SNOWPACK VARIABILITY ON WESTERN RANGELANDS

by

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INTRODUCTION

Wind often plays a dominant role in snow distribution on western rangelands, causing snow accumulation and melt to be extremely variable over even relatively small areas. This extreme variability in distribution causes problems in: (1) development of accurate flood and water supply forecast relationships; (2) verification and application of snowmelt models for various uses; (3) design and maintenance of roads and highways; (4) access to and suitability of recreation facilities; and (5) management of wildlife and livestock operations. Of particular interest in this study were the problems associated with snowmelt modeling. Accurate snowmelt models could be used to address other problems attributed to variable snow distribution.

Some hydrologic models completely ignore snow and are thus limited in their applicability. Most hydrologic models contain simple empirical relationships between air temperature and a coefficient to account for precipitation falling as snow and snow water in storage. Application of these models generally requires that snow distribution over the area of consideration be homogeneous. Thus even relatively small rangeland watersheds must be divided into hydrologic response units to account for variations in snow distribution, and in reality the size of these units changes as melt occurs. Applications of complete energy balance snowmelt models have been severely limited by a lack of adequate data sets, and have, therefore, not proved useful in day-to-day operations.

This study was designed to determine the variability in snow distribution, the relationship between precipitation gage catch and snow accumulation, and the relationship between snowmelt and streamflow from a 26 ha subbasin of the Reynolds Creek Experimental Watershed located in southwestern Idaho.

Description of Study Site and Instrumentation

The 26 ha Upper Sheep Creek subbasin used in this study is an upstream source area located on the east side of the Reynolds Creek Watershed (Robins et al., 1965). The basin is about 850 m long by 400 m in width with a southeast to northwest drainage through the center. Average slope is 25 percent, over an elevation range of 1840 to 2036 m. The primary runoff usually occurs from February through July, and is generated by snowmelt, mainly from deep drifts on the northeast-facing slopes. Average annual precipitation is a little over 400 mm. Vegetation varies in response to soils and moisture distribution, and includes grasses, sagebrush, shrubs, and aspen thickets. The Upper Sheep Creek soils developed from basaltic parent material and vary considerably in depth and profile development depending on aspect and micro-climate (Stephenson, 1977).

Instruments designed to continuously monitor precipitation, incoming solar radiation, wind direction and speed, air temperature, relative humidity, snowmelt (snowpack outflow), and soil moisture and temperature at four depths have been in operation since mid 1983. In addition, snow depth and snow water equivalent measurements at 30 and/or 60 m grid spacing (Fig. 1), and aerial photographs were obtained during the latter part of the accumulation period, and during all of the melt period each year. Streamflow is monitored continuously at two permanent v-notch weirs using strip chart recorders, and at four temporary v-notch weirs using pressure transducers and an automatic data acquisition system. One permanent

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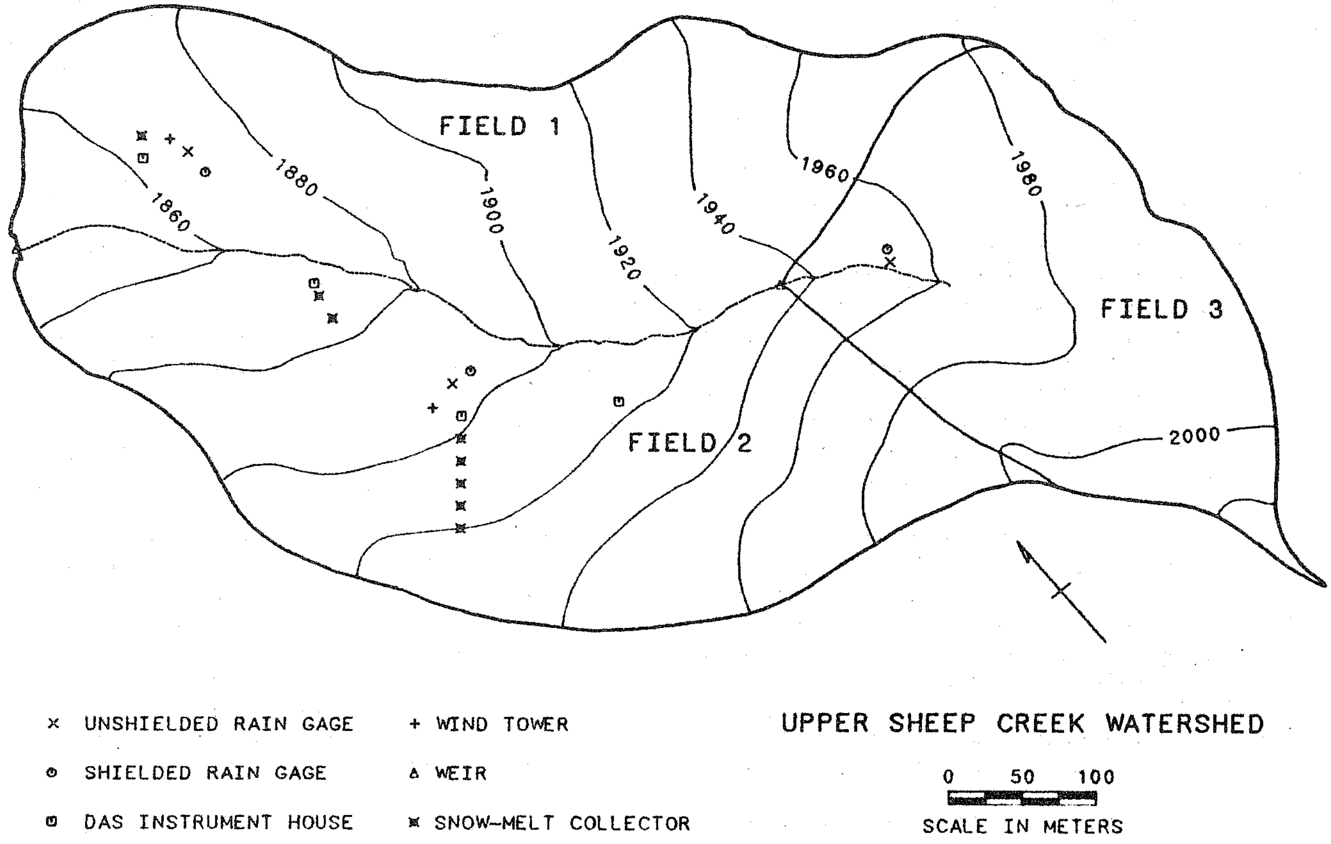

Figure 1. Upper Sheep Creek Watershed showing grid network, elevations, and instrumentation.

weir is located at the outlet of the basin, and the other monitors streamflow from the upper one third of the basin (field 3). The temporary weirs are spaced along the stream channel between the two permanent weirs (Fig. 1).

