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A SUBALPINE SNOWMELT RUNOFF MODEL

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ABSTRACT

A digital computer model for simulating daily watershed runoff from snowmelt under subalpine conditions has been developed in first-generation form.

Solar radiation is the primary source for snowmelt. The areal extent of snowcover is calculated with a submodel derived through stepwise multiple regression techniques. Insolation measured in or near the basin is adjusted to the latitude, slope, and aspect of each segment in the basin, then adjusted for albedo and combined with longwave radiation for the net radiation exchange producing potential snowmelts. These snowmelts are adjusted for snowpack conditions and distribution, and become the runoff from each segment to be routed through flow points as daily discharges.

Comparison of simulated flows with observed flows indicated reasonably satisfactory model performance. The model was developed and tested for the Nash Fork basin in southeastern Wyoming, but there are no theoretical reasons to prevent application of the model to other watersheds where snowmelt is the dominant source of streamflow.

Key Words: Computer/Flow Routing/Hydrology/Model/Radiation/Runoff/
Snow/Snowcover/Snow Distribution/Snowmelt/Subalpine/
Wyoming

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CHAPTER 1

INTRODUCTION

Model Concept

The objective of the model is to describe watershed system interactions as simply as possible in terms of data that could reasonably be obtained from, or reliably estimated for, a high-altitude mountain watershed having snowcover on at least a portion of the area for most or all of the year, and to closely reproduce observed daily streamflows at one or more points in the watershed. The model should be adaptable to other watersheds, at least to those at high altitudes in the Central Rocky Mountain region.

The study area, the Nash Fork basin in the Snowy Range of southeastern Wyoming, is typical of many watersheds of the Central Rocky Mountains. Snowcover usually begins in late September or early October, and can still be extensive in the upper portion through July, with some snow fields persisting throughout the year in most years. Strong winds compact the snow, and tend to keep several ridges and exposed areas essentially snow-free during most of the winter season. Rainfall is generally light, and is normally only a small contributor to runoff.

The snowpack behavior appears to be the controlling element to be modeled in this situation, whereas most watershed models are based upon rainfall-runoff relationships. With few exceptions,

the models examined avoid the deep snowpack watersheds and tend to minimize the effects of a snowpack upon runoff.

At the beginning of this study there did not appear to be a model suitable for adaptation to the conditions of the study area, and the decision was made to proceed with the development of a snowmelt runoff model for high-altitude watersheds based upon the situation in the Nash Fork basin. The resulting model is based upon the premise that solar radiation is the main source of the energy required for snowmelt, and that this is supplemented by longwave radiant energy. Modeling then becomes a process of describing the accretion, distribution, and decretion of the snowpack, with its decretion expressed as runoff at various flow points in the basin.

The model described in the following chapters is a base model intended as a framework around which to add components to better satisfy the research needs in the study area, and, hopefully, in other research areas. The results produced by this base model are quite satisfactory in many respects. Although the model was developed for the Nash Fork study area, considerations for general applicability, at least regionally, have been kept in mind.

Literature Review

Hydrologic modeling, in the sense of the complex calculations and large volumes of data processed in the operation of a model, has had to await the availability of modern computing devices. In the sense of an awareness of interactions between hydrologic variables, conceptual modeling may have had its beginnings when

the ancient peoples of China, India, and the Middle East used irrigation and water control to even out the variations between wet and dry seasons (Biswas, 1967). In the seventeenth century Perrault and Mariotte demonstrated that rainfall was sufficient to make springs and rivers flow throughout the year, and Halley demonstrated that evaporation from the ocean could more than replenish all springs and rivers (Biswas, 1968). This quantification certainly involved some concept of the hydrologic cycle, which is a form of model.

Work done in this century prior to the advent of the available computer provided some knowledge of relationships for snow modeling, plus a body of data with which the models could be tested. Church, in 1908, attempted to relate the water equivalent of a snowpack to runoff (Monson and Codd, 1961). Clyde (1931) recognized that runoff is a residual, and that the watershed losses are related to snow melting characteristics. From their fundamental research in the physics of snow, the Corps of Engineers (1956) developed model equations for the various processes of snow accumulation, melt, losses, and runoff. This work provided much of the basic information and relationships necessary for computer modeling. Many of the subsequent computer models are based upon some or all of these relationships and many are tested upon the data presented therein.

