SNOW COVER AT THE PROPOSED SHERWIN SKI AREA

Mammoth Lakes, California
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A. Introduction

This study reports on snow data collected for the proposed SSA, weather data pertinent to snow accumulation and ablation, and statistical analyses that allow prediction of conditions important to the ski potential and water resources of the area. The following tasks have been accomplished:

1. Observations of snow depth and average density were made by visiting the proposed SSA on skis during the winter 1987 between January and April, and calibrated using periodic snow pits.

2. Winter weather data were measured at sites at the proposed SSA and Mammoth Mountain for the same months that snow data were collected and are compared at different time scales.

3. Historical records of snow measurements have been acquired, calibrated, and compiled for statistical analysis.

4. Analyses of the snow data have been made to predict the snow cover conditions for average years for the entire study area and for subareas.

5. Calculations are made from the historical record, which when combined with the snow predictions, provide probabilities of opening parts of the proposed SSA for skiing by the Thanksgiving and Christmas holidays.

6. Estimates are made of the period suitable for snowmaking using an air temperature record from a site at a similar elevation to the base of the proposed SSA.

The snow data form part of a larger snow data base that includes observations from the winter 1985-1986 and historical data from nearby sites. Sites for snow cover measurements were selected based on potential usefulness and representation of the areas proposed as ski runs, or pods. Measurements obtained from several sample points augment similar data collected for a USFS study (Burak 1986). Wind velocity and air temperature are measured at the proposed Solitude Lodge site and at Mid-Chalet at Mammoth Mountain and compared. Ancillary historical data considered for analysis include the precipitation record from the Lake Mary Store, the snow mass record from the Mammoth Pass cooperative site, and observations from Mammoth Mountain.

The data analyses consist of: determination of the snow cover masses for the entire area; calculation of the probabilities of opening dates, by elevation zone and by pod; and estimation of the average period suitable for snow making before December 31.

B. Background

The alpine snow cover at the proposed SSA is unevenly distributed over the rugged terrain, with large spatial variations over small areas, but somewhat consistent variations with elevation and time of season. Previous studies use isohyets to extrapolate snow cover over the study area from a few points, which is inappropriate because of differences in storm characteristics, and wind redistribution (Dave Hart, Chief of Field Operations, DWR, personal communication; Cooley and Robertson 1985; Sack and Sheikh-Taheri 1985)

Another source of error in earlier reports of the water equivalent of snow cover in the Mammoth Basin is the type of data used in the estimates. These types include manual survey, snow pillow (point based), and precipitation gage (point based). Currently the best method to assess the distribution of snow cover over mountainous areas on the order of hectares is by manual survey (Gray and Male 1981), which we employ. Recent studies have shown that snow gages, which measure snow mass at a point, can have large biases that depend on factors related to location such as proximity to trees, wind speed, etc. These biases can result in over catch of snow, as is the case with some of the snow pillow installations, or drastic under catch of snow, the case with unshielded precipitation gages such as the sensor at the Lake Mary Store. Therefore, point-based gage should be calibrated with manual measurements, done at a snow course adjacent to the gage.

In this study we use the parameter snow water equivalent (SWE) to describe the amount of snow at points and over areas. Snow water equivalent is defined as the depth of water that would result if the snow pack were melted instantaneously. The term snow depth can be misleading because the average snow density varies significantly with time and location so the mass of the pack does not necessarily correspond to a particular depth. Another reason for using SWE is that it can readily be converted to hydrologic units such as acre feet for evaluation of recharge and runoff.

The ski potential of an area cannot be uniquely related to depth. For example, 12 inches of snow with a mean density of 150 kilograms per cubic meter (about 2 inches SWE) would not be sufficient for skiing, even if compacted by snowcat. This is a typical density resulting from early-season or very cold storms in the Mammoth area. On the other hand, 12 inches of snow with an average density of 500 kilograms per cubic meter (6 inches SWE) would be adequate for skiing on well-graded groomed slopes, and is a typical spring snow density.

1. Previous Studies

In 1973 the Department of Water Resources of the State of California (DWR) completed a preliminary draft of a two-year study of the water resources in the Mammoth Basin. The study uses two measurement points near the the proposed SSA; the Lake Mary Store precipitation gage, and the Mammoth Pass snow gage, as well as other courses and sensors. Assuming that 85 percent of the precipitation occurs as snowfall and that April 1 represents the maximum snow accumulation, an elevation-precipitation relationship is constructed using five snow courses in and near the basin (Figure 1). This relationship is modified to account for vegetative cover and used to construct 50-year-mean isohyetals of mean annual precipitation after an upward adjustment of 15 percent for non-snow precipitation (Figure 2). Estimates of the mean precipitation over the basin are then calculated by isohyetal-weighted summation. It was assumed that no snow sublimates subsequent to April 1 and that losses because of evapotranspiration accounted for about 48 percent of the mean annual precipitation.

While this method may yield a reasonable estimate of the mean precipitation over the entire Mammoth Basin, it does not apply to sub-areas because of the variation within the basin. Some of the measurement sites are clustered in the area immediately adjacent to Mammoth Mountain, which has anomalously high snow fall for a given elevation. When the data are extrapolated to other areas with no observations, the SWE of the snow cover is over estimated. As shown later, we arrive at a significantly different SWE-elevation gradient for the proposed SSA and therefore different isohyetals than those presented in the DWR (1973) study for the Mammoth Basin in general.

