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Estimating Snow Load in California for Three Recurrence Intervals

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A key to designing facilities in snowbound areas is knowing what the expected snow load levels are for given recurrence intervals. In California, information about snow load is available only for the Lake Tahoe Basin. About 280 snow courses in the State were analyzed, and snow load estimated and related to elevation on a river basin and statewide level. The tabulated snow load was estimated for three recurrence intervals—25, 50, and 100 years—for each snow course. No relationship was found between elevation and snow load on either a statewide or river basin level.

Retrieval Terms: snow load, estimates, California, recurrence intervals, snow water equivalent

The dramatic increase in outdoor recreation in California is centered largely in mountain areas where snow is the dominant precipitation form. If snow accumulation is excessive, it can damage or destroy buildings. Therefore, support structures for skiing, camping, and hiking—bridges, outbuildings, or residences—must be built to withstand harsh environmental conditions.

Architects, builders, and engineers need information on return periods of large snow accumulation in designing and constructing outdoor facilities. Managers of winter recreational areas are concerned about the return periods for below-average snow season. Maps of potential winter recreation sites in Montana and Nevada were based on snow load analyses.[1] Depth of snow cover affects wildlife population dynamics. Vegetative growth and reproduction are affected by the duration and, therefore, the magnitude of snow cover.

Ground snow load has been related to elevation. Boyd[2] created maximum snow depth charts for Canada and related roof snow loadings to ground loads. Ground snow loads were related to site elevation in counties in Oregon.[3] The ground loads there were also related to roof loadings based on coefficients developed in Canada; such coefficients varied, depending on size, angle, shape, and location of the roof.[4]

Other investigators have reported the linear relationship of elevation to snow accumulation.[5] This relationship held for an individual mountain and on a watershed level. Elevation was an important variable in predicting snow-water equivalent and, therefore, snow loads.[6]

Snow load values are now included in building codes in several parts of the Western United States.[1] The Lake Tahoe Basin, however, is the only area in California known to have delineated snow load zones.[7]

This note estimates expected snow loads for given recurrence intervals for areas in California that receive appreciable snowfall. It groups locations by major river basins, and presents minimum, maximum, and median estimates for three recurrence intervals: 25, 50, and 100 years.

METHODS

The data analyzed were from California Department of Water Resources snow course surveys.[8] The data for each snow course consisted of a set of yearly maximum snow-water equivalents. Each set of data was individually fitted to Gumbel's "first asymptotic distribution."[9] After fitting the data, I calculated the ground snow load by multiplying the predicted snow-water equivalent in inches by .0361 (1 ft^3/ 1728 in^3 * 62.4 lbs/ft^3) to compute pounds per square inch. The ground snow load was calculated for three return periods: 25, 50, and 100 years. Snow course elevation was correlated with snow load values, first with all the data grouped together and then with data grouped on a basin scale.

The annual maximum month-end snow water equivalent represented the yearly maximum on each snow course. Boyd[2] found maximum annual month-end depths of snow to be above 80 percent of the annual maximums based on daily measurements. I compared the maximum annual daily basis to the maximum annual month-end water equivalent values for several years of data from the Forest Service's Central Sierra Snow Laboratory (CSSL), near Soda Springs, Calif., located in the central Sierra Nevada at 6890 ft (2100 m) elevation. The laboratory records near daily snow-water equivalent information.

Several techniques may be used to estimate the distribution parameters. Magnuson[10] stated that Gumbel's method of moments produces a slightly biased estimate and that the "order statistics method"[11] offered unbiased minimum variance estimates. The order statistics method provides excellent results for small sets of data. Snow load values were calculated by both methods for several cases and a comparison was made between the values.

The fit of several of the snow courses was checked by plotting the snow water equivalent (inches) versus the reduced variate. The reduced variate is directly related to the return period and is determined by ranking the data from lowest to highest. The return period, T(m), for any rank m equals (n+1)/(n−m+1), in which n is the total sample size for the snow course. The probability associated with the return period T(m) is P=1−{1/[T(m)]} and the reduced variate equals −log[−log(p)]. Each of these points (reduced variate, snow-water equivalent) were plotted along with the Gumbel curve of estimated points.