The Stanford Watershed Model IV (Crawford and Linsley, 1966) is probably the best known and most widely used of the present-day models. It is primarily a rainfall-runoff model capable of

operating with very small time increments. A snowmelt subroutine was developed for the Model III version and included in the Model IV (Anderson and Crawford, 1964). The snowmelt subroutine is intended for watersheds having only seasonal or occasional snow-cover. The Stanford model was written in Subalgol language and was not readily adaptable to computers requiring a Fortran language.

Anderson (1968) utilized the Stanford Watershed Model III for routing from ground to gaging station in testing two approaches to modeling snow accumulation and melt for a relatively heavy snow-pack. The two approaches consisted of a simple energy balance and an empirical method using air temperature as an index to heat exchange.

The Verka basin in Sweden was modeled with a Fortran development of the Stanford model. There was a greater dependence on a snowmelt subroutine than for most areas of application of the Stanford model, but the investigators felt that both the snowmelt routine description and the program listing were inadequate for a translation to Fortran (Cawood, Thunvik, and Nilsson, 1971).

The necessity of digital computer hydrologic modeling of 140,000 sq mi (360,000 sq km) in Newfoundland resulted in the application of a grid system to the study areas to relate average precipitation, temperature, runoff, and physiographic characteristics. Snowmelt was considered as precipitation and resulting runoff, but no special treatment of snowmelt was used (Solomon et al., 1968).

Probably the earliest efforts to forecast streamflow volumes from snowmelt were those of the Division of Irrigation of the Bureau of Agricultural Engineering in 1936, and continued since 1939 by the Soil Conservation Service, as an outgrowth of the snow survey work begun by Church in 1908. The forecasts of runoff are based on the water equivalent of the snowpack as measured at index snow courses, using correlation techniques (Monson and Codd, 1961).

Riley, Chadwick, and Bagley (1966) used electronic analog simulation of an hydrologic system with small space increments and large time increments. A somewhat empirical approach was used for snowmelt, based on temperature and a radiation index. A second analog computer model for snowmelt simulation which considered different space-time increments without routing was developed by Riley, Chadwick, and Eggleston (1969).

A Russian model includes inflow from glacier melt, considers an "intensity of melting" as proportional to the average daily air temperature, and utilizes different coefficients of melt for open and forest areas (Borovikova). The model requires the solution of differential equations for the changes in the snowpack, and gives water content as a function of altitude.

A dynamic simulation model for snowmelt in Colorado subalpine watersheds simulates winter snow accumulation, energy balance, snowpack condition, and the resultant melt in time and space (Leaf and Brink, 1973). The snowpack is treated as a dynamic heat reservoir with energy input from longwave and shortwave radiation

adjusted for slope and aspect. Routing operations were subsequently added to the model (Brink and Leaf, 1973).

Studies of the factors affecting snow accumulation and melt, and the resulting runoff, contribute to the components of a snow-melt runoff model. Studies of a shallow snowpack in Vermont indicated that: (1) snowmelt was extremely sensitive to solar radiation as modified by topography; (2) air temperature was not a sensitive predictor of snowmelt runoff; (3) winter melt did not produce significant runoff; (4) refreezing at the soil surface permitted rapid runoff; (5) differences in aspect affected timing; and (6) while snow covered most of the plots the daily totals of runoff and radiation were related in a simple fashion, but no simple relation existed between runoff and air temperature (Dunne and Black, 1971).

A study of snowmelt in the Upper Peninsula of Michigan found that frozen ground thawed as snow accumulated beyond the amount needed for insulation and that the resulting ground melt and infiltration gave rise to a base flow twice that of summer. The authors propose that the condensation of water vapor occurs just above, rather than at, the snow surface, with the latent heat released to the air instead of to the snowpack (Santeford, Alger, and Meier, 1972). A computerized method for estimating areal precipitation, the reciprocal distance squared method, was developed by Wei and McGuinness (1973) to estimate the precipitation at an ungaged point from measurements at nearby gages.

Work by Larson (1971) in testing precipitation gage catches in windy areas indicated that weighing-type gages with Alter-type shields in an exposed location caught about two-thirds of the precipitation caught by a standard gage. Larson's work was directed toward the development and testing of a gage-shielding configuration that would provide reliable precipitation catches, especially of snow, in exposed locations. The resulting Wyoming Shield configuration was further tested in the Nash Fork study area and found promising for use as a standard gage even under severe exposure conditions (Rechard, Brewer, and Sullivan, 1973).

