to the case study form. In this way, the elevation, 50-year ground snow load, record maximum load, total years of record and number of years with no snow are transferred to the case study form for each nearby NWS station. For some locations in the tabulation not enough data were available to determine a 50-year ground snow load. Nonetheless, all information available for that location is transferred to the case study form since it is of some value in the analysis.

Then maps in the non-NWS series are examined to determine if there are any non-NWS stations within 25 miles (40 km) of the site of interest. Information on each non-NWS station found is obtained from the non-NWS tabulation and transferred to the case study form.

The new snow load map (Fig. 1) is consulted and the mapped ground snow load and any elevation limitations on it are listed on the case study form. If the case study is being done for a place in a CS zone, as is often the case, CS is listed as the ASCE 7-95 mapped value.

Since we conduct numerous snow load case studies we have computerized the assembly of information on case study forms. We input the name, latitude, longitude and elevation of the site of interest and, with a few manual prods, the form is printed out. Figure 4 is an example. It contains the station name instead of its number. The distance and azimuth of each station from the site of interest are calculated and tabulated automatically. Although the manual and computerized case study forms are slightly different, both contain all the information needed to do the case study.

4 OBTAINING AN ANSWER

Once the case study form is filled in, it is analyzed to obtain a ground snow load for that location.

4.1 NWS first-order stations

For all NWS first-order stations within 50 miles, we compare the (W.E.) values to the (DEPTH EQ) values. When the two ground snow load (P_g) values are about equal, we give Equation 1 credit for doing a good job of converting 50-year depths to 50-year loads in this area. When the values are not close, either the depth or water equivalent measurements are suspect or Equation 1 is not good at predicting loads here. Our investigations convince us to place somewhat more trust in the water equivalent values, but we keep an open mind as we examine the rest of the case study data. When non-NWS information is available, it is quite helpful in resolving questions about NWS first-order station information since it represents independent water equivalent (i.e., load) measurements, thereby sidestepping any depth-to-load-equation concerns.

Table 1. A portion of the NWS station tabulation for Maine. P_g is the ground snow load.

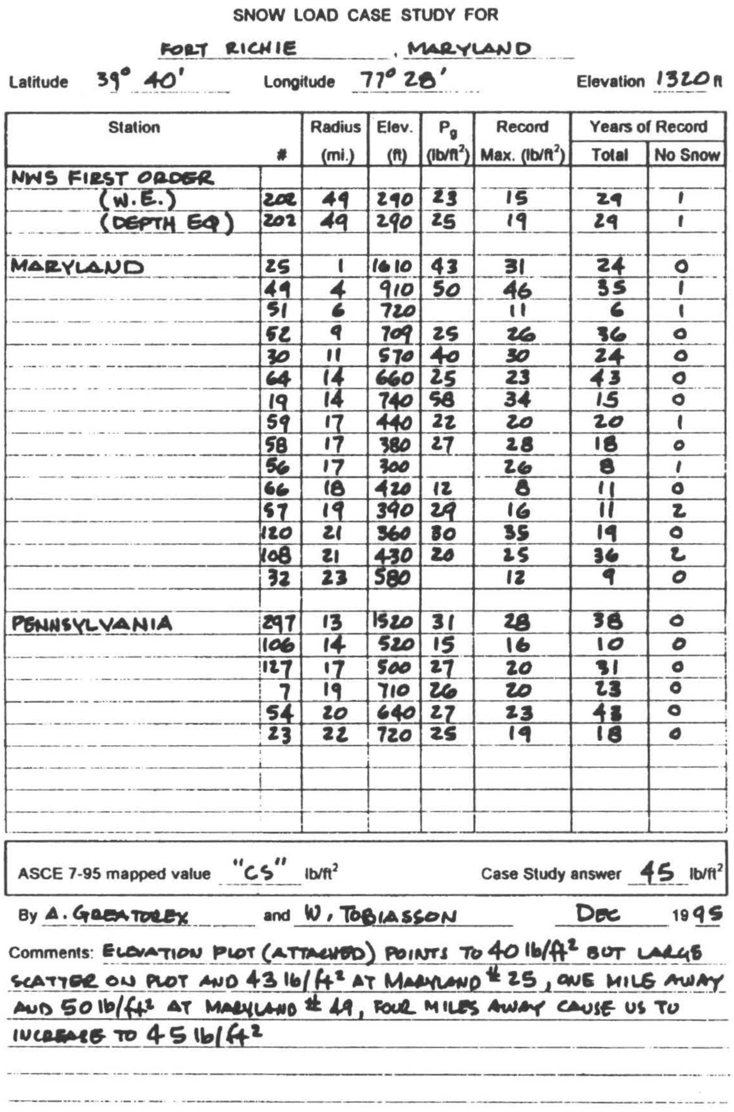
Sta	Elev	P_g	Rec	Years	
			Max	Tot	No
#	ft	lb/ft^2	lb/ft^2		Sno
Maine					
1	470	42	49	10	0
2	600		39	5	0
3	350	67	51	43	0
4	190	69	62	41	0
5	110	46	51	35	0
6	20	61	59	42	0
7	710		31	1	0
8	400		32	2	0
9	600	70	42	11	0
10	1060		48	8	0
11	420	154	44	15	0
12	560	94	101	31	0
13	70	56	45	37	0
14	80	35	25	16	0
15	**620**	**95**	**68**	**34**	**0**
15	620	85	76	43	0
16	1000		38	5	0
17	1000	94	57	23	0
18	360	81	62	42	0
19	400		25	4	0

