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The Effects of Elevation and Vegetation Type on Snow Accumulation and Melt in Logan Canyon, Utah

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THE EFFECTS OF ELEVATION AND VEGETATION TYPE ON SNOW ACCUMULATION AND MELT IN LOGAN CANYON, UTAH

by

Paul R. Thies

A thesis submitted in partial fulfillment
of the requirement for the degree

of

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on Snow Accumulation and Melt in

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by

Paul R. Thies, Master of Science

Utah State University, 1972

Major Professor: Dr. George E. Hart
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Snow accumulation and melt characteristics were studied in Logan Canyon, Utah. Three replications of aspen, conifer, and open field types at 6300, 7100, and 8000 feet were measured for snow depth and water content during 1972. Elevation was found to have the greatest effect on snow water content. The gradient of increasing water content with rise in elevation was found to be .51 inches/100 feet in the zone from 6300 to 7100 feet and 1.9 inches/100 feet from 7100 to 8000 feet. The cooler temperatures at higher elevations partially account for the 8000 foot zone beginning to melt 40 days after the 7100 foot zone, and the 7100 foot zone trailing the 6300 foot zone by 20 days. Although the snow at the 8000 foot elevation began melting later than the lower zones, it melted at twice the rate.

Vegetation cover type has no significant effect on the amount of snow deposited. However, the conifer type protects the snowpack from solar radiation causing the snowpack to have a significantly lower density than the snowpack assocaited with either aspen or open field. The snowpack under the conifer canopy melts 30 percent slower and remains 17 days longer.

(55 pages)

INTRODUCTION

The mountainous areas of Utah contribute approximately 70 percent of the streamflow in this state (Dorignac, 1967). The precipitation initiating this streamflow occurs primarily in the form of snowfall during the winter months, while the prolonged snowmelt period, lasting often into June, determines the seasonal distribution and quantity of runoff. A great dependence is placed on this water resource by an agrarian society such as found in much of the Intermountain area. In light of population growth trends, and projected irrigation needs for the future, the demand for water will increase. Consequently, the ability to manage snow water supplies has obvious economic and political advantages to private irrigation concerns, municipalities, and federal agencies.

With this dependence on snowpack water, emphasis in the future should be placed on management of wildland snow zones. In order to make timely management decisions, the influence of such factors as topography and vegetation on the snowpack should be understood. Increased water supplies for the future could be generated in some cases by changing the forest cover types of the mountain watersheds. For instance, in some special situations it may be desirable to delay the melting of the snowpack as late as possible, in which case a conifer cover type may be favored over aspen types. If elevational influences were better understood, weather modification attempts could be aimed at targets with known optimal elevation conditions. Finally, prediction of yearly supplies would be greatly enhanced if elevation and vegetative influences over the snowpack for an entire watershed were correlated to a few snow courses without having to spend years in calibration programs.

Very little is known about vegetative and topographic influences on snow in northern Utah. Snow research in relation to topography has been limited to meteorologic studies of elevation and atmospheric interrelationships on precipitation processes conducted by Lull and Ellison (1950) and Williams and Peck (1962). These studies do not furnish actual snow accumulation lapse rates or snowmelt lapse rates by elevation, and they furnish no information on the role of vegetation. Findings from snow studies in surrounding areas of the West can not be used here because of the large discrepancy in results. Anderson and West (1965) in California, found a 7-inch increase in snow water equivalent per 1000 foot rise in elevation, as compared to 10.5/1000 in Idaho (Packer, 1962); 4.0/1000 in Arizona (Gary and Coltharp); and 16.8/1000 in Colorado (U. S. Soil Conservation Service, 1965, 1966, 1967). Vegetation influences have not been studied in as much detail. Research by Dunford and Niederhof (1944) in Colorado and Gary and Coltharp (1967) in Arizona indicated that conifer types generally collected less snow than aspen stands. However, there are few studies which deal expressly with vegetational effects on snow water content and density changes during accumulation and melt. With insufficient information on vegetation influences and a wide range of results on elevational influences, extrapolation of past results for use in northern Utah would be difficult.

The purpose of this study is to investigate the elevational and vegetative effects on snow characteristics during accumulation and melt periods in Utah. The results of this study may be used in future decisions on snowpack management in meeting water needs for Utah. It will aid those working with weather modification in selecting target sites; and, finally, the results may help refine simulation models used to predict snowmelt runoff.

LITERATURE REVIEW

Introduction

Since this paper is concerned with the influence elevation and vegetative cover type has on the distribution and ablation of the snowpack, review of the literature will be limited to these two factors. Physical processes involved in snow accumulation and melt will be discussed in this section, while actual research findings of other studies will be used for comparison in the results and discussion area of this thesis.

Vegetation and accumulation

Forest canopies control the deposition process through interception, and channeling of wind patterns. In calm conditions, snow falls at a vertical rate of about 1 meter (m) per second. However, with even a moderate wind, the flakes move at approximately a 4 degree angle to the horizontal (Miller, 1964). This means a conifer canopy appears to be nearly a continuous cover to the falling snow. Therefore, the degree of roughness of the canopy surface will affect the surface pattern as seen by the falling snow. The snow will drift on the lee side of obstructions, or accumulate in depressions of the canopy. An evenaged stand presents a relatively smooth surface to the wind carried snow. This causes the snow to be either swept past the stand or deposited rather uniformly along the crown. An unevenaged stand offers a variety of obstructions and depressions caused by the complexity of tree heights and canopy sizes. This causes uneven snow deposition on to the canopy with subsequent results on the ground (Miller, 1964).

Hoover (1960) found that cover types do not affect the amount of snow collected in a watershed, but rather the snow distribution over the watershed. Initially, the conifer type intercepts some of the falling snow through adhesion to the leaf and twig surface and then cohesion to the first snow particles. Rather than being trapped by the foliage, the snow merely rests on these surfaces and can be easily removed by the wind. This study found that the conifer type lost the majority of the intercepted snow through redistribution by the wind, not from evaporation as previously assumed.

Small forest openings seem particularly efficient at trapping disproportionately more snow than the surrounding forest. Openings the size of four tree heights in diameter are especially adept at this trapping process (Anderson and West, 1965). Greater snow accumulation occurs when wind eddys carry snow-ladden air into the openings and deposit it there. Most of the snow brought into the opening remains while the snow deposited on the canopy is often picked up and redeposited. This redistribution along with interception losses causes the surrounding forest to collect less snow than the small openings.

Aspen stands may collect more snow than adjacent open fields. The determining factor appears to be the reduction in wind velocity and the amount of interference the leafless stand presents to the wind. In areas of little or moderate winds, aspen stands do not collect significantly more snow than open fields (Wilm, 1948). However, in windswept areas, the small amount of resistance to the wind offered by the aspen stand does cause more snow to be deposited (Swanson, 1970).

Vegetation and melt

Several sources contribute to the snowmelt process. Insolation, or the direct shortwave radiation reaching the snowpack, is the chief contributor to melt energy on clear days. Longwave radiation is another important source of melt energy, especially since snow acts as a black body for this type of radiation (U. S. Army Corps of Engineers, 1956). While radiation is important in the ripening and early melt of the snowpack, sensible heat gains prominance during late melt and periods of warm temperature. Dewalle and Meiman (1971), working in small forest openings, found that net radiation accounted for 54 to 62 percent of the energy involved in late season snowmelt. Vapor exchange accounted for 3 percent and sensible heat for 41 to 49 percent of the melt energy. This review will be limited to the discussion of radiation and sensible heat as the two most important factors in snowmelt.

A forest canopy shades the snowpack from solar radiation, thereby reducing the energy input during periods of low air temperatures. However, when the foliage temperature is warmer than the snow temperature, the canopy is a source of longwave energy and contributes to the melt. This is particularly true of conifers which have very deep, full canopies all year. Aspen is often a smaller tree in this area, and the sparse winter canopy furnishes little shade and longwave energy melt. However, the lower boles are exposed to the sun and become warm during the clear days thus furnishing longwave radiation to the pack immediately surrounding the bole. This leads to the characteristic circles of melted areas around the trunk early in the melt season. The open field sagebrush cover ceases to influence the snowpack once it is covered by the snowpack in early winter.

Elevation

Generally, winter storms react to an orographic influence as they pass over the Wasatch Mountain Range. The rising of the air mass results in higher elevations receiving more precipitation than the lower elevations. The exception is the cold lows which often cause the fronts to rise before they reach the mountains. Although there is still an increase in precipitation with higher altitude, the increase is not as great as with storms other than cold low storms (Williams and Peck, 1962).

In the Dewalle and Meiman (1971) study, the importance of sensible heat was substantiated when he found sensible heat supplies 41 to 49 percent of the melt energy. Sensible heat is a product of air temperature and wind and can be affected by changes in elevation. A rise in elevation means a decrease in both temperature and in sensible heat. Higher elevations will stay cooler until later in the melt season and thereby delay the ripening of the pack and beginning of snowmelt. However, as summer approaches, the days become longer and disproportionately warmer with increased chances of warm rains which would cause the pack to melt faster once it does begin to melt.

METHODS AND PROCEDURES

Site Description

Logan Canyon (Figure 1) is located in the Cache National Forest in northeastern Utah. It is about 23 miles long and 9 miles wide with a total area of 218 square miles. It is oriented generally north-south. The elevation ranges from 4500 feet at the mouth to nearly 10000 feet atop Mt. Naomi.

Logan Canyon offers many advantages for active snow research. It is a large canyon with a wide selection of sites, elevational ranges, and a variety of vegetative types, all necessary for this project. U. S. Highway 89 bisects the length of the canyon making it accessible during the winter. In addition, it is close to the campus of Utah State University and is currently one of the study areas for research in modification of winter cloud formations and computer simulation modeling of snowmelt processes being conducted by the Utah Water Research Laboratory.