Research concerned with insolation resulted in equations for calculation of the theoretical solar radiation received on an area adjusted for latitude, slope, and aspect, and in tables of these values for selected latitudes, slopes, and aspects (Frank and Lee, 1966). Cogley and McCann (1971), working with data from the Canadian Arctic, suggest that "... radiation is a better index of snowmelt runoff than is temperature." Research on a clear-cut watershed in New Hampshire by Federer (1968) indicated that during melt periods, net solar radiation provided sufficient energy for snowmelt and a small amount of evaporation, and that convective heat gain closely approximated the longwave radiation heat loss.

Measurements on a small, Ponderosa pine covered watershed in Arizona indicated that more than 90 percent of the snowpack left the watershed as runoff (Ffolliott and Hansen, 1968). Hutchison (1966) found that evaporation from wet soil surfaces greatly exceeded the evaporation from nearby snow in natural forest

openings at 9,000 ft (2,740 m) in Colorado. He concluded that the vapor pressure of the air was raised sufficiently to inhibit evaporation from snow, partly explained by the fact that the vapor pressure of the air immediately above the soil is not fixed by a temperature limit as it is over snow. Sublimation losses of wind-blown snow in southeast Wyoming were studied by Tabler (1973). He found that up to 83 percent of the blowing snow was evaporated during transport over a sufficiently long distance.

Aerial photography has been used in several investigations for determining the areal extent of snowcover. Leaf (1967) found snow depletion rates highly correlated with seasonal runoff volumes, consistency in the annual patterns of snow depletion, and consistency in the snow depletions as compared between watersheds. He also found that each watershed has a characteristic functional relationship between the extent of snowcover during the melt season and the accumulated runoff, which suggests the importance of snowcover information in forecasting (Leaf, 1969). Further work by Leaf and Haeffner (1971) showed that the characteristic relationship of a watershed does not change appreciably even though snowpack and weather conditions vary from year to year.

Snow density was found to be "... remarkably similar from year to year so that it is reasonable to suggest the character of the density at a specific time in the climatic calendar" (McKay and Findlay, 1971). McKay and Findlay further attribute snowpack compaction and high density values to wind action. Smith (1966) found snow density to be uniform, and snow depth highly variable,

over the study area in California, and that May and June evaporative losses were either nonexistent or low. He also reports that the Sierra Nevada snowpack did not retain water when it was applied as rain, probably due to a negligible cold content in the snowpack. Bartos and Rechard (1973) studied snow sampling techniques in a subwatershed of the Nash Fork basin in the Snowy Range of southeastern Wyoming, and also found snow densities to be uniform and snow depths highly variable. They suggest sampling along an irregular transect, with several depth samples for each density sample.

