SNOWPACK CHANGES AND WATER RELEASE AT A LOW ELEVATION SITE IN THE SIERRA NEVADA

by

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INTRODUCTION

The intermittent snowpack zone may be loosely defined as areas where snow covers the ground for one to three months in most years. Snow cover may accumulate and ablate completely several times during a winter in this zone, particularly on south facing slopes. The intermittent snowpack zone of the Sierra Nevada covers more than a third of most river basins on the west slope of the range. It is above the rainfall zone where occasional snowfall does not persist and below the snowpack zone where snow cover lasts more than three months. This zone of rapidly changing snow cover includes elevations between 700 m and 1200 m in the northern Sierra and between 1200 m and 1800 m in the extreme south. These approximate boundaries also depend on aspect, and snow cover throughout this area is often discontinuous. This region is primarily responsible for rapid changes in snow covered area observed from satellites.

The intermittent snow zone produces most of the winter season streamflow in major Sierra Nevada rivers. Both rainfall and snowmelt contribute to this mid-winter runoff. This zone also appears to be the primary flood producing area in the Sierra Nevada. During warm storms, the intermittent snowpack zone has been estimated to contribute twice as much water to streams as the rain zone and three times as much runoff as the higher elevation snowpack zone (Anderson, 1958). Substantial rainfall and convection-condensation snowmelt often combine to provide large inputs of water to the stream system (Hall and Hannaford, 1983). During warm storms, the availability of snow at these lower elevations may determine the magnitude of flood peaks (Harr, 1981). Sediment produced in this zone from surface erosion and mass movement associated with rain-on-snow events can also be substantial (McCaffrey and DeGraff, 1983; Bergman, 1987).

Although the above generalizations about the intermittent snow zone are well known, detailed descriptions of the snow hydrology of this zone in the Sierra Nevada are lacking. A long-term climate record at one location supplemented with snowpack density and snowpack outflow measurements in the last few years illustrate some snowpack properties and processes in the transient snow zone of the Sierra Nevada. This paper describes some of the attributes of the dynamic snowpack at this example location.

STUDY AREA

This study took advantage of the climate and snowpack record at Blue Canyon on the west slope of the central Sierra Nevada. This site at 1600 m along Interstate Highway 80 east of Sacramento is in the upper elevations of the intermittent snow zone. The site is basically level and open with a few nearby trees less than 5 m in height. The National Weather Service has maintained a manned observation station at Blue Canyon since 1938. Observations include precipitation, air temperature, snowfall, and snowpack water equivalence (SWE). Snowfall was collected from daily snowboards and SWE was obtained with a Federal sampler. Unadjusted values of SWE provided by the National Weather Service were used in this study despite the errors inherent in this method (Goodison, *et al.*, 1981:231). This study relied primarily on the snowfall and snowpack data from 1960 to 1980 that were originally compiled for another investigation. Because of the typical lack of snow at the study site in early winter, only data collected after January 1 were used here.

Information on snowpack structure and snowpack water release was collected at the same site by the U.S. Forest Service's Pacific Southwest Forest and Range Experiment Station. From 1978 to 1982, snowpack density profiles at 5 cm increments were obtained with a portable gamma-backscatter snow gage (Blincow and Dominey, 1974). This instrument allowed repeated measurements of the same volume of snow surrounding a single access tube. Since December 1984, outflow from the base of the snowpack has been measured with three adjacent snowmelt lysimeters of 20 m^2 area each. Discharge from each of these large collectors is measured with a tipping bucket and is recorded at hourly intervals.

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SNOWPACK CHARACTERISTICS

Snowpack water equivalence fluctuated greatly both within and between years (Figure 1). Substantial accumulation and melt were observed on several occasions in each of the months January through April. Individual storms often had dramatic effects on the snowpack — SWE increased severalfold during large cold storms and melted completely during large warm storms. Snowpack development at Blue Canyon showed little resemblance to the typical sequence of steady accumulation throughout the winter followed by steady melt in spring as observed at higher elevation sites with a lower proportion of mid-winter rain.