The three predominate vegetative types selected for this study were: (1) mixed conifer, including Douglas-fir (*Pseudotsuga menziesii*), subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), limber pine (*Pinus flexilis*), and lodgepole pine (*Pinus contorta*); (2) quaking aspen (*Populus tremuloides*); and (3) open field, with the predominate species being sagebrush (*Artemisia* spp.). Three sites of each type were studied at 6300, 7100, and 8000 foot elevations. The conifer type was deleted at 6300 feet since it occurs only as scattered

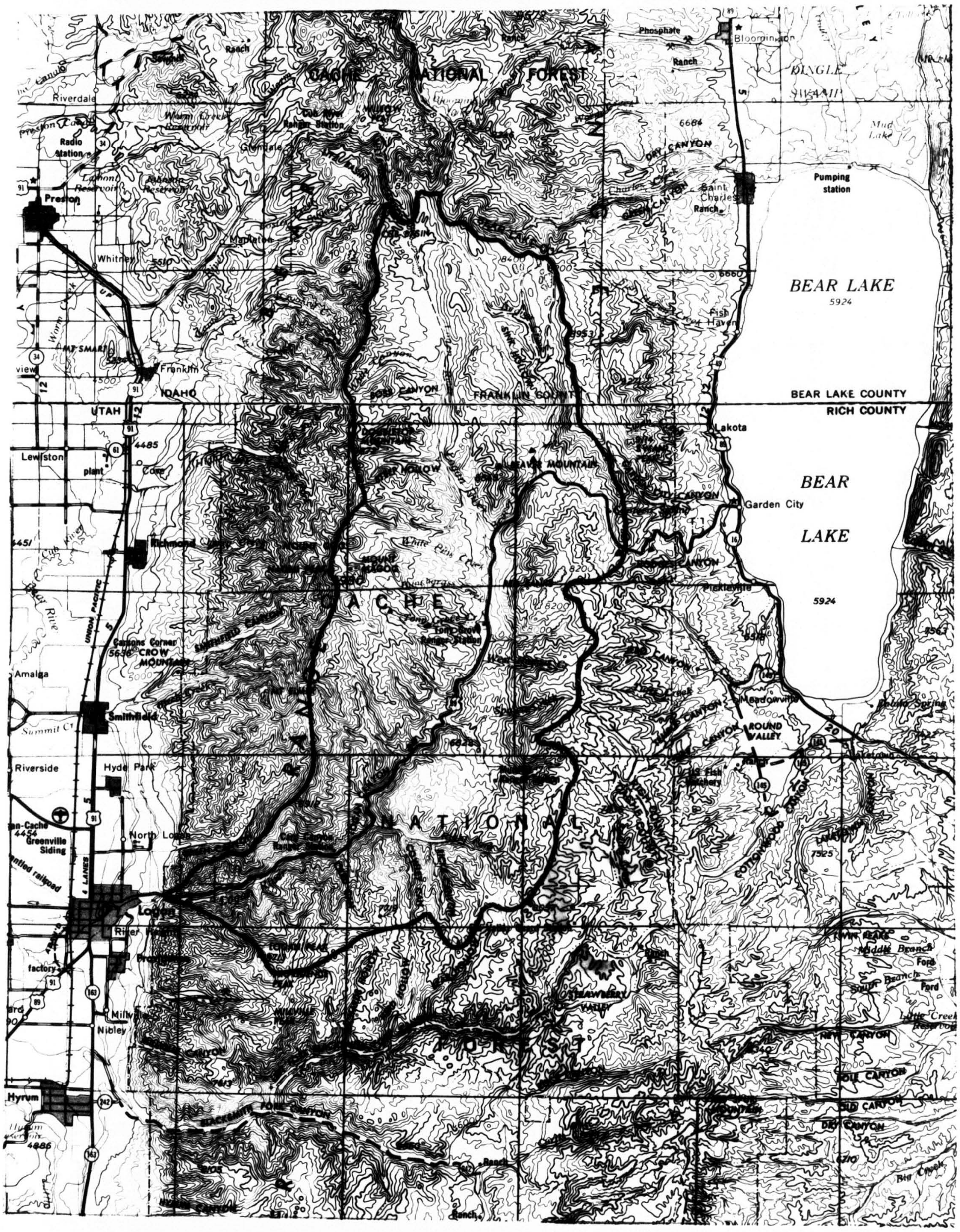

Figure 1. Boundary of Logan Canyon, Utah.

individuals. In all cases, the conifer stands were mature and unevenaged. To make the aspect effects uniform, the sites are nearly level where possible. In order to make the sites representative, the forest stands were selected with density, size class, and species composition characteristics similar to other stands in the area.

The guidelines used to select the snow courses for this study followed the recommendations of Anderson and West (1965). Anderson suggested sites be grouped together (Figure 2) whenever possible to minimize the differences in topographic shading and cold air drainages. The stands selected were representative of those in Logan Canyon, and the sites are nearly level. Each of the areas is accessible year around. The description of each site is presented in Table 1.

Sampling procedures

A 100-foot long straight line snow course was established in each site, similar to a design used by Eschner and Satterlund (1963) in New York. To minimize edge effects, the courses were set up at least two tree heights distance into the aspen and conifer stands. With the open field sites, the courses were located at least two tree heights distance from the boundary of the nearest forest stand. Ffolliott, Hansen, and Zander (1965) found that at a distance of two tree heights effects on the snowpack were minimal.

The snow courses were marked in the summer so as to avoid large rocks and tree stumps. Brush and downed trees were removed from each course so as not to hinder sampling.

The federal snow sampler (commonly referred to as the Mt. Rose Snow Tube) was selected for use on this project because it combines

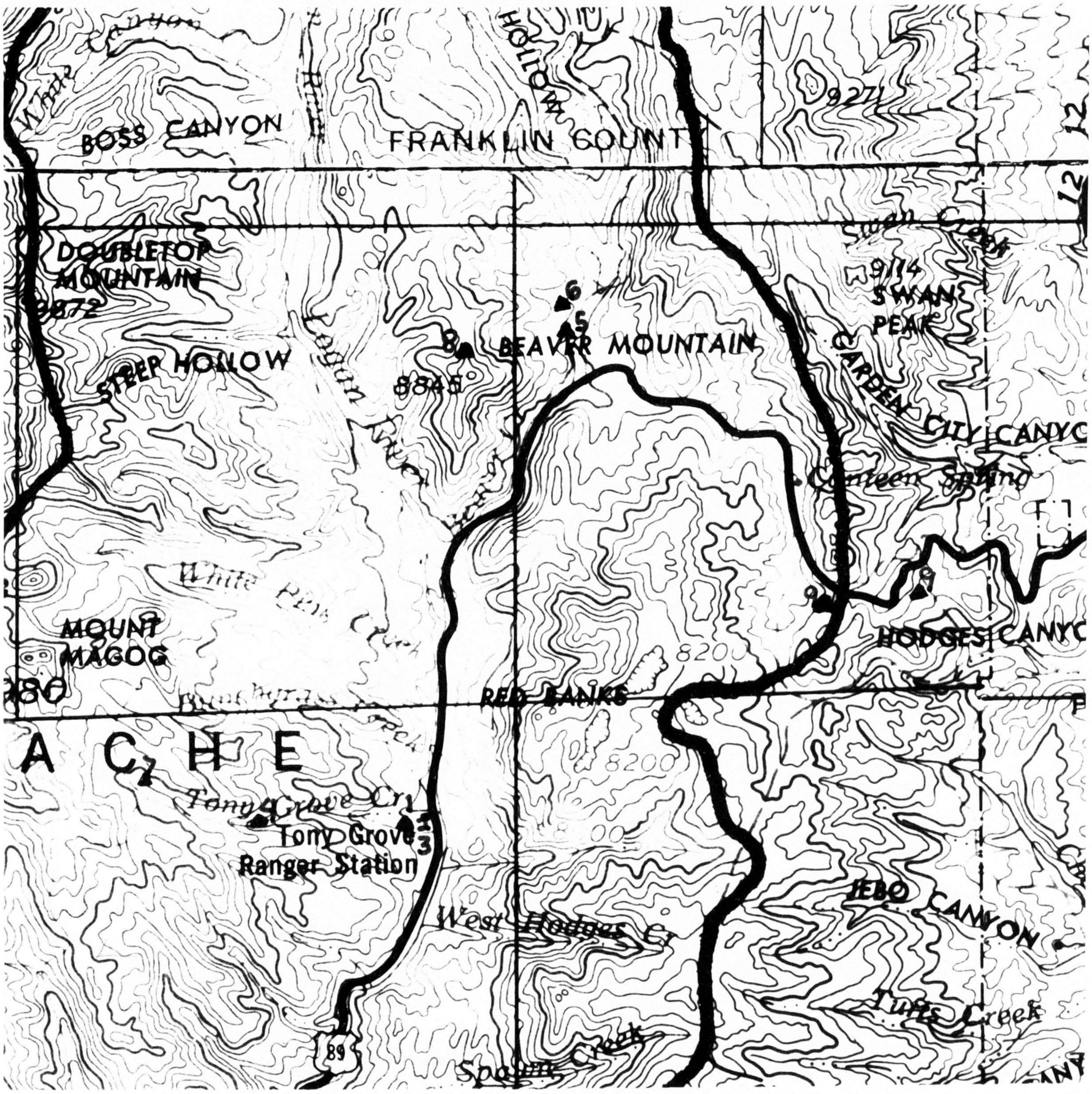

Figure 2. Location of study sites in Logan Canyon, Utah.