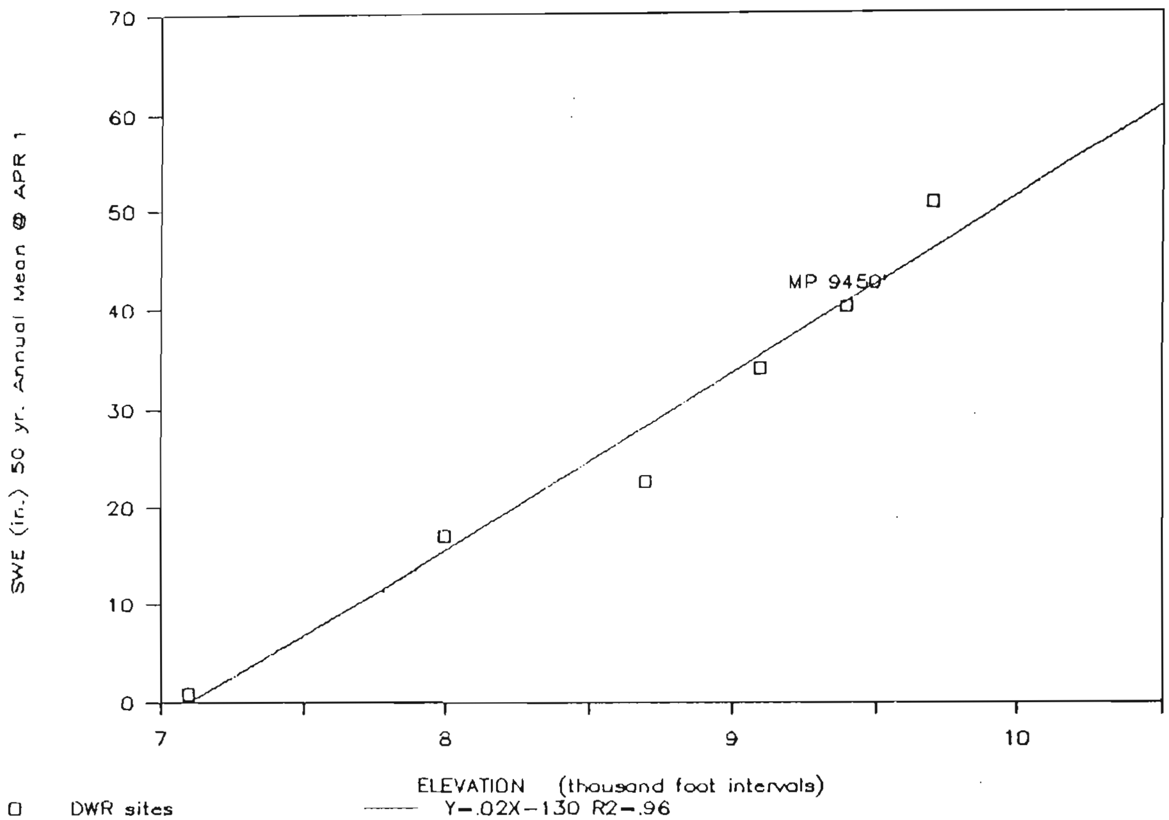

Figure 1. The elevation-gradient of snow water equivalent derived for the Mammoth Basin (DWR 1973).

This is primarily because we suspect the Lake Mary Store (8,900 feet) record represents an undercatch of snow fall, and the Mammoth Pass (9,450 feet) record is anomalously high, so that the slope of the SWE-elevation gradient is over estimated by several percent. In addition, the isohyetals in the DWR (1973) report are extrapolated to higher elevations than any measurement site, which compounds the error in basin-wide SWE owing to the overestimated slope of the SWE-elevation gradient.

A preliminary study of potential ski areas in the Mammoth area was completed by the USFS in 1980 (Martin 1980). Included in these studies is a description of the physical environment of the proposed SSA. Snow and wind data were collected during the snow season 1974-75 and seasons from 1979 to 1982 respectively. These consisted of snow depth observations, rounded to the nearest foot, obtained from depth stakes placed at three locations in the proposed SSA, instantaneous wind velocity measurements taken from helicopter instruments, and wind velocity and air temperature measurements recorded by a weather station near the base of the study area. The wind velocity and air temperature data are compared to similar data observed at the Mid-Chalet at Mammoth Mountain using statistical procedures in order to use the historical record at Mammoth Mountain to predict wind and air temperature conditions in surrounding areas. The snow data are compared subjectively with no statistical analysis, and because only depths were recorded the conclusions are disregarded.

In 1986 a report entitled Water Supply Analysis for Proposed Sherwin Ski Area was prepared by Triad Engineering Corporation and incorporated into the Proposed Sherwin Ski Area Feasibility Study (O'Conner and Sno-Tek 1986). The watershed analysis uses the isohyetals of the 50-year mean precipitation constructed in the DWR (1973) study. Therefore the reported amounts of snow cover and recharge are too high. Precipitation figures for the proposed SSA are estimated based on the area-weighted averages of the DWR isohyetals at 7868 acre-feet per year, or an area-average annual precipitation of about 27 inches. Losses from potential water production because of evapotranspiration are estimated at about 62 percent of the mean annual precipitation, based on vegetation types and areas in the study area. Adding losses owing to evapotranspiration bring the total estimated annual precipitation for the study area to 43.5 inches. If we assume that 85 percent is snow fall, the expected SWE is 37 inches. The mean annual recharge to the ground water is estimated at 2638 AF, and does not account for post-April 1 losses owing to sublimation.

The report "Preliminary Snow Cover Evaluation of Sherwin Ski Area" (Burak 1986) uses snow survey techniques at the proposed SSA and performs some elementary statistical procedures. Despite having only one season of data, good correlations are found between the Mammoth Pass snow pillow record and the snow course measurements from four sites at the proposed SSA. It should be noted that the measurements taken at the study area provide only an index to the snow water equivalent SWE, since the accuracy of the sampling method is biased (over samples). Based on these indices, the estimated SWE for elevations 9,100 feet, 9,500 feet (2 courses), and 10,500 feet are, respectively, 16 inches, 17 inches, and 15 inches SWE on April 1 for normal years.

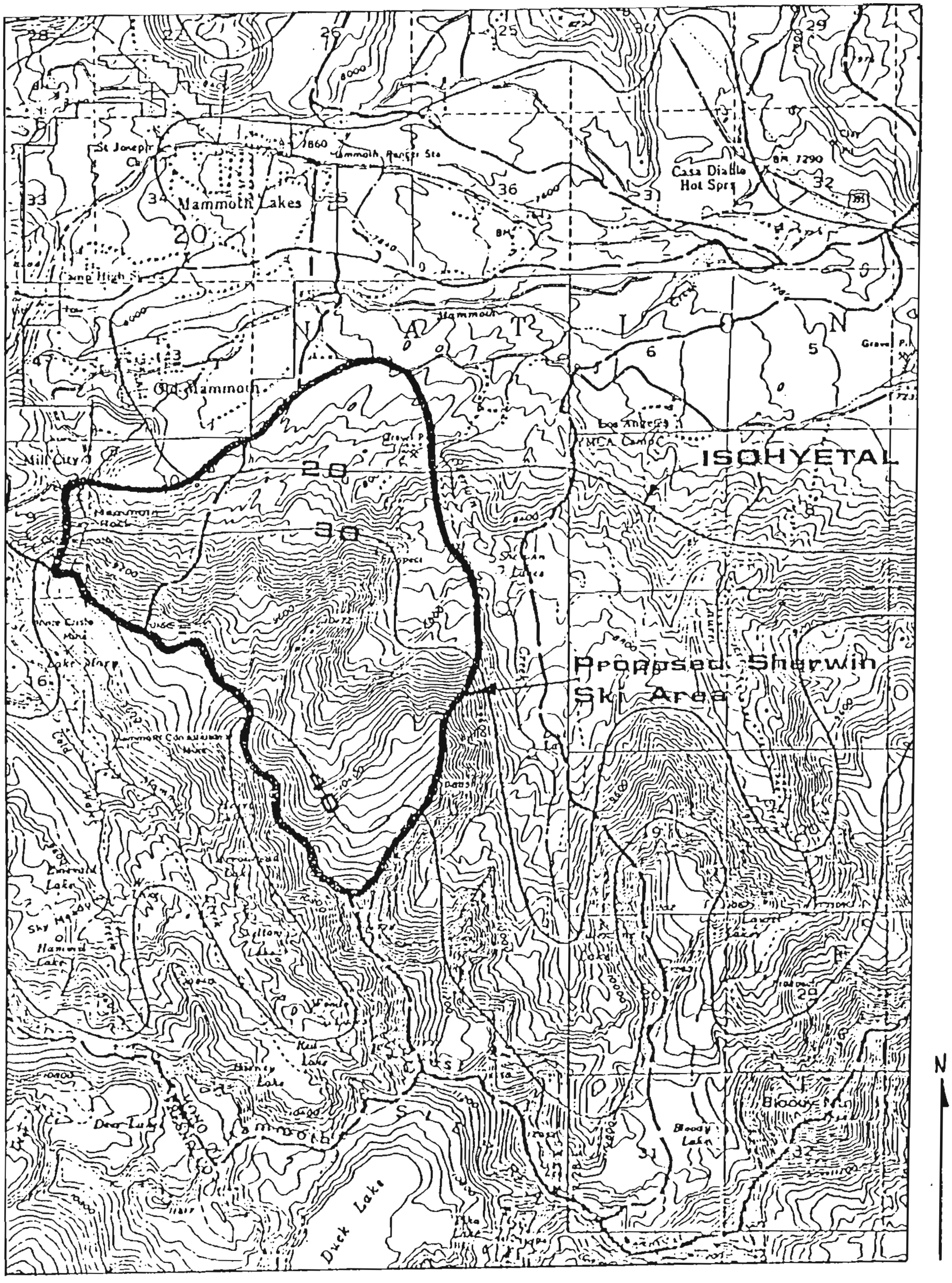

Figure 2. Isohyetals of 50-year mean annual precipitation for the Mammoth Basin. (from DWR 1973)

The values are calculated using the 50-year mean from the record for the Mammoth Pass cooperative site. It can be seen that the estimates are less than the SWE derived from the 1973 DWR study by at more than 50 percent.

