ERDC/CRREL TR-02-6

US Army Corps of Engineers®
Engineer Research and Development Center

Ground Snow Loads for New Hampshire

Wayne Tobiasson, James Buska, Alan Greatorex,
Jeff Tirey, Joel Fisher, and Steve Johnson

February 2002

Cold Regions Research and Engineering Laboratory

Approved for public release; distribution is unlimited.

Abstract: Because of New Hampshire's hilly landscape, mapped values of ground snow load are not available for much of its area. We conducted snow load case studies to establish ground snow loads for a specific elevation in each of the 259 towns in the state. That work was done by three researchers and three structural engineers practicing in New Hampshire. While our methods of analysis varied somewhat, our results were comparable and the feedback we received from each other was quite valuable. We also established a statewide elevation adjustment factor to transfer our snow load answers to other elevations in each town. We suggest that similar studies be conducted for other places in the United States where mapped values are not available because of extreme local variations in ground snow loads.

This project has been a collaborative effort by the Structural Engineers of New Hampshire (SENH) and the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL).

SENH

US Army Corps of Engineers®
Cold Regions Research & Engineering Laboratory

Technical Report
ERDC/CRREL TR-02-6

US Army Corps
of Engineers®
Engineer Research and
Development Center

Ground Snow Loads for New Hampshire

Wayne Tobiasson, James Buska, Alan Greatorex,
Jeff Tirey, Joel Fisher, and Steve Johnson

February 2002

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

PREFACE

This report was prepared by Wayne Tobiasson, P.E., Research Civil Engineer (retired volunteer); James Buska, Research Civil Engineer; and Alan Greatorex, Civil Engineering Technician of the Civil and Infrastructure Engineering Branch, Cold Regions Research and Engineering Laboratory (CRREL), Engineering Research and Development Center (ERDC), U.S. Army Corps of Engineers; and Jeff Tirey, P.E., Structural Engineer; Joel Fisher, P.E., Structural Engineer; and Steve Johnson, P.E., Structural Engineer of Structural Engineers of New Hampshire Inc. (SENH). SENH is a non-profit professional association of structural engineers. Mr. Tirey is a principal of Tirey and Associates, P.C. of Littleton, NH; Mr. Fisher is a Manager, Structural Engineering, with Rist-Frost-Shumway Engineering of Laconia, NH; and Mr. Johnson is a Structural Engineer with Vanasse Hangen Brustlin Inc. of Bedford, NH.

The authors thank George Blaisdell and Kathy Jones of CRREL for their reviews and comments on this report.

This work was sponsored by the U.S. Army Corps of Engineers, the New Hampshire Building Code Officials Association, and the following New Hampshire structural engineering firms:

- Altus Engineering
- CLD Consulting Engineers Inc.
- Emanuel Engineering
- H.E.B. Civil Engineers P.A.
- H.L.Turner Group
- Hayashi Corporation
- Hoyle, Tanner and Associates
- JSN Associates
- McFarland-Johnson, Inc.
- Rist-Frost-Shumway Engineering
- SEA Consultants
- Stahlman Engineering Corporation

- Steffensen Engineering
- Tirey and Associates, P.C.

About 60% of the work reported here was done on a volunteer basis.

Renee Melendy and Arlene Phillips of CRREL compiled our case study answers in such a way that the author of each value and comment was unknown to the rest of us.

CONTENTS

ILLUSTRATIONS

TABLES

Ground Snow Loads for New Hampshire

WAYNE TOBIASSON, JAMES BUSKA, ALAN GREATOREX, JEFF TIREY, JOEL FISHER, AND STEVE JOHNSON

1 INTRODUCTION

Determining appropriate snow loads is a critical step in the design of structures in cold regions. Because of New Hampshire's hilly terrain, there are extreme local variations in snow loads, and mapped values are not available in codes and standards for much of the state. In such areas the selection of an appropriate snow load is left to the authority having jurisdiction. In most cases such authorities know little about snow loads. Errors and inconsistencies result, which jeopardize public safety.

These problems prompted CRREL and Structural Engineers of New Hampshire Inc. (SENH) to work together to generate snow load values for all locations in the state except for a few high-elevation places.

For the design of structures in the United States, the primary resource document used by various building codes is American Society of Civil Engineers (ASCE) Standard 7, "Minimum design loads for buildings and other structures" (ASCE 2000). It is commonly referred to as ASCE 7-98. It is revised and reissued every few years. The next edition will be referred to as ASCE 7-02. The first step in determining design snow loads is to determine the ground snow load at the place of interest. ASCE 7-98 contains a map of the United States overlaid with that information. That map was made by Tobiasson and Greatorex of CRREL using data from 204 "first-order" National Weather Service (NWS) stations, where snow depths and snow loads are measured frequently, and data from about 11,000 other NWS "co-op" stations, where only the depth of snow on the ground is measured frequently. In some areas, extreme local variations in ground snow loads preclude mapping at a national scale. In those areas the national map contains the designation "CS" instead of a value. CS indicates that case studies are required to establish ground snow loads in these areas. In other areas the values presented on the map only apply up to certain elevations, which are shown in parentheses. Case studies are also required above such elevations.

Figure 1 presents the information from the ASCE 7-98 map for New Hampshire, showing county and town boundaries. The word "town," as used here, represents both incorporated towns and other unincorporated places. In total these 259 towns cover all of New Hampshire's land. The zoned values in Figure 1 are ground snow loads with a 2% annual probability of being exceeded (i.e., they represent a 50-year mean recurrence interval). As can be seen in Figure 1, all of New Hampshire is either in a "CS" area or the zoned values have elevation limits (the numbers in parentheses) above which case studies are needed. Thus, case studies are needed to determine ground snow loads for many structures in New Hampshire. Section 7.2, "Ground Snow Loads, p_g," of ASCE 7-98 requires that, in these situations, ground snow loads *"shall be based on an extreme value statistical analysis of data available in the vicinity of the site using the value with a 2% annual probability of being exceeded (50-year mean recurrence interval)."*

At CRREL a methodology has been developed to conduct snow load case studies. It and the data used are described in the paper, "Database and methodology for conducting site specific snow load case studies for the United States," which was presented at the Third International Conference on Snow Engineering (Tobiasson and Greatorex 1997). That database also contains information from an additional 3300 locations across the United States where ground snow loads are measured a few times each winter by other agencies and companies. These are referred to as "non-NWS" stations.

Figure 2 shows New Hampshire overlaid with town boundaries and the location of each station in the database used to perform case studies in New Hampshire. There are 1 NWS "first-order" station, 89 NWS "co-op" stations, and 91 "non-NWS" stations in New Hampshire. First-order stations in adjacent states within 50 miles (80 km) of the border and other stations within 25 miles (40 km) of the border were also used in our analysis. They are also shown in Figure 2. In total, 388 stations were available, of which 4 were NWS "first-order" stations; 192 were NWS "co-op" stations; and 192 were "non-NWS" stations. Of these stations, 302 had enough data to allow calculation of 50-year ground snow loads.

SENH is a nonprofit professional association of structural engineers. Several SENH members were concerned that the lack of definitive ground snow load guidance for much of New Hampshire was resulting in inconsistent design criteria. They felt that many engineers and local code officials did not know appropriate values. In a survey SENH conducted in 1995, 68% of the 220 towns that responded to the survey said they required, as a minimum, the value presented in the 1993 BOCA Code (BOCA 1993). However, over 80% of New Hampshire towns were in a blacked-out area of the snow load map in that code.

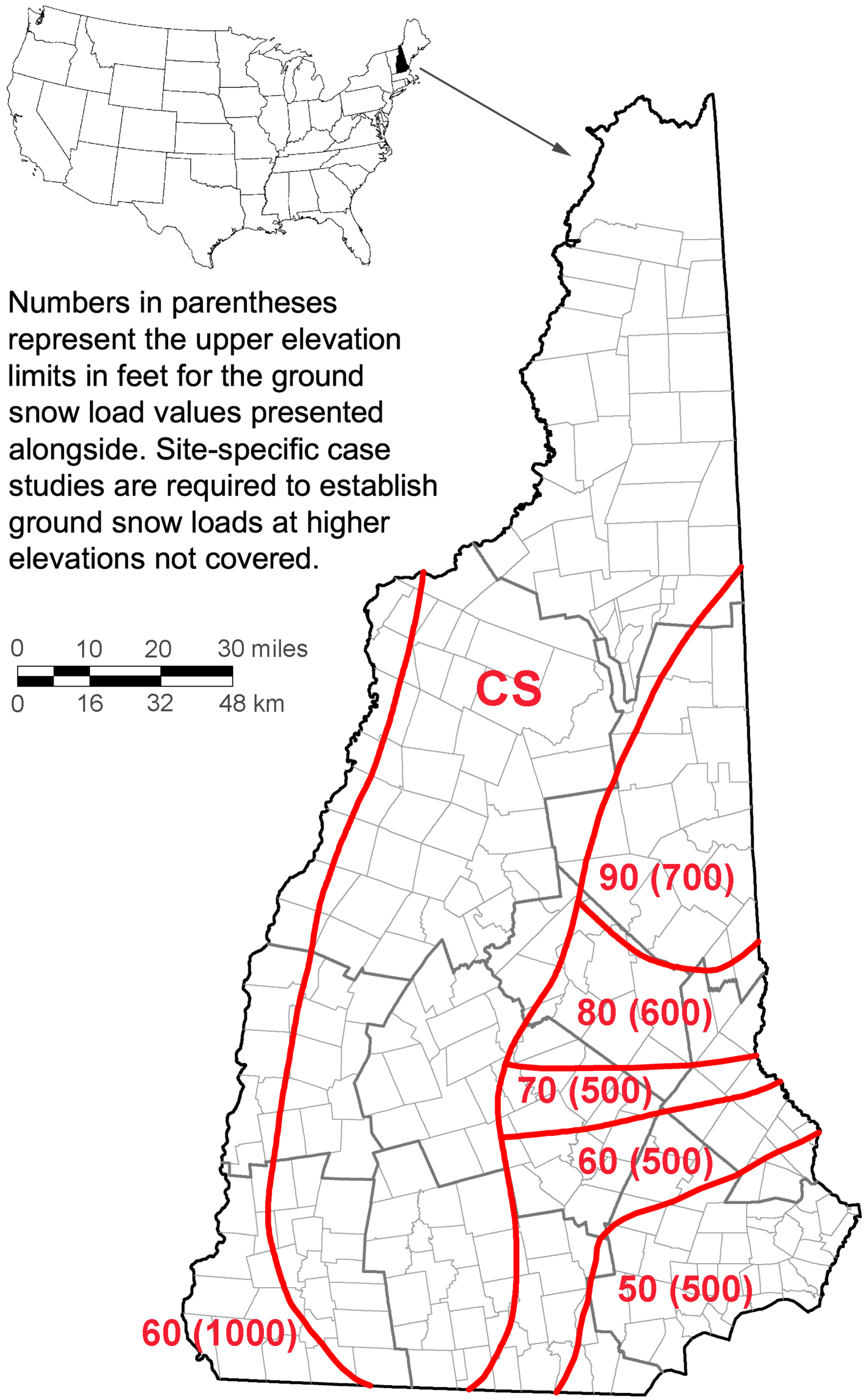


Figure 1. State of New Hampshire, showing town and county boundaries overlaid with the ground snow load information in ASCE 7. (To convert lb/ft^2 to kN/m^2, multiply by 0.048; for ft to m, multiply by 0.305.)

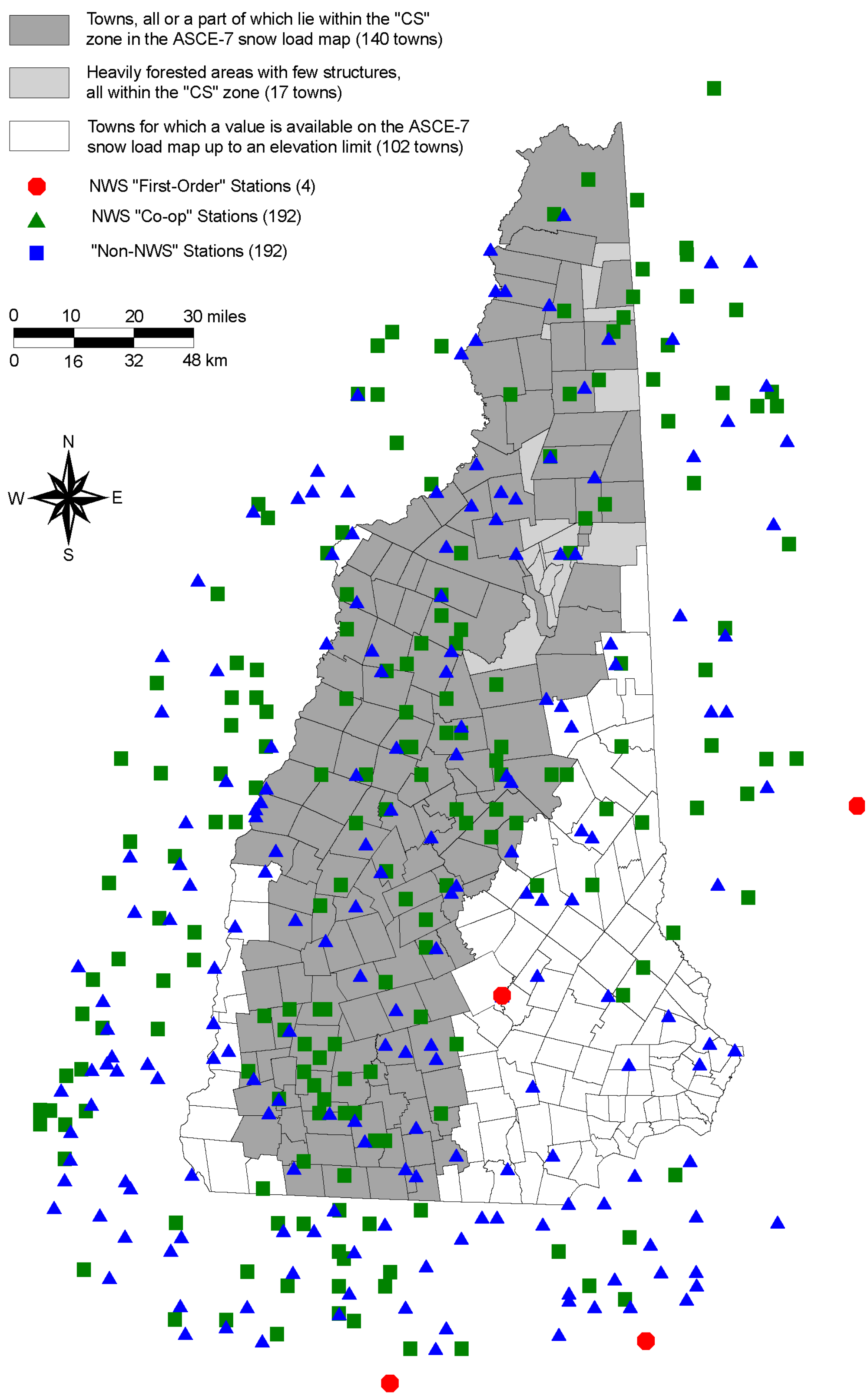


Figure 2. State of New Hampshire, showing stations where ground snow load information is available for our three categories of towns.