Table 1. Description of study sites

Site	Vegetation Type	Elevation (feet)	Basal Area (sq.ft/acre)	Slope %	Location	Exposure
1	Aspen	6300	84	8	Near Tony Grove Ranger Station	Partially sheltered in small drainage
	Open field	6300		6	Same as above	Exposed in the center of the meadow
2	Aspen	6300	89	10	Same as above	Partially sheltered on lee side of a small hill
	Open field	6300		6	Same as above	Partially sheltered near boundary of the meadow
3	Aspen	6300	94	8	Same as above	Partially exposed on top of small hill
	Open field	6300		5	Same as above	Partially sheltered near meadow boundary
4	Aspen	7160	96	11	Near Tony Creek Bridge of Tony Road	Sheltered by conifer stands on north and west sides
	Open field	7170		10	Adjacent to above aspen stand	Very exposed on a small ridge
	Conifer	7080	138	14	In a ravine adja-cent Tony Creek	Very sheltered in a ravine

Table 1. Continued

Site	Vegetation Type	Elevation (feet)	Basal Area (sq.ft/acre)	Slope %	Location	Exposure
5	Aspen	7080	97	14	West of the Beaver Mountain Road	Partially exposed next to small ravine
	Open field	7080		8	Same as above	Very exposed on small knoll
	Conifer	7060	140	9	Same as above	Sheltered on the lee side of a small hill
6	Aspen	7180	99	9	North of the Beaver Mountain Road	Partially exposed with a meadow on two sides
	Open field	7170		3	Same as above	Partially exposed
	Conifer	7150	160	3	Same as above	Sheltered in a large stand of conifer
7	Aspen	8000	115	8	East of Tony Grove Lake	Partially sheltered in a cirque
	Open field	8000		5	Same as above	Same as above
	Conifer	8120	172	9	West of Tony Grove Lake	Sheltered by large conifer stand and cirque
8	Aspen	8000	130	14	Beaver Mountain Ski area	Partially sheltered on the less side of a hill
	Open field	8050		4	Same as above	Very exposed on a ridge

Table 1. Continued

Site	Vegetation Type	Elevation (feet)	Basal Area (sq.ft/acre)	Slope %	Location	Exposure
8	Conifer	8120	150	16	Same as above	Partially sheltered on lee side of a hill
9	Aspen	7600	121	6	Sunrise Campground	Partially sheltered on lee side of a hill
	Open field	7850		6	Near Limber pine Trail	Sheltered on two sides by conifer stands
	Conifer	7840	154	9	Same as above	Partially exposed on a ridge

fair accuracy with direct water content measurements. Ten samples were extracted and weighed on each measurement date. Snow depths were measured to the nearest 1/2 inch and water content estimated to the nearest 1/2 inch. Each sample was inspected to insure that a complete core was present. It is possible for the bottom portion of the core to slip out during extraction from the pack resulting in an underestimate of water content and density. Also, a sample core could be taken on top of a previous sample hole, resulting in too low a water content reading. The average of the ten samples was used as the estimated snow depth and water content for the site.

Samples were collected at monthly intervals during the accumulation period starting January 1, 1972 and every two weeks during the melt period beginning March 1, 1972. Although the last samples were collected on May 21, 1972 the sites were visited every week until the last snow disappeared on June 30, 1972 to establish the number of days of snow cover. After the first measurement, all sites were visited on consecutive days to minimize time effects.

Temperature measurements

Temperature data were collected during 1970 winter at sites 1, 4, and 7. Hygrothermographs were used in the open field sites and maximum-minimum thermometers in the forested stands. Readings were made and charts were changed on a weekly basis; an adiabatic lapse rate was determined using weekly averages of the maximum-minimum temperatures.

An estimate of the degree days for the 1971-72 winter was made by applying the lapse rates, established during the winter of 1970-71, to temperature data collected from the University Summer Camp weather station.

Snowmelt definition

Active snowmelt is usually considered as beginning when the snowpack is in an isothermal condition, a state when the pack has a uniform temperature of 32° and an uniform density. Since neither snowpack temperature nor layer density measurements were taken, snowmelt in this study is considered to begin when the water content of the snowpack decreases.

Exposure definition

Exposure is a rather ambiguous term used several times in this paper. It relates to the degree that a site is unprotected to particularly hard, heavy winds, and solar radiation. An exposed site may be one situated in or near a cold air drainage, located in a saddle or on a ridge, or found on a point or prominent spot above the surrounding area. A sheltered site is one established in a ravine or partially protected by the topographic shading or adjacent timber.

Statistical analysis

In analyzing the snow data, several statistical methods were used including mean, standard deviation, correlation coefficient, and analysis of variance. A correlation coefficient was determined on the 10 samples taken from each site in an effort to identify errors and validate the snow measurement data. A low or negative correlation coefficient would indicate that as the depth of the snowpack increased, the water content decreased, a rather unlikely situation. On each occasion where a low or negative correlation coefficient appeared, the data was plotted to see if one or two samples were distinctly different. There individual data points were examined and perhaps eliminated if it was thought the pieces were irregular due to sampling error.

An analysis of variance and a two tailed student t-test were used to determine if a significant difference existed between the three cover types. A significance level of .90 was chosen for this study because snow depth and water content seems to have a large amount of inherent variability. This variability appears to be caused by snow deposition on the irregular surface of the ground, drifting due to the individual trees and rocks, and differences in melt due to changes in the micro-climate along the snow course. It was felt that a significance level of .90 was large enough to indicate a statistical significance between vegetative cover types without this significance being covered by the interference due to the inherent variability.

RESULTS AND DISCUSSION

Introduction

The results of this study will be discussed in two parts, first the effects of elevation on the snowpack and then the effects of vegetative cover. The effects of elevation and vegetation will be discussed in terms of snow water content, snow density, melt rate, and duration of snow cover. In this discussion it is important to remember that snow water content refers to the amount of snow water equivalent present at the time of measurement.

Elevation

Snow water content

As expected, the amount of snow water on the ground increases with higher elevations. This increase can be seen in Figure 3. The measurements are the average for each vegetative cover type at each of the three elevational zones and represents the maximum value observed during the period of accumulation.

This greater snow water accumulation at higher elevations is due to several conditions. A rather strong orographic influence along the Wasatch Front was described by Williams and Peck (1962), and is the most important factor.

A temperature gradient with respect to elevation may account for some of the accumulation differences. At lower elevations the snow on the ground after early snowfalls often melts with the ensuing warm days.

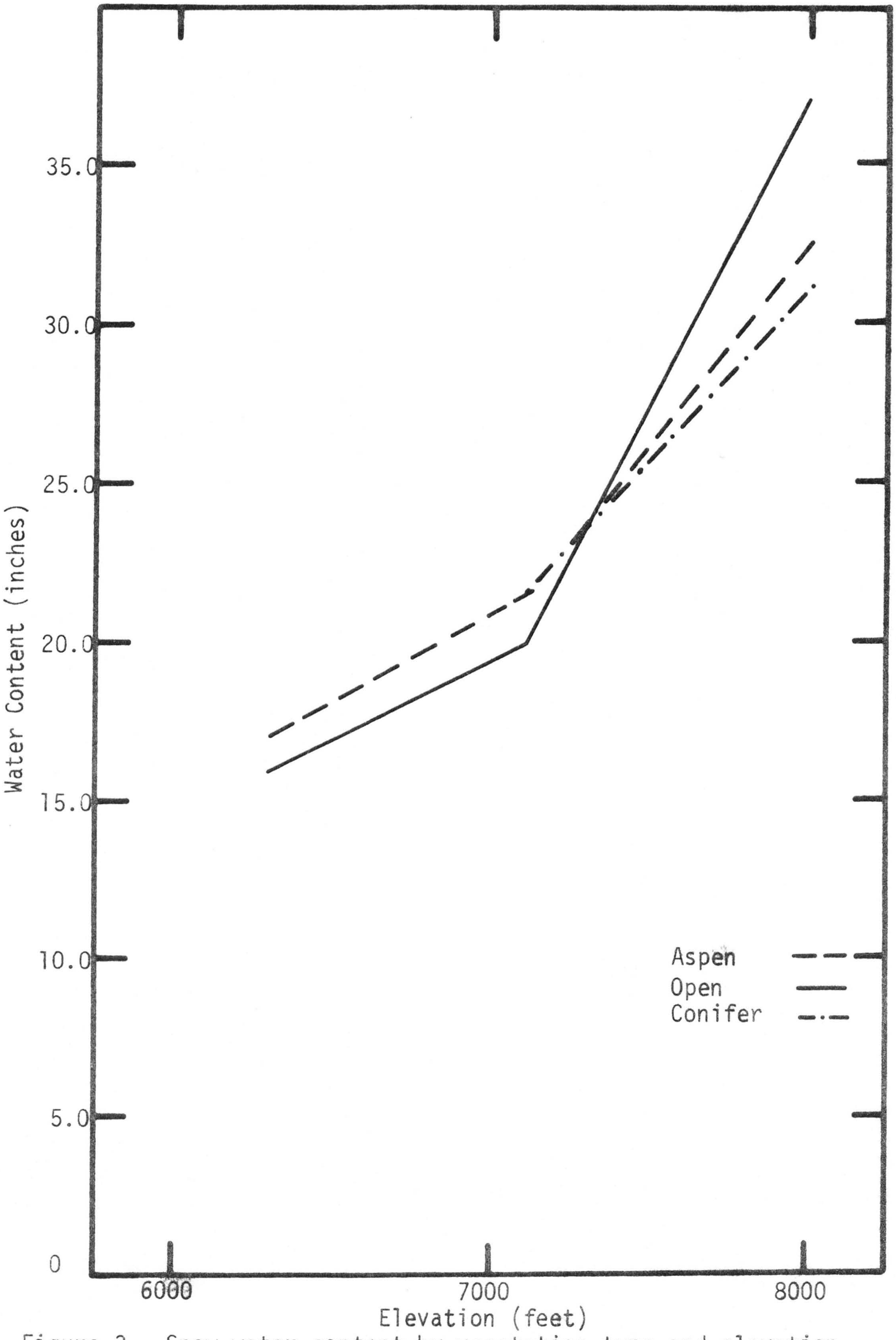

Figure 3. Snow water content by vegetation type and elevation (maximum).

The higher elevations begin accumulating a snowpack much earlier in the winter. Also the snowpack at higher elevations does not melt during the mid-winter melt periods often referred to as January thaws.