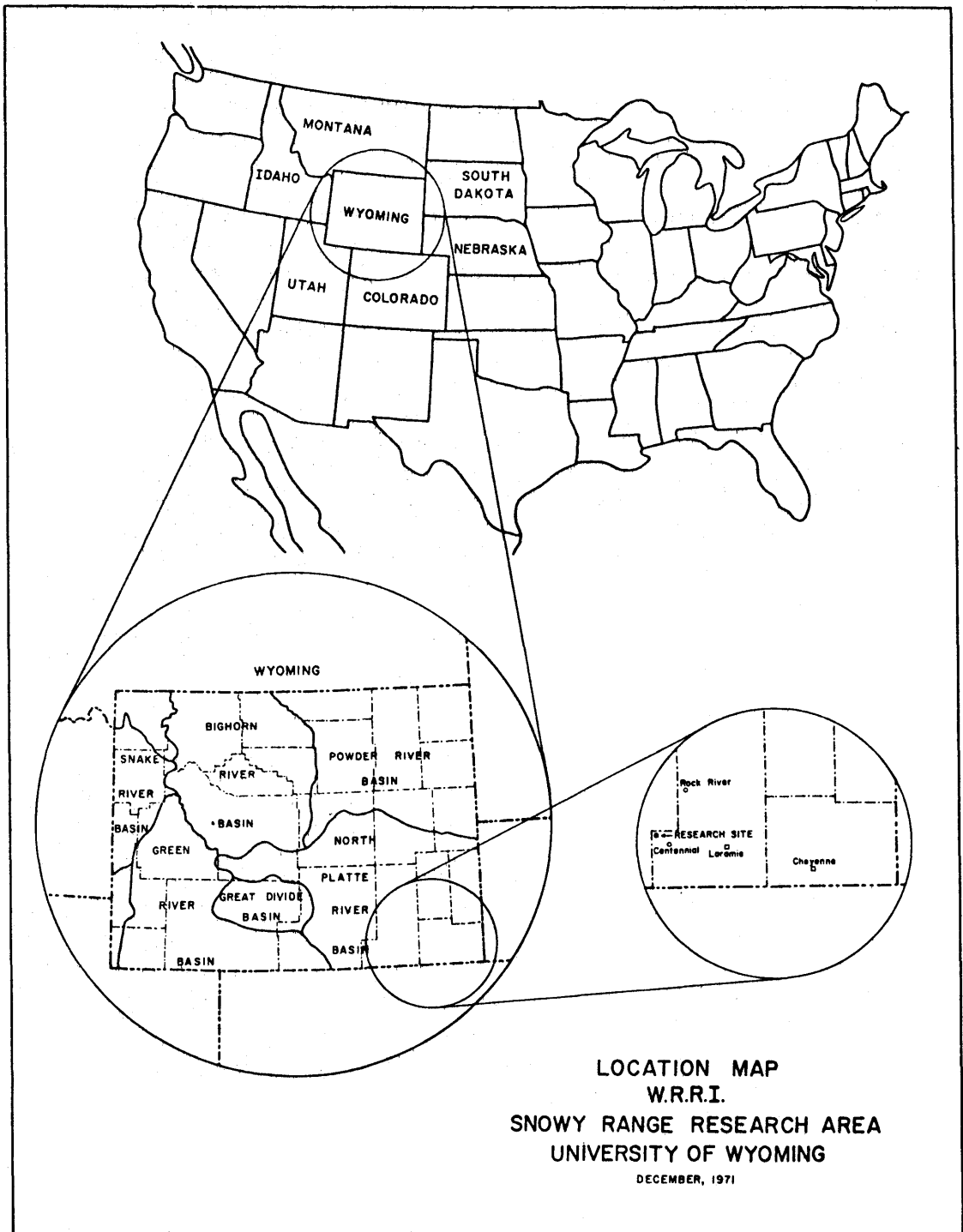


FIGURE 2-1

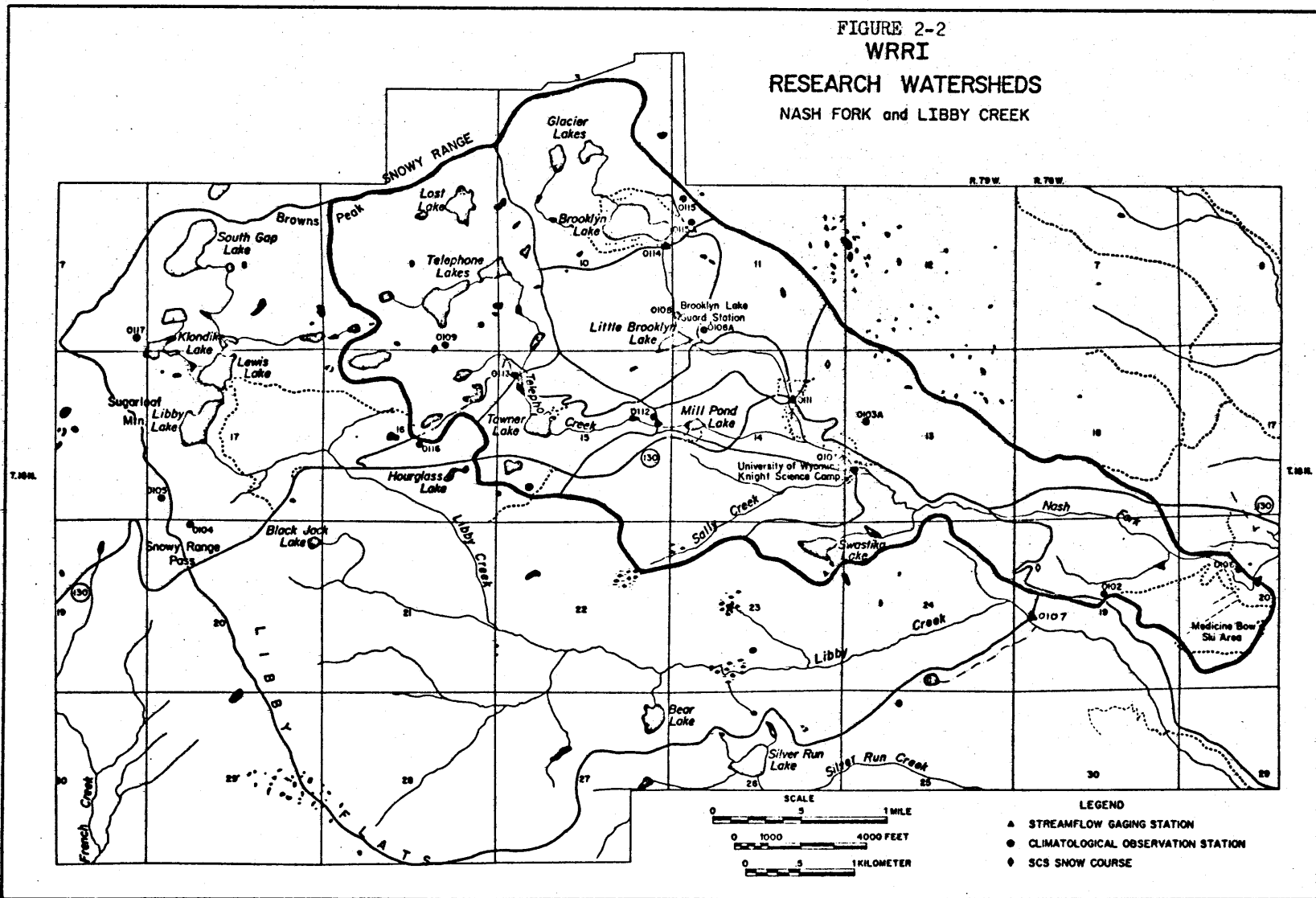
CHAPTER 2

THE RESEARCH AREA

The University of Wyoming Water Resources Research Institute utilizes the Nash Fork and Libby Creek watersheds on the east slope of the Snowy Range in southeastern Wyoming as one of its research areas. The Nash Fork basin was selected as the particular study area for the development of this subalpine snowmelt runoff model. The research area location is shown in Figure 2-1.

The Nash Fork basin is predominantly subalpine in character. It ranges from 9,100 ft (2,770 m) above sea level at the lower end of the study area to over 11,700 ft (3,570 m) above sea level. Principal tributaries entering the Nash Fork are Telephone Creek and Sally Creek; many other small tributaries, some intermittent, enter these streams. The study area covers 4,490 acres (1,820 hectares), or about 7 sq mi (18 sq km) and contains 20 lakes and numerous ponds, some of which may be dry at the end of the summer. Snow fields persist in the higher areas until late summer, and some remain throughout the summer in most years. The winter snowpack accumulation normally begins in late September or early October, and heavy snowfalls are not uncommon through May. Snowfall may occur during any month of the year. Rainfall is normally only a small part of the total precipitation and seldom makes a significant contribution to runoff, although a high-intensity rainstorm may be reflected in the hydrographs at the various gage stations. A prolonged spring rain falling upon a nearly ripe

FIGURE 2-2
 WRI
 RESEARCH WATERSHEDS
 NASH FORK and LIBBY CREEK