That map is an older version of the national snow load map in ASCE 7-98. It was also made by CRREL. In blacked-out areas of that map, no values are given because *"extreme local variations in snow loads preclude mapping at this scale."* Clearly, many of those who responded did not know they were located in areas where no ground snow load was provided by the 1993 BOCA Code. When ground snow loads are not available on that map, that code indicated that such loads *"shall be determined by the local jurisdiction requirements."* The SENH survey revealed that the manner in which such determinations were being made was inconsistent, and little or no technical evidence was available to support the values being used. Several SENH structural engineers felt that, for certain towns, design values were too low, and consequently, inappropriately high risks were being taken by some structural engineers and by the general public.

SENH members expressed interest in using the CRREL database and methodology to develop ground snow loads for each town in New Hampshire. Several volunteered their time to conduct case studies. All prior case studies had been done by two or three CRREL personnel familiar with the database and methodology. To see how well the methodology could be used by others to determine ground snow loads, CRREL personnel trained five practicing licensed SENH engineers in the case study methodology, and 20 case studies were done independently by the two groups.

This pilot study showed that comparable results could be achieved when the groups shared ideas. CRREL and SENH then entered into a Cooperative Research and Development Agreement (CRDA) to determine ground snow loads for 140 New Hampshire towns in the "CS" zone of the snow load map in the 1995 edition of ASCE Standard 7 (i.e., ASCE 7-95). The same snow load map is in ASCE 7-95 and ASCE 7-98 and will be in ASCE 7-02. These towns are shown with dark shading in Figure 2. Seventeen other "towns" in that zone in portions of the White Mountain National Forest, where little or no construction is to be expected, were not studied. These 17 "towns" are shown with light shading in Figure 2.

When we began this CRDA, we chose not to do case studies for the remaining 102 towns where, as shown in Figure 1, ground snow load values up to a limiting elevation were available on the snow load map in ASCE 7-95. The likelihood of obtaining somewhat better values when sites are studied in detail is acknowledged in Section C7.2 of the Commentary to ASCE Standard 7, which indicates that *"Detailed study of a specific site may generate a design value lower than that indicated by the generalized national map. It is appropriate in such a situation to use the lower value established by the detailed study. Occasionally a detailed study may indicate that a higher design value should be* *used than the national map indicates. Again, results of the detailed study should be followed."*

After completing our study of 140 towns, we did case studies for 6 of the remaining 102 towns as a test. Our case study answers, used with an "elevation adjustment factor," should be better than the mapped values. Based on the results of our six-town test we concluded that they were. Thus, we increased the scope of our initial study of 140 towns to 259 towns and thereby covered every "town" in the state.

2 ESTABLISHING CASE STUDY LOCATIONS

The elevation of New Hampshire land varies from sea level along its short coastline to 6,288 ft (1917 m) at the summit of Mount Washington, which is the highest point of land east of the Mississippi River in the northern half of the United States. Relative to the mountains of the American West, many of which have summit elevations exceeding 14,000 ft (over 4,000 m), Mount Washington is not high. However, what it lacks in elevation, it more than makes up for in meanness, as it is the place where the strongest winds on earth have been recorded. Those winds peaked at 231 mph (103 m/s). The White Mountains of New Hampshire are well known by climbers, hikers, and skiers, as are New Hampshire's picturesque villages, rolling farmland, and forests. Few buildings exist in New Hampshire at elevations exceeding 2,500 ft (762 m).

United States Geological Survey (USGS) 1:24,000-scale (1:25,000 when metric) topographic maps of the state were used to determine the coordinates of the geographical center, not the population center, of each town to the nearest minute of latitude and longitude. The case study was conducted there.

Town names are those used by USGS. Some differences exist on other maps and tabulations. They are slight variations except for Livermore, which is also known as "Unorganized Territory."

The USGS maps show topography, town boundaries, roads, and buildings. We did not use the elevation of the geographical center as the case study elevation but, instead, determined six elevations for each town: (1) lowest land; (2) lowest building; (3) lower limit of most buildings; (4) upper limit of most buildings; (5) highest building; and (6) highest land. Significant elevation differences exist within most towns, as shown in Appendix A, which summarizes the information we obtained from the USGS "quad sheets" for each town.

We chose an elevation near the upper limit of most buildings as our case study elevation to encompass most construction. Usually we rounded down to the nearest 100 ft (30.5 m), occasionally somewhat more. However, when the difference in elevation between the upper and lower limits of most buildings was only a few hundred feet (about 100 m), we rounded up. Had we done these case studies at lower elevations, failure to apply the elevation adjustment factor would have resulted in inappropriately low design loads for some of the buildings in each town. We reasoned that by providing a single value at a relatively high elevation, such a mistake would result in over-design rather than an unsafe structure.

The case study elevation for each town is also presented in Appendix A. Since much higher ground was present in most towns than is represented by our database, an upper limit on elevation was needed for any ground snow loads developed.

Summary statistics for the elevation information in Appendix A are at the end of that appendix. The minimum, median, average, and maximum case study elevations for these New Hampshire towns are 50, 1000, 1030, and 2500 ft, respectively. Some land in 75 of the 259 towns is higher than 2500 ft (762 m). In 8 of those towns, buildings currently exist above 2500 ft.

Prior case studies done at CRREL had indicated that design snow loads in northern New England increase, on average, by 2.0–2.5 lb/ft^2 for every 100 feet (0.31–0.39 kN/m^2 for every 100 m) of increase in elevation. With the "buildable" elevation range in many towns in excess of 500 ft (152 m) [and in some towns in excess of 1000 ft (305 m)], it was evident that a single value, appropriate for use at the higher buildable elevations in a town, would result in significant over-design at lower elevations. For example, for a town with a 700-ft (215-m) elevation difference between the maximum and minimum buildable elevations, over-design at the lower buildable elevations would be 14–17.5 lb/ft^2 (0.67–0.84 kN/m^2). Thus, we decided to use an elevation adjustment factor to adjust our answer at the case study elevation for each town to other elevations in that town.

Another reason that argued for the introduction of an elevation adjustment factor and an upper limit on elevation was the ever-rising maximum buildable elevation in many towns as development proceeds up hillsides.

Thus, for each town we did not generate a single ground snow load for all places in that town; instead we generated a value at an elevation above that of most building sites that would be adjusted to other elevations in that town using an elevation adjustment factor.

3 CASE STUDY FORMS AND GUIDELINES

Case study forms were computer-generated for each town. Figures 3 and 4 present such forms for the town of Salisbury. The data available in the vicinity are tabulated on the first page or two as shown in Figure 3. For many towns, that tabulation contains data from neighboring states. For Salisbury, periods of record range from 4 to 44 years; about half the information is from NWS first-order and co-op stations and half is from non-NWS stations. Ground snow loads are available in the vicinity at elevations from 350 to 1500 ft (107 to 457 m), bracketing the 900-ft (274-m) elevation chosen for the Salisbury case study.

The final page of each case study (Fig. 4) contains two plots of ground snow load (p_g) vs. elevation. The upper plot (called the "nearest values" plot) contains just the data from the nearest six to nine stations, while the lower plot (called the "all values" plot) contains all the data available within a 25- to 30-mile (40- to 48-km) radius, plus any NWS first-order data within 50 miles (80 km). As shown in Figure 4, the elevation of interest is highlighted on each plot as a dark vertical line. Each plot also contains a straight line of best fit using least squares. The ground snow load where the line of best fit crosses the elevation of interest is shown in a box to the right of each plot. For some towns that ground snow load is similar on the two plots, but for other towns it is quite different. Salisbury was chosen to show how much the two plots could vary. For most towns the two plots are not as different as those of Salisbury.

In the Northeast, ground snow loads generally increase with increasing elevation up to the treeline. Above the treeline they may decrease because of wind action. The straight line of best fit in the nearest-values plot in Figure 4 has a negative slope (i.e., elevation adjustment factor) of –1.7 lb/ft^2 per 100 ft (–0.26 kN/m^2 per 100 m). The few data points on this nearest-values plot result in an unrealistic slope, so the ground snow load answer of 68 lb/ft^2 (3.3 kN/m^2) is not to be trusted. The all-values plot in Figure 4 contains enough data points to generate a physically more realistic slope of 2.5 lb/ft^2 per 100 ft (0.39 kN/m^2 per 100 m) and thus a more believable ground snow load of 80 lb/ft^2 (3.8 kN/m^2), which is our case study answer at an elevation of 900 ft (274 m) for Salisbury.

Data from near the 6288-ft (1917-m) summit of Mt. Washington created problems. The tabulated ground snow load there is only 56 lb/ft^2 (2.7 kN/m^2), which is far below the ground snow load at many other places at elevations below 1000 ft (305 m). The high winds on that treeless summit result in ground snow load measurements that are much too low to be used for our purposes. The lines of best fit on several plots containing the Mt. Washington value have negative slopes. Figure 5 shows how the Mt. Washington value adversely