Local topography is yet another factor influencing the snow water accumulation results. While all six plots at the 6300 foot elevation are in a small area located in the vicinity of the Tony Grove Ranger Station, the 8000 foot sites are scattered over a 25 square mile area. If there exists a physiographic factor affecting precipitation in the vicinity of the Tony Grove Ranger Station, this factor would affect all the 6300 foot sites, perhaps causing a generally high or low precipitation reading from that of the average 6300 foot site in Logan Canyon. On the other hand, it seems unlikely such a local influence would exist on sites scattered over a wide area such as exist in the 8000 foot zone of Logan Canyon.

At times it is necessary to estimate the snow water depth between or beyond known elevation values. To facilitate interpolation or extrapolation of these results, a gradient of maximum snow water content with elevation was calculated. The zone from 6300 to 7100 feet has a gradient of .5 inch/100 foot change in elevation. The zone from 7100 feet to 8000 feet has gradient of 1.9 inches/100 foot change in elevation. These results compare with the gradients found in other parts of the West. Gary and Coltharp (1967) found a gradient of .4 inch/100 foot in Arizona while Packer (1962) found a gradient of 1.05 inch/100 foot in Idaho.

Snow density

Snow density is often used as a predictor of snow melt timing. The density of snow increases through the winter from less than .1 for freshly fallen snow to .5 or more during melt. Elevation appears to have little effect on snow density. As seen in Figure 4, the average open field density for the three elevations show little difference. Figure 4 also shows that the 8000 foot zones reach a higher maximum snow density than the lower zones. This higher snow density at 8000 feet is due primarily to a large volume of free water in the snowpack because of a high snowmelt rate, and because free water puddles above ice lenses common in the snowpack at 8000 feet. Late in the spring, the snow density at 8000 feet decreases. This decrease in density occurs because as the snowpack melts the ice lenses disappear allowing the free water to move freely through the snowpack.

Snowmelt rate

The rate of snowmelt is calculated by dividing the maximum snow water content by the number of days in the snowmelt period. Figure 5 shows the rate of snowmelt increase with elevation and the difference between vegetation types. The 6300 foot elevation zone has an average melt rate of .30 inches/day while the 7100 foot zone has a melt rate of .34 inches/day. The 8000 foot zone has a melt rate of .76 inches/day which is two times greater than the lower zones. The greater melt rate is due to several factors. The melt period occurs later in the spring with a greater energy input through a higher number of degree days and more insolation due to a higher sun angle and longer days.

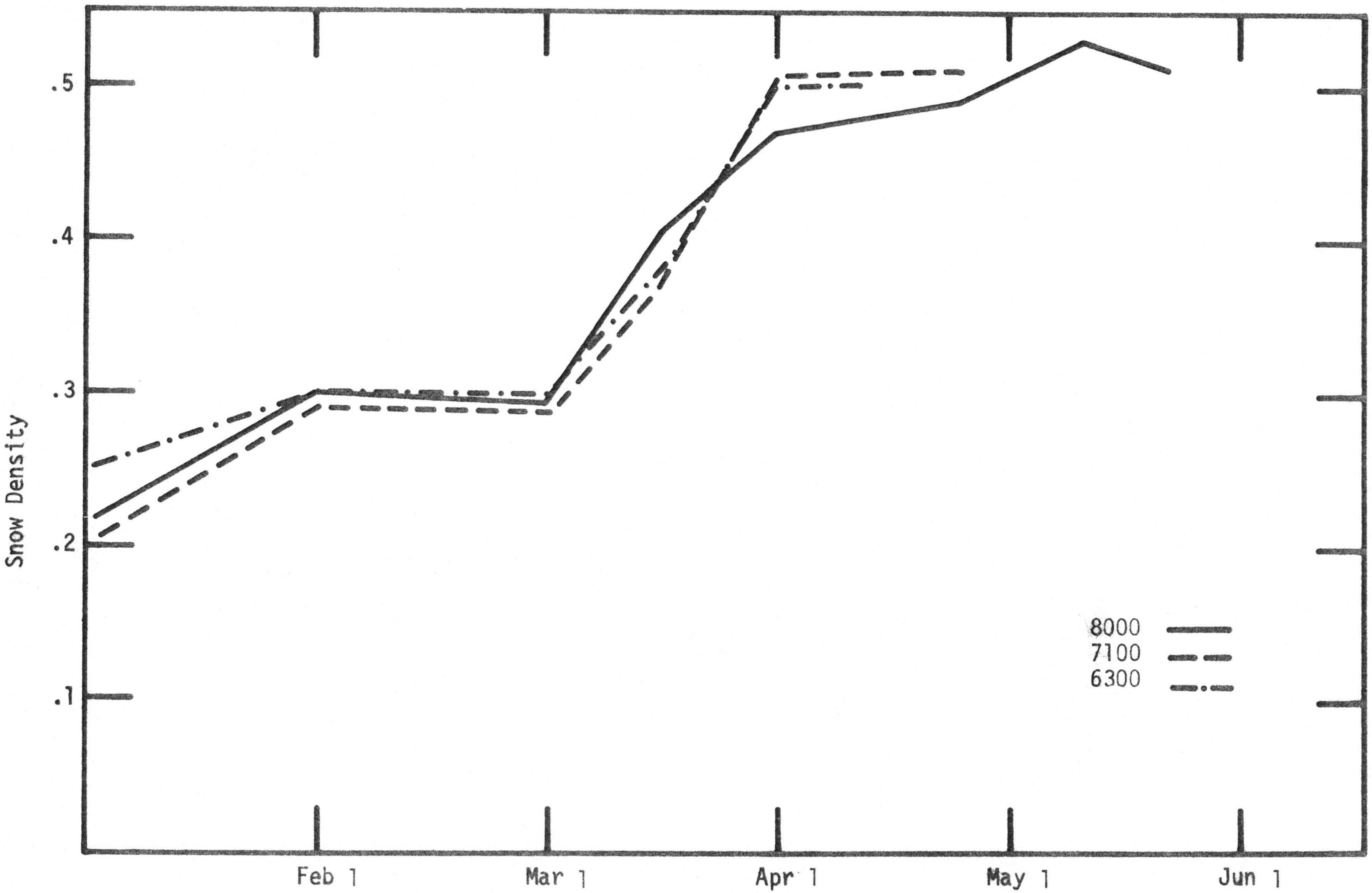

Figure 4. Average density of three open field plots at each elevation.

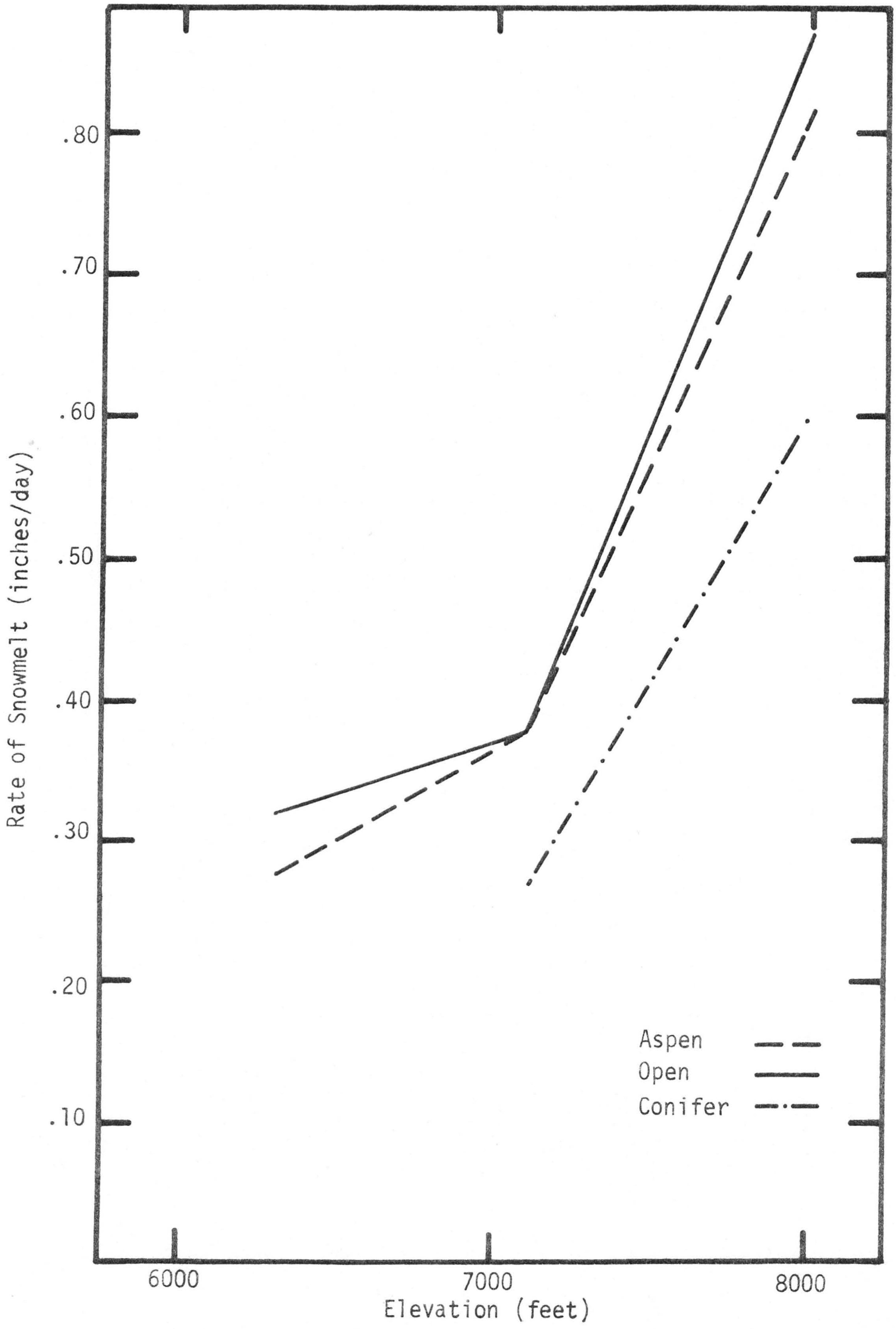

Figure 5. Rate of snowmelt by vegetation type and elevation.