snowpack can result in flooding, but this has not been a common experience. Strong westerly winds are common during the winter and cause many deep drifts, with some areas blown free of snow much of the time. The snow is compacted by the wind action and, together with crusts formed between snowstorms, results in a very dense snowpack. Forest cover ranges from generally dense Lodgepole pine stands in the lower basin through a Spruce-Fir zone with large open parks to the mostly open subalpine areas of the upper basin, which contain small stands of wind-ravaged trees. Willows and other brush are found in meadows along the streams, and most of the open areas are grassy. There are many exposed rocks, and some rock fields. A map of the Nash Fork and Libby Creek research watersheds is shown in Figure 2-2.

The Medicine Bow Ski Area is located at the lower end of the Nash Fork basin. Snowmobile traffic is increasing throughout the basin and was quite heavy at the conclusion of the field work for this project. The effect of this traffic on the behavior of the snowpack is not yet known. The research area is entirely contained in the Medicine Bow National Forest. Additional physical and hydrometeorological information about the research area is reported by Rechar and Smith (1972).

Instrument Sites

The Nash Fork and Libby Creek basins have been instrumented for many research projects, and, so far as possible, the instrumentation and the sites have been selected to satisfy as many needs as practical at one site. Only those sites of concern to this

project will be discussed; and these site locations are shown in Figure 2-2.