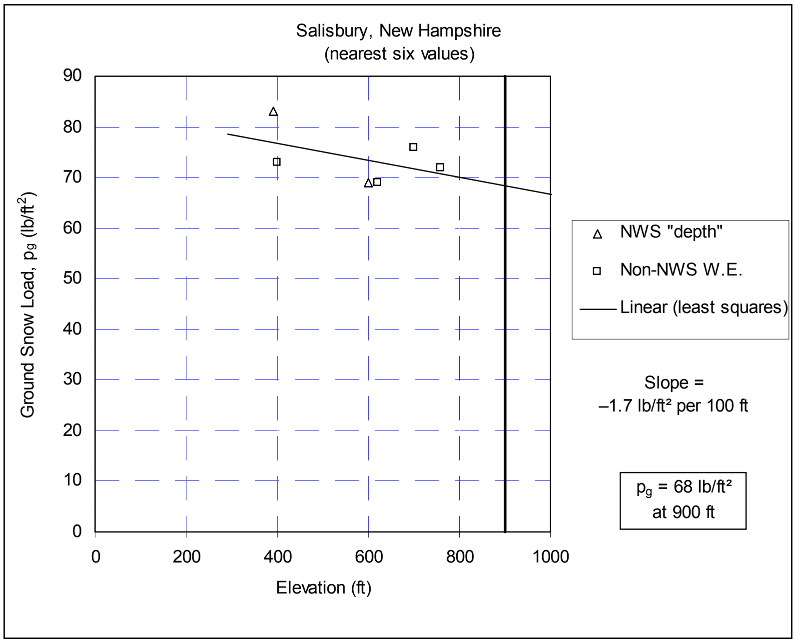
SNOW LOAD CASE STUDY FOR

Salisbury, New Hampshire

Latitude 43° 23' N Longitude 71° 46' W Elevation 900 ft

Station	Radius (mi.)	Azimuth (from site)	Elev. (ft)	P_g (lb/ft²)	Record Max. (lb/ft²)	Years of Record Total	Years of Record No Snow	P_g/P_{max} Ratio
NWS FIRST ORDER								
CONCORD (W.E.)	18	125	350	63	43	40	0	1.47
CONCORD WSO AP ("DEPTH")	18	125	350	44	38	44	0	1.16
NEW HAMPSHIRE (NWS co-op)								
BLACKWATER DAM	5	143	600	69	59	44	0	1.17
FRANKLIN	7	56	390	83	94	13	0	0.88
FRANKLIN FALLS DAM	8	54	430	72	67	44	0	1.07
SOUTH DANBURY	10	311	930	101	85	22	0	1.19
NEW LONDON	11	279	1340		51	9	0	
BRADFORD	14	236	970	75	73	39	0	1.03
BRISTOL 2	14	9	590		27	8	0	
WEST HENNIKER	16	201	500		59	5	0	
GRAFTON	16	315	840	101	67	25	2	1.51
MOUNT SUNAPEE	16	261	1260	132	78	18	2	1.69
GILMANTON	18	79	1030	86	55	16	0	1.56
LAKEPORT	19	61	560	69	68	34	0	1.01
LAKEPORT 2	19	61	500	67	28	11	2	2.39
ALEXANDRIA	19	339	1370		38	5	0	
GILMANTON 2 E	20	83	800		23	4	0	
WEARE	21	174	720	50	32	20	0	1.56
NEWPORT	21	270	790	78	57	39	1	1.37
NORTH CHICHESTER	21	109	360		27	8	0	
DEERING	22	201	1010	83	41	16	0	2.02
EAST DEERING	22	189	790	77	65	26	0	1.18
SOUTH WEARE	23	171	700	82	71	18	0	1.15
ALTON	25	84	800		28	5	0	
NEW HAMPSHIRE (NON-NWS)								
SALISBURY	1	90	760	72	54	40	0	1.33
ANDOVER	4	315	700	76	61	32	0	1.25
BLACKWATER	5	166	620	69	56	40	0	1.23
FRANKLIN FALLS	7	45	400	73	54	39	0	1.35
SOUTH DANBURY	10	315	800	74	62	40	0	1.19
DAY POND	12	218	780	83	62	29	0	1.34
LITTLE SUNAPEE	15	287	1490	93	59	31	0	1.58
NEW LONDON	15	287	1170	86	75	26	0	1.15
CHASE VILLAGE	16	180	700	81	59	29	0	1.37
GRANLIDEN	17	276	1220	89	60	31	0	1.48
SADDLE HILL	18	33	1020	73	69	41	0	1.06
GILFORD	18	49	1000	90	71	40	0	1.27
CARDIGAN MOUNTAIN	19	336	1500	72	64	15	0	1.13
NEW HAMPTON	19	24	560	76	62	41	0	1.23
GRAFTON CENTER	19	317	900	69	60	24	0	1.15
NELSON BROOK	20	78	770	89	55	11	0	1.62
EVERETT DAM	22	159	460	78	53	29	0	1.47
WASHINGTON	22	236	1500	88	64	22	0	1.38
MEREDITH	22	43	880	80	62	40	0	1.29
WASHINGTON	22	237	1340	90	61	11	0	1.48
WEIRS BEACH	23	54	520	50	38	27	0	1.32
HOYT HILL	24	360	950	72	73	41	0	0.99
SALMON BROOK	25	223	1300	88	57	22	0	1.54

Figure 3. Case study data tabulation for the town of Salisbury. (To convert lb/ft^2 to kN/m^2, multiply by 0.048; for miles to km, multiply by 1.61; for ft to m, multiply by 0.305.)



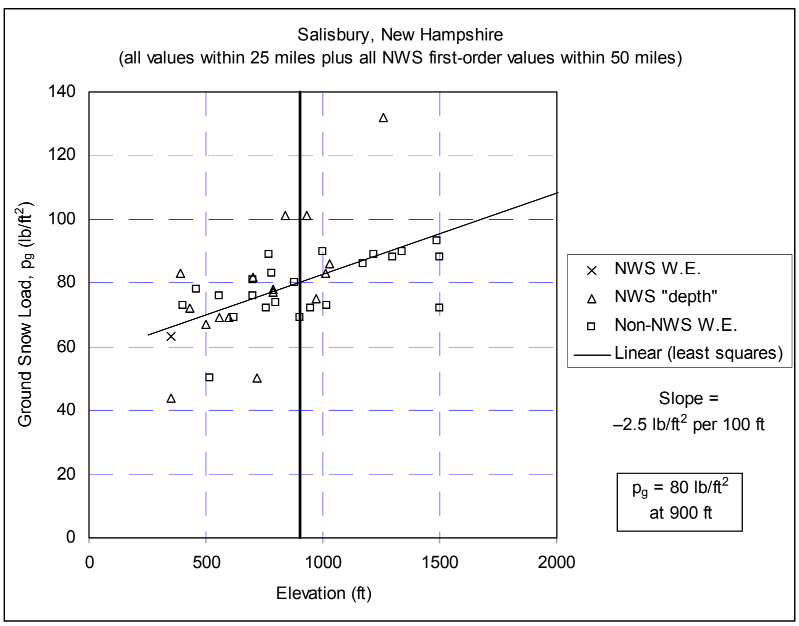


Figure 4. Case study plots for the town of Salisbury. Note that the scales on the two plots differ. NWS W.E. indicates a value based on snow load (i.e., water equivalent) measurements at a NWS first-order station. NWS "depth" indicates a load value based on snow depth measurements at a NWS first-order or co-op station. Non-NWS W.E. indicates a value based on snow load measurements at a non-NWS station. (To convert lb/ft^2 to kN/m^2, multiply by 0.048; for miles to km, multiply by 1.61; for lb/ft^2 per 100 ft to kN/m^2 per 100 m, multiply by 0.157.)

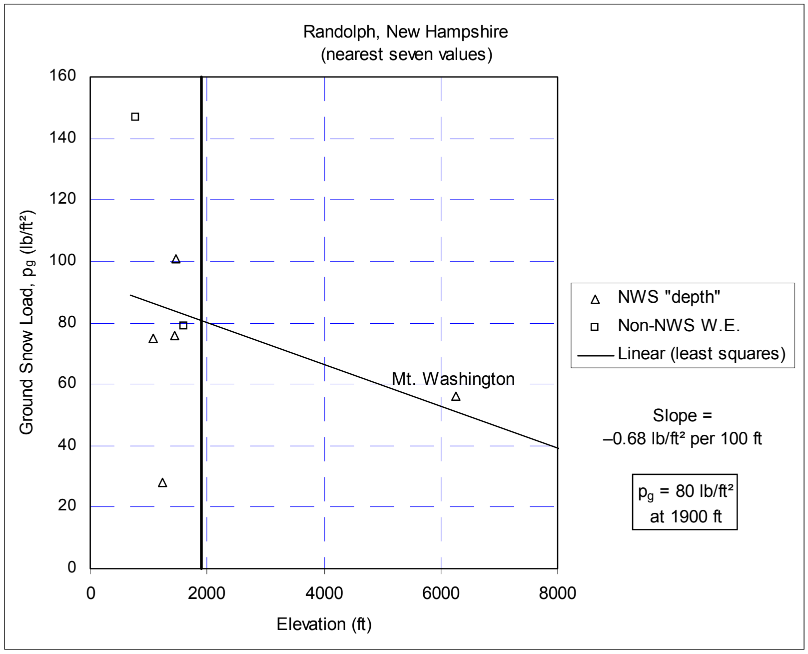


Figure 5. Nearest-values plot for Randolph, showing the adverse effect of the station near the windswept summit of Mt. Washington on the slope of the line of best fit. (To convert lb/ft^2 to kN/m^2, multiply by 0.048; for ft to m, multiply by 0.305; for lb/ft^2 per 100 ft to kN/m^2 per 100 m, multiply by 0.157.)

influences the nearest-values plot for Randolph. The line of best fit has a physically unrealistic negative slope, and the ground snow load where that line crosses the elevation of interest is too low to be accepted. The adverse influence of Mt. Washington's low value is very great for Randolph since the six remaining data points are all at much lower elevations and the elevation differences among them are relatively small. On the all-values plot, other stations counteract Mt. Washington's low value; the slope increases to 1.8 lb/ft^2 per 100 ft (0.28 kN/m^2 per 100 m), and the intercept at 1900 ft (579 m) increases to 111 lb/ft^2 (5.3 kN/m^2). When all this was considered, our answer for Randolph became 110 lb/ft^2 (5.3 kN/m^2) at 1900 ft (579 m).

While Mt. Washington and a few other stations frustrated us, their implications were worth considering. Mt. Washington's redeeming value was to remind us that our elevation adjustment factor should not be applied above the treeline.

Each of the three CRREL researchers and the three SENH structural engineers involved was provided with (1) a copy of the "data and methodology" report mentioned previously (Tobiasson and Greatorex 1997), (2) several representative case studies done by CRREL previously, and (3) written guidance by Tobiasson and Greatorex for conducting case studies. That guidance is presented in Appendix B.

We began by working on 40 towns, about half of which were in the rugged northern portion of the state and the rest in the rolling hills of southwestern New Hampshire. We each conducted our analysis in our own way and forwarded our "preliminary" ground snow load answers and comments to two individuals at CRREL, who tallied them without divulging the author of each value and then sent the tally to each of us. We each privately re-assessed our answers in light of the answers and comments of the others and then sent in our "semi-final" answers, which were tallied in a similar fashion and returned to us.

We then developed a "team semi-final" answer, rounded to the nearest 5 lb/ft^2 (0.24 kN/m^2), for each town by throwing out the highest and lowest answer and averaging the remaining four answers. If that resulted in an answer exactly midway between possible rounded answers, we used any comments to go up or down. For example, if the four answers were 60, 60, 65, and 65, and the only comment, provided with one of the 60s, was, "perhaps 65," our answer would be 65. Had that comment been "perhaps 55," our answer would have been 60. If the "tie" could not be broken, we reconsidered the high and low answers and any comments associated with them. If a tie persisted, we then chose the higher value. On occasion, our discussions caused individuals to revise their semi-final answers during this process.

We met shortly thereafter to discuss our various methods of analysis and our answers and to arrive at a final answer for each of the 40 towns. At that meeting most of our time was spent resolving ties and discussing the difficulties mentioned above. As a result of our first meeting, we each made some changes to our method of analysis. We then repeated the process for the remaining 100 towns being studied in the portion of the state within the "CS" zone of the ASCE 7-98 snow load map. Our findings to that point are presented in Tobiasson et al. (2000). Thereafter, we ran the six-town test mentioned previously and decided to expand the scope of this project to include a case study for every town in the state. Before we conducted the remaining case studies, we made improvements to the case study forms, as will be discussed.

4 VARIOUS WAYS OF ARRIVING AT ANSWERS

The three individuals representing CRREL had done many case studies and were comfortable with the case study forms and the guidelines for analysis. They used the existing methodology, giving more weight to closer stations and stations with longer periods of record. They gave little weight to stations with less than about 15 years of record, and they gave little weight to stations where the ratio of the 50-year ground snow load (i.e., p_g on the case study tabulation) to the largest ground snow load ever measured there (i.e., the Record Max value on the case study tabulation, hereafter called p_{max}) was greater than 1.6. (The p_g/p_{max} ratio will be discussed further, later in this report.) They flagged such stations on the nearest-values plot and added a few stations somewhat farther away, but with longer periods of record, to replace them. Often more stations were added than were eliminated. Then they either "eyeballed" or calculated a new line of best fit in their quest for that case study's answer. When eyeballing a line of best fit, they gave it a slope of 2–2.5 lb/ft^2 per 100 ft (0.31–0.39 kN/m^2 per 100 m), based on the written guidelines mentioned above and attached as Appendix B.

Two of them found it valuable to bound the filtered data by upper and lower lines at one of these slopes. Their answers were usually somewhat above the midpoint of the upper and lower bounds at the case study elevation. The third individual devoted additional attention to the geographical position of stations used in his analysis. He plotted the spatial relationship of stations surrounding the point of interest for some case studies.

The three practicing structural engineers from SENH had participated in the pilot study. Each had developed a slightly different way of doing case studies. They chose not to work on the case study plots, believing them to contain enough information of limited value to hide trends of interest. They only used the better stations in the data tabulation in their analyses, and they assumed an elevation adjustment factor of 2.0–2.5 lb/ft^2 per 100 ft (0.31–0.39 kN/m^2 per 100 m).

One of them believed that the NWS co-op information, since it is based on measurements of the depth of snow on the ground, not measurements of the weight of that snow, is inferior to the non-NWS values, which are measurements of the weight. The other five individuals (two from SENH and three from CRREL) believed that the NWS and non-NWS data sets were of comparable value, each having its own strengths and weaknesses. For example, the few readings taken each winter at most of the non-NWS stations result in lower values since the annual maximum is likely to be missed, but it can also result in a bigger range of annual maximums. The net result can be to create either bigger or smaller 50-year ground snow loads than would result if readings were available daily, as they are for the NWS co-op stations.

The individual who focused on the non-NWS data included NWS information only when few non-NWS data were available. He sought to have 6 to 8, and occasionally 10, stations with 20 or more years of record in his analysis.

He only used stations where the p_g/p_{max} ratio was less than 1.5. He re-plotted the p_g values selected vs. elevation and used a straight-line, least-squares fit to establish a preliminary answer. That answer was modified with consideration given to the slope of his trend line and the scatter of points. When several points at about the elevation of interest fell above the trend line, he increased his preliminary answer.

The other two SENH structural engineers considered both NWS and non-NWS data, but one of them gave more weight to the non-NWS information because it eliminated the step of having to relate snow depths to snow loads (see equation 1 in Tobiasson and Greatorex 1997). Both of these individuals developed selection criteria that eliminated from consideration a number of the stations on the case study form. The acceptance criteria of one individual were (1) at least 15 years of record; (2) less than 15, sometimes 20, miles (24, sometimes 32, km) away; and (3) a p_g/p_{max} ratio of no more than 1.75 for non-NWS stations and no more than 1.5 for NWS stations. The other individual's acceptance criteria were (1) at least 20 years of record; (2) less than 15 miles (24 km) away; and (3) a p_g/p_{max} ratio of no more than 1.5. Variations in the distance limit reflect terrain variability in the state and the number of stations available in the vicinity. Overall, their acceptance criteria were much the same as those used by the other four participants.