Table 1—*Estimates of snow loads for three recurrence intervals, California*

River basin and elevation range(ft)	25 Years			50 Years			100 Years		
	Min	Max	Median	Min	Max	Median	Min	Max	Median
				Pounds/square inch					
				North Coast Area					
North Coast[1] (5500-6700)	1.19	3.10	2.27	1.36	3.50	2.56	1.53	3.89	2.85
Trinity (5100-7200)	1.43	4.15	2.66	1.64	4.75	3.01	1.85	5.34	3.36
				Sacramento Drainage					
Pit (4700-7300)	0.33	2.44	0.95	0.40	2.74	1.09	0.46	3.03	1.22
Sacramento (5600-7900)	1.90	4.10	3.14	2.17	4.65	3.53	2.43	5.19	3.92
McCloud (4500-6250)	1.33	3.10	2.12	1.56	4.51	2.41	1.78	3.90	2.69
Feather (4600-8500)	0.68	5.58	1.92	0.79	6.24	2.18	0.90	6.90	2.43
Yuba (5600-7400)	1.56	3.73	2.58	1.79	4.19	2.95	2.02	4.64	3.30
American (5300-8500)	1.24	3.21	2.34	1.43	3.59	2.67	1.62	3.97	3.03
Mokelumne (4350-8000)	0.72	3.63	2.52	0.86	4.07	2.85	1.00	4.51	3.17
				San Joaquin Drainage					
Stanislaus (4750-9250)	0.95	3.58	2.30	1.12	4.05	2.62	1.28	4.50	2.93
Tuolumne (6500-9850)	1.76	3.43	2.49	2.04	3.88	2.85	2.32	4.35	3.22
Merced (7000-10300)	2.20	3.19	2.58	2.46	3.60	2.92	2.72	4.00	3.25
San Joaquin (6800-11450)	1.37	3.08	2.39	1.62	3.51	2.74	1.85	3.94	3.10
Kings (6600-11200)	1.64	2.86	2.56	1.90	3.27	2.91	2.14	3.68	3.26
Southern Sierra[2] (6500-9500)	1.52	3.26	1.91	1.77	3.77	2.22	2.01	4.28	2.51
Kern (7650-11350)	1.06	2.12	1.73	1.26	2.42	2.00	1.44	2.72	2.27
				Lahonton Area					
North Lahonton[3] (5700-6500)	0.43	2.18	0.90	0.50	2.46	1.02	0.58	2.75	1.14
Truckee (5900-9000)	0.91	3.83	1.79	1.07	4.34	2.03	1.24	4.85	2.28
Lake Tahoe Basin (6250-8200)	0.85	3.72	1.44	0.99	4.15	1.64	1.11	4.58	1.85
Walker (7900-9500)	0.92	2.60	1.65	1.05	2.94	1.87	1.19	3.27	2.08
Mono Lake Basin (9150-10400)	2.00	2.67	2.26	2.28	3.05	2.56	2.55	3.43	2.85
Owens (8300-11300)	0.73	3.15	1.35	0.87	3.56	1.56	1.00	3.98	1.78
				Southern California					
Colorado Desert[4] (6500-7800)	0.98	2.12	1.67	1.15	2.51	1.99	1.33	2.88	2.30
Southern Calif.[5] (5800-8600)	0.23	0.99	0.82	0.28	1.16	0.99	0.33	1.33	1.16

[1] The North Coast area includes snow courses in the Eel, Scott, and Shasta Rivers and the Stoney Creek course.

[2] The Southern Sierra includes the Kaweah and Tule Rivers and Deer Creek.

[3] The Northern Lahonton area includes snow courses in the Susan River and Surprise Valley.

[4] The Colorado Desert includes snow courses in the Mojave Desert and the Whitewater River.

[5] The Southern California district includes courses in Piru Creek and the Santa Ana and San Gabriel Rivers.