We always examine each first-order station's years of record and its record maximum values before deciding how much we trust its 50-year value.

A first-order station only a few miles (kilometers) away from the site of interest is given more weight than one close to 50 miles (80 km) away. Elevation differences are also an important issue and are considered in a similar way.

4.2 NWS co-op stations

This is usually the largest body of information on the case study form. Since it is arranged state-by-state according to distance ("radius" on the form) from the site of interest, the uppermost stations in each state's array are the most valuable. If there are a few stations within 12 to 15 miles (19 to 24 km) with long periods



SNOW LOAD CASE STUDY FOR

FORT RICHIE , MARYLAND

Latitude 39° 40' Longitude 77° 28' Elevation 1320 ft

Station	#	Radius	Elev.	P_g	Record	Years of Record	
		(mi.)	(ft)	(lb/ft^2)	Max. (lb/ft^2)	Total	No Snow
NWS FIRST ORDER							
(W.E.)	202	49	290	23	15	29	1
(DEPTH EQ)	202	49	290	25	19	29	1
MARYLAND	25	1	1610	43	31	24	0
	49	4	910	50	46	35	1
	51	6	720		11	6	1
	52	9	709	25	26	36	0
	30	11	570	40	30	24	0
	64	14	660	25	23	43	0
	19	14	740	58	34	15	0
	59	17	440	22	20	20	1
	58	17	380	27	28	18	0
	56	17	300		26	8	1
	66	18	420	12	8	11	0
	57	19	390	29	16	11	2
	120	21	360	80	35	19	0
	108	21	430	20	25	36	2
	32	23	580		12	9	0
PENNSYLVANIA	297	13	1520	31	28	38	0
	106	14	520	15	16	10	0
	127	17	500	27	20	31	0
	7	19	710	26	20	23	0
	54	20	640	27	23	48	0
	23	22	720	25	19	18	0

ASCE 7-95 mapped value "CS" lb/ft^2 Case Study answer 45 lb/ft^2

By A. GREATOREX and W. TOBIASSON DEC 1995

Comments: ELEVATION PLOT (ATTACHED) POINTS TO 40 lb/ft^2 BUT LARGE SCATTER ON PLOT AND 43 lb/ft^2 AT MARYLAND # 25, ONE MILE AWAY AND 50 lb/ft^2 AT MARYLAND # 49, FOUR MILES AWAY CAUSE US TO INCREASE TO 45 lb/ft^2