Duration of snow cover

The number of days of snow cover from January 1, 1972 is increased with higher elevation. The 8000 foot sites maintain a snow cover 22 days longer than the 7100 foot site and they have snow cover 22 days longer than the 6300 foot zones (Figure 6). The number of days of snow cover is a function of snow depth, rate of snowmelt and the beginning of snow melt. It is interesting to note that 22 days is the difference in days of snow cover between the respective elevations. This is a further indication that at higher elevations, the deeper snowpack begins melting later and at a faster rate.

Snowmelt initiation

The beginning of snowmelt is delayed with an increase in altitude. Snowmelt begins 14 days later at 7100 feet than at 6300 feet, and the 8000 foot zone begins to melt 40 days after the 7100 foot zone. This delay at the higher elevations is due primarily to disproportionately deeper snowpack. That is, with a much deeper pack, more time and energy is needed to bring the pack to an isothermal condition. It is interesting to note that on March 1, 1972, when snowmelt began at 6300 feet, this zone had received an estimated 22 degree days, the 7100 foot area had 2 degree days, and the 8000 foot zone compiled no degree days. The increase in altitude caused a decrease in temperature and magnitude of degree days with consequent delay in snowmelt.

Vegetation Effects

Snow water content

Until late in the melt period, no statistical difference existed in the water content of the snowpack for the three cover types within each

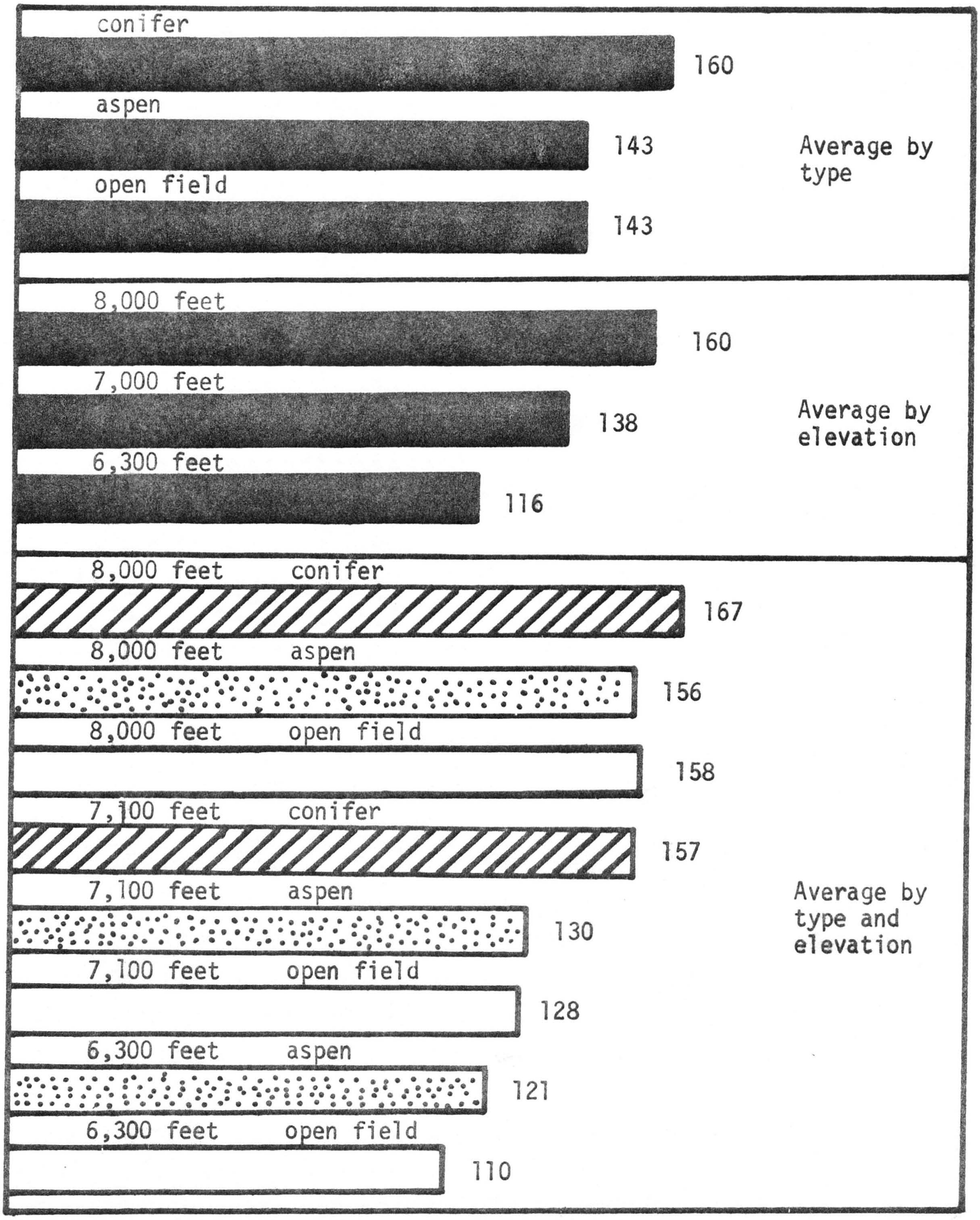

Figure 6. Days of snow cover from January 1, 1972 by type and elevation.

elevation zone. For example, as seen in Table 2, no statistical difference in water content is present until April 1, 1972 at 6300 feet, April 24, 1972 at 7100 feet, and May 24, 1972 at 8000 feet. At that time, the respective snowpacks had been losing water for at least two weeks. The statistical difference in water content between aspen and open at 6300 feet on February 1, 1972 is probably due to the January thaw that occurred at that time. The statistical difference in the water content of the snowpack found late in the melt period between conifer and the other types is due to the slower melt rate of the snowpack under the conifer type. The snowpack associated with the aspen and open field type have nearly the same water content throughout the winter.

Although statistically not significant (early in the winter), the snowpack under the conifer type generally has lower values of water content than the snowpack with the aspen type or the open field, as seen in Table 2. The two exceptions are sites 5 (Figure 7) and 8 (Figure 8),both open field sites. Both of these open field sites are extremely exposed and wind-swept causing some deposited snow to blow off and be redeposited. The conifer stands are all unevenaged, mature stands which both intercept substantial quantities of snow and channel wind patterns for deposition in associated clearings. With dry snow, much of the intercepted snow is swept off the crowns and redeposited elsewhere. Of the remaining intercepted snow, some is evaporated, and the remainder falls through or melts and goes into streamflow. These various processes account for the conifer type catching smaller quantities of snow water.

Table 2. Mean snow water content and density of three replications (mean of 10 samples from each of the three replications)

Date	Aspen Water Content	Aspen Density	Open Water Content	Open Density	Conifer Water Content	Conifer Density
			6300 Feet[a]			
1/ 1/72	7.4	.24	4.5	.20		
2/ 1/72	15.7*	.32*	14.2*	.30*		
3/ 1/72	17.0	.30	15.8	.30		
3/15/72	15.9	.38	13.8	.38		
4/ 1/72	12.1*	.49	8.6*	.50		
4/10/72	8.4*	.49	5.2*	.50		
4/24/72	4.4	.48	----	---		
5/10/72	----[b]	---	----	---		
5/21/72	----[b]	---	----	---		
			7100 Feet			
1/ 1/72	6.4	.19	6.2	.19	6.0	.20
2/ 1/72	16.8	.27	16.8	.29	16.7	.28
3/ 1/72	18.1	.29	16.7	.29	15.8	.26
3/15/72	21.4	.43	19.8	.42	21.5	.41
4/ 1/72	18.4	.50*	16.6	.51*	20.8*	.45*
4/10/72	----[c]	---	----	---	----	---
4/24/72	13.4*	.51	13.2*	.51*	21.9*	.47*
5/10/72	1.4*	.51	.3*	.51	15.8*	.51
5/21/72	----[b]	---	----	---	7.6	.53
			8000 Feet			
1/ 1/72	8.3	.21	9.2	.21	7.5	.21
2/ 1/72	24.1	.30	23.6	.29	19.8	.29
3/ 1/72	27.2	.31	26.7	.30	21.4	.29
3/15/72	31.3	.41	31.9	.41	25.2	.36
4/ 1/72	32.4	.49*	34.6	.47*	28.4	.42*
4/10/72	----[c]	---	----	---	----	---
4/24/72	32.7	.51*	37.1	.49*	31.3	.44*
5/10/72	22.4	.56*	26.9	.53*	26.7	.48*
5/21/72	10.8*	.57	13.4*	.51	21.0*	.51