RESULTS AND DISCUSSION

Maximum, minimum, and median snow loads were estimated for three recurrence intervals: 25, 50, and 100 years (*table 1*). The estimates are by river basin, because areas of homogeneity can be better captured by using a hydrologic unit instead of county boundaries. Variability was eliminated because of the number and placement of the snow courses. In areas having only a few measured snow courses per basin, the data have been grouped by the California Department of Water Resource's water areas. These groups aid in the graphic display of the data, and do not explain variability. For example, the Southern Coastal area contains one snow course from the Santa Ana River, San Jacinto River, and Piru Creek areas. By grouping the snow courses, a range of values could be offered for an area instead of a single value for each basin.

The values in *table 1* apply to ground snow loads—not to roof snow loads. The Canadian Building Code uses a basic coefficient of 0.80, indicating that roof snow load will generally be 80 percent of ground snow load. This coefficient can change depending upon the size and shape of the roof. Building heat and angle of exposure also play an important role in determining roof snow load.

The values are predictable. The east side of the Sierra Nevada (Lahonton Area) has load values that are lower, on the average, than those on the west side. The east side values are mostly in the 1.39 to 2.08 pounds per square inch (97.7 to 146.3 g/cm^2) range whereas the west side values are in the 2.08 to 2.78 (146.3 to 195.50) range. Notable exceptions on the low side are the Pit River values which probably reflect the effect of a Mount Shasta shadow. Another exception is the maximum value for the Feather River Basin. This high value reflects the Upper Lassen Peak snow course which is notorious for its extreme depths.

Some typical snow loads for the Stanislaus River Basin are 2.30, 2.62, and 2.93 pounds per square inch (161.7, 184.2, 206.0 g/cm^2) for the 25-, 50-, and 100-year return periods, respectively. The standard error about the 25-year estimate (2.30) is ± .347 pounds per square inch (24.4 g/cm^2). The standard errors generally run between 10 and 20 percent of the estimate for the 25-year estimate, but with extrapolation to higher return periods they will increase.

Although past research suggested that snow load was related to elevation, I found little correlation between snow load and elevation on a statewide basis. The confidence intervals around the statewide correlation coefficient contained zero. Correlations based on basin groupings were higher, but only a quarter of the basins had coefficients greater than 70 per-