Precipitation is measured using a dual-gage system especially designed for the wind and snowy conditions in this area (Hamon, 1973). The gages are National Weather Service official recording precipitation gages spaced 6.1 m apart with orifices placed at 3.05 m above the ground surface. One gage is unshielded, and the other is equipped with a modified Alter shield on which each leaf is rigidly constrained (Hamon, 1973). Actual precipitation is a function of the ratio between the precipitation recorded in the two gages. Three sets of dual-gages are located on the Upper Sheep Creek basin to represent different aspects, elevations, and divisions or fields on the watershed (Fig. 1).

Snow samples were obtained from each grid point using standard snow sampling techniques and the Rosen type snow sampler (Jones, 1983). Manpower limitations were such that it required two days to collect a 30 m grid sample (Fig. 1), and sampling criteria dictated that the two days be storm free so that measurements on the different days would be comparable.

A total of 13 ground level snowmelt (snowpack outflow) collectors were installed on the basin (Fig. 1). Five collectors were installed at 15 m intervals on a transect perpendicular to and running through the middle of one of the main drifts on a northeast-facing slope. Two collectors were installed on a south-facing slope where the snowpack is generally quite shallow (300 mm or less) and is intermittent. Two sets of three collectors each were installed near the center of the lower two-thirds of the basin in an area of general snowpack which neither blows away, melts, or drifts to any great extent during the normal snow season (Fig. 1). One set of collectors was installed in a brushy area and the other in a relatively open area. Nine of the collectors consisted of a standard 203 mm diameter raingage receptacle placed so that the rim was about 25 mm above the ground surface. Four of the collectors were made of 150 mm diameter plastic pipe which was cut in half lengthways to form either 150 mm x 1220 mm or 150 mm x 2440 mm collection troughs. These were also installed so that the edge of the collector was about 25 mm above the ground surface. The two sets of collectors near the center of the basin consisted of one 203 mm diameter collector, one 150 mm x 1220 mm collector, and one 150 mm x 2440 mm collector. Melt water collected in the receptable flowed downslope beneath the ground through a plastic pipe into a heated instrument shelter and through a raingage tipping-bucket mechanism. Each tip of the bucket is recorded on an automatic data acquisition system, thus providing rate and volume of snowmelt.

A cross section through the main drift showing the location of the five collectors, with respect to the depth of snow as measured on March 8, 1984 and the ground surface, is presented in Figure 2. As shown, two of the collectors are downhill from the main drift, two are under the main section of the drift, and the remaining collector is under the upper edge of the drift. The location of the heated instrument shelter with respect to the collectors is also shown.

RESULTS

A. Snowpack Variability

Typically, snow accumulation and melt on the basin follow a certain pattern. Snow accumulation usually begins in November and first appears on north-facing slopes and in brushy pockets. As snowfall increases, the upper edges of drifts start to build on the leeward side of the ridges, and a general snow cover forms over most of the remaining watershed area. Ridges and south-facing exposures usually experience several periods of snow accumulation and melt during the winter due to strong winds and solar radiation. The general snow cover and drifts normally continue to increase in depth (and width in the case of drifts), often absorbing rain or melt which occurs during occasional warm periods, until maximum accumulation is reached, typically near the first of April.

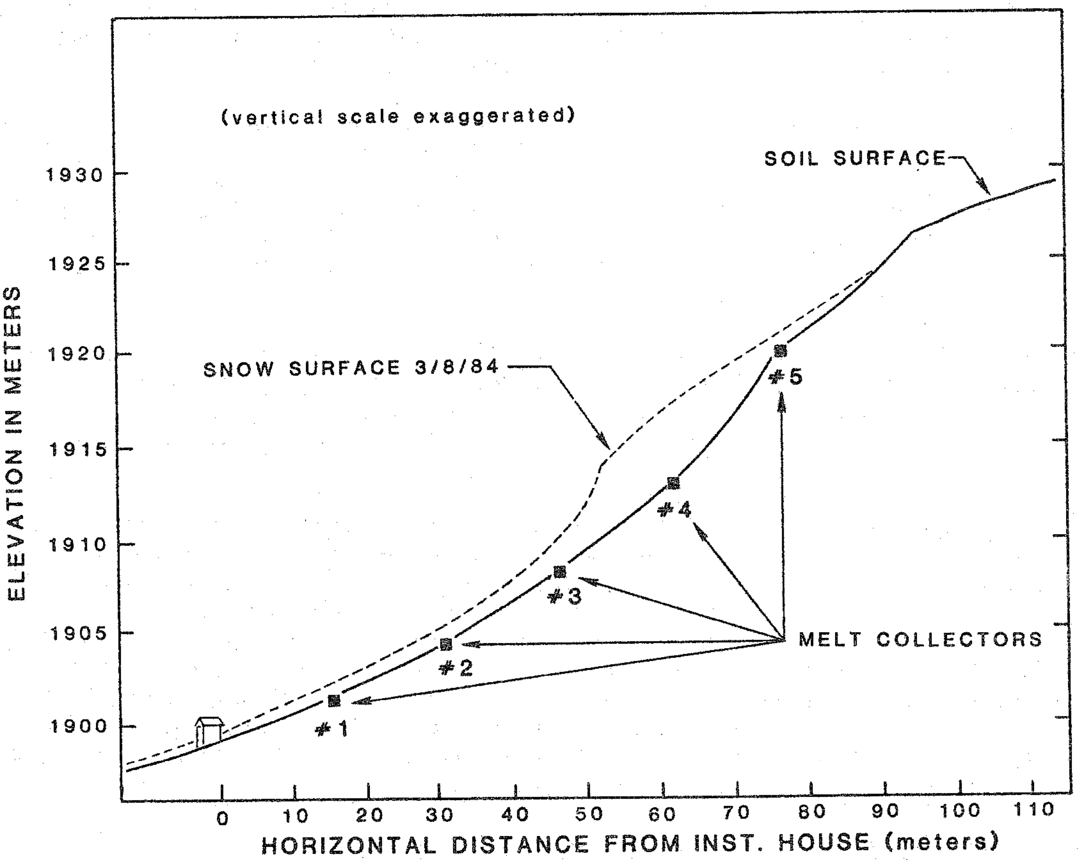

Figure 2. Soil and snow surface profiles on north-facing slope, melt collectors, and instrument shelter for March 8, 1984 at Upper Sheep Creek Watershed.

After maximum accumulation occurs and melt begins, the ridges and south-facing slopes are generally depleted of snow in a matter of hours. The general snow cover melts next, and most of the snow is melted within a few warm days, leaving only the isolated drifts. The remaining drifts often cover only 10 to 15 percent of the surface area of the basin. Ablation of the drifts does not usually occur until the general or surrounding snow cover is gone. Ablation then occurs mostly from the edges inward, and snow in these drifts usually lasts until early June.