2. Summary

The use of isohyetals to extrapolate snow cover over mountainous topography can lead to large errors when isohyetal values are applied to small areas with no measurement sites. In the case of the Mammoth Basin, two of the highest gages used are on and adjacent to an area of anomalously high snow fall. Hence the DWR (1973) study over estimates the relationship between elevation and snow accumulation. This error is compounded because the snow cover is assumed to continue to increase with elevation, despite the lack of corroborating data. At the proposed SSA, a significant proportion of the terrain lies above the highest snow course in the Mammoth Basin, in the zone of greatest uncertainty in snow accumulation. The SSA feasibility study uses the erroneous isohyetals in a detailed study of the hydrology of a small sub-watershed in the Mammoth Basin to arrive at estimates of mean annual snow fall, and ground water recharge that are too high. This error is repeated in the Climate section of the study (O'Connor and Sno-Tek 1986). The USFS snow survey study (Burak 1986) reports measurements that show the general overestimation of snow fall at the proposed SSA.

C. Measurements

The measurements performed at the proposed SSA include average snow depth and density observed at snow courses located throughout the area, and wind speed and air temperature monitored continuously at the crest of Horn Ridge near the site of the proposed Solitude Lodge. Other measurements include snow surveys at the Lake Mary Store precipitation gage, at Mammoth Pass, and at Mammoth Mountain, and weather measurements at Mammoth Mountain.

1. Site Selection

The snow courses used in the USFS study are measured, with additional snow courses that were selected on the basis of representativeness to the proposed ski pods and ancillary data sites. The statistical relationships computed in this study are more robust than the USFS study because of the additional data points and the extreme differences between the 1985-86 and the 1986-1987 snow seasons.

Measurement sites are chosen to represent the average accumulation and ablation of the snowpack for a variety of elevations ranging from 7,800 to 10,500. In general, they are located away from avalanche paths, depressions where ponding might occur, and wind scoured ridges. The courses are located on gentle terrain, with slopes of three to five degrees, in sparsely forested or in clear areas. One wind scoured site is used at an elevation of 10,500 feet, which is a proposed location for a lodge facility. Figure 3 shows the locations of the snow courses at the study area.

Snowcreek Base, proposed SSA, 7,800 feet: This site lies in an open meadow with sparse timber including lodgepole pine and a slope of approximately 3%. It is protected from the wind, except from the northeast, by adjacent moraines.

Lake Mary Store, 8900 feet: The snow course at this site is located adjacent to the Lake Mary Store precipitation gage in a clear site on the south east shore of Lake Mary. The slope is about 1 to 2% and the vegetation consists of low shrubs and grass. The site is protected from storm winds by the adjacent forest, but is vunerable to post-frontal winds blowing over the lake.

Lower Solitude Canyon, proposed SSA, 8,900 feet: This site is located in the bench below the Canyon Lodge site, in mixed mountain forest. The slope is about 2 to 4% with little wind effect during storm activity. This site was chosen because of its similarity to the Lake Mary Store site.

Canyon Lodge, proposed SSA, 9,100: Aspen, lodgepole, western white pine, with hemlock on the southern boundary comprise the vegetation of this site, located in pod H. The slope is about 1%, and it is protected from the wind by Horn Ridge to the north and timber all along the perimeter.

West Solitude Bowl, proposed SSA, 9,500: This site is located in pod J, with scattered lodgepole pine with a 4% side slope to the main transect. Some snow redistribution is likely because the site is moderately exposed to the wind.

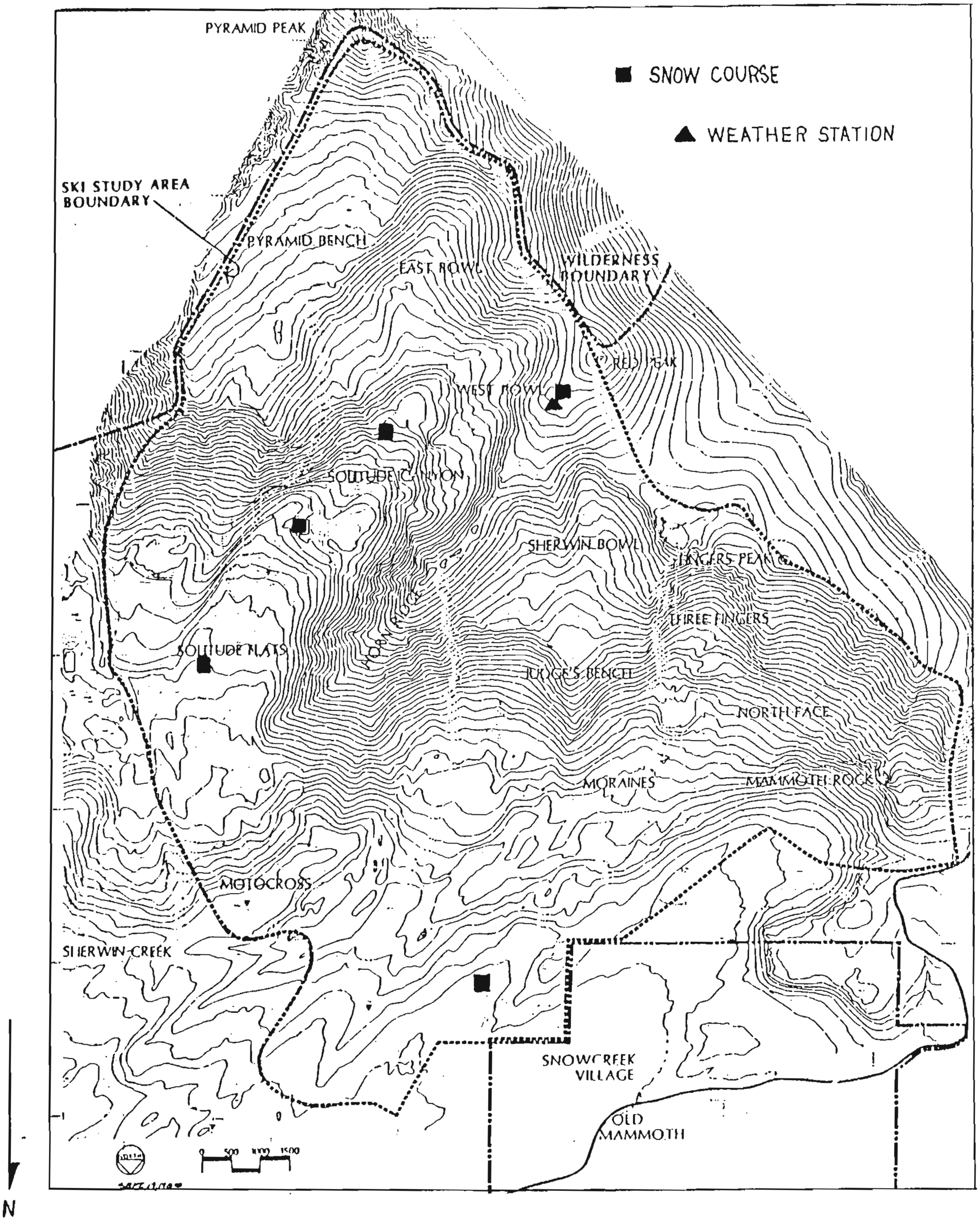

Figure 3. Locations of snow measurement sites at the proposed SSA.