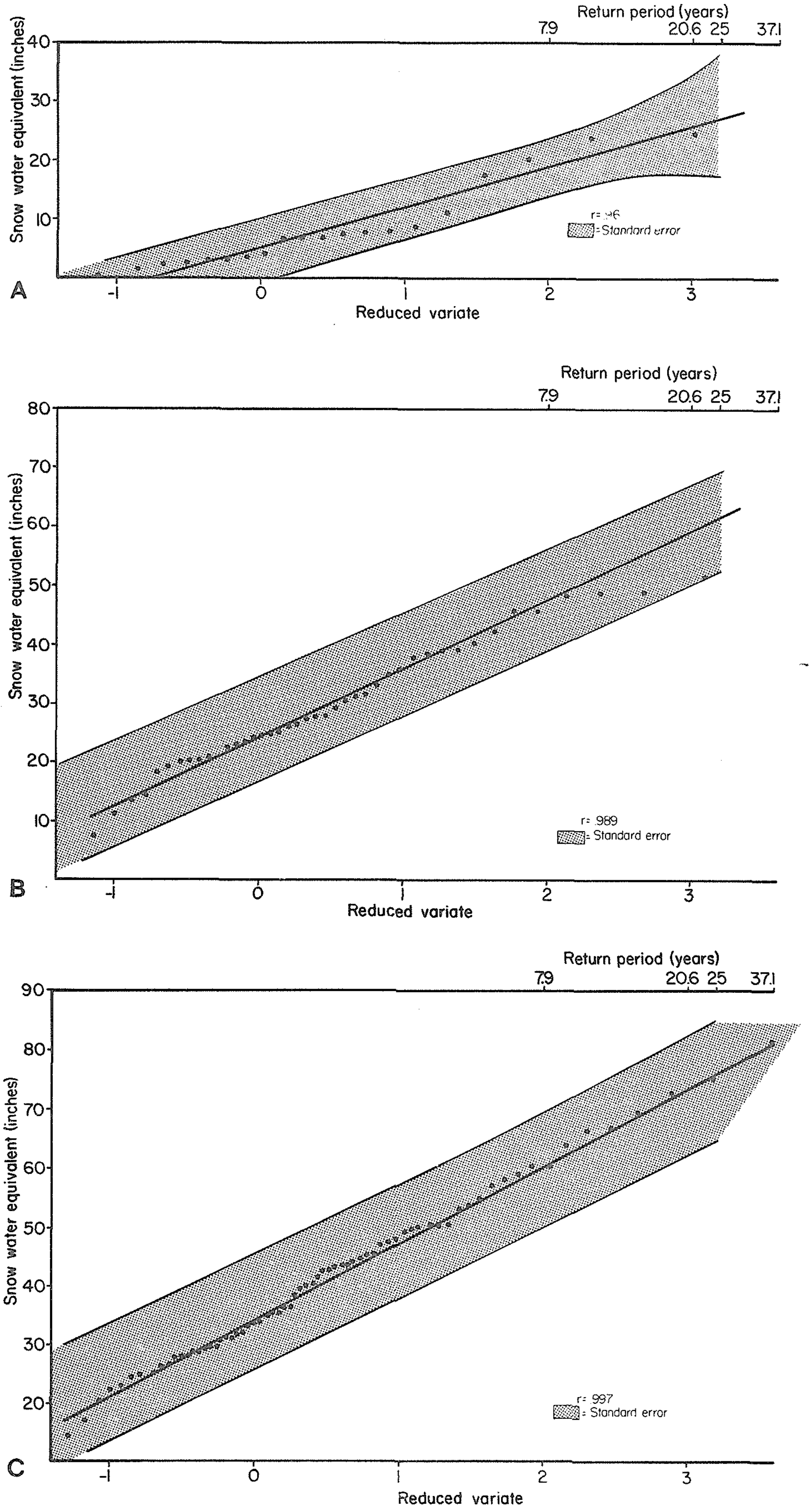

Figure 1—The theoretical line fit very closely to *the actual snow-water equivalent for three snow* courses with different record lengths: (*A*) Mt. Pinos, 20 years; (*B*) Sawmill Flat, 44 years; (*C*) *Donner Pass, 73 years.*

Table 2—*Snow course number, elevation (feet), record length (years), and 25-year estimate, standard error*