1. Snow Depth. Immediately after snowfall events the entire watershed is covered, but this condition usually persists for only a short time. Strong winds, common for this area and period, soon redistribute the snow, blowing it from exposed source areas mostly on ridges and south slopes that are dominated by low growing vegetative varieties that have adapted to the low moisture regimes and shallow soils associated with these areas to the lee side of ridges where depths may exceed 5 m. Radient energy also contributes to snow loss from these same source areas, especially when patches of darker vegetation and soils become exposed and absorb more heat. A typical snow depth distribution is shown in Figure 3 for April 4, 1984 which represents conditions near the time of maximum accumulation for 1984, and shortly after a snowfall event. Figure 3 illustrates the problems that would be encountered in properly describing average snowmelt conditions on fields 2 and 3 if the field boundaries shown were selected.

Aerial photographs taken at about two-week intervals during the 1984-1987 snowmelt seasons (April-June) indicate that similar snow drift patterns form each year. Earlier studies also indicated similar patterns of drift formation from year to year (Rawls and Jackson, 1979). Snow depth measurements indicate that the depth of the drifts and more particularly the width of the drifts vary from year to year depending on snow volume, even though general drift patterns remain relatively consistent.

2. Snow Density. Snow density is often assumed to be rather uniform, varying much less over short distances than does snow depth. Therefore, snow samples to determine density are taken only once out of each five snow depth samples according to standard sampling procedures (Jones, 1983). An often cited "rule of thumb" indicates that 305 mm of snow produces 25 mm of water, thus implying a uniformity of new fallen snow with a density of only 8.3 percent. In reality, snow density is found to vary with time, depth, distance, and climatic region (Bilello, 1985; Ferguson, 1985; Ling, 1985).

In this study, density was determined for each sample at each grid point if conditions permitted. There were situations after very dry snowstorms when it was impossible to keep a core in the snow tube, and times when very shallow snow density could not be determined. The spatial variations in density for April 4, 1984 are shown in Figure 4. Densities on this day were noted to vary from less than 15 to over 50 percent, and appeared to be related mainly to depth and vegetative cover. The range of densities shown are typical of values obtained in 1985-1987 measurements also.

Variations in density with time and accumulation of snow are also observed each year. First, as snow accumulates in the drifts, the density increases, and second, as the snowmelt season begins, the snowpack ripens and the densities increase. Again, it is obvious that an assumption of uniform conditions over the three fields indicated would not be truly representative.

3. Snow Water Equivalent. Values of snow water equivalent (SWE) at each grid point can be obtained using the depth and density values shown in Figures 3 and 4. A map of snow water equivalent for April 4, 1984 would appear very similar to the pattern in Figure 3 of snow depth. For April 4, 1984, SWE ranged from zero to over 1500 mm, and represents the amount of water stored in the snowpack that is available for evaporation, infiltration, and runoff. The location of this stored water with respect to the stream channel is important in understanding and modeling this hydrologic system. In this case, most of the stored water in fields 1 and 3 is located along or adjacent to the stream. In field 2, however, the majority of the water is stored 90 to 150 m upslope from the stream, thus causing a different response to streamflow upon melting.

B. Relationship Between Precipitation Gage Catch and SWE

As previously discussed, snow usually begins to accumulate at Upper Sheep Creek in early November. The accumulation is far from uniform however, due to winds and topography as shown in Figure 3. Since most forecasting and modeling schemes use precipitation records

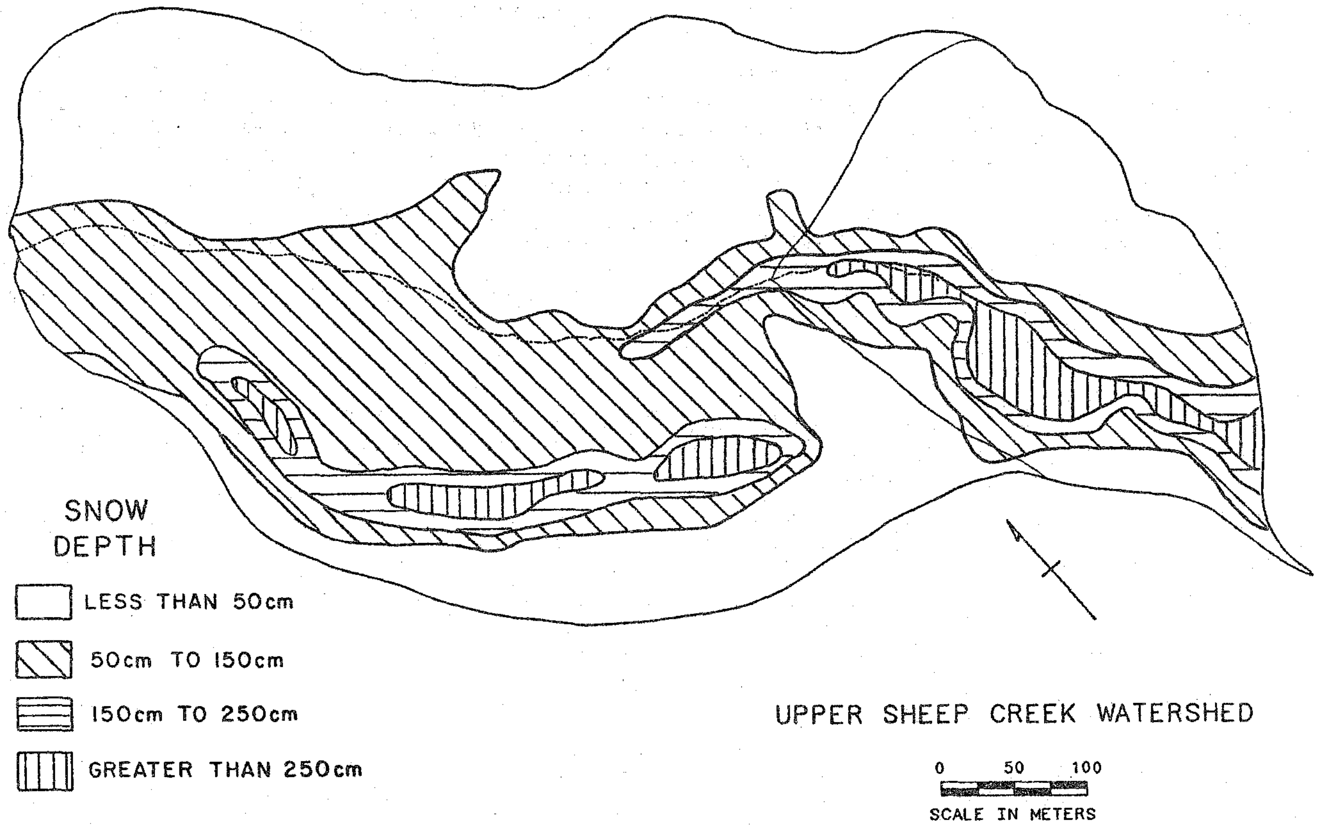

Figure 3. Snow depths at Upper Sheep Creek Watershed on April 4, 1984.