Mammoth Mountain Snow Study Plot, 9,600 feet: This site is located about 150 yards east of the Mid-Chalet facility on Mammoth Mountain. The terrain is flat, with a slope of less than 1%, and the vegetation cover is essentially nonexistent. Because of the terrain and vegetation situation, the area is subject to wind scour uniformly over the plot.

Solitude Lodge, proposed SSA, 10,500: This site is located on the wind-swept saddle between Red Peak and rock outcropping, which separates pods C and I. Sparse whitebark pine characterizes the vegetation and the slope is about 4 to 8%. High variability in snow cover was encountered because of wind effects.

2. Measurement Techniques

Techniques modified from the standard USDA Soil Conservation Service snow survey methods generate a large number of sample points. Each snow survey site consists of at least 10 sample points located on two roughly orthogonal transects, which are predetermined for each site. All depths and SWE estimates are obtained with a Mt. Rose Sampler, sometimes termed a Federal sampler. Data sampled at each point includes total snow depth, length of the sampler core, weight of the empty tube, and total weight of the tube and core. The point-sample of SWE is obtained from the net weight of the snow in the tube. An estimate of the average density of the snow pack can be calculated by dividing the SWE by the total depth.

Examinations of bias of the Mt. Rose sampler suggested by Letvak (1978) and carried out by Farnes et al. (1982) show that the standard Federal sampler (Mt. Rose) oversamples SWE by up to 10%. Snow tube measurements must be calibrated to determine the "true" or absolute SWE with a snow pit for a given date (Farnes et al. 1982). The SWE measurements for this study are calibrated with periodic snow pits. In this procedure, a snow pit is dug to the ground and at least five density samples are obtained each 4 inches from the surface to the base. These density samples are used to calculate an accurate absolute average density and total SWE. Next to the pit four or more snow cores are sampled with the Mt. Rose sampler and weighed so that the bias can be determined from the average. We assume that the correction factor is constant while the snow pack remains relatively unchanged, that is until the next storm, wind-scour event, or melt episode.

Examples of the calibration data are shown in Tables 1 and 2.

TABLE 1 : Snow Pit, March 11, 1987

DEPTH (cm)	SAMP. 1 (kg/m^3)	SAMP. 2 (kg/m^3)	SAMP. 3 (kg/m^3)	SAMP. 4 (kg/m^3)	Samp.5 (kg/m^3)
00-10	294	318	329	324	332
10-20	354	323	344	371	356
20-30	303	308	317	295	340
30-40	361	349	378	381	359
40-50	335	344	337	341	336
50-60	334	344	331	332	333
60-70	327	316	310	314	314
70-80	324	317	307	311	314
80-90	283	287	288	318	312
90-100	290	280	281	282	284
100-110	218	225	244	240	245
110-120	202	200	205	210	209
120-133	205	207	218	217	206

The average SWE for the pit measurements is 15.3 inches.

TABLE 2 : Mt. Rose SWE Samples, March 11, 1987

MEASURE	SAMP. 1	SAMP. 2	SAMP. 3	SAMP. 4
DEPTH	52.0"	51.5"	51.0"	50.0"
SWE	16.3"	16.4"	15.0"	16.0"

The average SWE from the Mt. Rose samples is 15.9 inches.

The density profile data from the pit are averaged and multiplied by depth to yield an average "absolute" measure of SWE. The Mt. Rose sampler data are also averaged and compared with the data obtained from the pit. This particular comparison showed that the core sampler over estimated the SWE by 0.038, or slightly less than 4%. But in other cases (less SWE) the difference was higher, approaching 11 percent. A linear function is used to calculate the correction factor for the snow course average for a particular date [SWE' = (-0.005)SWE + 0.131]. Calibrated manual survey data are used in all data analysis procedures described below.

3. Weather Measurements

Wind direction and speed and air temperature are measured at the proposed Solitude Lodge site with a Belfort mechanical weather station. These data are expressed as a continuous record on a chart. The station record are be compared with meteorological measurements monitored at the snow study plot on Mammoth Mountain, 9600 feet (Davis and Marks 1980). Air temperature data were also obtained from the USFS Mammoth Ranger Station (7,650 feet).

D. Historical Snow Data

Snow depth and SWE measurements have been obtained from areas near SSA including Lake Mary Store, Mammoth Pass, Mammoth Mountain, and Minarets Courses 1,2, and 3. The Minarets courses are not considered for further analysis because of low elevation and characteristics that are less representative of areas at the proposed SSA than the other sites.

Lake Mary Store, 8,900 feet: The Lake Mary Store precipitation gage is a standard Belfort weighing gage that is unshielded. The gage sits on top of a tower at the south east end of the shore of Lake Mary. The performance of gages of this type has been tested by many studies, which show that the ratio of gage catch to true snow fall (measured on the ground) decreases as the wind speed increases (e.g. Allis et al. 1963; Goodison and McKay 1978; Goodison and Metcalfe 1982; and Sturges 1984). This characteristic is particularly severe for unshielded gages.

Daily data for 1987 have been requested from the Los Angeles DWP to compare to surveys carried out in the area adjacent to the gage, with no response. This data base is not used in the statistical comparisons with SSA because wind speed is not measured at this site so that estimates of expected error cannot be made. In addition, data from the gage to compare to the manual measurements are unavailable.

Mammoth Pass, 9,450 feet: Estimates of SWE were obtained from the snow pillow record, and the manual survey record provided by the California Cooperative Snow Survey (historical record) and by the Department of Water and Power of the City of Los Angeles (specific dates). This site has a southern aspect with open timber, mostly lodgepole pine, and a slope of about 1 to 2%. The timber provides substantial protection from the wind.