North Coast Area				
************************				
Shasta River				
1	6700	48	2.43	0.31
2	6200	38	1.39	0.19
3	5850	48	1.19	0.18
Scott River				
5	6600	38	2.41	0.33
311	6200	36	2.15	0.30
4	5900	33	2.70	0.42
278	5900	33	3.12	0.42
298	5700	29	1.67	0.26
285	5500	33	2.81	0.39
Trinity River				
9	7200	38	2.30	0.30
10	6700	38	3.43	0.49
11	6500	37	3.16	0.47
13	6400	32	2.66	0.38
12	6200	37	4.16	0.63
16	6000	36	2.93	0.46
15	5700	36	1.94	0.29
14	5400	43	1.83	0.29
17	5100	38	1.43	0.23
Eel River				
63	6000	36	1.57	0.25
Stoney Creek				
62	6200	39	2.27	0.31
Sacramento Drainage				
************************				
Sacramento River				
18	7900	53	4.11	0.59
20	6900	47	1.91	0.28
19	6800	39	3.15	0.41
21	6200	41	3.42	0.48
22	5600	38	2.94	0.51
Mccloud River				
23	6250	39	2.67	0.37
24	5550	33	2.12	0.30
25	5400	38	3.11	0.43
26	5000	38	1.82	0.30
27	4500	38	1.33	0.24
Pit River				
28	7300	43	0.79	0.11
29	7200	53	1.08	0.14
30	7100	53	1.17	0.15
31	6700	35	0.81	0.14
32	6700	43	2.28	0.30
33	6500	37	2.46	0.31
35	6350	53	1.01	0.14
343	5900	33	0.90	0.15
37	5300	40	0.33	0.08
41	4700	35	0.41	0.09
Feather River				
336	8500	35	5.60	0.70
47	8250	53	5.37	0.65
48	7100	41	1.83	0.26
279	6800	35	3.32	0.46
75	6700	50	2.26	0.30
280	6700	32	1.40	0.20
53	6250	52	2.90	0.41
52	6200	44	2.52	0.35
51	6200	53	2.02	0.28
290	6050	31	1.47	0.23
54	5900	52	2.95	0.42
353	5800	20	0.69	0.20
50	5750	52	1.41	0.30
354	5650	20	0.69	0.18
49	5600	43	3.67	0.50
55	5600	52	1.42	0.23
56	5400	46	2.25	0.36
58	5400	53	1.83	0.27
57	5200	41	2.62	0.40
59	5100	52	1.38	0.22
60	4850	53	1.14	0.19
61	4600	53	0.92	0.16
Yuba River				
65	7400	38	3.74	0.49
66	7200	52	3.74	0.48
67	7200	52	3.48	0.47
68	7100	50	3.13	0.42
70	7100	39	3.47	0.45
71	7100	40	3.35	0.44
69	6900	73	2.77	0.36
72	6800	26	2.57	0.35
76	6700	53	3.36	0.44
74	6700	46	2.37	0.33
78	6500	51	2.32	0.34
77	6500	53	2.87	0.38
79	5950	32	2.03	0.27
80	5900	61	2.24	0.36
82	5800	32	1.56	0.25
81	5700	30	2.14	0.36
83	5650	52	1.90	0.31
277	5400	33	2.59	0.38
85	5200	57	2.12	0.35
American River				
106	8500	53	2.47	0.32
297	8400	29	3.02	0.39
331	8400	32	2.96	0.41
107	8000	44	2.29	0.32
338	7500	24	2.93	0.68
108	7450	43	2.61	0.35
110	7300	42	2.61	0.35
111	7100	42	2.41	0.35
109	7100	53	1.87	0.27
316	6900	26	2.91	0.44
113	6800	42	2.18	0.30
320	6700	39	2.40	0.32
115	6600	47	3.22	0.41
289	6550	44	2.10	0.29
114	6300	30	2.94	0.38
120	6100	45	2.27	0.37
123	5750	51	2.18	0.37
122	5750	27	1.89	0.29
124	5700	41	1.24	0.21
322	5600	28	1.80	0.27
128	5300	36	2.25	0.44
127	5300	47	1.24	0.21
Mokelumne River				
129	8000	53	2.50	0.33
130	7900	31	3.10	0.41
131	7800	46	3.65	0.46
132	7500	52	2.70	0.36
133	7200	45	3.02	0.42
134	6700	53	2.01	0.28
339	6600	48	2.04	0.27
135	6500	46	2.54	0.37
136	5500	42	1.20	0.23
137	4350	40	0.73	0.15
201	6950	43	2.33	0.41
202	6800	43	2.07	0.34
204	6800	39	2.39	0.38
Kings River				
222	11200	52	2.58	0.38
299	10700	28	2.81	0.44
307	10650	30	2.67	0.42
223	10300	52	2.61	0.37
225	9800	52	2.56	0.37
224	9700	54	2.80	0.41
309	9500	24	2.26	0.56
229	9000	45	2.87	0.44
228	9000	40	2.69	0.38
226	8850	52	2.74	0.47
227	8800	53	2.49	0.37
232	8500	53	2.39	0.36
233	8300	53	2.69	0.42
230	8250	53	2.20	0.35
234	8200	53	2.22	0.35
308	8050	27	2.71	0.44
236	7600	53	2.35	0.37
237	7600	52	1.69	0.29
238	7400	28	2.19	0.34
239	6950	51	2.17	0.38
240	6600	52	1.65	0.27
Kaweah River				
292	9000	31	3.27	0.54
243	8600	58	3.03	0.46
244	8500	53	2.35	0.35
245	8000	35	2.15	0.37
246	6500	53	1.62	0.25
Tule River				
247	7000	46	1.53	0.26
248	6600	46	1.68	0.27