Both then adjusted each selected ground snow load to the case study elevation by using an elevation adjustment factor of 2.0–2.5 lb/ft^2 per 100 ft of elevation difference (0.31–0.39 kN/m^2 per 100 m). Both then determined the average value of the ground snow load at that elevation for all the stations selected. In the vicinity of Mt. Washington, where a station or two had a value quite different from this average, a second average was often calculated, eliminating the outliers. One individual developed separate averages for all data and for non-NWS data and gave more weight to the non-NWS average. He always plotted all the data he analyzed and frequently referred back to the case study plots before finalizing his answer.

A review of each individual's final answers indicates that no one's approach caused them to be consistently much lower or much higher than the group's final answer; the processes we each developed tended to generate similar answers. We expect that if any one of us had used our method of analysis alone, without receiving feedback from the others along the way, we may have arrived at significantly different answers for some towns. Thus, we conclude that there is great merit in involving several individuals in a way that they periodically receive anonymous feedback from each other.

This process allowed the group to determine most answers before our meetings and precluded the need to discuss many of the case studies at those meetings. When we met, we concentrated on the few case studies on which we had remaining concerns or where there was a significant variation in answers. This left time for us to explore ways of improving the process, ways of simplifying our findings, and ways of incorporating them into the national standard (i.e., ASCE Standard 7) and into practice within New Hampshire. It also allowed us time to discuss our increasing understanding of the variation of ground snow loads in New Hampshire.

5 p_g/p_{max} RATIO

For 69 of the 302 stations shown in Figure 2, where a 50-year ground snow load (p_g) had been calculated, the p_g/p_{max} ratio exceeded 1.5. Often, the 50-year ground snow load at such stations greatly exceeded other ground snow loads in the vicinity. For example, the upper data point in the all-values plot in Figure 4 has a high p_g/p_{max} ratio of 1.7. Responding to this complication proved to be the most controversial aspect of our analysis. To better understand what was happening, we examined probability plots of several of these stations and determined that, for them, the log-normal distribution used to generate the ground snow load values on the case study forms does not fit the actual trend in lower probabilities very well. Log-normal probability plots for Waterville Valley, Milford, and Milan are shown in Figure 6. The least-squares line of best fit (i.e., the log-normal answer) for Waterville Valley fits the data reasonably well at the 2% annual probability of being exceeded value (i.e., the 50-year mean recurrence interval value), which is to be used for design. The p_g/p_{max} ratio there is 1.11. For Milford the log-normal answer greatly exceeds the data trend there. The p_g/p_{max} ratio there is 1.76. For Milan the log-normal answer is well below the data trend and the p_g/p_{max} ratio is 0.76. Similar plots for other stations with high and low p_g/p_{max} ratios also indicated that the log-normal distribution did not fit those measured values that well. With this evidence we gave little weight in our analysis to stations with high or low p_g/p_{max} ratios.

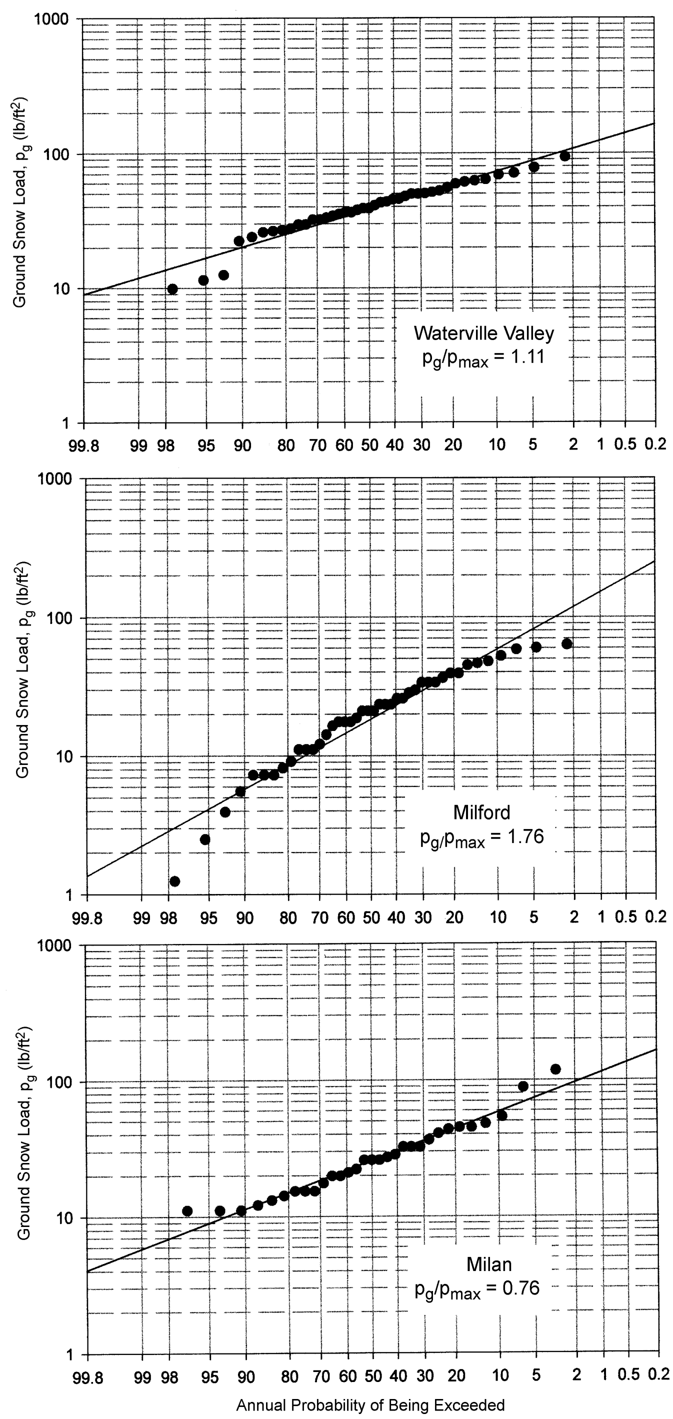


Figure 6. Log-normal probability plots for Waterville Valley, Milford, and Milan, which have p_g/p_{max} ratios of 1.11, 1.76, and 0.76, respectively. (To convert lb/ft^2 to kN/m^2, multiply by 0.048.)

6 INTERCEPT COMPARISONS

Once we had arrived at team answers for the first 140 case studies, we compared them to the intercept values on the nearest-values and all-values plots on the last page of those case study forms (e.g., Fig. 4). The nearest-values plot intercepts did not agree with our team answers well at all. Only 59 of them were within 5 lb/ft^2 (0.2 kN/m^2) of our 140 team answers. For 50 stations the nearest-values plot intercepts were from 10 to 38 lb/ft^2 (0.5 to 1.8 kN/m^2) away from our team answers. The all-values plot intercepts were within 5 lb/ft^2 (0.2 kN/m^2) of our team answers for 116 of the 140 case studies (i.e., 83% of the time). However, for 8 stations the all-values intercepts were 10–20 lb/ft^2 (0.5–1.0 kN/m^2) away from our team answers. Thus, while the all-values intercepts provide good indications of our team answers most of the time, further study will occasionally result in significantly different, better answers.

7 ELEVATION ADJUSTMENT FACTOR

The elevation adjustment factor was also examined on the nearest-values and all-values plots of the first 140 case studies. It is the slope of the line of best fit on those plots (e.g., see Fig. 4). On the nearest-values plot that factor varied widely between 13.5 lb/ft^2 per 100 ft (2.12 kN/m^2 per 100 m) and –9.0 lb/ft^2 per 100 ft (–1.41 kN/m^2 per 100 m). The average value of this widely divergent set of numbers was 1.8 lb/ft^2 per 100 ft (0.28 kN/m^2 per 100 m). We place little value on this average, as it is significantly influenced by some slopes that are physically unrealistic. Stations such as Mt. Washington create these inappropriate slopes. On the all-values plot the slopes make somewhat better physical sense, but Mt. Washington and a few other stations still create problems. These slopes vary from 5.3 lb/ft^2 per 100 ft (0.83 kN/m^2 per 100 m) to –3.0 lb/ft^2 per 100 ft (–0.47 kN/m^2 per 100 m) and average 2.4 lb/ft^2 per 100 ft (0.38 kN/m^2 per 100 m).

We further examined the elevation adjustment factor by studying each station in our database. We excluded stations with less than 15 years of record, others with an elevation above 2500 ft (762 m), and others with p_g/p_{max} ratios less than 0.9 or greater than 1.7. For the remaining stations the line of best fit of their elevation to their 50-year ground snow load, p_g, produced a slope of 2.1 lb/ft^2 per 100 ft (0.33 kN/m^2 per 100 m), as shown in Figure 7. While we expect that the elevation adjustment factor varies from place to place in New Hampshire, we do not have enough data to support such differences. Thus, we have used an elevation adjustment factor of 2.1 lb/ft^2 per 100 ft (0.33 kN/m^2 per 100 m) for all New Hampshire towns.

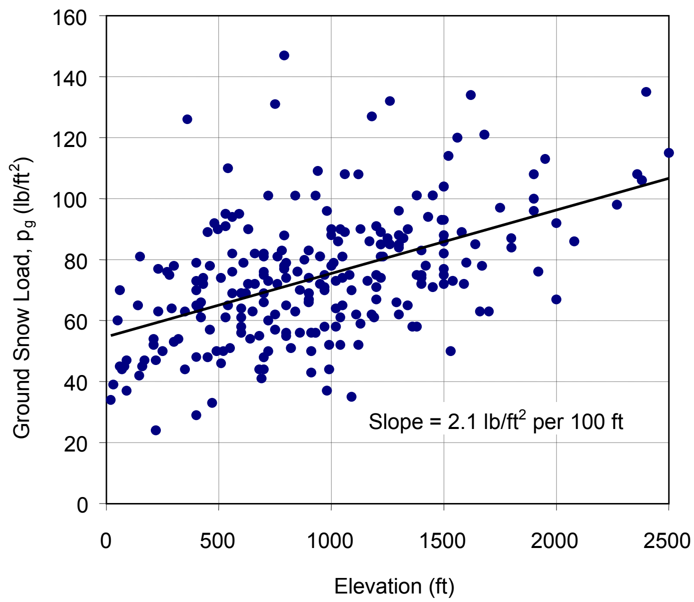


Figure 7. Elevation adjustment factor for the 236 highest-quality stations used in our analyses: 2.1 lb/ft^2 per 100 ft (0.33 kN/m^2 per 100 m). (To convert lb/ft^2 to kN/m^2, multiply by 0.048; for ft to m, multiply by 0.0305.)

We have not fully investigated the upper limit above which our elevation adjustment factor does not apply. At this time it seems safe to use it up to an elevation of 2500 ft (762 m) in New Hampshire, which is well below the treeline. At higher elevations up to the treeline, which is at about 4500 ft (1370 m) in New Hampshire, a larger elevation adjustment factor may be needed. Above the treeline the use of an elevation adjustment factor may not be appropriate. Thus, at all places above 2500 ft (762 m) in New Hampshire, case studies are still needed to determine ground snow loads. Since few structures are built above 2500 ft (762 m) in New Hampshire, our upper limit affects very little construction.

8 ONE LOAD AND ONE ELEVATION CORRECTION FACTOR FOR ALL OF NEW HAMPSHIRE?

After we had completed the first 140 case studies, in an attempt to make our final product as user friendly as possible, we investigated the possibility of simplifying all this to a single “New Hampshire ground snow load” with a single “New Hampshire elevation adjustment factor.” We used an elevation adjustment factor to bring our 140 case study answers to an elevation of 1000 ft (305 m) and then displayed those values on a map of the state. Had they all been about the same, the proposed simplification would have been possible. However, they ranged from lows of 60–70 lb/ft^2 (2.9–3.4 kN/m^2) in the northern portion of the state to 90–100 lb/ft^2 (4.3–4.8 kN/m^2) progressing south into the heart of the White Mountains, then back down to 75–85 lb/ft^2 (3.6–4.1 kN/m^2) farther south in the central portion of the "CS" area shown in Figure 1, then to 70–80 lb/ft^2 (3.4–3.8 kN/m^2) in the southwestern portion of the state (i.e., the bottom of the "CS" zone in Figure 1). We concluded that this amount of variability would preclude the simplification that we hoped might be possible.

9 MODIFICATION OF CASE STUDY TABULATIONS AND PLOTS

After achieving our initial objective of establishing ground snow loads for 140 towns in the "CS" area of the snow load map in ASCE Standard 7 and doing, as a test, case studies for six towns not in the "CS" zone, we decided to expand our coverage to include the rest of the state. However, before proceeding, we agreed to improve the case study forms and plots. Values of the p_g/p_{max} ratio were added to the tabulation. The Salisbury tabulation in Figure 3 does, in fact, contain the p_g/p_{max} ratios along the right margin to illustrate that improvement. We excluded from the plots, stations with any of the following:

- Less than 15 years of record;
- A p_g/p_{max} ratio in excess of 1.7;
- A p_g/p_{max} ratio less than 0.9; or
- An elevation above 2500 ft (762 m).

Thus, on these newer plots the captions (e.g., "nearest six values" and "all values") refer to stations that were not excluded. Any station not plotted was shown in subdued print on the tabulation. These improvements noticeably reduced the time it took each of us to do the 113 remaining case studies. The plots in Figure 4 are not the improved versions.