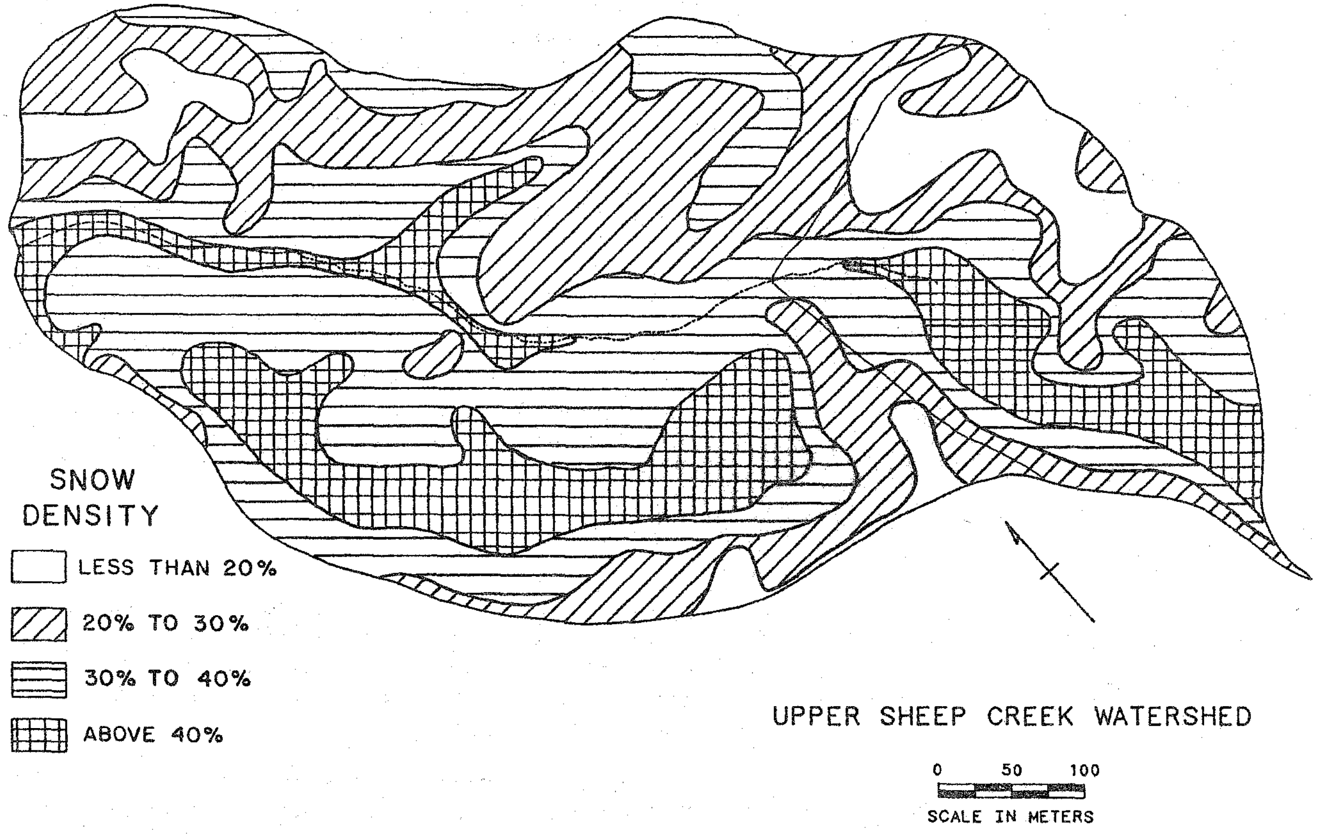

Figure 4. Snow density at Upper Sheep Creek Watershed on April 4, 1984.

from standard gages as input, the question arises as to how well accumulated precipitation gage catch represents water stored in the snowpack on such a basin.

In this study a set of dual precipitation gages was installed on each of the three fields comprising Upper Sheep Creek. The amount of precipitation caught by the two gages is adjusted using relationships and parameters developed during the dual-gage study (Hamon, 1973) to determine the amount of precipitation occurring at the ground surface. However, on the Upper Sheep Creek Basin what falls on the ground may not represent what is available in storage because of redistribution by the wind. The snow on south-facing slopes may melt or blow away, while snow on north-facing slopes continues to accumulate. A comparison between accumulated gage catch (adjusted) and the average SWE for each field on the ground at or near the time of maximum accumulation for the 1984-1987 snow accumulation periods is shown in Table 1.

Table 1. Accumulated precipitation (precip.) and snow water equivalent (SWE) for four snow accumulation seasons on the three fields comprising the Upper Sheep Creek basin (values in millimeters).

	Field 1		Field 2		Field 3		Basin Average	
Accumulation Period	Precip.	SWE	Precip.	SWE	Precip.	SWE	Precip.	SWE
11/16/83 - 4/4/84	434	99	508	356	559	361	503	272
11/1/84 - 3/28/85	302	36	384	279	396	345	358	221
11/8/85 - 2/25/86	246	8	343	231	361	343	318	193
11/7/86 - 4/2/87	188	0	211	71	246	140	216	94

Since the snow melts rather rapidly in most instances, the SWE on field 1 is a function of the amount of snowfall and time since the last snow storm, and has little relationship to accumulated gage catch except on a storm-by-storm basis. Snow accumulation on fields 2 and 3 represents only 33-73 percent and 57-95 percent of accumulated precipitation, respectively. Snowfall during 1987 was considerably below normal (about 40%) and peak accumulation may have occurred between measurement periods, thus the 1987 comparision may not be truly representative.

Although the average SWE at maximum accumulation on field 1 may not correlate with accumulated precipitation, the amount of snowmelt collected was the same or slightly more than the accumulated precipitation for 1986 and 1987. This was surprising since field 1 was always thought to be a source area for drifts over the ridge. Fields 2 and 3 both have large drop zones as evidenced by the drifts shown in Figure 3. However, the SWE at maximum accumulation is still less than the accumulated precipitation as shown in Table 1. Since these accumulations represent 3.5 to 5 months of activity, evaporation losses and ground melt from the larger snow covered areas could easily be the cause of these differences. In any case, it would be difficult to use precipitation gage catch directly to represent SWE on the fields at the start of the snowmelt season without considering location characteristics such as wind patterns, topography, and climate.

C. Snowmelt Variability

Snowpack outflow was measured as previously described, in order to better understand the melting processes and variability. The amount of outflow collected during the 1984-1987 snowmelt seasons from three collectors located on a transect of the main drift in field 2 is presented in Figures 5-8. Outflow from the 30 m and 75 m collectors were not included because of similarity in results and to simplify the figures.