Figure 3. "Manual" case study form for Fort Richie, Maryland.

of record, their collective answer often overpowers anything the rest of the co-op stations farther away can contribute. But, at times, the most valuable information lies farther away. For example, the closest three co-op stations on the Figure 4 case study form for Scranton, Pennsylvania, do not have enough information to permit calculation of P_g values. The next two stations have long records (44 and 38 years) but they are at a much higher elevation than Scranton. Finally the sixth and seventh stations, 16 and 17 miles (26 and 27 km) away have relatively long periods of record and elevations about the same as Scranton.

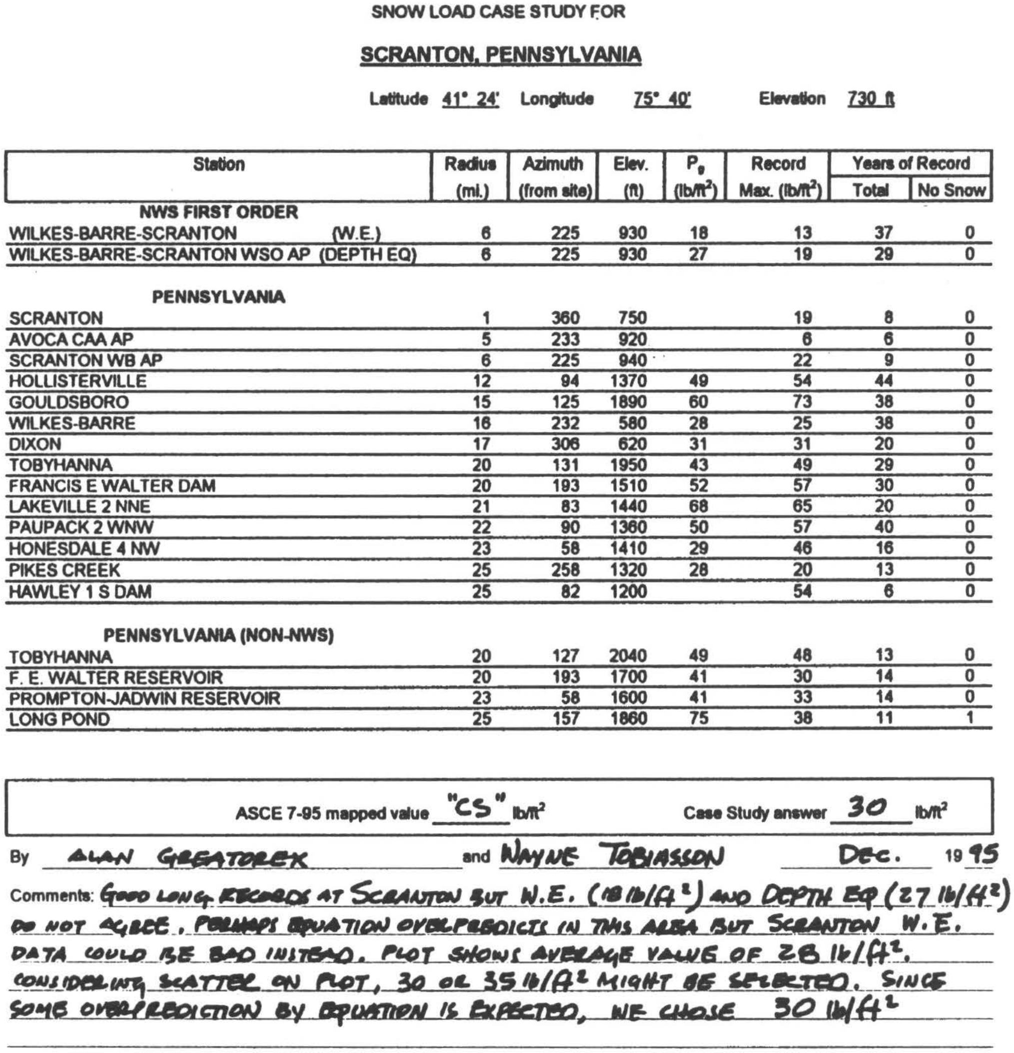
4.3 Non-NWS stations

These records are based on water equivalent (i.e., load) measurements, not depth measurements, so they are somewhat more valuable than those of NWS co-op stations with similar periods of record. However, fewer readings are taken each winter and these stations are frequently at higher elevations than most sites of interest. Nonetheless, some sites of interest are best represented by these stations.

4.4 Elevation vs. P_g plots

Figures 3 and 4 illustrate case studies where the answer does not become self evident after a few minutes of examining the form. In such situations elevation vs. P_g plots are helpful. Often we plot the 6 to 10 nearest stations, make a copy of that plot then add all other stations within 25 miles (40 km) to the plot. The two plots give us an appreciation for the effect of distance.

Figure 5 shows the 10-closest-values plot for