[a]Conifer not present at 6300 feet

[b]Indicates melt complete

[c]No samples collected

*Indicates significant difference at .90 level

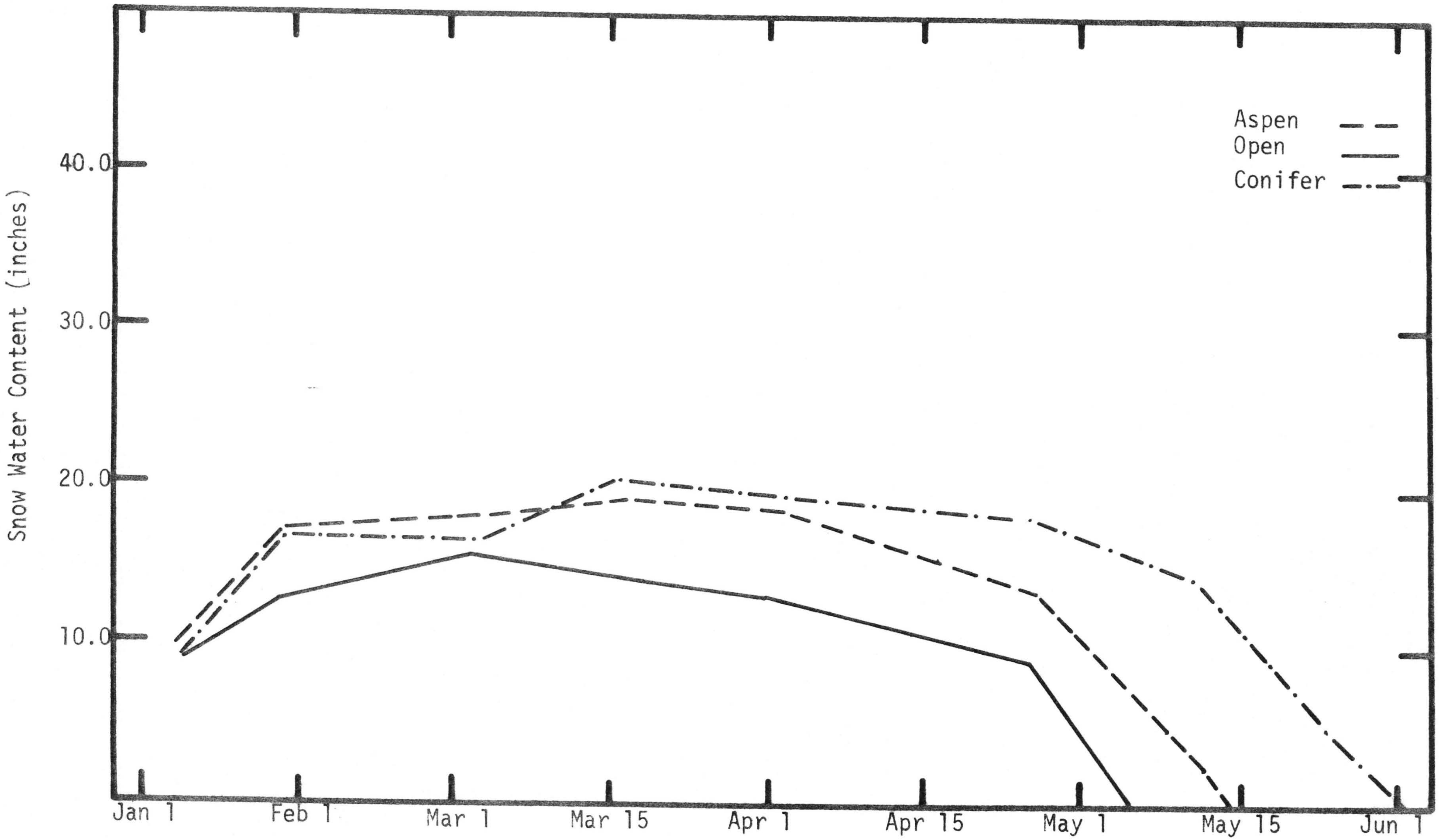

Figure 7. Snow water content for site 5 by type.

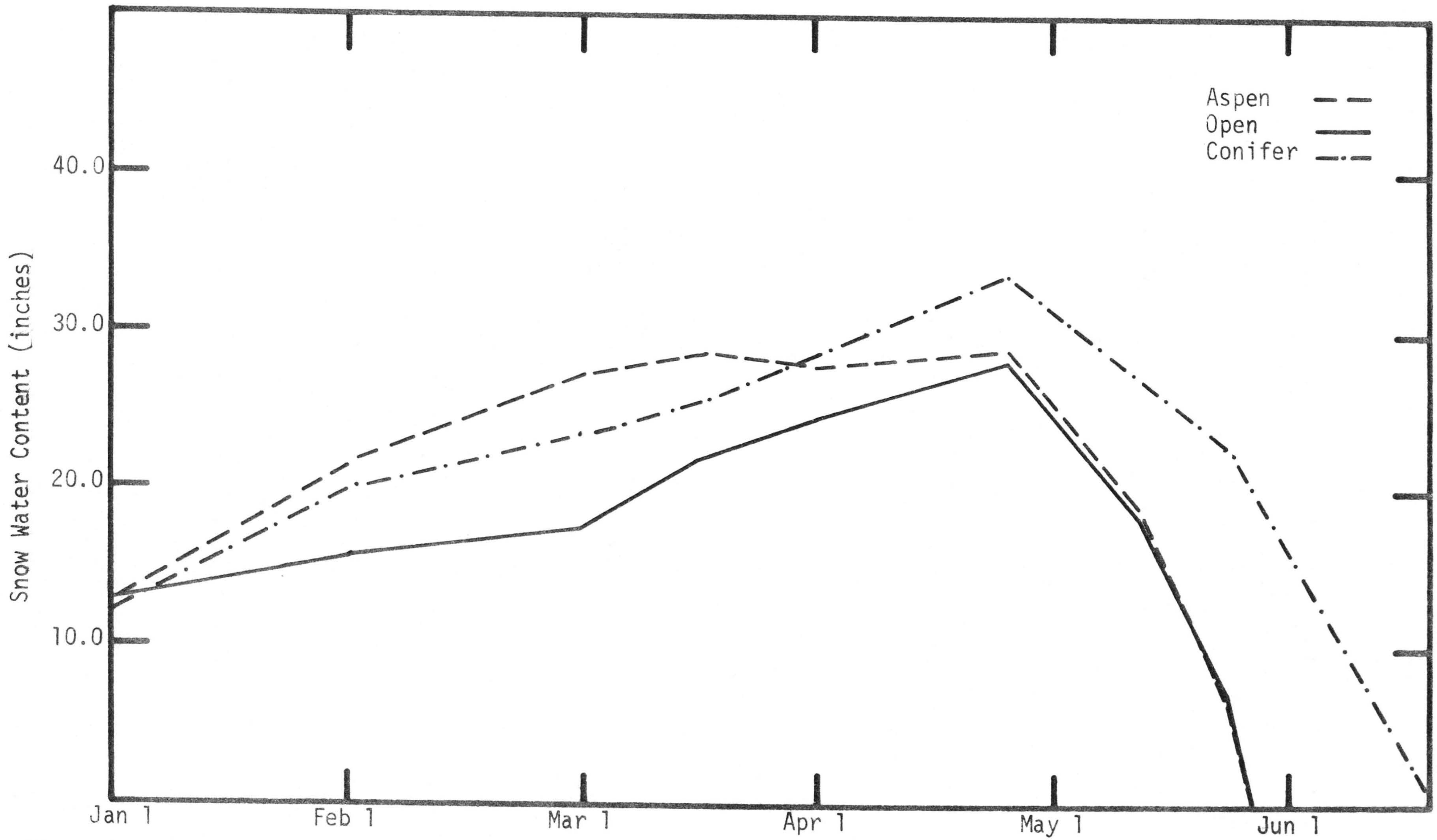

Figure 8. Snow water content for site 8 by type.

Snow density

The snowpack under the aspen and open field types ripens at about the same rate and has no statistical differences in density as seen in Table 2. The snowpack under the conifer type ripens slower than under the open field and aspen types. Consequently, by March 2, 1972, at 7100 feet and March 15, 1972, at 8000 feet, there were statistical differences between the density of the snowpack under the conifer and the other cover types (Table 2).

Snowmelt rate

The melt rate of the snowpack under the conifer type is almost 30 percent slower than the snowpack of either the aspen or open field type as seen in Figure 5. Canopy shading from solar radiation is the major contributor to the slower snowmelt rate. The snowpack under the aspen and open field type melt at the same rate because of the leafless aspen canopy furnishes negligible shade. Because of the slower melt rate, the conifer type retains a snowpack longer into the spring. At 7100 feet, the snow remains under the conifer for 18 more days than the average of the aspen and open field, while the conifer stands at 8000 feet maintain a snowpack for 20 additional days. In comparision, Gary and Coltharp (1967) found the snowpack under the conifer type to retain the snowpack 28 days longer than the open field type.

Other Considerations

Temperature

Air temperature was measured during the 1971 winter, and the results are shown in Appendix Table 3. A temperature lapse rate of 5.3°/1000 foot change in elevation was calculated from the data. This corresponds with the 4.5°/1000 foot change calculated along a gradient on the east side of the canyon from the Summer Camp to the College Forest.

It should be noted that there was some rather large temperature differences between elevational zones and between cover types at the same elevation. Atmospheric conditions such as cold air movements down drainages and local temperature inversion layers contribute to the problem. Instrument problems also plagued data collection. High wind frequently blew snow into weather shelters and coated the hydrographs. Maximum-minimum thermometer covers were occasionally blown off the stand or packed with blown snow. These conditions combine to cast some doubt on the validity of the temperature lapse rate of 5.3°/1000 foot of change in elevation.

Rainshadow affects

The data from the 7100 and 8000 foot sites suggest that a rather pronounced rainshadow effect occurs in Logan Canyon. Figure 9 shows the average water content of the three cover types at 8000 feet for sites 7, 8, and 9 and 7100 foot site 4. As seen in Figure 2, site 7 is the western-most site; site 9 is the eastern-most site. The rain-shadow is created by a unique combination of atmospheric and topographic