Deer Creek

249	7300	45	1.53	0.26

Kern River

250	11350	34	2.03	0.33
251	11050	35	1.52	0.27
252	10900	35	1.78	0.30
253	10700	34	1.76	0.29
254	10650	34	1.87	0.31
275	10650	34	1.73	0.29
255	10650	34	1.76	0.29
257	9750	35	1.58	0.26
256	9600	34	1.68	0.28
258	9000	53	2.13	0.32
259	8700	50	1.17	0.20
260	8500	50	1.39	0.24
262	8400	52	1.94	0.33
264	8350	50	1.90	0.32
261	8300	53	1.43	0.25
263	8000	41	1.07	0.21
265	7650	53	1.08	0.20

San Joaquin Drainage

Stanislaus River

345	9250	22	2.74	0.58
344	8900	23	3.01	0.64
323	8800	31	3.60	0.49
138	8100	53	2.86	0.39
139	7800	52	1.80	0.27
141	7550	53	2.80	0.36
140	7500	52	1.89	0.27
142	7300	46	2.29	0.33
143	7250	53	1.58	0.23
144	6650	44	2.32	0.34
146	6550	31	2.33	0.34
145	6500	52	1.60	0.23
147	5750	39	1.65	0.27
149	4750	45	0.95	0.18

Tuolumne River

157	9850	57	2.04	0.27
158	9400	35	2.20	0.30
159	9300	35	3.26	0.46
161	8600	53	1.99	0.32
162	8400	34	3.44	0.48
163	8000	37	3.17	0.44
165	7900	35	3.09	0.46
166	7800	34	3.06	0.43
164	7800	35	3.35	0.46
167	7700	37	3.14	0.45
173	6700	45	2.49	0.39
168	6700	45	2.22	0.38
169	6700	36	2.14	0.34
171	6500	53	2.06	0.30
172	6500	46	1.76	0.30

Merced River

175	10300	30	2.21	0.28
176	8700	48	3.20	0.43
177	8200	45	2.70	0.38
178	8150	53	2.43	0.33
179	7000	53	2.73	0.39
180	7000	52	2.47	0.34

San Joaquin River

182	11450	33	2.56	0.39
183	11300	52	2.65	0.38
184	10600	38	2.80	0.41
276	10400	34	2.66	0.39
185	10100	40	2.16	0.31
186	10100	37	2.28	0.33
187	10000	37	2.28	0.33
188	9700	39	1.81	0.27
189	9450	52	2.38	0.34
191	9100	44	2.23	0.31
190	9100	53	2.82	0.38
192	8850	37	2.59	0.40
193	8400	43	2.84	0.42
346	8300	23	2.68	0.64
194	8000	39	2.97	0.45
324	7800	25	1.70	0.29
196	7450	53	3.08	0.45
347	7250	23	2.57	0.66
198	7250	53	1.37	0.26
197	7150	53	3.09	0.46
200	7000	43	2.05	0.33
199	7000	50	1.88	0.30

Lahonton Area

Surprise Valley

313	6500	25	0.92	0.14
349	6400	25	0.43	0.08
350	6000	25	0.76	0.15
314	5900	25	0.87	0.12

Susan River

45	6450	43	2.19	0.30
46	5700	43	1.38	0.22

Truckee River

334	9000	72	2.34	0.32
86	8450	46	2.88	0.36
64	7800	53	3.02	0.40
318	7500	29	3.84	0.54
88	7000	42	1.79	0.26
89	7000	53	2.25	0.31
91	6500	46	1.24	0.19
90	6500	46	1.44	0.20
92	6400	52	1.42	0.22
342	6000	24	1.30	0.30
95	5900	47	0.91	0.17

Lake Tahoe Basin

96	8200	70	3.74	0.45
97	8100	69	3.06	0.37
98	8000	65	1.36	0.20
332	8000	54	1.56	0.20
99	7500	66	2.07	0.27
337	7350	54	1.12	0.19
100	7300	53	1.06	0.17
385	7100	21	1.80	0.46
101	7000	70	2.95	0.37
333	6900	41	0.99	0.14
103	6500	39	1.44	0.22
104	6400	53	0.86	0.14
105	6250	67	1.18	0.19