10 TIME DEVOTED TO THE ANALYSIS

Obtaining the latitudes, longitudes, and elevations in Appendix A from the USGS "quad sheets" was time consuming. Each town took about 12.5 minutes when two of us worked together. Thus, 0.42 man-hours were spent on this per town, for a total of 108 man-hours.

Once the latitude, longitude, and elevation for each case study were determined, a case study tabulation and plots were computer-generated for each town. When only one or two of these are done at a sitting, each case study takes about 30 minutes. About half that time is spent developing maps of the area and verifying that the elevation provided fits. However, with over 100 case study forms to do at once, and with no mapping necessary, the 259 forms for this study were produced by one individual at a rate of about one every 5.6 minutes, for a total of 24 man-hours.

We analyzed the case studies in three phases. Phase 1 involved the first 40. Some of those case studies took twice as long as others, and we all worked at different rates. During the latter portions of Phase 1 most of our time and attention were directed to the few towns where the group had a divergence of opinion. We met for most of a day to finalize our answers on these 40 towns. On Phase 1 we each spent an average of 32.5 minutes per town. Since there were six of us doing each case study, in total we spent 3.25 man-hours per town. This includes the time we spent meeting to discuss our answers and reach a consensus.

An additional 106 case studies were conducted in Phase 2. The average time each of us spent on each Phase 2 town was about 24.2 minutes, for a total of 2.42 man-hours per town. Our pace for Phase 2 was somewhat faster than for Phase 1, which was to be expected.

The final 113 case studies were done in Phase 3. Our average time to do each case study dropped to only 19.1 minutes. Thus, 1.91 man-hours were spent on each Phase 3 town. A portion of the reduction in time for Phase 3 can be attributed to our improving abilities, while another portion was due to the fact that these case studies were in flatter areas of the state, outside the “CS” zone, where answers were easier to obtain from the database. The changes made to the case study forms prior to doing the final 113 case studies significantly reduced the time we spent filtering out data that did not meet our selection criteria.

For the entire project involving 259 towns, our average analysis time per case study was 23.3 minutes, so we devoted an average of 2.33 man-hours to the analysis of each town. The total time spent on the analysis of case study forms was 603 man-hours.

When the times to establish the latitude, longitude, and elevation of each town, produce the case study forms, manage this process, and have a third party compile our various answers in such a way to provide anonymous feedback are also considered, the total time for each case study was 3.15 man-hours. In total, we devoted 815 man-hours to this analysis and averaged 31.5 minutes per case study.

When the time to develop this co-operative agreement, conduct various studies as questions arose, write and present a conference paper, produce this final report, prepare a letter to each town in New Hampshire, have our findings incorporated into the Commentary of ASCE 7-02, and make several presentations on this work at gatherings of engineers is included, the total time increases to about 2000 man-hours.

About 60% of the work reported here was done on a volunteer basis. All of us had difficulties, at one time or another, finding time for this big volunteer project among our other activities.

11 FINDINGS

Our answers for New Hampshire's 259 towns are presented in Table 1. The location of each town is shown in Figure 8. The numbers on the map are those in Table 1 just to the left of the names of the towns. The ground snow load given in Table 1 *only* applies at the elevation listed beside it. To determine the ground snow load at elevations other than those listed in Table 1 (i.e., at elevations other than those where the case studies were conducted), the values in Table 1 should be increased or decreased by an elevation adjustment factor of 2.1 lb/ft^2 per 100 ft (0.33 kN/m^2 per 100 m). For example, in Hanover, where the Table 1 value is 75 lb/ft^2 at 1300 ft (3.6 kN/m^2 at 396 m), at an elevation of 900 ft (274 m) the answer would be

$$75 + (2.1/100)(900–1300) = 75 – 8 = 67 \text{ lb/ft}^2$$

or

$$3.6 + (0.33/100)(274 – 396) = 3.6 – 0.4 = 3.2 \text{ kN/m}^2.$$

In Hanover at an elevation of 1600 ft (488 m) the answer would be

$$75 + 6 = 81 \text{ lb/ft}^2$$

or

$$3.6 + 0.3 = 3.9 \text{ kN/m}^2.$$

Since it is common to round ground snow loads to the nearest 5 lb/ft^2 (0.24 kN/m^2), 67 lb/ft^2 (3.2 kN/m^2) would round to 65 lb/ft^2 (3.1 kN/m^2) and 81 lb/ft^2 (3.9 kN/m^2) would round to 80 lb/ft^2 (3.8 kN/m^2).

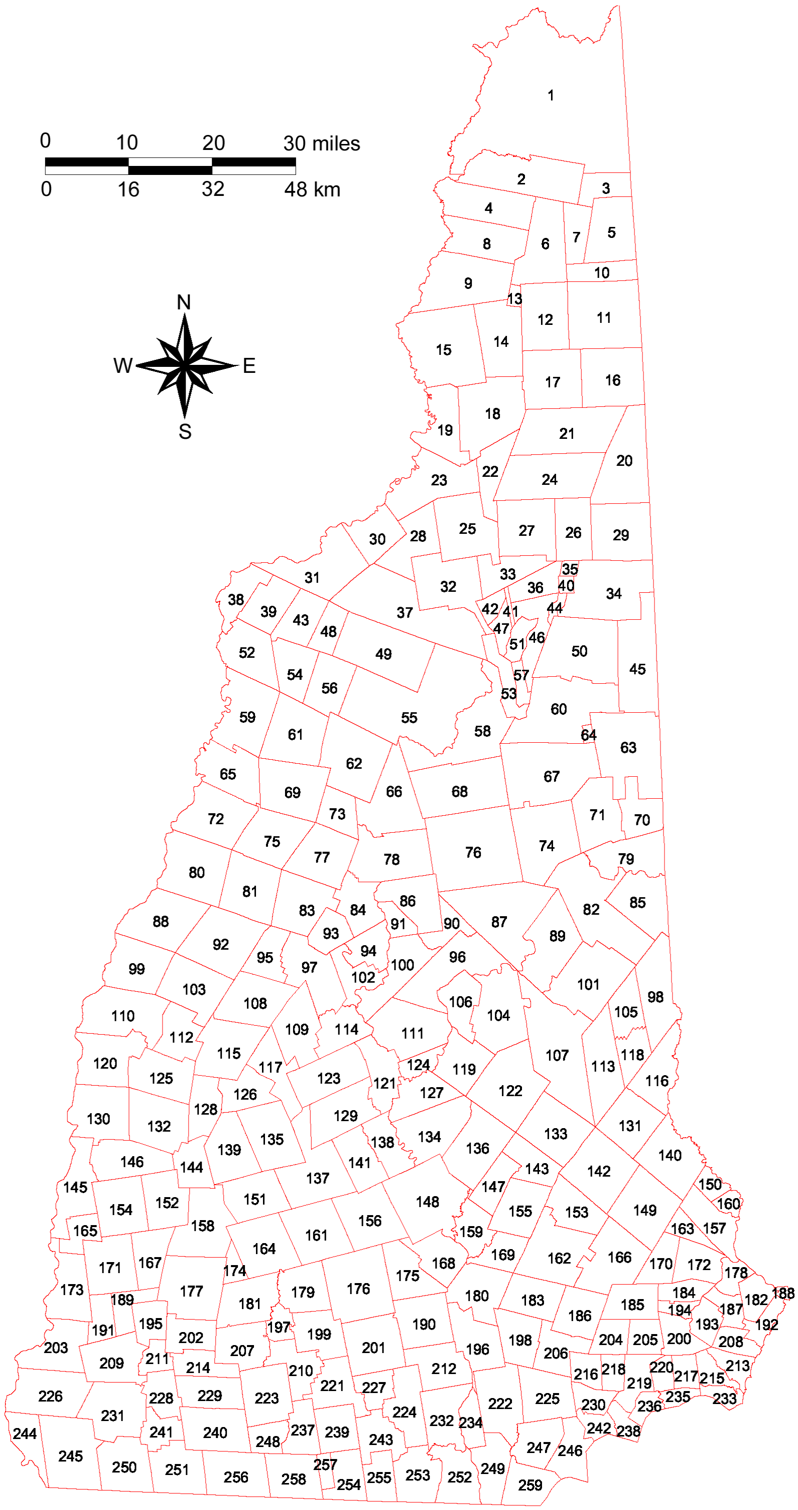


Figure 8. Location of each New Hampshire town presented in Table 1.

Table 1. Ground snow load (p_g) at a specific elevation for all New Hampshire towns.

Map no.	Town	p_g* (lb/ft^2)†		Elevation (ft)**
154	Acworth	90	@	1500
67	Albany	95	@	1300
97	Alexandria	85	@	1100
169	Allenstown	70	@	700
171	Alstead	80	@	1300
107	Alton	90	@	900
224	Amherst	70	@	600
123	Andover	80	@	900
181	Antrim	80	@	1000
91	Ashland	75	@	800
242	Atkinson	55	@	400
3	Atkinson & Gilmanton Academy Grant	85	@	1600
198	Auburn	65	@	500
133	Barnstead	85	@	900
149	Barrington	70	@	500
60	Bartlett	100	@	1200
52	Bath	65	@	1000
47	Beans Grant	105	@	1800
34	Beans Purchase	120	@	2000
212	Bedford	70	@	700
119	Belmont	80	@	900
197	Bennington	80	@	1000
61	Benton	90	@	1600
24	Berlin	100	@	1600
37	Bethlehem	105	@	1800
138	Boscawen	75	@	700
168	Bow	75	@	800
151	Bradford	85	@	1200
205	Brentwood	50	@	250
94	Bridgewater	80	@	1000
102	Bristol	80	@	1000
105	Brookfield	90	@	800
255	Brookline	60	@	500
16	Cambridge	90	@	1300
78	Campton	85	@	1300
92	Canaan	80	@	1200
183	Candia	75	@	700
134	Canterbury	80	@	900
32	Carroll	95	@	1700
90	Center Harbor	80	@	900
41	Chandlers Purchase	120	@	2500
145	Charlestown	80	@	1100
45	Chatham	90	@	500
206	Chester	65	@	500
226	Chesterfield	70	@	1000
147	Chichester	75	@	700
130	Claremont	85	@	1100
2	Clarksville	90	@	2000
8	Colebrook	80	@	1600
9	Columbia	80	@	1600
148	Concord	70	@	600
63	Conway	95	@	900
120	Cornish	85	@	1100
42	Crawfords Purchase	110	@	1800
125	Croydon	90	@	1200
51	Cutts Grant	110	@	1700
30	Dalton	80	@	1300
109	Danbury	85	@	1000
218	Danville	55	@	300
162	Deerfield	70	@	700
179	Deering	85	@	1200

* These loads *only* apply at the elevations listed. For lower elevations reduce the load by 2.1 lb/ft^2 for every 100 ft of elevation difference. For higher elevations up to 2500 ft, increase the load by 2.1 lb/ft^2 for every 100 ft of elevation difference. Examples are presented in the text. Do not use this information above 2500 ft: Conduct a site-specific snow load case study.

† To convert lb/ft^2 to kN/m^2, multiply by 0.048.

** To convert feet to meters, multiply by 0.305.

Table 1 (cont.). Ground snow load (p_g) at a specific elevation for all New Hampshire towns.

Map no.	Town	p_g* (lb/ft^2)†		Elevation (ft)**	Map no.	Town	p_g* (lb/ft^2)†		Elevation (ft)**
225	Derry	65	@	600	26	Gorham	100	@	1400
7	Dixs Grant	90	@	1700	144	Goshen	90	@	1400
6	Dixville	90	@	1900	108	Grafton	90	@	1400
81	Dorchester	80	@	1400	112	Grantham	90	@	1400
157	Dover	60	@	200	210	Greenfield	80	@	1100
229	Dublin	90	@	1600	187	Greenland	50	@	100
17	Dummer	90	@	1400	40	Greens Grant	105	@	1700
175	Dunbarton	75	@	800	257	Greenville	75	@	1000
172	Durham	55	@	150	83	Groton	80	@	1200
220	East Kingston	50	@	200	57	Hadleys Purchase	100	@	1500
56	Easton	85	@	1400	64	Hales Location	90	@	800
70	Eaton	95	@	1000	230	Hampstead	55	@	300
85	Effingham	85	@	600	213	Hampton	50	@	150
73	Ellsworth	90	@	1400	215	Hampton Falls	50	@	150
103	Enfield	85	@	1300	207	Hancock	85	@	1300
185	Epping	55	@	300	88	Hanover	75	@	1300
155	Epsom	75	@	800	214	Harrisville	90	@	1500
11	Errol	90	@	1600	53	Harts Location	100	@	1300
13	Ervings Location	100	@	2100	59	Haverhill	75	@	1200
200	Exeter	50	@	200	93	Hebron	80	@	900
131	Farmington	85	@	800	161	Henniker	80	@	1000
251	Fitzwilliam	75	@	1300	114	Hill	85	@	1100
199	Francestown	80	@	1100	164	Hillsborough	80	@	1000
49	Franconia	95	@	1700	244	Hinsdale	60	@	700
121	Franklin	75	@	700	86	Holderness	80	@	1000
79	Freedom	90	@	1000	253	Hollis	60	@	500
204	Fremont	50	@	250	180	Hooksett	70	@	600
104	Gilford	90	@	1200	156	Hopkinton	80	@	800
122	Gilmanton	90	@	1100	249	Hudson	60	@	400
189	Gilsum	80	@	1200	50	Jackson	115	@	1800
190	Goffstown	75	@	800	240	Jaffrey	80	@	1300

* These loads *only* apply at the elevations listed. For lower elevations reduce the load by 2.1 lb/ft^2 for every 100 ft of elevation difference. For higher elevations up to 2500 ft, increase the load by 2.1 lb/ft^2 for every 100 ft of elevation difference. Examples are presented in the text. Do not use this information above 2500 ft: Conduct a site-specific snow load case study.