As noted in Figures 5-8, the melt is quite different each year. In 1984, the initial melt of significance occurred in mid April, and snow at the 15 m and 45 m collectors had largely melted before significant outflow under the deepest part of the drift (60 m) occurred. Once the drift became isolated average outflow at the 60 m collector was a rather high 55 mm/day until all of the snow had melted. In 1985, outflow began the first of April

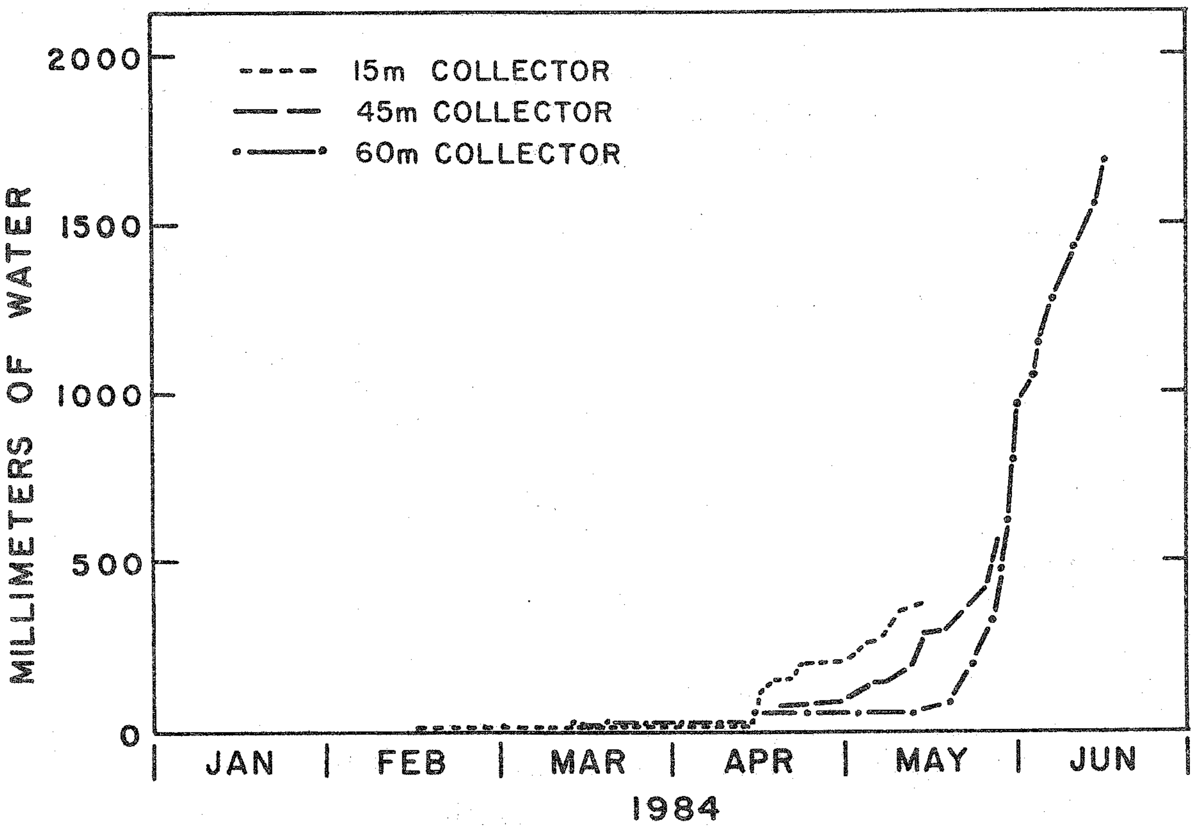

Figure 5. Daily accumulated snowpack outflow from a north-facing slope at Upper Sheep Creek for the 1984 snowmelt season.

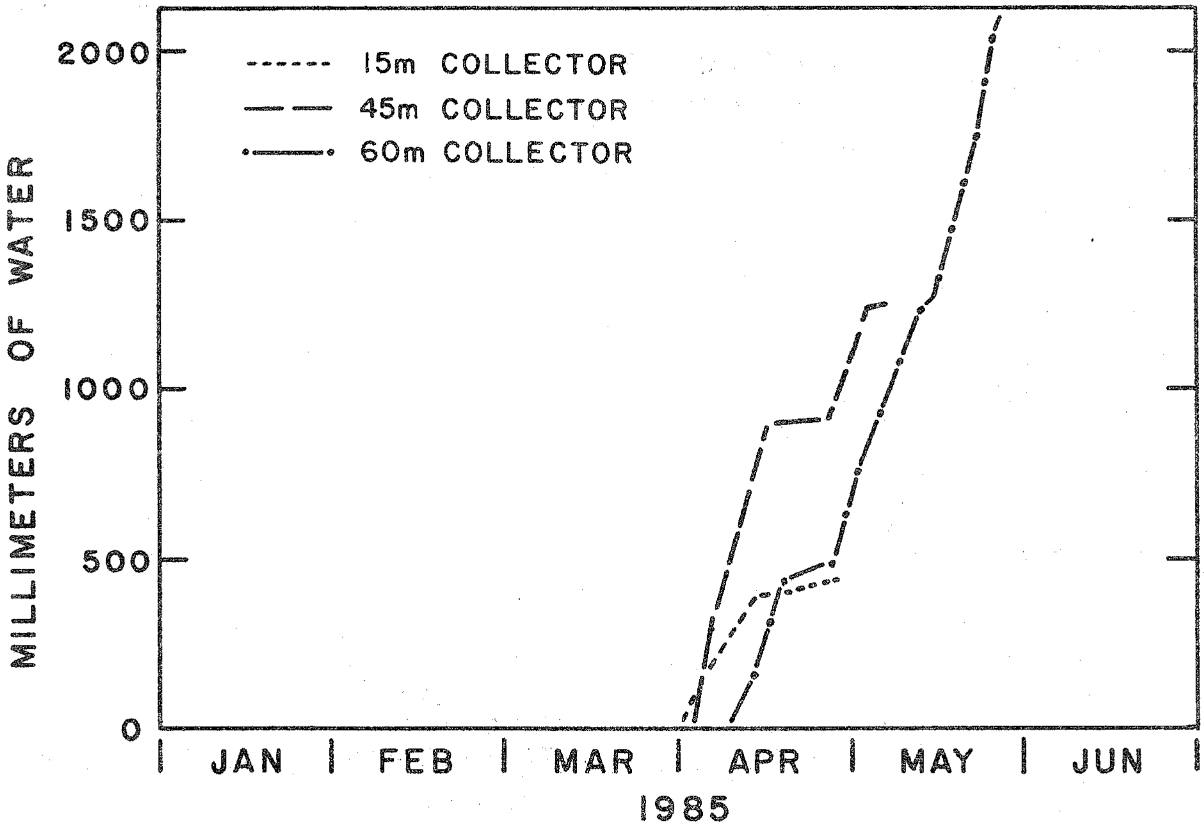

Figure 6. Daily accumulated snowpack outflow from a north-facing slope at Upper Sheep Creek for the 1985 snowmelt season.