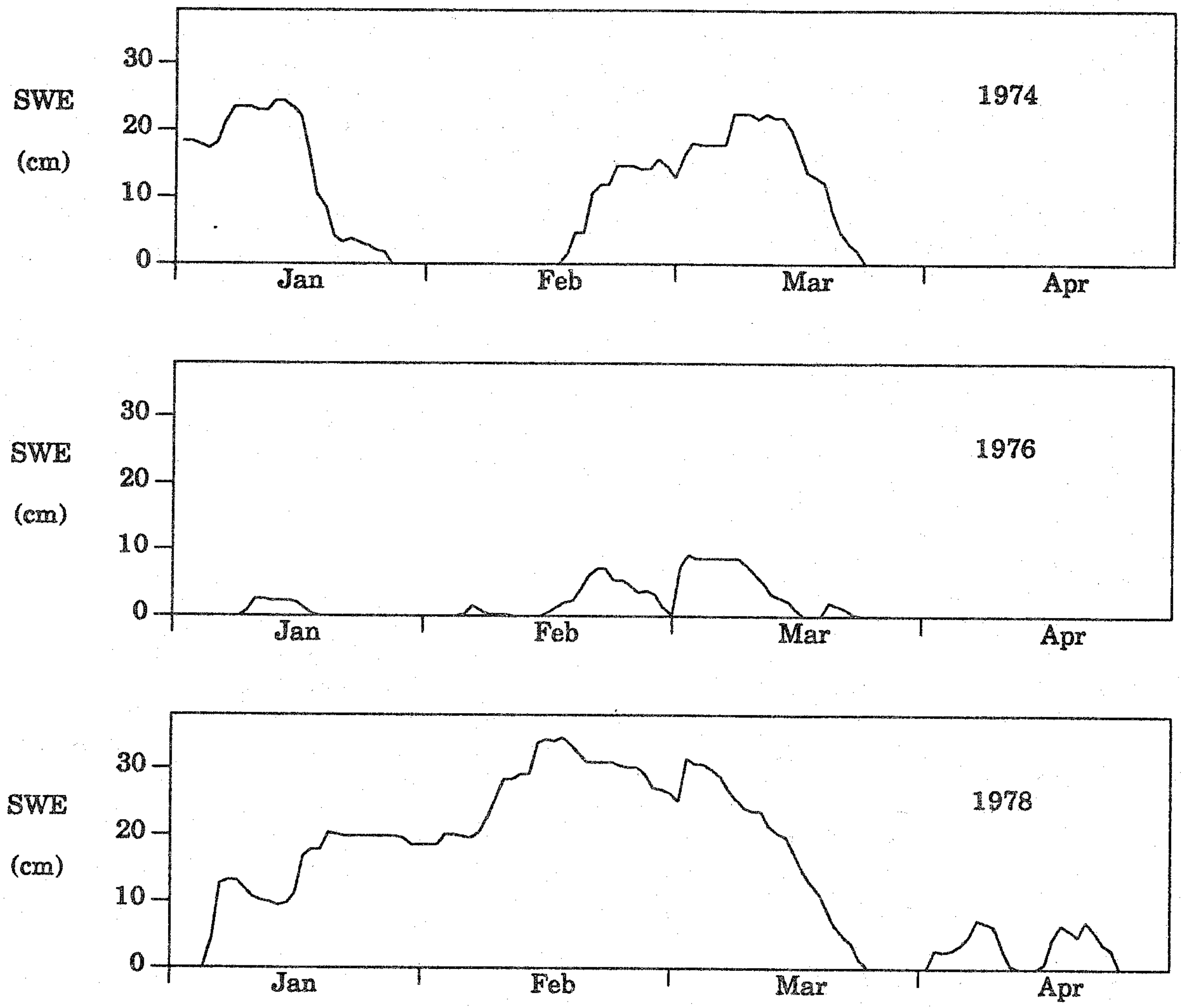

Figure 1. Snowpack development at Blue Canyon during three example years.