SNOW LOAD CASE STUDY FOR

SCRANTON, PENNSYLVANIA

Latitude 41° 24' Longitude 75° 40' Elevation 730 ft

Station	Radius (mi.)	Azimuth (from site)	Elev. (ft)	P_g (lb/ft^2)	Record Max. (lb/ft^2)	Years of Record Total	Years of Record No Snow
NWS FIRST ORDER							
WILKES-BARRE-SCRANTON (W.E.)	6	225	930	18	13	37	0
WILKES-BARRE-SCRANTON WSO AP (DEPTH EQ)	6	225	930	27	19	29	0
PENNSYLVANIA							
SCRANTON	1	360	750		19	8	0
AVOCA CAA AP	5	233	920		6	6	0
SCRANTON WB AP	6	225	940		22	9	0
HOLLISTERVILLE	12	94	1370	49	54	44	0
GOULDSBORO	15	125	1890	60	73	38	0
WILKES-BARRE	16	232	580	28	25	38	0
DIXON	17	306	620	31	31	20	0
TOBYHANNA	20	131	1950	43	49	29	0
FRANCIS E WALTER DAM	20	193	1510	52	57	30	0
LAKEVILLE 2 NNE	21	83	1440	68	65	20	0
PAUPACK 2 WNW	22	90	1360	50	57	40	0
HONESDALE 4 NW	23	58	1410	29	46	16	0
PIKES CREEK	25	258	1320	28	20	13	0
HAWLEY 1 S DAM	25	82	1200		54	6	0
PENNSYLVANIA (NON-NWS)							
TOBYHANNA	20	127	2040	49	48	13	0
F. E. WALTER RESERVOIR	20	193	1700	41	30	14	0
PROMPTON-JADWIN RESERVOIR	23	58	1600	41	33	14	0
LONG POND	25	157	1860	75	38	11	1

ASCE 7-95 mapped value "CS" lb/ft^2 Case Study answer 30 lb/ft^2

By ALAN GREATOREX and WAYNE TOBIASSON DEC. 1995

Comments: GOOD LONG RECORDS AT SCRANTON BUT W.E. (18 lb/ft^2) AND DEPTH EQ (27 lb/ft^2) DO NOT AGREE. PERHAPS EQUATION OVERPREDICTS IN THIS AREA BUT SCRANTON W.E. DATA COULD BE BAD INSTEAD. PLOT SHOWS AVERAGE VALUE OF 28 lb/ft^2. CONSIDERING SCATTER ON PLOT, 30 OR 35 lb/ft^2 MIGHT BE SELECTED. SINCE SOME OVERPREDICTION BY EQUATION IS EXPECTED, WE CHOSE 30 lb/ft^2

Figure 4. "Computerized" case study form for Scranton, Pennsylvania.