† To convert lb/ft^2 to kN/m^2, multiply by 0.048.

** To convert feet to meters, multiply by 0.305.

Table 1 (cont.). Ground snow load (p_g) at a specific elevation for all New Hampshire towns.

Map no.	Town	p_g* (lb/ft^2)†		Elevation (ft)**
25	Jefferson	100	@	1700
209	Keene	70	@	900
217	Kensington	50	@	200
22	Kilkenny	95	@	1700
219	Kingston	50	@	200
106	Laconia	80	@	900
23	Lancaster	75	@	1300
54	Landaff	80	@	1300
165	Langdon	80	@	1000
99	Lebanon	80	@	1200
170	Lee	55	@	200
152	Lempster	95	@	1600
55	Lincoln	95	@	1400
43	Lisbon	75	@	1100
234	Litchfield	60	@	250
31	Littleton	75	@	1200
58	Livermore	100	@	1500
222	Londonderry	65	@	500
136	Loudon	80	@	900
33	Low & Burbanks Grant	105	@	1800
39	Lyman	75	@	1200
80	Lyme	70	@	1100
221	Lyndeborough	80	@	1000
163	Madbury	60	@	200
71	Madison	90	@	1100
196	Manchester	70	@	500
228	Marlborough	80	@	1300
167	Marlow	90	@	1600
35	Martins Location	100	@	1300
254	Mason	75	@	1000
96	Meredith	80	@	1000

Map no.	Town	p_g* (lb/ft^2)†		Elevation (ft)**
232	Merrimack	60	@	400
118	Middleton	90	@	800
21	Milan	95	@	1500
243	Milford	70	@	600
12	Millsfield	90	@	1700
116	Milton	90	@	800
38	Monroe	65	@	1000
227	Mont Vernon	75	@	900
87	Moultonborough	80	@	900
252	Nashua	60	@	400
202	Nelson	90	@	1500
201	New Boston	80	@	800
188	New Castle	50	@	50
113	New Durham	90	@	900
100	New Hampton	80	@	1000
258	New Ipswich	80	@	1300
126	New London	95	@	1400
139	Newbury	90	@	1300
194	Newfields	50	@	150
178	Newington	50	@	100
184	Newmarket	50	@	200
132	Newport	85	@	1200
236	Newton	50	@	250
208	North Hampton	50	@	100
127	Northfield	75	@	800
19	Northumberland	75	@	1200
153	Northwood	80	@	800
166	Nottingham	65	@	500
14	Odell	90	@	1800
95	Orange	90	@	1500
72	Orford	70	@	1100

* These loads *only* apply at the elevations listed. For lower elevations reduce the load by 2.1 lb/ft^2 for every 100 ft of elevation difference. For higher elevations up to 2500 ft, increase the load by 2.1 lb/ft^2 for every 100 ft of elevation difference. Examples are presented in the text. Do not use this information above 2500 ft: Conduct a site-specific snow load case study.

† To convert lb/ft^2 to kN/m^2, multiply by 0.048.

** To convert feet to meters, multiply by 0.305.

Table 1 (cont.). Ground snow load (p_g) at a specific elevation for all New Hampshire towns.

Map no.	Town	p_g* (lb/ft^2)†		Elevation (ft)**
82	Ossipee	85	@	1000
259	Pelham	55	@	400
159	Pembroke	70	@	700
223	Peterborough	75	@	1000
65	Piermont	75	@	1400
44	Pinkhams Grant	115	@	2000
1	Pittsburg	80	@	1700
143	Pittsfield	80	@	900
110	Plainfield	90	@	1300
238	Plaistow	55	@	300
84	Plymouth	75	@	900
182	Portsmouth	50	@	100
27	Randolph	110	@	1900
186	Raymond	60	@	500
250	Richmond	65	@	1100
256	Rindge	80	@	1300
140	Rochester	70	@	500
160	Rollinsford	60	@	200
211	Roxbury	80	@	1300
77	Rumney	85	@	1300
192	Rye	50	@	100
246	Salem	55	@	300
129	Salisbury	80	@	900
111	Sanbornton	80	@	1000
216	Sandown	60	@	400
76	Sandwich	85	@	1100
46	Sargents Purchase	115	@	2000
233	Seabrook	50	@	100
5	Second College Grant	85	@	1500
248	Sharon	80	@	1300
29	Shelburne	90	@	800

Map no.	Town	p_g* (lb/ft^2)†		Elevation (ft)**
150	Somersworth	60	@	250
235	South Hampton	50	@	200
115	Springfield	95	@	1500
18	Stark	80	@	1200
4	Stewartstown	90	@	2000
177	Stoddard	90	@	1600
142	Strafford	80	@	800
15	Stratford	70	@	1100
193	Stratham	50	@	150
20	Success	100	@	1600
48	Sugar Hill	90	@	1600
195	Sullivan	90	@	1400
128	Sunapee	90	@	1400
191	Surry	80	@	1100
135	Sutton	85	@	1100
231	Swanzey	65	@	800
74	Tamworth	85	@	1000
237	Temple	85	@	1300
36	Thompson & Meserves Purchase	120	@	2500
66	Thornton	85	@	1200
124	Tilton	80	@	900
241	Troy	75	@	1300
89	Tuftonboro	85	@	1100
146	Unity	90	@	1500
98	Wakefield	95	@	900
173	Walpole	80	@	1200
137	Warner	80	@	800
69	Warren	80	@	1300
158	Washington	95	@	1700
68	Waterville Valley	105	@	1800

* These loads *only* apply at the elevations listed. For lower elevations reduce the load by 2.1 lb/ft^2 for every 100 ft of elevation difference. For higher elevations up to 2500 ft, increase the load by 2.1 lb/ft^2 for every 100 ft of elevation difference. Examples are presented in the text. Do not use this information above 2500 ft: Conduct a site-specific snow load case study.

† To convert lb/ft^2 to kN/m^2, multiply by 0.048.

** To convert feet to meters, multiply by 0.305.

Table 1 (cont.). Ground snow load (p_g) at a specific elevation for all New Hampshire towns.

Map no.	Town	p_g* (lb/ft^2)†		Elevation (ft)**
176	Weare	80	@	900
141	Webster	75	@	700
75	Wentworth	80	@	1200
10	Wentworth Location	80	@	1300
203	Westmoreland	65	@	800
28	Whitefield	80	@	1400
117	Wilmot	90	@	1200
239	Wilton	75	@	900
245	Winchester	60	@	700
247	Windham	60	@	400
174	Windsor	85	@	1200
101	Wolfeboro	90	@	1000
62	Woodstock	85	@	1200

* These loads *only* apply at the elevations listed. For lower elevations reduce the load by 2.1 lb/ft^2 for every 100 ft of elevation difference. For higher elevations up to 2500 ft, increase the load by 2.1 lb/ft^2 for every 100 ft of elevation difference. Examples are presented in the text. Do not use this information above 2500 ft: Conduct a site-specific snow load case study.

† To convert lb/ft^2 to kN/m^2, multiply by 0.048.

** To convert feet to meters, multiply by 0.305.

12 CONCLUSIONS

On average, each of us devoted about 24 minutes to the analysis of each "town" (i.e., each case study). The average time for each case study increased to about 32 minutes when the times necessary to determine case study locations and elevations, prepare case study forms, and manage the process are considered. Since there were six of us and 259 towns, our total time for the analysis phase of this project was about 820 man-hours. When all aspects of this project are considered, our total time to complete the project was about 2000 man-hours.

The intercept of the line of best fit on a case study's all-values plot provided a good indication of our team answer in most cases, but in a few cases it was not a very good indication. Thus, simply using the all-values intercept is not recommended.

The three practicing structural engineers involved chose to modify the case study analytical procedure developed by CRREL, each in his own way. Nonetheless, when coupled with our anonymous feedback process, it was easy for us to reach a consensus in almost all cases.

As shown in Figure 6 the log-normal extreme value distribution does not fit every data set that well. By setting limits on the p_g/p_{max} ratio and filtering out stations with very low or high ratios, such problems can be reduced. Stations with p_g/p_{max} ratios greater than about 1.5 were given little weight, and those with ratios above about 1.7 were largely discounted in our analysis. Stations with p_g/p_{max} ratios less than about 0.9 appear to create similar problems. Alternatively other extreme value distributions or fitting methods may be worth considering.

An elevation adjustment factor of 2.1 lb/ft^2 per 100 ft (0.33 kN/m^2 per 100 m) works well for New Hampshire to an elevation of about 2500 ft (about 762 m). At higher elevations, site-specific case studies are still needed to determine ground snow loads. *The elevation adjustment factor used for New Hampshire should not be assumed to apply in other parts of the country.*

The case study process involves a more detailed examination of an area than was achieved some years ago when the national snow load map was made at CRREL. Thus, the case study process can be expected to produce a more accurate ground snow load. Since these case studies have been done according to the requirements of ASCE 7-98, it is appropriate to use the values in this report for all places in New Hampshire. In other words, for places in New Hampshire where ground snow loads can be determined from the map in ASCE 7-98, the values in Table 1 supersede those values. Table 1 is being added to Commentary Section C7.2 of ASCE 7-02 to acknowledge the value of such case studies and to promote such work by others. While nothing in the Commentary of ASCE Standard 7 is mandatory, that information has been subjected to consensus review and is a valuable, physical portion of the Standard. Rejecting or ignoring any of the guidance in the Commentary incurs significant risks.

The ground snow loads presented in Table 1, like the loads presented in ASCE Standard 7, are minimum values. They may be increased by the user, if judged appropriate.

Another product of this study is an SENH letter to each "town" in New Hampshire providing the ground snow load and elevation values in Table 1 for that town. Each letter also indicates that the methodology we used to generate these values meets the requirements of ASCE Standard 7, so our values are appropriate to use where case studies are needed and they supercede the values on the ground snow load map in ASCE Standard 7 in places where ground snow loads are mapped.

13 RECOMMENDATIONS

With the hope that structural engineering organizations and others in other states will conduct similar studies, we have discussed ways of simplifying the procedure we used for New Hampshire.

The elevation adjustment factor should be determined at the onset of any study. The filters we used in New Hampshire when developing our elevation adjustment factor [i.e., excluding stations with less than 15 years of record, an elevation over 2500 ft (762 m), or a p_g/p_{max} ratio less than 0.9 or more than 1.7] are worth considering. The potential variability of an elevation adjustment factor across a state should be investigated and, if necessary, regionalized factors developed.

At least three people should independently do each case study. Our preference is for five or six. When the participants are from different parts of a state, the probability increases that valuable local knowledge will be incorporated into findings.

The anonymous feedback feature used in the New Hampshire study is extremely important to incorporate into future studies.

It may be possible to simplify the process we used in New Hampshire by reducing the number of case studies that are conducted. We expect that we could have done about as well in New Hampshire if we had done case studies not at the geographical center of each town but on a 10- to 12-mile (16- to 19-km) grid. For Vermont, now considering a similar project, this would reduce the number of case studies from close to 250 to about 100. If this is done, all case studies should be done at the same elevation. For Vermont an elevation of 1000 ft (305 m) has been suggested. By plotting such grid answers on a map of the state that also contains the boundaries of each town and drawing isolines, a value can be determined for each town. Using the elevation adjustment factor, this value can be converted to a rounded elevation somewhat below the upper buildable elevation in that town. Then a table similar to Table 1 in this report can be generated.

Not only could this more than cut the number of case studies needed by more than half, but it also could greatly reduce the “quad sheet” work to the determination of only one elevation (i.e., the upper buildable elevation) for each town. The need to determine the latitude and longitude of the geographical center of each town is also eliminated.

These changes should reduce labor by about half without significantly reducing the quality of the product. Additional labor savings may be possible by using rapidly advancing geographic information system (GIS) software.

We expect that this approach will work westward up to, but not into, the Rocky Mountains. Other studies conducted in that area have shown that the elevation adjustment factor is non-linear, increasing significantly with elevation. Our approach would need to be modified to account for that non-linearity in much of the West. Because of the size of western states, the likelihood of regional variations in the elevation adjustment factor would require further study.

LITERATURE CITED

American Society of Civil Engineers (2000) Minimum design loads for buildings and other structures. ASCE Standard 7-98. Reston, VA.

Building Officials and Code Administrators International, Inc. (BOCA) (1993) *The BOCA National Building Code/1993*. Country Club Hills, IL.

Tobiasson, W., and A. Greatorex (1997) Database and methodology for conducting site specific snow load case studies for the United States. In *Snow Engineering, Recent Advances. Proceedings of the Third International Conference on Snow Engineering,* Sendai, Japan, 1996. Rotterdam: A.A. Balkema. http://www.crrel.usace.army.mil/techpub/CRREL_Reports/html_files/Cat_A.html

Tobiasson, W., J. Buska, A. Greatorex, J. Tirey, J. Fisher, and S. Johnson (2000) Developing ground snow loads for New Hampshire. In *Snow Engineering, Recent Advances and Developments. Proceedings of the Fourth International Conference on Snow Engineering,* Trondheim, Norway, 2000. Rotterdam: A.A. Balkema. http://www.crrel.usace.army.mil/techpub/CRREL_Reports/html_files/Cat_A.html

APPENDIX A. COORDINATES OF THE GEOGRAPHICAL CENTER AND ELEVATION INFORMATION FOR EACH TOWN IN NEW HAMPSHIRE.