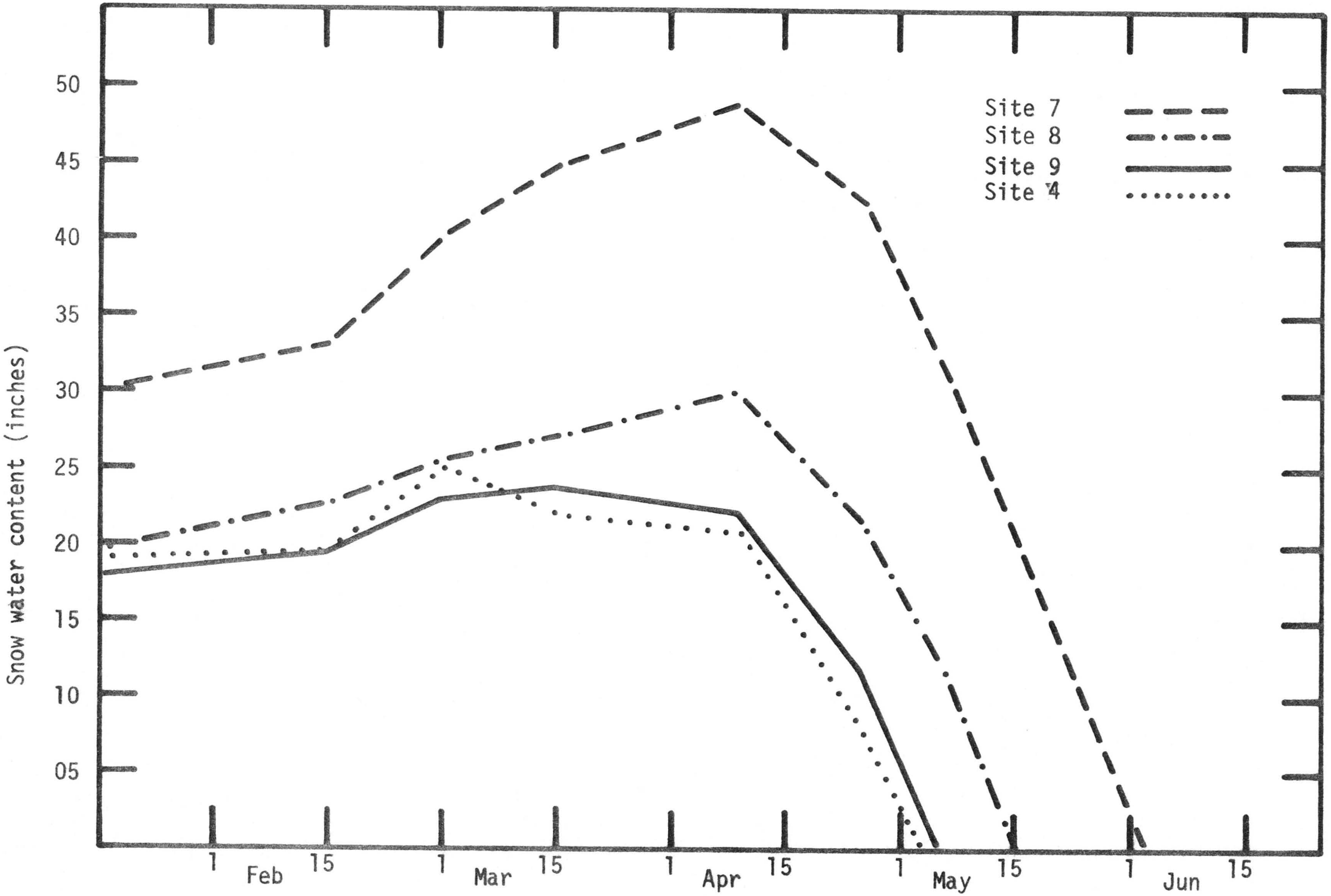

Figure 9. Rainshadow effect.

conditions. The vast majority of storms in this area move in a easterly direction (Williams and Peck, 1962). In moving east across the upper Logan Canyon, the storms encounter three ridge lines (Figure 1) each succeeding ridge lower than the previous one. Therefore, the orographic influence on the storm and the resulting precipitation would be greater on the west side and decreasing to the east. This would explain why the 8000 foot sites on the west boundary of the watershed collected more snow water than the middle ridge which, in turn, collected more water than the eastern boundary sites (Figure 9). It should be noted that site 7 is located in a cirque on the lee side of the canyon's western boundary. This probably accounts for some of the greater snow catches. However, site 4 is sufficiently far enough away from the cirque to be unaffected.

This rainshadow effect may be more important than elevation in some cases. For example, in Figure 9, the 7100 foot site 4 collected as much or more water as the 8000 foot site 9. This implies that modeling a simple delineation of a watershed by cover type and elevational zone may not be sufficient to fully explain the processes taking place.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Elevation effects the snowpack in several ways. Higher elevations collect more snow water as seen in Figure 3. This greater snow water content at higher elevations is due to several conditions. Orographic influences on storms cause more snow to be deposited at higher elevations, and the colder temperatures at higher elevations allows the early snows to accumulate while the snow at lower elevations melts. A gradient of snow water content with elevation was calculated to be .5 inches/100 foot rise in elevation in the 6300 to 7100 foot zones, and 1.9/100 foot in the 7100 to 8000 foot zones. Higher elevations also delay the beginning of the snowmelt. Snowmelt begins 14 days later at 7100 feet than at 6300 feet. The 8000 foot zone begins to melt 40 days after the 7100 foot zone. Although the snowpack begins melting later in the spring, the melt rate is greater. Figure 5 shows the melt rate at 8000 feet to be twice that of either the 6300 or the 7100 foot zones. The days of snow cover from January 1 increases with elevation. The 8000 foot elevation retains the snowpack 22 days longer than the 7100 foot zone, which has a snow cover 22 days longer than the 6300 foot sites.

Vegetative cover type seems to have little statistical significance on the snow water content early in the winter as seen in Table 2. However, between the snowpack under the conifer and the other cover types, the statistical difference does appear in the snow water content during the spring melt. The conifer type protects the snowpack from solar radiation causing the snowpack to ripen slower to remain longer into the spring, and melt 30 percent slower than the other cover types.

A rather pronounced rainshadow is indicated from the results as seen in Figure 9. This rainshadow may be a more important influence than either elevation or vegetation cover.

Recommendations

To develop a study that includes good site selection, sound statistical design, and a workable sampling schedule is probably the most difficult part of snow research. Site selection is very important because snow research is conducted in the field, often under less than controlled conditions. This invariably produces the problem of selecting sites which most clearly exhibit the factors under investigation, for example aspect, while minimizing confounding factors such as percent slope, exposure, and topographic shading. A preliminary survey for several winters may help in selecting those sites which minimize confounding factors. However, the researcher must be aware that selecting sites in this manner may add unacceptable bias into the statistical design.

The high inherent variability in snow depth and water content, present even in a small area of the snowpack, complicates the statistical design. In order to partition out as much of this variability as possible,in the statistical analysis there must be replications of all sites. In this study three replications appeared adequate.

Establishing a field design with enough sites for a good statistical design may create an ungainly data collection problem in terms of time available for field work. In planning the time available for field work, accessibility of the sites and the frequency of sampling are two factors that must be considered. Because of the time required to reach inaccessible sites in the winter, sites should be located close to roads that are kept open year around. Sites should be sampled every two weeks so that trends may be detected early and followed. However, to take many samples from several snow courses on each site every two weeks may require more time than the researcher has available. To optimize the time available for field work, it is probably more important to have several replications than to gather a great number of samples from one snow course. From the experience of this study, 15 samples from one snow course is adequate. The researcher should carefully consider his sampling schedule to insure he has adequate time and resources available to do the work before beginning the study.

The snow course should be inspected in the summer before any winter sampling takes place. The summer visit allows the researcher to avoid large boulders, tree stumps or large depressions, and to remove the brush and logs from the snow course. The snow course should be clearly marked and followed closely during sampling so that measurements are made with as much consistency as possible from week to week. A carefully designed study in terms of field design and statistical design will improve the reliability of the data and save much time in analysisising the results.

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APPENDICES

Appendix A
Temperature

Table 3. Temperature data--1971

Instrument =	Type six				Type six			Thermograph		
Measurement	Elevation	Conifer			Aspen			Open Field		
Period 1971	(feet)	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave
January 23-30	6,300				48	21	34.5	52	20	36
	7,000	39	21	30	44	20	32	46	25	35.5
	8,000	33	14	23.5	46	22	34	36	20	28
January	6,300				50	- 5	22.5	54	3	25.5
30-	7,000	42	2	22	24	- 3	10.5	48	3	22.5
February 5	8,000	35	- 2	16.5				44	- 4	20
February	6,300				43	2	22.5	52	3	27.5
5-13	7,000	40	1	20.5	42	- 4	19	48	3	25.5
	8,000	35	1	18	37	0	18.5	35	3	19
February	6,300				46	10	28	49	5	22
13-20	7,000	39	14	26.5	40	14	27	45	19	32
	8,000	36	14	25	48	13	30.5	40	9	24.5
Februray	6,300				39	- 4	17.5	40	- 1	19.5
20-27	7,000	36	- 2	19	33	- 4	14.5	30	- 1	14.5
	8,000	26	- 4	15	14	- 6	4	29	-10	9.5
February	6,300				44	- 8	18	49	-11	19
27-	7,000	39	- 8	15.5	42	-10	16	36	- 8	14
March 18	8,000	32	- 8	12	32	-10	11	32	-11	10.5
March	6,300				58	12	35	52	12	32
18-	7,000	49	12	30.5	43	7	18	42	14	28
Apr 3	8,000	41	3	22	43	1	22	34	8	21
Apr	6,300				64	20	42	61	18	39.5
3-18	7,000	42	16	29	58	14	36	52	14	33
	8,000	47	10	28.5	59	8	33.5	30	8	19
Apr	6,300				54	26	40	53	25	39
18-29	7,000	44	25	34.5	53	20	36.5	44	20	32
	8,000	38	19	28.5	53	17	35	44	16	30

Appendix B

Snow Cover

Table 4. Days of snow cover from January 1, 1972

Site	Cover Type	Date of Snow Disappearance	Days of Snow Cover
1	Aspen	Apr 28	119
	Open	Apr 12	103
2	Aspen	May 1	122
	Open	Apr 24	115
3	Aspen	May 1	122
	Open	Apr 21	112
4	Aspen	May 11	132
	Open	May 10	131
	Conifer	Jun 9	161
5	Aspen	May 11	132
	Open	May 4	125
	Conifer	May 30	151
6	Aspen	May 5	126
	Open	May 7	128
	Conifer	May 31	152
7	Aspen	Jun 6	159
	Open	Jun 10	162
	Conifer	Jun 30	182
8	Aspen	May 25	146
	Open	May 24	145
	Conifer	Jun 17	169
9	Aspen	May 15	136
	Open	May 19	140
	Conifer	May 30	151

Appendix C

Snow Data

Table 5. Summary of snow data 1971-72 (10 samples unless otherwise indicated)