Scranton. Note that two of the values are from non-NWS stations. The least squares line of best fit is shown along with the value of P_g at the elevation of the site of interest. Since it is usually possible to arrive at appropriate answers without having to calculate the least squares best-fit value, we only generate that information in our computerized version.

Such plots not only clarify any elevation effect but they also illustrate the amount of scatter in the local database. Since there is generally noticeable scatter in such records, we usually select a value somewhat above the least squares best-fit value.

Figure 6 shows the all-values-within-25-miles (40 km) plot for Fort Richie. The plot of the nearest eight values generated the same P_g value of 39 lb/ft^2 (1.87 kN/m^2). Considering the scatter of points on the plot and the 50 lb/ft^2 (2.40 kN/m^2) value at Edgemont only 4 miles (6 km) away where a long record is available, we chose 45 lb/ft^2 (2.16 kN/m^2) as our Fort Richie answer. Our concern with the 58 lb/ft^2 (2.78 kN/m^2) at Boonsboro (14 miles or 23 km away) was not great since it is based on only 15 years of record during which the record maximum value was only 34 lb/ft^2 (1.63 kN/m^2).

Another two individuals examining the Fort Richie case study form (Fig. 4) and elevation plot (Fig. 6) might have settled on 50 lb/ft^2 (2.40 kN/m^2). We would find that hard to argue against, since the data available do not permit loads to be established with great accuracy.

Case study answers are rounded to the nearest 5 lb/ft^2 (0.24 kN/m^2) up to a value of 40 lb/ft^2 (1.92 kN/m^2) and to the nearest 10 lb/ft^2 (0.48 kN/m^2) above 40 lb/ft^2 (1.92 kN/m^2). Table 2 shows the lower and upper limits used for mapped zones and case study answers. For example, if our best estimate of a case study answer is 37 lb/ft^2 (1.77 kN/m^2) we would round that down to P_g = 35 lb/ft^2 (1.68 kN/m^2). If our best estimate was 38 lb/ft^2 (1.82 kN/m^2) we would round that up to 40 lb/ft^2 (1.92 kN/m^2).

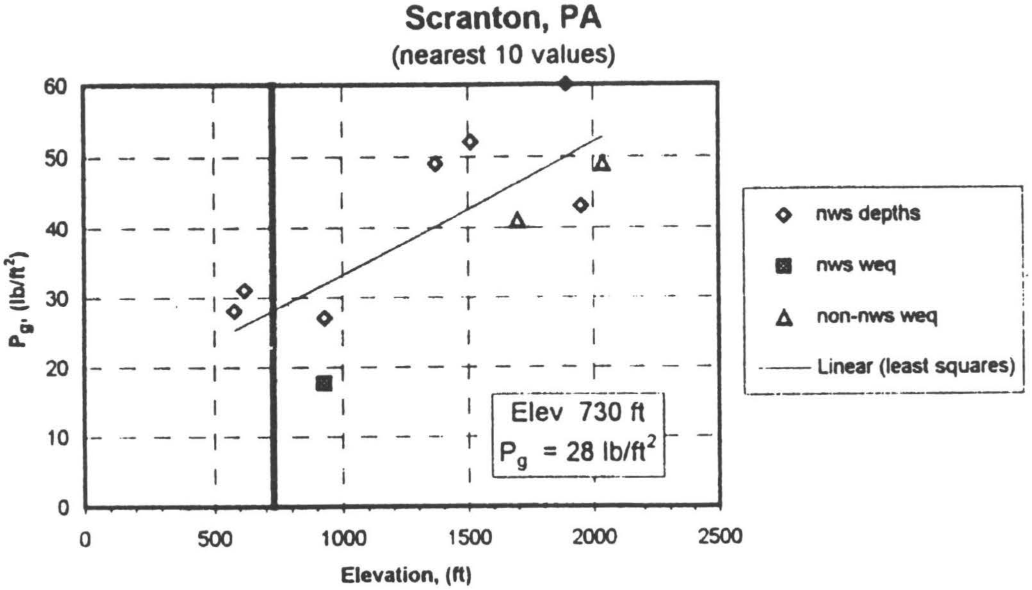


Figure 5. Elevation plot for Scranton, Pennsylvania.