Town	*Latitude (deg min)*		*Longitude (deg min)*		*Minimum elevation (ft)**	*Minimum building elevation (ft)**	*Low elevation limit of most buildings (ft)**	*High elevation limit of most buildings (ft)**	*Maximum building elevation (ft)**	*Maximum elevation (ft)**	*Case study elevation (ft)**
Acworth	43	13	72	18	650	660	720	1580	1590	1930	1500
Albany	43	58	71	16	460	470	470	1300	1320	3480	1300
Alexandria	43	38	71	50	480	500	500	1200	1370	2400	1100
Allenstown	43	8	71	23	200	210	220	720	730	830	700
Alstead	43	7	72	19	430	440	440	1400	1610	1800	1300
Alton	43	28	71	15	500	510	510	1000	1160	1910	900
Amherst	42	52	71	37	190	200	210	650	820	860	600
Andover	43	27	71	48	500	520	600	850	1020	2290	900
Antrim	43	3	71	59	600	620	650	1200	1300	2040	1000
Ashland	43	43	71	38	460	480	520	900	1000	1390	800
Atkinson	42	51	71	10	50	60	80	350	380	390	400
Atkinson & Gilmanton Academy Grant	44	59	71	8	1380	1390	1390	1670	1670	2620	1600
Auburn	42	59	71	21	250	260	260	480	550	580	500
Barnstead	43	21	71	16	490	500	500	1000	1110	1200	900
Barrington	43	13	71	3	140	140	150	470	500	610	500
Bartlett	44	5	71	15	490	500	500	1250	1250	3370	1200
Bath	44	11	72	0	420	440	450	1000	1180	1980	1000
Beans Grant	44	13	71	23	1600	NA	NA	NA	NA	4310	1800
Beans Purchase	44	17	71	7	900	3970	3970	3970	3970	4830	2000
Bedford	42	57	71	32	110	140	140	700	780	830	700
Belmont	43	28	71	28	460	470	470	950	1110	1360	900
Bennington	43	0	71	54	600	650	700	970	1060	2020	1000
Benton	44	2	71	52	800	820	820	1660	1660	4800	1600
Berlin	44	29	71	16	900	910	940	1850	1930	3900	1600
Bethlehem	44	16	71	36	870	900	900	1820	2200	4760	1800
Boscawen	43	19	71	40	260	260	300	750	850	920	700
Bow	43	8	71	32	200	200	230	900	910	910	800
Bradford	43	14	71	59	630	640	640	1200	1270	2100	1200
Brentwood	42	59	71	2	50	70	80	250	260	270	250
Bridgewater	43	40	71	41	460	470	480	1200	1640	1910	1000
Bristol	43	37	71	43	320	410	440	1080	1080	1800	1000
Brookfield	43	32	71	5	520	520	540	800	1480	1870	800
Brookline	42	45	71	40	230	240	250	500	670	810	500
Cambridge	44	40	71	6	1180	1250	1250	1300	1320	2780	1300
Campton	43	50	71	40	480	530	540	1400	1800	2550	1300
Canaan	43	41	72	2	800	810	810	1200	1440	2220	1200
Candia	43	3	71	19	210	220	220	700	710	940	700
Canterbury	43	21	71	32	250	260	280	900	1100	1380	900
Carroll	44	17	71	30	1060	1140	1180	1700	1900	3540	1700
Center Harbor	43	42	71	31	500	510	510	950	950	1120	900
Chandlers Purchase	44	16	71	22	2320	2570	2570	2570	2570	4760	2500

* To convert feet to meters, multiply by 0.305. NA means there are essentially no buildings in this town.

Town	Latitude (deg min)		Longitude (deg min)		Minimum elevation (ft)*	Minimum building elevation (ft)*	Low elevation limit of most buildings (ft)*	High elevation limit of most buildings (ft)*	Maximum building elevation (ft)*	Maximum elevation (ft)*	Case study elevation (ft)*
Charlestown	43	14	72	24	290	300	300	1300	1320	1680	1100
Chatham	44	9	71	3	390	390	390	540	900	3560	500
Chester	42	58	71	15	170	180	180	530	550	640	500
Chesterfield	42	53	72	27	220	230	240	1100	1160	1430	1000
Chichester	43	15	71	24	340	350	360	800	980	1010	700
Claremont	43	23	72	20	290	300	340	1200	1260	1960	1100
Clarksville	45	1	71	19	1100	1100	1100	2000	2180	3080	2000
Colebrook	44	54	71	25	1000	1040	1040	1770	1920	2760	1600
Columbia	44	50	71	28	920	970	1000	1700	1720	3720	1600
Concord	43	14	71	34	200	220	230	610	710	860	600
Conway	44	1	71	4	400	400	420	900	1000	2370	900
Cornish	43	28	72	19	300	310	330	1180	1550	2320	1100
Crawfords Purchase	44	16	71	24	1610	NA	NA	NA	NA	2890	1800
Croydon	43	27	72	12	780	790	790	1150	1230	2760	1200
Cutts Grant	44	12	71	20	1320	NA	NA	NA	NA	4720	1700
Dalton	44	23	71	41	790	850	890	1480	1810	2150	1300
Danbury	43	31	71	52	660	690	740	1000	1330	2320	1000
Danville	42	56	71	7	140	150	150	310	330	350	300
Deerfield	43	8	71	15	210	220	230	770	880	1080	700
Deering	43	4	71	51	600	600	600	1270	1270	1550	1200
Derry	42	53	71	17	200	200	210	570	580	600	600
Dixs Grant	44	55	71	12	1520	1580	1580	1900	2180	3280	1700
Dixville	44	53	71	16	1360	1600	1600	1900	1900	3440	1900
Dorchester	43	46	71	59	870	950	950	1400	1700	3190	1400
Dover	43	12	70	53	0	10	10	220	280	300	200
Dublin	42	53	72	5	920	960	980	1600	1780	2840	1600
Dummer	44	40	71	15	980	1000	1000	1400	1550	2300	1400
Dunbarton	43	6	71	37	350	350	380	860	890	920	800
Durham	43	7	70	56	0	10	10	140	140	280	150
East Kingston	42	56	71	1	40	70	100	200	260	310	200
Easton	44	8	71	47	1000	1020	1020	1380	1380	3920	1400
Eaton	43	54	71	3	440	450	470	1050	1430	1650	1000
Effingham	43	45	71	3	380	400	400	650	960	1880	600
Ellsworth	43	54	71	46	1040	1080	1100	1400	1440	3310	1400
Enfield	43	36	72	7	750	760	760	1350	1460	2110	1300
Epping	43	3	71	5	90	100	100	280	340	470	300
Epsom	43	13	71	20	290	300	300	800	900	1410	800
Errol	44	46	71	8	1190	1230	1250	1600	1630	2280	1600
Ervings Location	44	48	71	21	2020	NA	NA	NA	NA	2830	2100
Exeter	42	59	70	58	20	20	20	230	240	250	200
Farmington	43	22	71	5	240	260	260	850	1110	1360	800
Fitzwilliam	42	46	72	9	880	890	890	1300	1340	1890	1300
Francestown	42	59	71	49	590	590	600	1200	1340	2070	1100
Franconia	44	11	71	40	900	910	910	2000	4040	5240	1700
Franklin	43	27	71	39	250	280	350	700	750	1300	700
Freedom	43	49	71	4	380	400	400	1100	1260	1810	1000

* To convert feet to meters, multiply by 0.305.

NA means there are essentially no buildings in this town.

Town	Latitude (deg min)		Longitude (deg min)		Minimum elevation (ft)*	Minimum building elevation (ft)*	Low elevation limit of most buildings (ft)*	High elevation limit of most buildings (ft)*	Maximum building elevation (ft)*	Maximum elevation (ft)*	Case study elevation (ft)*
Fremont	42	59	71	7	120	130	130	240	270	320	250
Gilford	43	34	71	23	500	510	510	1300	1320	2380	1200
Gilmanton	43	26	71	22	530	540	540	1200	1240	1940	1100
Gilsum	43	3	72	16	670	690	720	1300	1500	1640	1200
Goffstown	43	1	71	34	160	160	160	800	1260	1320	800
Gorham	44	23	71	12	740	760	760	1420	1420	3020	1400
Goshen	43	17	72	7	940	950	950	1450	1730	2530	1400
Grafton	43	35	71	58	830	840	840	1500	1600	2180	1400
Grantham	43	31	72	9	920	930	930	1400	1480	2650	1400
Greenfield	42	57	71	52	670	700	700	1300	1330	2280	1100
Greenland	43	2	70	50	10	10	10	110	110	140	100
Greens Grant	44	18	71	13	1320	1580	1580	1700	1700	2540	1700
Greenville	42	46	71	48	660	720	840	960	1050	1120	1000
Groton	43	44	71	52	620	620	620	1300	1560	2310	1200
Hadleys Purchase	44	7	71	20	880	NA	NA	NA	NA	3160	1500
Hales Location	44	2	71	10	470	500	500	700	620	1440	800
Hampstead	42	53	71	10	180	200	210	330	340	400	300
Hampton	42	56	70	50	0	10	10	130	140	150	150
Hampton Falls	42	55	70	53	0	10	10	120	160	230	150
Hancock	42	59	72	0	680	680	690	1400	1440	1990	1300
Hanover	43	43	72	12	390	400	400	1440	1590	2300	1300
Harrisville	42	57	72	6	950	950	970	1500	1600	1910	1500
Harts Location	44	8	71	22	760	770	770	1320	1480	3920	1300
Haverhill	44	5	71	59	400	420	450	1350	1360	2320	1200
Hebron	43	42	71	48	590	600	600	900	1000	2230	900
Henniker	43	11	71	49	400	410	410	1100	1200	1550	1000
Hill	43	32	71	46	320	330	400	1100	1250	1900	1100
Hillsborough	43	9	71	56	550	570	600	1100	1100	1750	1000
Hinsdale	42	48	72	30	200	220	230	760	1160	1370	700
Holderness	43	45	71	35	480	480	480	1000	1210	2080	1000
Hollis	42	45	71	35	160	180	180	450	570	820	500
Hooksett	43	4	71	26	180	190	190	670	730	900	600
Hopkinton	43	12	71	42	350	360	360	840	840	920	800
Hudson	42	46	71	25	90	100	110	380	430	520	400
Jackson	44	11	71	12	720	730	730	1950	1950	3870	1800
Jaffrey	42	50	72	3	860	870	900	1350	1520	3150	1300
Jefferson	44	24	71	28	1030	1040	1040	1970	2110	3900	1700
Keene	42	57	72	18	470	480	480	900	1030	1380	900
Kensington	42	56	70	57	30	40	40	230	260	300	200
Kilkenny	44	30	71	24	1710	NA	NA	NA	NA	4080	1700
Kingston	42	55	71	4	100	120	120	220	250	340	200
Laconia	43	34	71	28	480	490	490	900	940	960	900
Lancaster	44	29	71	33	850	850	850	1280	1540	3290	1300
Landaff	44	9	71	53	560	580	580	1400	1640	2330	1300
Langdon	43	10	72	23	300	320	450	1100	1280	1340	1000
Lebanon	43	38	72	15	320	340	360	1400	1400	1660	1200

* To convert feet to meters, multiply by 0.305.

NA means there are essentially no buildings in this town.

Town	*Latitude (deg min)*		*Longitude (deg min)*		*Minimum elevation (ft)**	*Minimum building elevation (ft)**	*Low elevation limit of most buildings (ft)**	*High elevation limit of most buildings (ft)**	*Maximum building elevation (ft)**	*Maximum elevation (ft)**	*Case study elevation (ft)**
Lee	43	7	71	0	60	70	80	190	210	270	200
Lempster	43	14	72	11	1020	1020	1020	1600	1810	2330	1600
Lincoln	44	6	71	35	760	780	780	1400	2730	4700	1400
Lisbon	44	14	71	52	560	580	600	1100	1430	1600	1100
Litchfield	42	51	71	27	100	110	120	230	280	360	250
Littleton	44	19	71	48	650	700	700	1300	1670	2200	1200
Livermore	44	2	71	29	1280	NA	NA	NA	NA	4680	1500
Londonderry	42	53	71	24	140	150	160	480	500	530	500
Loudon	43	19	71	27	320	320	360	900	1020	1040	900
Low & Burbanks Grant	44	19	71	22	1530	NA	NA	NA	NA	5550	1800
Lyman	44	16	71	57	650	650	650	1200	1350	2300	1200
Lyme	43	49	72	8	390	400	400	1200	1380	3240	1100
Lyndeborough	42	54	71	47	260	310	450	1150	1320	1780	1000
Madbury	43	11	70	57	0	10	40	200	280	330	200
Madison	43	54	71	9	440	440	450	1200	1240	1560	1100
Manchester	42	59	71	27	100	120	130	480	510	570	500
Marlborough	42	54	72	11	630	640	640	1300	1300	1400	1300
Marlow	43	8	72	13	1060	1100	1200	1600	1700	1960	1600
Martins Location	44	20	71	13	1130	1230	1230	1280	1280	2600	1300
Mason	42	45	71	45	350	380	400	1000	1040	1050	1000
Meredith	43	38	71	30	480	490	490	1070	1230	1410	1000
Merrimack	42	51	71	31	100	120	120	430	480	510	400
Middleton	43	29	71	4	480	500	520	800	900	1670	800
Milan	44	34	71	12	980	1000	1000	1600	1680	2810	1500
Milford	42	49	71	40	210	230	230	630	630	810	600
Millsfield	44	46	71	16	1300	1300	1300	1730	1830	3470	1700
Milton	43	27	71	0	250	260	300	860	990	1080	800
Monroe	44	17	72	1	440	460	500	950	1040	2300	1000
Mont Vernon	42	54	71	41	340	440	450	850	880	990	900
Moultonborough	43	44	71	23	500	510	510	950	950	2990	900
Nashua	42	46	71	29	90	110	110	420	420	420	400
Nelson	42	59	72	8	1080	1140	1220	1500	1710	2240	1500
New Boston	42	58	71	41	300	300	300	800	920	1280	800
New Castle	43	4	70	43	0	10	10	40	50	60	50
New Durham	43	28	71	8	400	420	540	1000	1240	1700	900
New Hampton	43	37	71	37	320	470	470	1060	1060	1840	1000
New Ipswich	42	45	71	52	820	830	850	1300	1420	1880	1300
New London	43	25	71	59	760	780	780	1380	1420	1760	1400
Newbury	43	19	72	2	680	680	680	1300	1410	2730	1300
Newfields	43	2	70	58	10	10	10	140	140	240	150
Newington	43	6	70	50	0	10	10	100	100	100	100
Newmarket	43	4	70	58	10	10	20	170	180	280	200
Newport	43	22	72	12	590	630	650	1200	1420	1880	1200
Newton	42	52	71	3	90	100	110	240	260	280	250
North Hampton	42	58	70	50	0	10	10	120	120	160	100

* To convert feet to meters, multiply by 0.305.