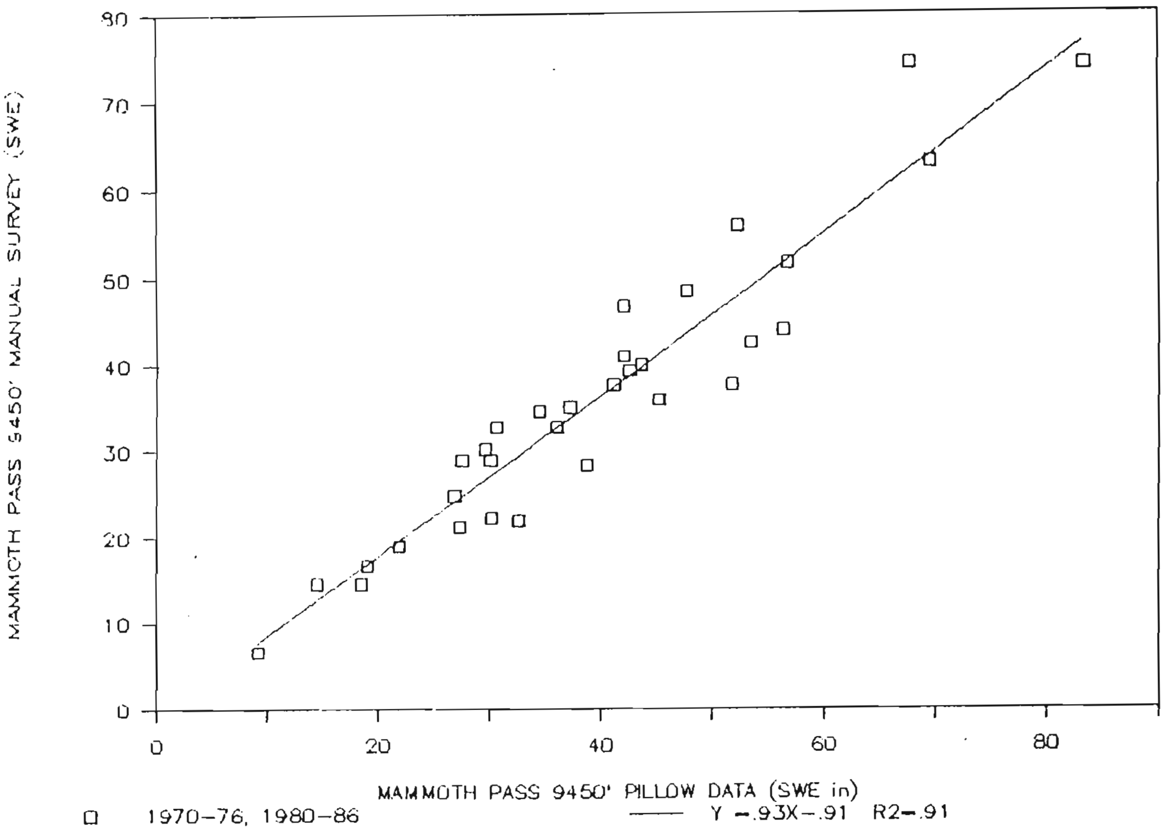

Figure 4. Comparison of manual survey and snow pillow data from Mammoth Pass (9,450 feet). Symbols show data points.

The manual survey data form a 50-year record that began in 1928, and consists of measurements starting each year on February 1, that continue on the first of each month to May. The pillow record consists of daily data that start in 1970. These two data sets are compared statistically using least-squares regression and evaluated using the correlation coefficient. In general, there is almost a one-to-one relationship between the two data sets, with the pillow data being slightly higher than the manual survey data. This relationship is used to correct the pillow data whenever they are used in data analysis procedures with the proposed SSA, and is shown in Figure 4.

Mammoth Mountain, 9,000 and 9,600 feet: SWE estimates were obtained from depth measurements and average densities at the cooperative snow study plot east of mid Chalet at 9,600 feet. Data on SWE at this site are available starting in 1982, and snow pillow data are available for a longer period. The snow pillow record will not be used as an indicator parameter because the site is subject to severe wind scour and the observations are not considered representative of the snow cover conditions in the Mammoth Lakes watershed (Ron Taylor, LA DWP, personal communication). Opening dates and the corresponding SWE were obtained from the Main Lodge study plot for the years 1982 to 1987.

E. Data Analysis

The data analyses described here are based on elementary statistical procedures and assumptions that idealize the distribution of the snow cover at the proposed SSA. The accuracy and reliability of these calculations will be discussed in the Results section. A record of historical data can be used to predict conditions where there is not a long record if a high degree of covariation between the data sets can be shown. For example, the Mammoth Pass snow pillow record is a good indicator of SWE because it shows a high degree of covariation with manual surveys taken at the same site, as well as good correlations with snow courses at the study area (Burak 1986).

1. Snow

The procedure for compiling the raw snow observations starts with computing the average SWE for each course for a particular date. These averages are then entered into a computer spreadsheet and compiled with data from the 1985-86 snow season. A total of 56 snow course observations are shown, each the average of at least 10 SWE measurements, making the combined data base for snow measurements at the proposed SSA over 560 observations. Experience dictates that the SWE averages for the study area be classified according to elevation, which also facilitates estimates of the potential ski season by elevation.

Paired sets of SWE values are drawn from the data base for statistical analysis. Standard statistical procedures (Snedecor and Cochran, 1980) are used to compare the variation in snow data between the SSA sites and the historical record from Mammoth Pass. Least-squares linear equations are calculated to determine the line of best fit between data sets. Next, simple bivariate correlation coefficients are calculated. These coefficients measure the closeness of the relationship between the paired data sets. That is, the correspondence between the accumulation and ablation rates between SSA sites and the other sites is estimated with this simple analysis.

The following assumptions are made for our estimates of SWE at the study area: 1) The snow courses at the study area are representative of larger areas at the same elevations. 2) On a storm-by-storm basis there is a regular difference between accumulation at a particular SSA snow course and at an indicator site. 3) This difference will show a smaller variation when many storms are averaged. 4) The elevation-area weighted average of the SWE estimates represents an accurate estimate of the total SWE at the proposed SSA.

The raw snow data from courses at the study site are calibrated based on snow pit observations. It was found that the correction factor is a linear function of SWE, with a correlation coefficient of 0.995. The data from the snow pillow at Mammoth Pass are also calibrated, based on manual surveys made at the adjacent snow course. The calibration function for this case has a correlation coefficient of 0.95. Next, a calibrated data set is generated for dates when manual snow data are unavailable, and this data set is used in the analyses. Table 3 lists the data-set pairs used.

Table 3. Pairs of data sets analyzed.

9,450' Mammoth Pass	vs.	7,800' proposed SSA
9,450' Mammoth Pass	vs.	8,900' proposed SSA
9,450' Mammoth Pass	vs.	9,100' proposed SSA
9,450' Mammoth Pass	vs.	9,500' proposed SSA
9,450' Mammoth Pass	vs.	10,500' proposed SSA

The relationships obtained from the calculations described above are used to determine a predicted SWE-elevation gradient for the study area for an average year on April 1, and to compute SWE-time relationships for the different snow courses. These predictions are used to estimate the total average SWE on April 1 for water resources evaluation, and the probabilities of opening parts of the area on specific dates for skiing.

To estimate the probability that a location has enough snow for skiing, a minimum SWE must be determined. Data from the Main Lodge at Mammoth Mountain for the seasons 1982 through 1987 show that the average SWE on the opening dates is 4.2 inches. In this study we will assume that the proposed SSA requires 5 inches SWE because the granitic surface material need more snow to fill in than the pumice on Mammoth Mountain (Martin 1980). Table 4 shows the depths of snow that correspond to this and greater SWE for different snow conditions. The average densities used to generate the depth vary with accumulation as well as time and treatment.

Table 4. Snow depths corresponding to different SWE.

SWE	EARLY WINTER DEPTH	MID-WINTER DEPTH	EARLY SPRING DEPTH	MACHINE GROOMED DEPTH
5"	33"	20"	12"	9"
10"	50"	34"	22"	16"
15"	65"	43"	32"	23"
20"	80"	56"	40"	29"

Table 5 shows the average densities used in the above table.