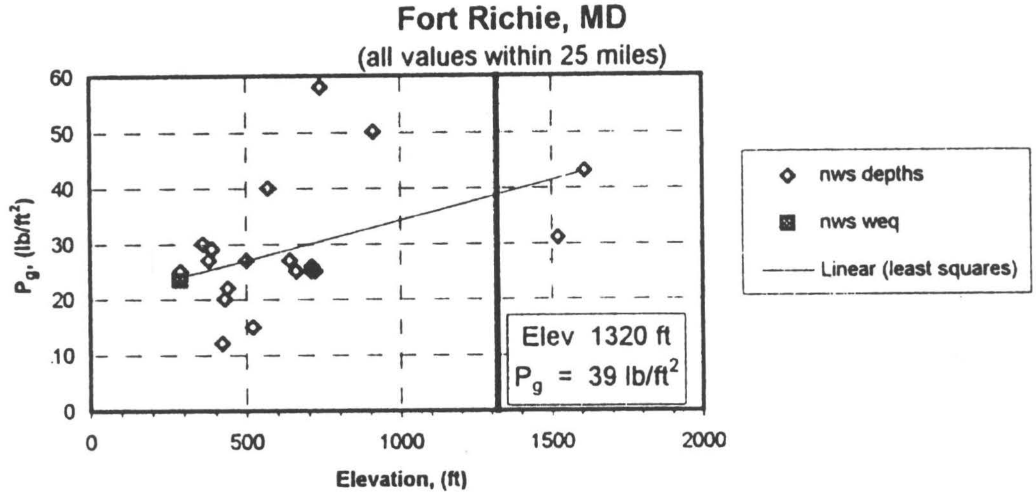


Figure 6. Elevation plot for Fort Richie, Maryland.

5 CONCLUSIONS AND RECOMMENDATIONS

We have conducted over 400 case studies using the data and methodology described in this article. The case study answer is self-evident and uncontroversial after a few minutes of study for some sites of interest, but inconsistencies and considerable variability exist in the data available for many sites. Plots of P_g vs. elevation are quite helpful but, even with them, we often arrive at somewhat different answers. We have always been able to agree upon a single answer after a brief discussion of issues.

We recently initiated cooperative work with structural engineering associations from Maine and New Hampshire. We provided computerized case study forms and snow load vs. elevation plots for many sites of interest to them and have trained their volunteers to conduct snow load case studies. We are also analyzing the same material and will compare results. If we and they arrive at similar answers, we will have gained confidence in our methodology. If answers do not agree, we hope to incorporate any lessons learned into our report (Tobiasson and Greatorex 1996) before it is published.

Perhaps we will conduct similar studies for other states. Alternatively we may be able to simply pass that task along to others to do it on their own using the information in our report. We may place the database and computerized case study procedure on the worldwide web.

It will be interesting to compare case study results for the Rocky Mountain States with the values devel-

Table 2. Upper and lower limits of snow load zones (lb/ft^2).

Upper Limit	2	7	12	17	22	27	32	37
ZONE	*0*	*5*	*10*	*15*	*20*	*25*	*30*	*35*
Lower Limit	0	3	8	13	18	23	28	33
Upper Limit	44	54	64	74	84	94	104	
ZONE	*40*	*50*	*60*	*70*	*80*	*90*	*100*	
Lower Limit	38	45	55	65	75	85	95	

To convert lb/ft^2 to kN/m^2, multiply by 0.0479

oped years ago by several structural engineering groups in those states using a variety of methods. Perhaps all this can lead to a consistent analytical approach for determining ground snow loads for design purposes all across the nation.

Once a large body of case studies accumulates, it should be possible to use them to improve the national map.

6 REFERENCES

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