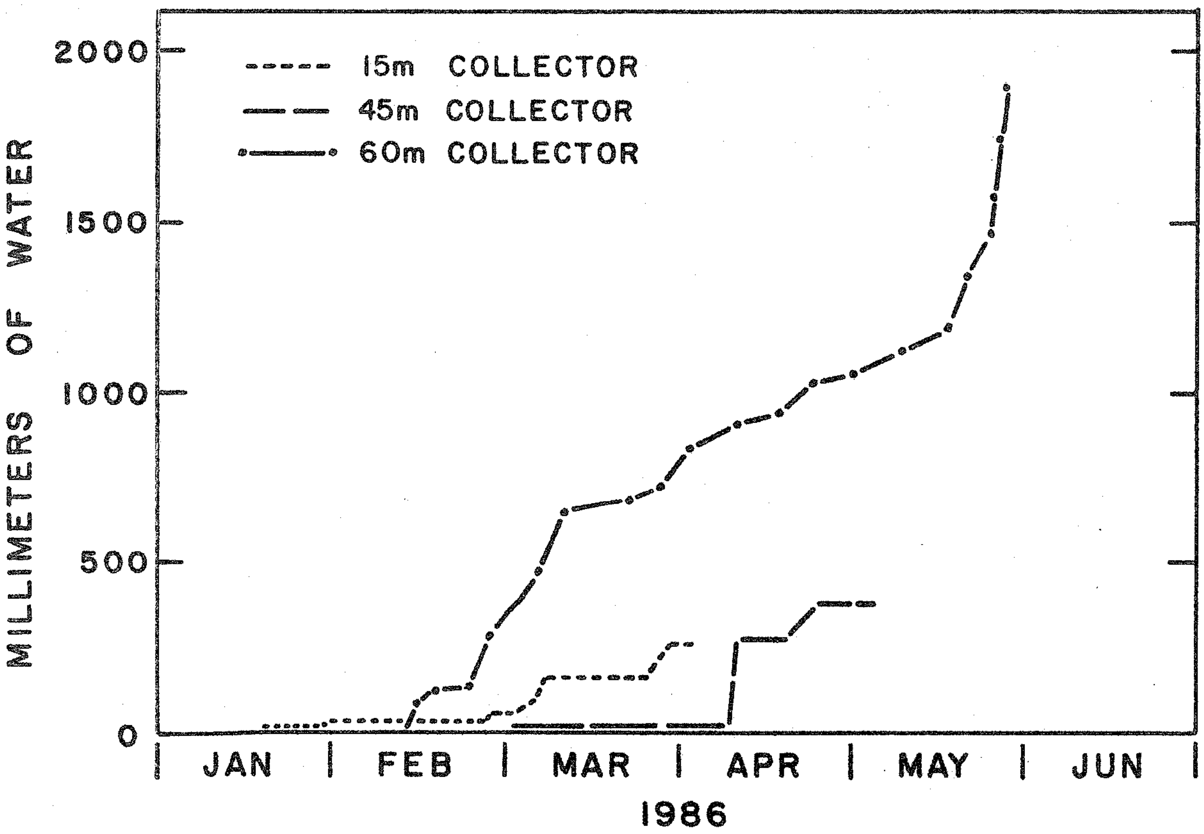

Figure 7. Daily accumulated snowpack outflow from a north-facing slope at Upper Sheep Creek for the 1986 snowmelt season.

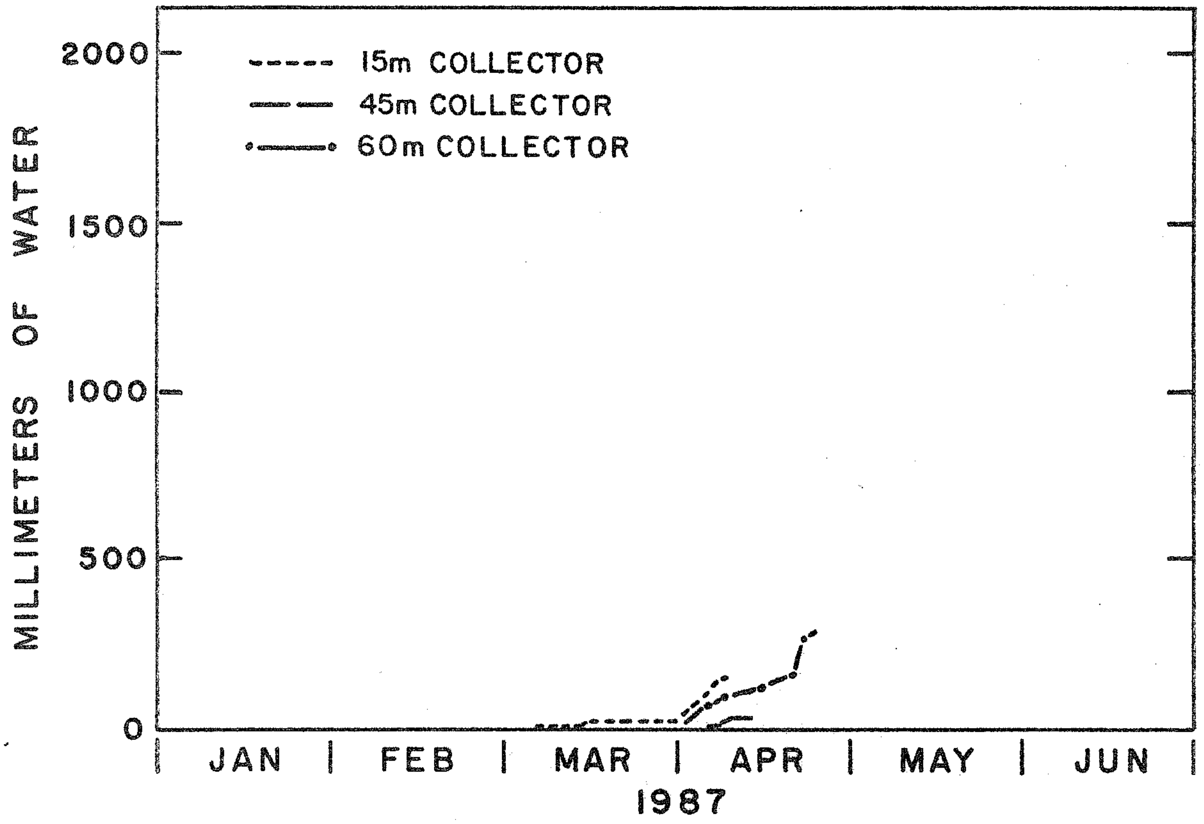

Figure 8. Daily accumulated snowpack outflow from a north-facing slope at Upper Sheep Creek for the 1987 snowmelt season.

at the 15 m and 45 m collectors which were covered by 100-150 mm of snow, and snow at the 15 m site had essentially melted before outflow began at the 60 m collector. Total melt-out of the snowpack occurred in less than 60 days in 1985, and outflow rates were high (30-55 mm/day) at all collectors right from the beginning, except for a brief cold period in mid April. The melt characteristics during 1986 were quite different in that intial melt occurred the first of February, and outflow from the deep drift (60 m collector) continued, although at a relatively slow rate (average 13 mm/day) until mid May. In mid May after the drift became isolated, the outflow rate at the 60 m collector increased dramatically and averaged 65 mm/day until all the snow had melted. The year 1986 was also characterized by six distinct events between February 1 and late April. In 1987 the snowpack was only about 40 percent of normal. Melt started near the first of April, and even the deepest drift was gone by April 20.