NA means there are essentially no buildings in this town.

Town	Latitude (deg min)		Longitude (deg min)		Minimum elevation (ft)*	Minimum building elevation (ft)*	Low elevation limit of most buildings (ft)*	High elevation limit of most buildings (ft)*	Maximum building elevation (ft)*	Maximum elevation (ft)*	Case study elevation (ft)*
Northfield	43	25	71	35	260	280	400	860	1000	1500	800
Northumberland	44	35	71	31	850	870	870	1300	1400	2650	1200
Northwood	43	13	71	13	330	380	450	800	860	1150	800
Nottingham	43	8	71	7	120	140	150	550	600	980	500
Odell	44	43	71	22	1480	1600	1600	2350	2350	3660	1800
Orange	43	40	71	57	960	980	1000	1700	1850	3120	1500
Orford	43	54	72	5	400	400	400	1200	1380	2910	1100
Ossipee	43	44	71	9	410	410	410	1000	1100	1780	1000
Pelham	42	44	71	19	130	130	130	400	530	570	400
Pembroke	43	11	71	27	200	200	230	750	830	1000	700
Peterborough	42	53	71	57	700	700	700	1000	1200	2200	1000
Piermont	43	59	72	2	400	410	460	1350	1400	2720	1400
Pinkhams Grant	44	16	71	15	1610	1960	1960	2030	2030	3050	2000
Pittsburg	45	9	71	15	1000	1100	1100	1800	2060	3380	1700
Pittsfield	43	18	71	18	350	400	460	960	1140	1330	900
Plainfield	43	33	72	17	320	340	380	1300	1480	2650	1300
Plaistow	42	51	71	6	40	50	60	270	280	380	300
Plymouth	43	45	71	43	480	490	490	900	1120	2190	900
Portsmouth	43	3	70	47	0	10	10	80	100	100	100
Randolph	44	24	71	19	1380	1380	1380	1900	1910	3950	1900
Raymond	43	2	71	12	160	160	170	480	480	620	500
Richmond	42	46	72	17	500	540	600	1180	1300	1620	1100
Rindge	42	45	72	0	910	910	920	1350	1380	1500	1300
Rochester	43	18	70	59	110	130	150	480	560	580	500
Rollinsford	43	13	70	50	10	20	40	180	210	300	200
Roxbury	42	57	72	12	590	600	600	1300	1450	1630	1300
Rumney	43	50	71	48	440	480	480	1320	1320	2880	1300
Rye	43	1	70	45	0	10	10	120	140	150	100
Salem	42	47	71	13	110	110	110	280	300	380	300
Salisbury	43	23	71	46	570	600	660	900	900	1900	900
Sanbornton	43	31	71	36	300	420	480	900	1250	2000	1000
Sandown	42	56	71	11	180	190	190	400	430	500	400
Sandwich	43	50	71	27	560	570	570	1160	1760	3960	1100
Sargents Purchase	44	14	71	17	1240	3810	3810	6290	6290	6290	2000
Seabrook	42	53	70	52	0	10	10	100	130	220	100
Second College Grant	44	55	71	6	1200	1300	1300	1400	1400	2820	1500
Sharon	42	49	71	56	800	900	1000	1200	1320	2050	1300
Shelburne	44	23	71	5	700	700	700	800	860	3960	800
Somersworth	43	15	70	53	70	80	120	270	280	300	250
South Hampton	42	53	70	58	90	100	100	200	210	280	200
Springfield	43	30	72	3	1020	1030	1030	1500	1560	2300	1500
Stark	44	36	71	24	900	920	950	1200	1240	3730	1200
Stewartstown	44	58	71	25	1000	1050	1050	2200	2600	2990	2000
Stoddard	43	5	72	7	1250	1260	1300	1500	1760	2150	1600
Strafford	43	17	71	9	250	260	280	860	1020	1400	800

* To convert feet to meters, multiply by 0.305.

NA means there are essentially no buildings in this town.

Town	*Latitude (deg min)*		*Longitude (deg min)*		*Minimum elevation (ft)**	*Minimum building elevation (ft)**	*Low elevation limit of most buildings (ft)**	*High elevation limit of most buildings (ft)**	*Maximum building elevation (ft)**	*Maximum elevation (ft)**	*Case study elevation (ft)**
Stratford	44	42	71	31	860	900	900	1100	1400	3600	1100
Stratham	43	1	70	54	10	20	20	160	180	290	150
Success	44	31	71	5	1220	1300	1300	1600	1600	3570	1600
Sugar Hill	44	13	71	48	880	900	900	1600	1720	2080	1600
Sullivan	43	1	72	13	810	1000	1060	1450	1470	1730	1400
Sunapee	43	23	72	5	920	930	930	1440	1490	1590	1400
Surry	43	2	72	20	490	530	530	1100	1220	1560	1100
Sutton	43	20	71	56	450	480	550	1100	1560	1800	1100
Swanzey	42	52	72	18	450	460	460	730	890	1410	800
Tamworth	43	51	71	17	420	440	450	1100	1160	2690	1000
Temple	42	50	71	52	800	820	850	1300	1300	2100	1300
Thompson & Meserves Purchase	44	18	71	17	1640	2570	2570	2720	2720	5910	2500
Thornton	43	55	71	39	550	560	600	1160	1200	2600	1200
Tilton	43	28	71	35	390	400	400	870	870	870	900
Troy	42	50	72	12	730	1000	1000	1300	1390	1890	1300
Tuftonboro	43	41	71	15	500	510	510	1100	1120	2920	1100
Unity	43	18	72	16	550	550	690	1500	1700	2010	1500
Wakefield	43	36	71	1	460	470	480	940	1020	1100	900
Walpole	43	5	72	25	240	250	260	1380	1460	1650	1200
Warner	43	17	71	49	380	400	400	800	1100	2000	800
Warren	43	57	71	53	680	680	700	1300	1750	3300	1300
Washington	43	11	72	5	870	900	910	1600	1700	2470	1700
Waterville Valley	43	57	71	30	920	1440	1440	1880	3450	4120	1800
Weare	43	5	71	43	300	310	350	850	960	1210	900
Webster	43	18	71	43	380	380	400	700	780	860	700
Wentworth	43	52	71	56	540	580	600	1400	1520	2600	1200
Wentworth Location	44	51	71	8	1250	1260	1260	1280	1480	2940	1300
Westmoreland	42	58	72	26	220	240	290	800	980	1510	800
Whitefield	44	23	71	35	890	900	900	1380	1700	1710	1400
Wilmot	43	27	71	55	640	660	680	1200	1400	2950	1200
Wilton	42	50	71	46	350	350	350	950	960	1020	900
Winchester	42	47	72	24	240	300	400	700	900	1420	700
Windham	42	48	71	18	140	140	150	420	450	460	400
Windsor	43	7	72	2	960	1060	1160	1250	1250	1610	1200
Wolfeboro	43	37	71	10	500	510	510	1100	1220	1420	1000
Woodstock	44	0	71	44	600	620	620	1840	2420	4170	1200
Summary statistics for each column of elevation information shown above.											
Minimum value					0	10	10	40	50	60	50
Median value					480	480	490	1100	1240	1880	1000
Average value					560	580	600	1070	1200	1950	1030
Maximum value					2320	3970	3970	6290	6290	6290	2500

* To convert feet to meters, multiply by 0.305.

NA means there are essentially no buildings in this town.

APPENDIX B. GUIDELINES ON CONDUCTING CASE STUDIES

The guidance below was provided at the beginning of this study of New Hampshire towns. As this report indicates, improvements have been made as a result of this study. Therefore, this initial guidance should be considered along with the improvements and alternative methods of analysis discussed in this report.

Guidance on how to conduct snow load case studies

By Wayne Tobiasson and Alan Greatorex, CRREL

This brief write-up should be used together with information in the conference paper "Database and Methodology for Conducting Site Specific Snow Load Case Studies for the United States" (Tobiasson and Greatorex, 1997). We suggest that you first read the conference paper for general information, then finish reading this brief write-up for additional information on the case study process.

Never put all your faith in results from a single station but do not completely dismiss any station because its values do not fit with others around it.

"Misfits" in 50-year mean recurrence interval values (i.e., p_g values) are often due to short periods of record. A 50-year p_g based only on 10 or 15 years of record can be good or bad. Once 20 to 30 years of data are available, it is hard to dismiss that p_g as being a bad extrapolation from limited data. When a p_g is based on more than 30 years of data, give a lot of weight to it. However, if the p_g value of a station with more than 30 years of record is more than about 1.5 times the "Record Max" observed there, we give little weight to that p_g. We have determined that a few very low annual maximums can cause a p_g value for a station to be higher than if those values are not considered. This is one of the limitations (in our judgment) of extreme value statistics, but we know of no other approach that produces as reliable design values across the board, so we live with it.

The plots do not give any consideration to years of record or distance from the site. When the plots do not point to a clear answer, we examine the tabulation and check off stations with long periods of record within 10 to 15 miles (16 to 24 km) of the site. Then we highlight those stations on the "all stations" plot. By giving extra weight to them and "eyeballing" in a new "least squares" line, the answer may present itself.

In most places, stations within a 10 or 15 mile (16 to 24 km) radius are much more valuable than stations farther away. That is why we like to look at two plots. However, the "least squares" line on the "nearest 6" (or whatever) plot, since it contains just a few points, often has a slope that is less believable than the slope on the "all stations" plot. The slope of each "least squares" line is written near the legend (e.g., 2.43 lb/ft^2 per 100 ft). Slopes of 2.0 to 3.0 lb/ft^2 per 100 ft (0.31 to 0.47 kN/m^2 per 100 m) seem about right for northern New England. Sometimes it is valuable to set up the "all stations" slope or a slope of about 2.5 lb/ft^2/100 ft (0.39 kN/m^2 per 100 m), on the "nearest 6" plot and eyeball an answer using it.

One of us likes to consider snow belts, snow shadows, lake effects, weather patterns and such when he studies a site. The other does not feel he knows enough about such matters in each place to accurately consider such variables so he does not use this approach. Our different approaches are usually not the reason why we occasionally come up with different answers. We think it is valuable to arrive at our answers from different viewpoints. We urge independent analysis by two or more individuals instead of round table concurrent analysis by a team since group dynamics can adversely influence results in the latter setting. We recommend that groups only be used thereafter to resolve differences among individual answers.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YY)*
February 2002

2. REPORT TYPE
Technical Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Ground Snow Loads for New Hampshire

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Wayne Tobiasson, James Buska, Alan Greatorex, Jeff Tirey, Joel Fisher, and Steve Johnson

5d. PROJECT NUMBER
4A762784AT42

5e. TASK NUMBER

5f. WORK UNIT NUMBER
AT42-AP-001

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, New Hampshire 03755-1290

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CRREL TR-02-6

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of the Chief of Engineers
Washington, DC 20314

10. SPONSOR / MONITOR'S ACRONYM(S)

11. SPONSOR / MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

Available from NTIS, Springfield, Virginia 22161.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Because of New Hampshire's hilly landscape, mapped values of ground snow load are not available for much of its area. We conducted snow load case studies to establish ground snow loads for a specific elevation in each of the 259 towns in the state. That work was done by three researchers and three structural engineers practicing in New Hampshire. While our methods of analysis varied somewhat, our results were comparable and the feedback we received from each other was quite valuable. We also established a statewide elevation adjustment factor to transfer our snow load answers to other elevations in each town. We suggest that similar studies be conducted for other places in the United States where mapped values are not available because of extreme local variations in ground snow loads.

15. SUBJECT TERMS

Design load	New Hampshire	Statistical analysis
Ground snow load	Snow	Structural engineering
Meteorological data	Snow load	United States

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
U	U	U	U	46	

DEPARTMENT OF THE ARMY
ENGINEER RESEARCH AND DEVELOPMENT CENTER, CORPS OF ENGINEERS
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY, 72 LYME ROAD
HANOVER, NEW HAMPSHIRE 03755-1290

Official Business