Table 5. Snow densities (SWE fraction) corresponding to different SWE and times.

SWE	EARLY WINTER DENSITY	MID-WINTER DENSITY	EARLY SPRING DENSITY	MACHINE GROOMED DENSITY
5"	0.15	0.25	0.40	0.55
10"	0.20	0.29	0.44	0.60
15"	0.23	0.35	0.47	0.65
20"	0.25	0.36	0.50	0.70

The probabilities of sufficient snow by the Thanksgiving and Christmas holidays are obtained by using the daily snow pillow observations from the Mammoth Pass historical record. Daily observations are available for the years 1971 to 1986, except for 1976-1979, and probabilities have been calculated based on specific classes of SWE, obtained for the average between November 18 and 23; and December 18 and 23. The probabilities for the 9,500 foot elevation zone are in agreement with the relative frequency of opening dates at the Main Lodge at Mammoth Mountain.

The probabilities of opening the various proposed pods are based on when the average SWE for the entire pod is 5 inches, and the assumption that under ideal conditions, the snow could be redistributed effectively by snowcat. This is an unrealistic assumption for some of the pods, and the pods omitted from this analysis because of a reverse SWE-elevation gradient are c, g, i, j, and k. We could not assume that snow could be effectively redistributed in an upslope direction. This estimate also assumes that little snow could be moved from other pods to a particular one. Other assumptions include; a linear gradient in elevation of SWE occurs along the pods, and terrain modification will not significantly affect the snow accumulation in a proposed pod.

2. Air Temperature

Air temperatures at the crest of Horn Ridge near the proposed Solitude Lodge site (10,500 feet) were recorded for January through March, 1987. This data is compared with observations at Mammoth Mountain, near the Mid-Chalet at a study plot, using least squares regression of different averages over time as well as instantaneous readings.

Air temperature data from the USFS Mammoth Ranger Station are summarized with the statistics of the wintertime distribution for the period 1975 to 1982. This is done to estimate the average period prior to December 31 suitable for snow making.

3. Wind

Wind data from the station near at the proposed Solitude Lodge site are summarized in the Results section. The speed and direction averages are computed for fair weather, pre-frontal storm conditions, and post-frontal storm conditions.

F. Results and Discussion

1. Snow

The SWE for each of the courses (elevation zones) is estimated based on linear regression with a calibrated 50-year record from the Mammoth Pass cooperative site. The analyses show the following average April 1 values of SWE (Table 6).

Table 6. Predicted average April 1 SWE.

SITE ELEV.	EST. SWE	CORR. COEF.	APPROX. DEPTH
7800'	10.7"	0.94	26"
8900'	14.9"	0.98	32"
9100'	19.5"	0.96	38"
9500'	19.3"	0.97	41"
10500'	17.9"	0.87	37"

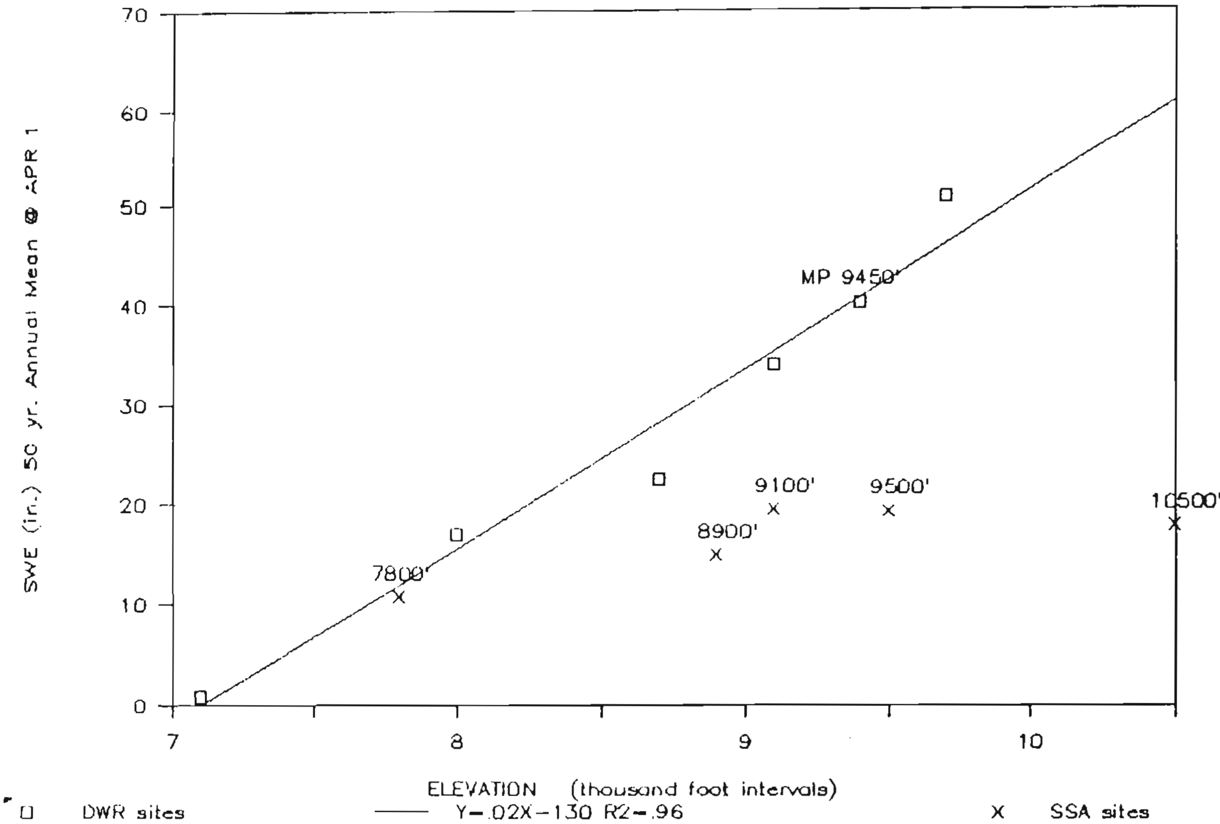

Figure 5. Predicted average April 1 SWE for the proposed SSA verses elevation, shown with estimates from DWR (1973) report.

The predicted average April 1 SWE verses elevation is shown in Figure 5 along with the original DWR (1973) relationship. One can see significantly less increase in snow cover with elevation than estimated by the DWR report for an average April 1 condition. The estimated average SWE for the entire study area is 17.7 inches. Figure 6 shows predicted accumulation rates for the different elevations, based on the 50-year record from Mammoth Pass.

The probabilities are shown for potential opening dates in November and December by elevation in the Table 7.

TABLE 7. Probabilities of sufficient natural snow for skiing by Thanksgiving (Nov.) and by Christmas (Dec.).