Although melt characteristics are different each year, some patterns do appear. For example, the high rates of outflow (50 mm/day or more) from the main drift occur after the general snow cover has melted, which generally occured by mid May when the snowpack was normal or above normal. The snowpack outflow varies temporally and spatially, and is related to snow depth and metamorphism of the snowpack.

The snowpack outflow from three locations on the basin exposed to general snow cover rather than drifts is shown in Figure 9 for 1986. Output from one collector of the two or more at each location was selected to represent the melt conditions. The D3 collector is located in a low sagebrush setting on the south-facing slope of field 1. The G6 and J10 collectors are located in field 2, G6 being in an area of medium to high sagebrush toward the lower part of the field, and J10 being in a high sagebrush area on the lower end of the transect of collectors that intersects the main drift in this field (Fig. 1).

The solid line (Fig. 9) representing the accumulated snowpack outflow from the D3 collector on the south-facing slope is greater than outflow from either of the sites on the north-facing slope, which experience deeper snow cover. Although this appears backwards, it also occurred in 1987. Two possible explanations for this apparent disparity are: (1) all three sites collect essentially the same amount of water, but evaporation losses (assume an average rate of 1 mm/day) from sites G6 and J10 are much greater since they are snow covered from November to mid April, while site D3 is bare almost 50 percent of the time; or (2) site D3 collects more water--it collects snow up to about the height of the brush (as do the other sites), but the trapped snow melts between events at D3 and thus the storage area is emptied each time and can collect a proportionately greater amount each event. The light dashed line at the bottom of Figure 9 represents the outflow from D3 on an event basis and shows not only the number and magnitude of events, but also the amount of time the site is bare or snow covered.

Snowmelt models based on simple temperature relationships would not describe the variability in snowmelt shown in Figure 9 for these two fields. On field 1 the snow may accumulate and melt several times, while on field 2, the snow accumulates and stays until spring melt-out. Some method of accounting for the difference in energy balance on each field would be required to account for the outflows noted. Adjustments to gage precipitation would also need to be different for each field, even when on-site gages are present. A study of the topography, wind patterns, and exposures could provide a basis for both adjusting precipitation input and energy relationships.

D. Runoff Variability

The variability in runoff as recorded at the lower, or outlet, weir at the Upper Sheep Creek site, is shown in Figure 10 for the years 1984-1986. There was no measurable runoff in 1987 when snowpack was only about 40 percent of normal (see Table 1 and Fig. 8). An analysis of Figures 5-8 and Figure 10 indicate that streamflow correlates closely with snowpack outflow. For example, the initial rises and peaks in streamflow each year correspond to melt of the general snow covered area and are found to occur anytime between late February and mid April. The larger and later rises and peaks are associated with the high rates of snowpack outflow from the main drifts which occur after the general snow cover is gone, usually between late April and mid to late May.

The shape of the streamflow hydrograph also corresponds to the general snowmelt characterstics. For example, snowmelt during 1985 occurred at a high rate over a period of less than 60 days. The hydrograph for 1985 shows that most of the flow occurred during a two to three week period and flow lasted for only about 100 days total. On the other hand,

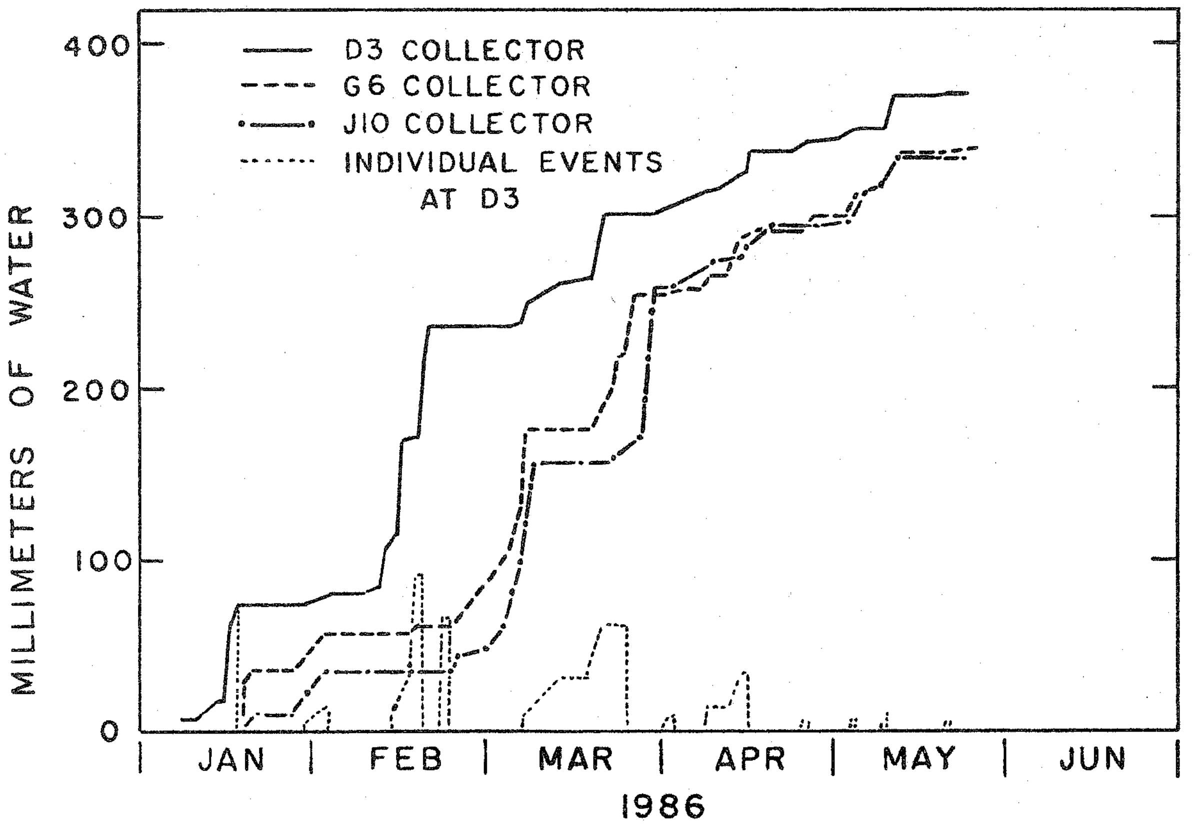

Figure 9. Daily accumulated snowpack outflow from a south-facing slope (D3), a flat area (G6), and a north-facing slope (J10) at Upper Sheep Creek for the 1986 snowmelt season.

snowmelt began early in 1986 and continued at a low to moderate rate for over 120 days. The streamflow hydrograph for 1986 indicates that there was a series of snowmelt events with the main peak accounting for a much smaller portion of the total flow. Streamflow lasted for about 150 days during 1986. Total basin runoff for 1985 and 1986 was 82 and 95 mm (average depth of the basin area), respectively. Thus the smaller amount of flow produced the greatest peak flow because of the rapid melt over a short period.