A thin snow cover was present by January 1 in most years. However, snow was absent on this date in 7 out of the 21 years examined, and SWE was less than 5 cm on this date in four other years. The mean SWE on January 1 over this period of 21 years was 12 cm. The snowpack generally increased during January to produce an average of 17 cm SWE by February 1. However, a snowpack failed to accumulate or melted completely before February 1 in 7 years. In 1961 and 1963, persistent snow cover was still absent by March 1. Some snow was present on this date in the other 19 years, although SWE was less than 5 cm in three of these cases. Mean SWE on March 1 was 24 cm. Melt exceeded accumulation during March in 14 out of the 21 years, leaving an average of 19 cm SWE on April 1. Snow melted quickly throughout April in most of the years. Snow was present at the study site on May 1 in only 5 years. Snow cover disappeared for the season as early as March 17 (1970) and as late as May 21 (1967).

Seasonal peak water equivalence varied from 9 cm (in 1976 and 1977) to about 70 cm (in 1969 and 1975) during the 21 years examined here. Peak SWE was less than 25 cm in 8 years and more than 50 cm in 5 years. During these 21 years, peak SWE occurred in January in 6 years, in February in 3 years, in March 9 times, and in April in 3 years. At Blue Canyon, snowmelt results from both solar radiation during clear weather and condensation and convection during warm storms. Although either energy source can cause melt at any time of the snow season, clear-weather snowmelt equaled or exceeded snowmelt associated with warm storms in all months examined here and increased from January through April. Although warm storms with high snowlines are less common in March and April than in November through January, solar radiation input to the snowpack is much higher during and around these late season storms. Monthly decreases in SWE associated with rain events averaged 5 cm in January, 3 cm in February, 5 cm in March, and 3 cm in April. In all months, melt amounts probably would have been even greater if the snow cover had not disappeared. The largest monthly losses associated with rain occurred in January 1974 (22 cm). Clear-weather snowmelt averaged 5 cm in January, 8 cm in February, 13 cm in March, and 17 cm in April. These amounts were often limited by snow disappearance, which was often more of a limiting factor than energy input. High rates of snowmelt are common at Blue Canyon because the snow surface does not freeze at night as often as it does at higher elevations.

Weekly profiles of snowpack density showed a relatively homogeneous snowpack without the strongly layered structure of snowpacks at higher elevations. There were some dramatic exceptions to this generalization, but the nearly continuous addition of liquid water to the surface led to relatively consistent densities throughout the profile. Except for surface layers immediately following snowfall, densities of most of the snowpack were between 350 and 450 kg m^{-3}. High density layers such as surface crusts did not appear to be as common as in snowpacks at higher elevations.

SNOWPACK WATER RELEASE

Measurement of outflow from the base of the snowpack allows us to observe the actual release of liquid water rather than just inferring it from changes in snowpack properties with their inherent sampling and measurement errors. In general, water was discharged from snowpack (when present) at Blue Canyon on all days except those when a thin snow cover was frozen throughout its depth or after prolonged snowfall. The most common condition for the absence of water release to the soil was the absence of a snowpack. In February, the number of days with less than 1 mm of measured outflow in 1985, 1986, 1987, and 1988 were 8, 7, 5, and 4, respectively. In March, the corresponding numbers were 11, 9, 3, and 5. Some uncertainty exists in these numbers due to incomplete knowledge of snow presence at the site and some missing data. More than 1 mm of water was released on most of the days when snow was present in December and January as well.

In 12 out of 16 months of record, water release exceeded 10 mm per day on at least four days. Water release exceeded 50 mm per day on 15 occasions from 1985 to 1988. All of these large values resulted from rainfall and the associated convection-condensation melt. The largest daily discharge in our records was 230 mm on February 17, 1986, which was almost entirely rain. An example of the hydrograph of snowpack outflow for the mid-February 1986 rain-on-snow event illustrates the flood generation potential from the intermittent snow zone (Figure 2). Discharge from radiation-induced melt in March and April typically ranged from 10 to 40 mm per day. The snowpack caused only a couple of hours delay between the onset of rainfall and the beginning of water release to the soil. An increase in outflow due to snowmelt was usually noted within 1 or 2 days following snowstorms.