Walker River

150	9500	36	1.43	0.21
151	9400	59	2.62	0.36
152	8800	51	1.80	0.24
153	8500	45	1.50	0.21
154	250	49	0.92	0.15
155	7900	59	1.84	0.30

Mono Basin

281	10400	39	2.68	0.41
181	9800	55	2.01	0.29
287	9750	44	2.26	0.32
286	9600	45	2.07	0.29
282	9150	43	2.31	0.34

Owens River

284	11300	32	1.94	0.31
220	11100	57	1.23	0.20
212	10800	51	1.30	0.22
221	10600	57	1.07	0.17
213	10300	56	1.53	0.24
217	10000	57	1.88	0.30
209	10000	57	1.26	0.19
218	9800	57	1.60	0.27
219	9700	57	1.40	0.23
205	9500	55	3.16	0.44
214	9300	53	0.96	0.16
210	9050	56	1.10	0.19
206	9000	55	2.21	0.31
215	8850	50	0.74	0.14
211	8700	57	0.83	0.14
216	8400	52	0.73	0.14
208	8300	54	1.67	0.26
207	8300	39	1.54	0.24

Southern California

Mojave Desert

305	7600	33	1.82	0.34
306	7550	29	2.14	0.40
304	7400	33	1.68	0.34
272	6500	27	0.98	0.19

Whitewater River

296	7800	28	1.54	0.28

Piru Creek

310	8600	20	0.99	0.29

Santa Ana River

303	5800	23	0.23	0.08

San Jacinto River

293	7500	20	0.82	0.28

cent. Several of the basins exhibited near zero correlation.

Several reasons for the lack of the elevation-snow load relationship include: (1) These snow courses are located to predict runoff and not a snow load-elevation relationship. Valley locations are common for several reasons including ease of access and gaging logistics. The course may be located in an area with maximum or minimum snow accumulation. (2) These courses are located on variable terrain. Two courses at the same elevation but on different aspects can have very different snow loads. The variability of terrain in combination with directions of incoming storms will have a profound influence on deposition. (3) Several of the river basins have less than five snow courses. With so few points it would be hard to evaluate an elevational gradient unless the snow courses were perfectly located along an elevational transect.

The fit of the data to the "first asymptotic distribution" is controlled by the sample variability and the number of years of record. Plots of three snow courses of record lengths 20, 44, and 73 years reveal that the difference between the Gumbel curve and the plotted points is relatively small (*fig. 1*). The data fit better when the length of record is longer. The correlation coefficients between predicted and observed snow loads for the above sample sizes are 0.96, 0.991, and 0.997, respectively. The standard errors for the 25-year estimates are provided for each snow course used in the analysis (*table 2*). The standard error for the 25-year estimate is plotted around the Gumbel curve (*fig 1*). The standard error will decrease for return periods less than 25 years.

Gumbel's method of moments estimators tend to give slightly biased results.[9] A comparison of the order statistic method to the method of moments shows the estimate of the latter to be greater than the former estimate in all cases compared. The variability in the data was larger than the savings from Lieblien's method. The decrease in variance, however, did not warrant the use of Lieblein's method.

Using month-end values could lead to an underestimation of yearly maximums. Boyd[2] used 76 stations in Canada to compute a ratio of 1.236 monthly to yearly maximum snow depths. I did a similar analysis on month-end water equivalent values from the Central Sierra Snow Laboratory to produce a ratio of 1.09 month-end to yearly maximum. The difference in ratios is due to the greater variability in snow depth in comparison to snow water equivalent in Canada. This correction ratio was not used in this analysis because it only represents a single point in the Sierra Nevada.

The underestimation in yearly maximum might be compensated for by using a snow tube and the bias in the method of moments estimator. The snow tube typically overestimates the snow water content by as much as 12 percent.[12] The difference between the method of moments and the order statistics estimate for an average of 10 sample snow courses at the 100-year return period was 10 percent of the estimate. The bias decreases as the return period shortens.