Analysis of Figures 5-8 and Figure 10 also indicates that the early peaks are associated with channel melt and overland flow as the general snow cover melts. The larger peaks occurred in mid to late May and were produced by subsurface flow associated with the rapid melting of the main drifts after the general snow cover was gone.

CONCLUSIONS

Snow distribution on western rangelands can exhibit considerable spatial and temporal variability due to the effects of winds and topography. Since general wind patterns tend to repeat each year, snowdrifts also tend to develop in certain patterns, although the depth and width of the drifts change in relation to winter precipitation amounts and types.

The relationship between accumulated precipitation and snow accumulation varied with field and gage exposure. While accumulated precipitation and accumulated snowpack outflow from a south-facing field were in close agreement, the snow water equivalent at any give time and accumulated precipitation up to that time may not show any correlation. This appears to be due to frequent melt cycles and loss or gain from blowing snow. On north-facing fields, accumulated precipitation and snow water equivalent show more correlation, but considerable differences still exist due to blowing snow and evaporation losses. Adjustments to precipitation amounts for modeling purposes could be required for each field according to slope, aspect, wind patterns, and topography, and depending on the size of the basin involved and the level of output detail needed.

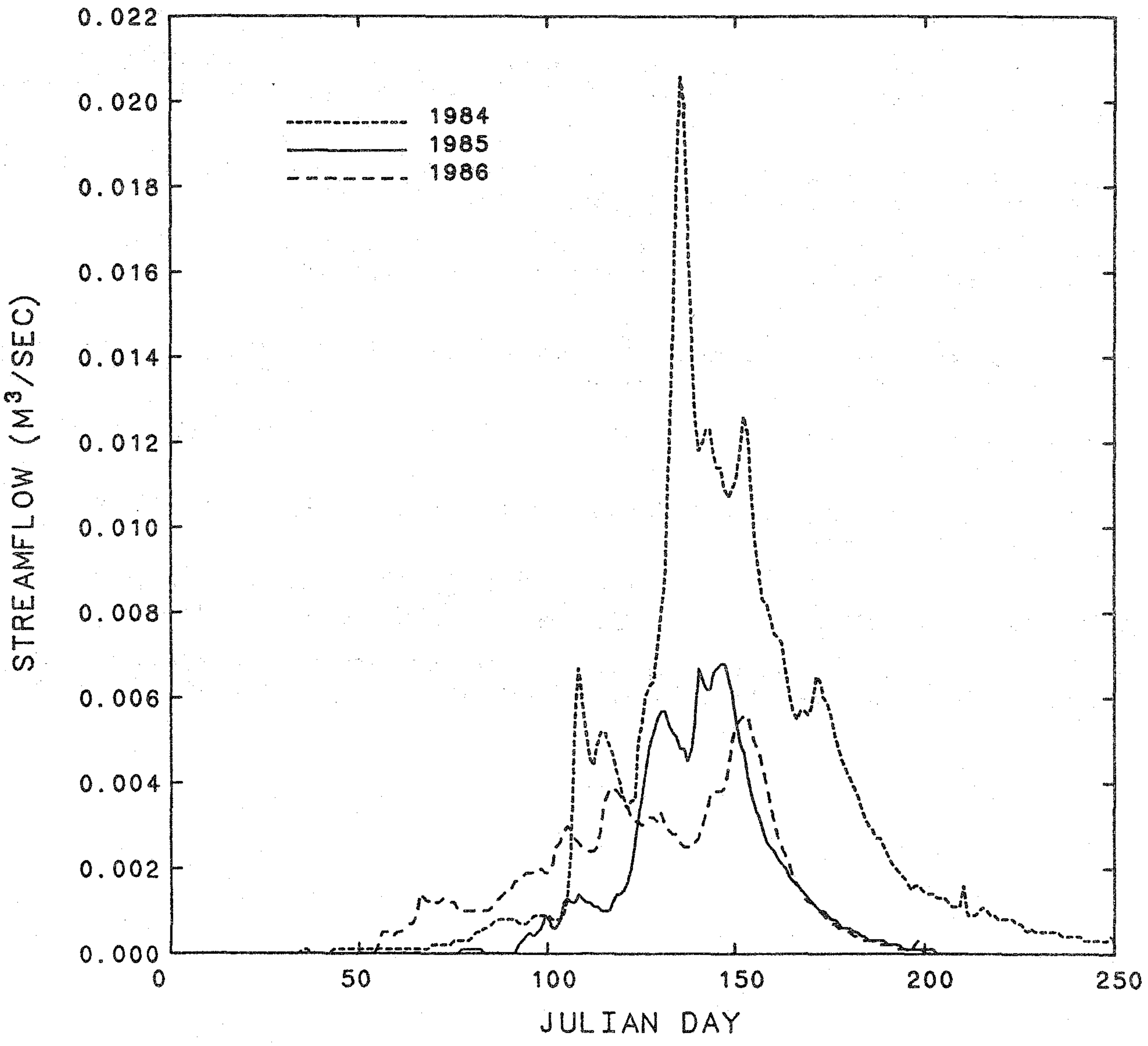

Figure 10. Streamflow as recorded at the outlet weir to Upper Sheep Creek for the 1984-1986 snowmelt runoff seasons.

Streamflow correlated closely with snowmelt amounts and rates. Early streamflow peaks were associated with melting of the general snow cover and snow in the channels, and involved overland flow. Later, much larger peaks were associated with rapid melt rates from isolated drifts, and were attributed to subsurface flow. There was no measurable streamflow from the basin when snowpack was only 40 percent of normal, thus indicating losses to evapotranspiration and seepage are at least 40 percent of normal snowpack.

Water supply and flood forecasting techniques currently in use produce adequate results for most years. However, attempts to make model simulations match observed flows by changing parameter values on other years seem to be futile, since no amount of adjusting produces the desired trace. The variability in snow accumulation and melt described in this study could cause these problems. A better understanding of the processes involved and the development of adequate methods of accounting for the variabilities noted may be required before improved modeling procedures are produced.

ACKNOWLEDGEMENT

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