ELEV.	Prob.(Nov.)	Prob.(Dec.)
7,800	0.12	0.40
8,900	0.38	0.67
9,100	0.73	0.76
9,500	0.75	0.80
10,500	0.50	0.73

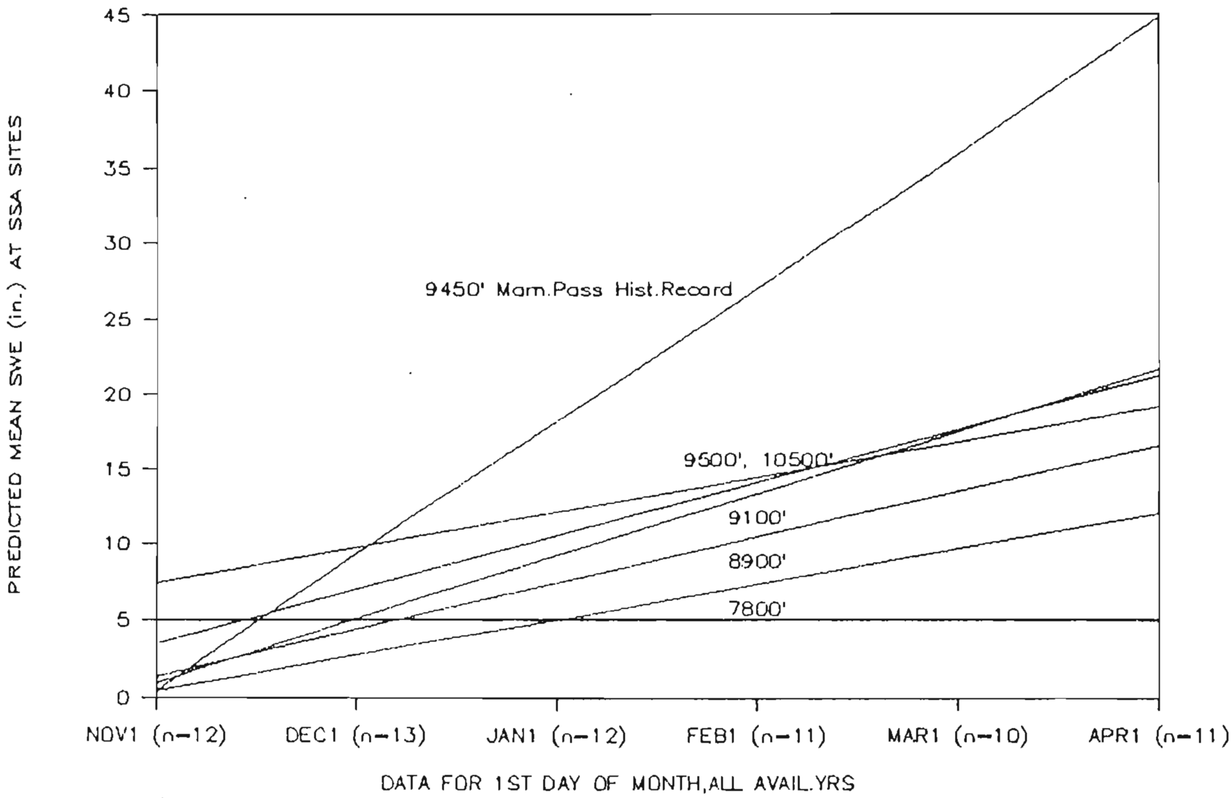

Figure 6. Predicted average accumulation rates for different elevations at the proposed SSA, and the actual average accumulation at Mammoth Pass. Horizontal line is the minimum SWE required for skiing. The SSA rates prior to Dec. 1 are an artifact of the equations used.

The probabilities of opening for some of the proposed pods for the same periods are shown in Table 8.

TABLE 8. Probabilities of sufficient natural snow for skiing by Thanksgiving (Nov.) and by Christmas (Dec.).

POD	Prob.(Nov.)	Prob.(Dec.)
a	0.42	0.67
b	0.38	0.46
d	0.20	0.46
e	0.19	0.42
f	0.20	0.46
h	0.44	0.55

Proposed pods c, g, i, j, and k were omitted from these calculations because measurements show a decrease of SWE with elevation in these areas. For expected probabilities for these proposed pods see the elevation probabilities. If the assumption of effective snow redistribution by snowcat is accepted, then these probabilities are likely to be more accurate. This is because the equations exhibit less error for values near the mean.

2. Weather

The analysis of the meteorological conditions shows that the average storm track is southwesterly and aligned with Mammoth Pass, which partially explains the variation in SWE at the study area and at Mammoth Pass and Mammoth Mountain. An additional factor may be the rain shadow effects of the Mammoth Crest.

The air temperatures from the proposed SSA show a close correspondence with the measurements of air temperature from the snow study plot on Mammoth Mountain (9,600 feet) if weekly averages are used. However, comparison of instantaneous observations of air temperature at the two sites show no significant correlation. The conclusion that can be drawn is that for the same elevation, above 9,500 feet, the air temperatures at the proposed SSA average about 3 degrees centigrade warmer than the air temperatures on Mammoth Mountain. This assumes a linear environmental lapse rate. We cannot accurately determine differences between air temperatures at the study area and Mammoth Mountain for lower elevations because of a lack of adequate data.

Air temperature data from the USFS Mammoth Ranger Station are summarized for the months November, December, and January in Table 9.

Table 9. Analysis of Mammoth Ranger Station (7,650 feet) air temperature data.

Month	Mean Minimum Temp. C	Standard Deviation C	Standard Error of Mean C	Mean Temp. C
Nov.	-4.6	4.9	0.5	-0.45
Dec.	-8.1	5.9	0.4	-5.05
Jan.	-7.1	7.4	0.5	-3.20

This table suggests that suitable snow making conditions occur most nights in November and for extended periods in December.

The wind data obtained from the station at the proposed Solitude Lodge site on the crest of Horn Ridge are summarized in Figure 7, which shows a wind rose for the months January, February, March, and part of April. Wind data were also obtained from the USFS for the base area of the proposed SSA for 1979-1980 (Figure 8).