CONCLUSIONS

The estimates of snow loads for three recurrence intervals (*table 1*) provide a range of values from minimum to maximum. Managers who want to design for snow loads of 25, 50, and 100 years can select the pressures their structures must withstand by consulting the table. But they will have to decide in which part of the spread in values their particular structure lies. Because of the nature of the data collected, it was not possible to formulate elevational gradient curves on either a watershed or statewide basis. To do so, it would be necessary to obtain data from more snow courses covering the complete range of environmental conditions.

END NOTES AND REFERENCES

[1] Farnes, P. E. *Montana areas with adequate snowfall for winter recreation.* Bozeman, MT: Snow Survey and Water Forecast Unit, Soil Conservation Service, U.S. Department of Agriculture; 1969. 1 p.

McAndrew, D. W. *Snow load analysis and recreational uses of snow data.* In: Proceedings of the 41st Annual Meeting, Western Snow Conference; 1973 April 17-19; Grand Junction, CO. Fort Collins, CO: Colorado State Univ.; 1973; 69-74.

McAndrew, D. W.; Roda, J. D. *Nevada areas with adequate snowfall for winter recreation.* Reno, NV: Snow Survey and Water Forecast Unit, Soil Conservation Service, U.S Department of Agriculture; 1971. 1 p.

[2] Boyd, D. W. *Maximum snow depths and snow loads on roofs in Canada.* In: Proceedings of the 29th Annual Meeting, Western Snow Conference; 1961 April 11-13; Spokane, WA. Fort Collins, CO: Colorado State Univ.; 1961: 6-16.

[3] Structural Engineers Association of Oregon and U.S. Department of Agriculture, Soil Conservation Service. *Snow load analysis for Oregon;* 1971. 8 p.

[4] National Research Council. *National building code of Canada.* NRC 5800. Ottawa, Canada: Associate Committee on the National Building Code; 1960: 567-578.

[5] Garstka, W. U. *Interpretations of snow surveys.* Trans. Am. Geophys. Union 30(3): 412-420; 1949.

[5] Hannaford, J. F.; Wolfe, C. G.; Miller, R. W. *Graphical method for determination of area-elevation weighting of snow course data.* In: Proceedings of 26th Annual Meeting, Western Snow Conference; 1958 April 16-18; Bozeman, MT. Fort Collins, CO: Colorado State Univ.; 1958: 73-82.

Schaerer, P. A. *Variation of ground snow loads in British Columbia.* In: Proceedings of the 38th Annual Meeting, Western Snow Conference; 1970 April 21-23; Victoria, BC. Fort Collins, CO: Colorado State Univ.; 1970: 44-48.

Seligman, B. A. *Snow structure and ski fields.* New York: MacMillan and Company; 1936: 456-458.

[6] Berg, N. H.; Hannaford, M. A. *Application of a snowpack water-equivalent model to rain-on-snow events in the central Sierra Nevada.* In: Proceedings of the 51st Annual Meeting, Western Snow Conference; 1983 April 19-21; Vancouver, WA. Fort Collins, CO: Colorado State Univ.; 1983: 155-158.

[7] U.S. Department of Agriculture, Soil Conservation Service. *Lake Tahoe Basin snow load zones.* Reno, NV: Snow Survey and Water Forecast Unit; 1970. 1 p.

[8] California Resources Agency. Bulletins 129, 120. 1971. Sacramento, CA: Department of Water Resources; 1971. 385 p.

[9] Gumbel, E. J. *Statistics of extremes.* New York: Columbia University Press; 1958: 201-254.

[10] Magnuson, M. D. *Discussion of "Maximum snow depths and snow loads on roofs in Canada."* In: Proceedings of the 29th Annual Meeting, Western Snow Conference; 1961 April 11-13; Grand Junction, CO. Fort Collins, CO: Colorado State Univ.; 1961: 17-19.

[11] Lieblein, J. A. *A new method of analyzing extreme value data.* Tech. Note 3053. Washington, DC: National Advisory Committee for Aeronautics; 1954. 67 p.

[12] Peterson, N. R.; Brown, A. J. *Accuracy of snow measurements.* In: Proceedings of the 43d Annual Meeting, Western Snow Conference; 1975 April 23-25; Coronado, CA. Fort Collins, CO: Colorado State Univ.; 1975: 1-5.

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