Site 0101 is located at the Centennial Ranger Station, which is out of the research area, at an elevation of 8,440 ft (2,570 m). It is operated jointly with the U.S. Forest Service and was used here only as a temperature site for estimation of missing records at sites within the study basin. Details of the instrumentation are given by Rechar and Smith (1972).

Site 0103, Knight Science Camp, is at an elevation of 9,910 ft (3,020 m). This site provides continuously recorded data on precipitation, temperature, relative humidity, streamflow (Sally Creek), and wind run from a totalizing anemometer. Site 0103 is used as a temperature and precipitation site in the model.

The site on Libby Flats, 0104, was removed in 1971. At an elevation of 10,900 ft (3,320 m) and in an exposed location, it was extremely difficult to keep instruments operating during the winter months. Some temperature records were available to aid in the estimation of missing records at other sites.

The outflow gage for the study area is at Site 0106, Nash Fork below Ski Area, at an elevation of 9,100 ft (2,770 m). The water stage recorder was installed at the end of the 1966 water year. A nearby weather station was established for the 1970 water year to provide temperature, relative humidity, and precipitation data on continuous recorders and wind data from a totalizing anemometer. This site is used as a temperature and precipitation site for the model.

The main instrument site for the basin is Site 0108 at Little Brooklyn Lake, elevation 10,400 ft (3,170 m). Instrumentation at this site was begun near the end of the 1966 water year. Of interest in this study are the data for solar radiation (both totalized and continuously recorded), wind (both totalized and continuously recorded with direction), and continuously recorded temperature, relative humidity, and precipitation. This site is the location of the base station for the solar radiation and daily wind run data as used in the model, and is also used as a temperature and precipitation site.

Site 0109, Telephone Lakes, was moved to its present location for the 1970 water year. It is at an elevation of 10,750 ft (3,280 m). Recorded temperature and relative humidity data are available for those times when the recorder was operating. The totalized wind run and temperature data could be used to aid in estimations at other sites.

Water stage is continuously recorded at Site 0111, Nash Fork above Brooklyn Lodge. This site is located just above the confluence of Telephone Creek with Nash Fork at an elevation of 10,120 ft (3,080 m).

Telephone Creek below Middle Pond, Site 0112, began as a site for continuous recording of water stage. A weather station was added at the end of the 1969 water year to provide continuously recorded temperature and relative humidity data plus totalized wind run. It is at an elevation of 10,330 ft (3,150 m), and is used as a temperature site in the model. Continuous records of

water stage are obtained at Site 0113, Telephone Creek above Towner Lake. The site is at an elevation of 10,520 ft (3,210 m).

Site 0114, Nash Fork at Brooklyn Lake, was installed in December, 1971, for a continuous water stage record of the outflow from Brooklyn Lake. The elevation at this site is 10,525 ft (3,210 m).

A recorder for wind speed and direction was operated briefly at Site 0116 near the Towner Lake Road at the west side of the Nash Fork basin. Wind data from this site were almost identical with Site 0108, and Site 0116 was discontinued. The brief record does provide some data for estimation of missing wind records at Site 0108.

The severe winter weather conditions in the basin caused instrument malfunctions at times due to freeze-up of pens and mechanisms, snow blowing into instrument shelters and into the instruments, icing, and snow accumulating on the cover-glasses of solar radiation sensors. At times the weather made visits to the upper sites impossible without undue risk of lives, and data were lost due to inability to replace charts, wind clock mechanisms, and replenish ink supplies on schedule. Water stage recorders were vulnerable to stilling-well freezing at those sites not having a "bubble-gage" installation, even though propane heaters were installed in the wells.

Data Preparation

Preparation of the necessary input data for operation of the model consists of obtaining the necessary physical and

meteorological data, determining reasonable estimates for those data that are missing, and ordering the data and coding them for keypunching. Streamflow data have been published for all gaging stations operated by the Wyoming WRRRI through the 1972 water year (Allen and Smith, 1972; 1973). They are used for comparison of the simulated flows from the model.