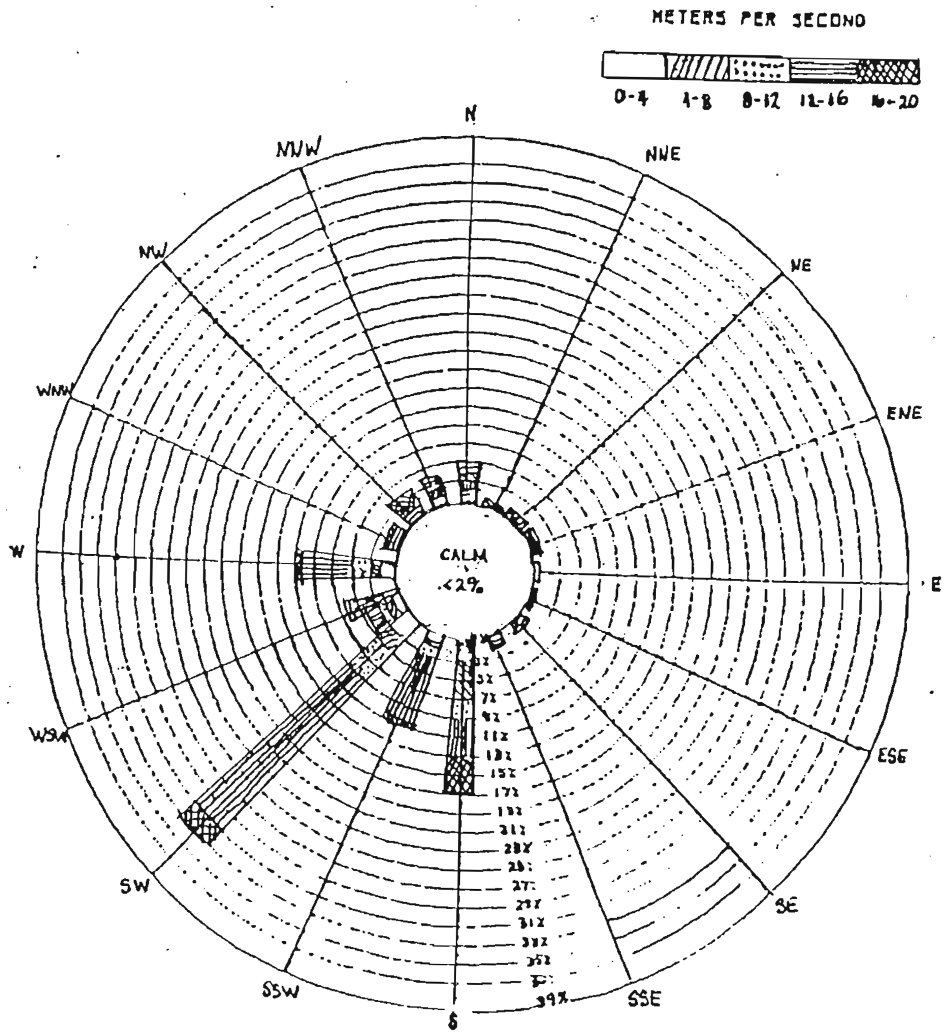

Figure 7. Wind rose of frequency, direction and amplitude for measurements taken from 10,500 feet at the proposed SSA, 1987.

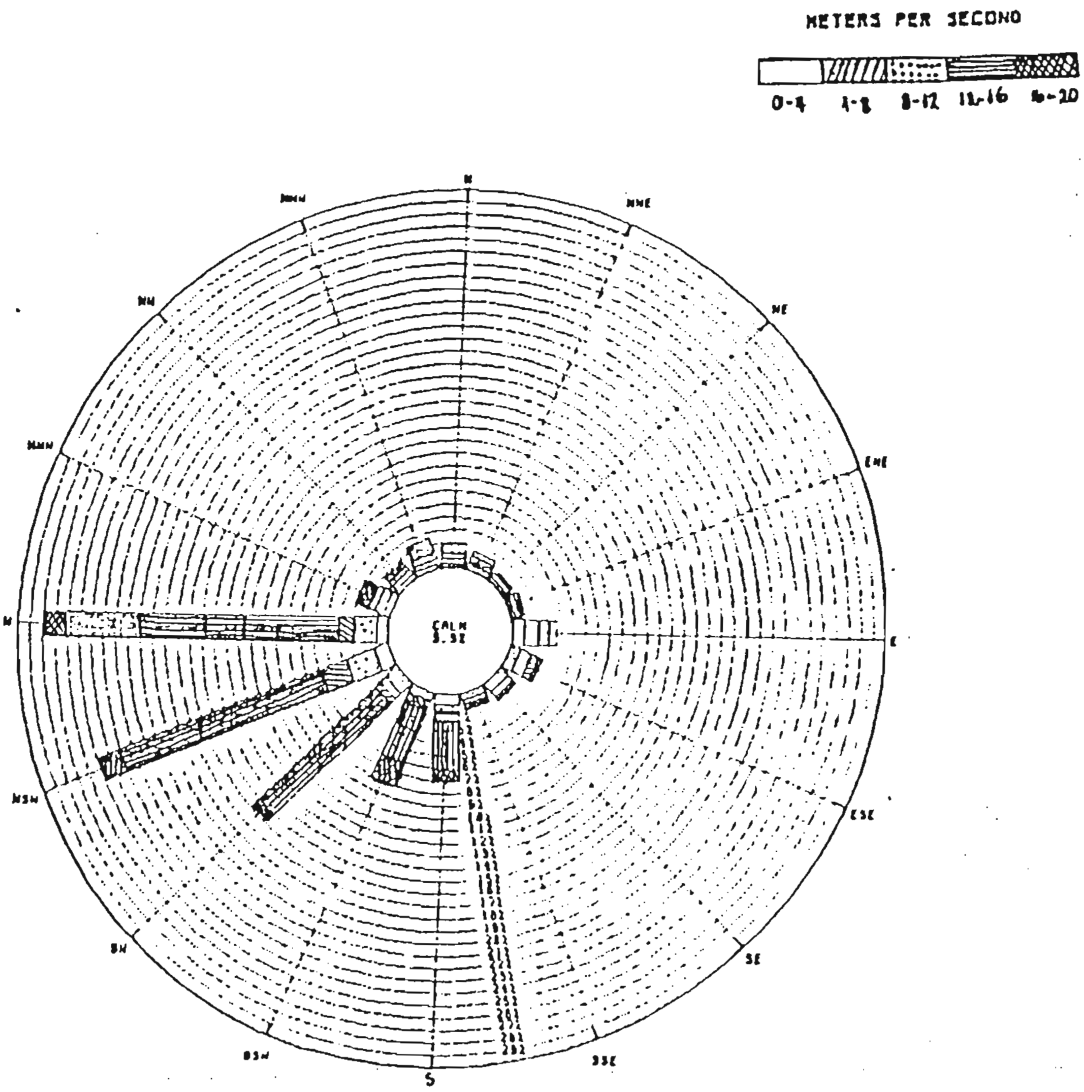

Figure 8. Wind rose of frequency, direction and amplitude for measurements taken from 7,800 feet at the proposed SSA, 1979-1980.

G. Summary

Previous reports on the snow conditions of the proposed SSA are in error because they overestimate the amount of snow cover. This is because the existing distribution of snow measurement sites consists of low elevation snow courses and sensors scattered around the Mammoth Basin and moderate-elevation courses clustered near Mammoth Mountain, a zone of relatively high snow fall. There are no established high-elevation snow courses that would provide representative data for the proposed SSA. In addition, the existing data bases provide only an index of the actual snow cover because the data are not calibrated, in the absolute sense, to true SWE.

This report shows a high degree of correlation between SWE at different elevations at the study area and the historical record at the Mammoth Pass cooperative snow survey site. The record from Mammoth Pass is used to predict snow accumulation rates and various snow cover characteristics. The average April 1 SWE for the entire proposed SSA is predicted to be 17.7 inches. This contrasts with the value estimated by the feasibility study (O'Conner and Sno-Tek 1986), which is about 37 inches SWE.

Probabilities are computed for the occurence of adequate natural snow fall for skiing by Thanksgiving and by Christmas. These are supplemented with estimates of the average accumulation rates for the different snow courses at the study area.

Winter weather data from the 10,500 foot level and the 7,800 foot level at the proposed SSA are summarized in Tables and rose diagrams.

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Route 1, Box 1137, Crowley Lake, CA 93546

April 16, 1987

Mr. Ed Smith
Resource Concepts Inc.
340 N. Minnesota St.
Carson City, Nevada 89701

Dear Mr. Smith,

I enclose a copy of our report on the snow conditions at the proposed Sherwin Ski Area, completed as a subcontract to Resource Concepts Inc., RFP R5-BVC-87-01.

Any questions or comments will be welcome. If I am not available, please contact Bert Davis at (619) 935-4903.

Sincerely,

Susan Burak

Susan Burak
619-935-4696

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Snow Resource Consultants

Route 1, Box 1137, Crowley Lake, CA 93546

April 16, 1987

Mr. Dave Ellis
Design Workshop Inc.
710 East Durant
Aspen, Colorado, 81611

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