Sample Date	Site No.	Cover Type	Snow Depth (inch)	Water Content (inch)	Snow Density (%)	Samples Less Than 10
Dec 19	1	No Samples Collected				
Jan 6	2	Aspen	32.6	8.7	.27	
		Open	30.5	8.3	.27	
Dec 18	3	Aspen	28.7	6.1	.21	
		Open	22.5	4.5	.20	
Dec 19	4	Aspen	34.6	3.7	.11	
		Open	32.2	3.2	.10	
		Conifer	24.4	2.3	.10	
Jan 6	5	Aspen	37.4	10.3	.28	
		Open	33.0	9.2	.28	
		Conifer	34.4	9.5	.28	
Dec 18	6	Aspen	25.8	5.1	.20	
		Open	30.7	6.2	.20	
		Conifer	29.1	6.3	.22	
Dec 19	7	Aspen	43.7	5.8	.13	
		Open	49.3	7.1	.14	
		Conifer	27.4	4.5	.16	
Jan 6	8	Aspen	48.4	13.2	.27	
		Open	49.1	13.2	.27	
		Conifer	46.2	12.7	.28	
Dec 18	9	Aspen	27.8	6.0	.22	
		Open	34.6	7.2	.21	
		Conifer	25.9	5.3	.21	
Jan 30	1	Aspen	44.2	14.5	.33	
		Open	44.6	13.8	.31	
Jan 28	2	Aspen	50.8	16.5	.33	
		Open	48.9	15.3	.31	
Jan 27	3	Aspen	52.0	16.0	.31	
		Open	47.1	13.6	.29	
Jan 30	4	Aspen	73.0	19.0	.26	
		Open	68.0	20.4	.30	
		Conifer	64.1	17.2	.27	

Table 5. Continued

Sample Date	Site No.	Cover Type	Snow Depth (inch)	Water Content (inch)	Snow Density (%)	Samples Less Than 10
Jan 28	5	Aspen	64.7	16.7	.26	
		Open	46.5	13.3	.29	
		Conifer	61.9	16.9	.27	
Jan 27	6	Aspen	52.0	14.8	.29	
		Open	59.0	16.7	.28	
		Conifer	55.3	16.0	.29	
Jan 30	7	Aspen	101.3	32.4	.32	
		Open	106.2	34.6	.33	
		Conifer	77.2	24.0	.31	
Jan 28	8	Aspen	77.4	21.5	.28	
		Open	66.7	16.2	.24	
		Conifer	69.7	19.9	.29	
Jan 27	9	Aspen	58.9	18.4	.31	
		Open	66.3	19.9	.30	
		Conifer	54.7	15.5	.28	
Mar 1	1	Aspen	50.4	14.9	.30	
		Open	46.4	14.1	.30	
Mar 2	2	Aspen	57.7	18.3	.32	
		Open	56.1	18.4	.33	
Feb 29	3	Aspen	60.2	17.9	.30	
		Open	53.3	15.0	.28	
Mar 1	4	Aspen	72.7	21.4	.29	
		Open	64.2	17.6	.27	
		Conifer	66.0	16.7	.25	
Mar 4	5	Aspen	64.1	17.5	.27	
		Open	50.8	15.6	.31	
		Conifer	60.4	16.8	.28	
Feb 29	6	Aspen	49.9	15.5	.31	
		Open	60.5	16.9	.28	
		Conifer	54.3	13.8	.25	
Mar 1	7	Aspen	111.9	36.7	.33	
		Open	113.6	37.7	.33	
		Conifer	82.6	24.8	.30	
Mar 4	8	Aspen	86.2	27.1	.31	
		Open	70.9	17.7	.25	
		Conifer	76.3	23.5	.31	
Feb 29	9	Aspen	61.2	17.7	.29	
		Open	80.5	24.8	.31	
		Conifer	60.4	15.9	.26	

Table 5. Continued

Sample Date	Site No.	Cover Type	Snow Depth (inch)	Water Content (inch)	Snow Density (%)	Samples Less Than 10
Mar 13	1	Aspen	35.2	13.0	.37	
		Open	31.7	11.5	.36	
Mar 16	2	Aspen	44.9	16.6	.37	
		Open	41.6	16.6	.40	
Mar 13	3	Aspen	45.3	18.2	.40	
		Open	35.9	13.4	.37	
Mar 14	4	Aspen	60.7	27.8	.46	
		Open	53.6	24.0	.45	
		Conifer	62.2	25.0	.40	
Mar 16	5	Aspen	46.9	18.9	.40	
		Open	37.3	14.4	.38	
		Conifer	48.0	19.7	.41	
Mar 13	6	Aspen	40.6	17.6	.43	
		Open	49.1	21.1	.43	
		Conifer	47.9	19.8	.41	
Mar 14	7	Aspen	103.2	44.0	.43	
		Open	108.0	44.4	.41	
		Conifer	84.0	31.4	.37	
Mar 16	8	Aspen	69.1	28.6	.41	
		Open	56.6	21.9	.39	
		Conifer	69.4	25.6	.37	
Mar 13	9	Aspen	52.6	21.2	.40	
		Open	70.2	29.4	.42	
		Conifer	52.6	18.5	.35	
Apr 1	1	Aspen	17.3	8.4	.49	
		Open	11.4	5.6	.49	
Apr 1	2	Aspen	25.9	12.5	.48	
		Open	21.4	10.6	.50	
Apr 1	3	Aspen	30.8	15.3	.50	
		Open	19.2	9.7	.50	
Apr 2	4	Aspen	46.7	23.4	.50	
		Open	39.1	19.3	.49	
		Conifer	57.0	23.8	.41	
Apr 3	5	Aspen	37.7	18.4	.49	
		Open	24.6	12.7	.52	
		Conifer	40.9	19.2	.47	
Apr 4	6	Aspen	26.4	13.4	.51	
		Open	34.7	17.7	.51	
		Conifer	41.9	19.4	.46	

Table 5. Continued

Sample Date	Site No.	Cover Type	Snow Depth (inch)	Water Content (inch)	Snow Density (%)	Samples Less Than 10
Apr 2	7	Aspen	96.9	48.9	.50	
		Open	106.5	50.6	.48	
		Conifer	81.2	34.3	.42	
Apr 3	8	Aspen	60.3	27.9	.46	
		Open	56.3	24.4	.43	
		Conifer	76.6	28.6	.37	
Apr 4	9	Aspen	40.1	20.4	.51	
		Open	56.7	28.9	.51	
		Conifer	49.5	22.3	.45	
Apr 10	1	Aspen	9.1	4.4	.48	9
		Open	1.6	.8	.52	3
Apr 10	2	Aspen	19.4	9.6	.50	
		Open	14.3	9.6	.50	
Apr 10	3	Aspen	22.9	11.3	.49	
		Open	10.8	5.3	.49	
Apr 23	1	Aspen	2.5	1.3	.50	4
		Open	----------Snow Melted-----------------			
Apr 23	2	Aspen	10.2	5.1	.50	9
		Open	----------Snow Melted-----------------			
Apr 23	3	Aspen	14.8	6.8	.46	
		Open	----------Snow Melted-----------------			
Apr 23	4	Aspen	37.2	19.2	.51	
		Open	34.3	18.2	.53	
		Conifer	59.8	28.0	.47	
Apr 24	5	Aspen	26.5	12.9	.49	
		Open	17.5	8.7	.49	
		Conifer	38.2	18.2	.48	
Apr 24	6	Aspen	15.5	8.1	.52	
		Open	24.8	12.7	.51	
		Conifer	41.6	19.6	.47	
Apr 23	7	Aspen	97.5	50.8	.52	
		Open	111.5	56.3	.50	
		Conifer	87.8	38.6	.44	
Apr 24	8	Aspen	60.6	29.1	.48	
		Open	62.7	27.9	.45	
		Conifer	83.0	33.7	.41	
Apr 24	9	Aspen	35.5	18.3	.51	
		Open	52.3	27.0	.52	
		Conifer	46.8	21.7	.47	

Table 5. Continued

Sample Date	Site No.	Cover Type	Snow Depth (inch)	Water Content (inch)	Snow Density (%)	Samples Less Than 10
	1		------------------Snow Melted----------------			
	2		----------------------at---------------------			
	3		-----------------6000 foot sites-------------			
May 9	4	Aspen	4.4	2.4	.54	7
		Open	1.7	.9	.51	3
		Conifer	39.5	19.9	.50	
May 10	5	Aspen	3.6	1.7	.48	4
		Open	---------------Snow Melted------------------			
		Conifer	27.1	13.6	.51	
May 10	6	Aspen	---------------Snow Melted------------------			
		Open	---------------Snow Melted------------------			
		Conifer	27.4	14.0	.51	
May 9	7	Aspen	71.6	40.6	.57	
		Open	90.5	48.7	.54	
		Conifer	75.6	37.8	.50	
May 10	8	Aspen	34.6	18.8	.54	
		Open	36.6	18.5	.51	
		Conifer	61.1	27.2	.45	
May 10	9	Aspen	13.4	7.9	.57	
		Open	23.7	13.4	.54	
		Conifer	29.8	15.0	.50	
	1		------------------Snow Melted----------------			
	2		----------------------at---------------------			
	3		-----------------6000 foot sites-------------			
	4	Aspen	---------------Snow Melted------------------			
		Open	---------------Snow Melted------------------			
		Conifer	22.7	12.3	.56	
	5	Aspen	---------------Snow Melted------------------			
		Open	---------------Snow Melted------------------			
		Conifer	8.8	4.6	.52	8
	6	Aspen	---------------Snow Melted------------------			
		Open	---------------Snow Melted------------------			
		Conifer	11.1	5.8	.52	8
	7	Aspen	44.3	27.0	.61	
		Open	60.3	33.3	.55	
		Conifer	63.2	33.2	.53	
	8	Aspen	9.7	5.3	.54	
		Open	14.3	6.8	.47	
		Conifer	45.1	22.8	.51	
	9	Aspen	---------------Snow Melted------------------			
		Open	---------------Snow Melted------------------			
		Conifer	12.1	6.0	.50	8

VITA

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