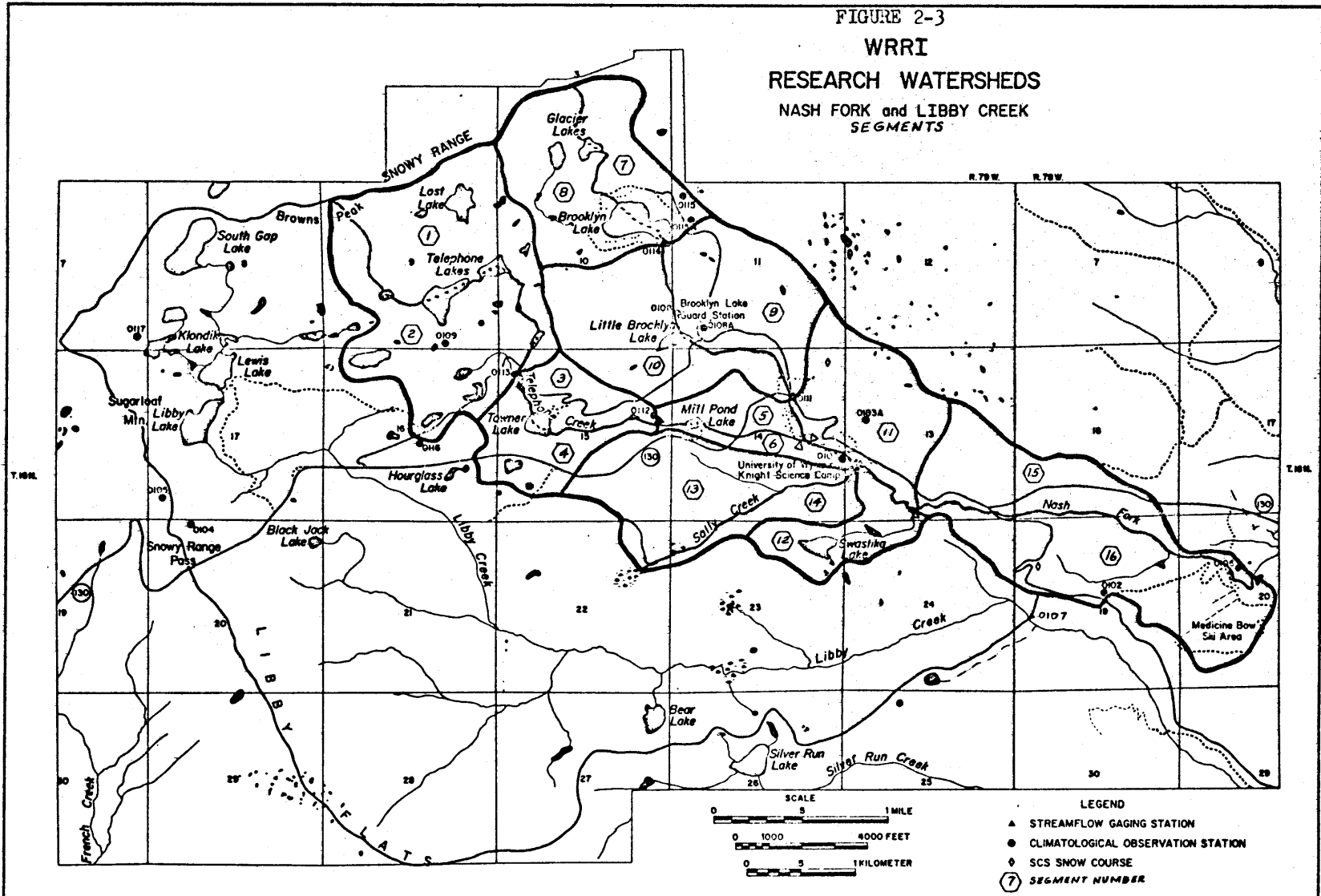
The latitude of the base station for observed solar radiation is determined either from solar observations or from a map. For this study, Site 0108 at Little Brooklyn Lake was selected as the base station and its latitude determined as 41.364°N .

The principal streams in the study area (Nash Fork and its tributaries, Telephone and Sally Creeks) were subdivided into eight reaches with actual or "potential" gaging stations (flow points) at the downstream ends of the reaches. The subwatersheds containing each of these reaches were further divided into two segments, such that each stream reach passed between two segments. This scheme divided the study area into 16 segments as shown in Figure 2-3.

Streamflow values for initializing the streamflow calculation are not overly critical. Their effect diminishes after a few days of calculation, and they may be entered as an average set of values. Inspection of the flows at the start of the water year to be run and at the end of the previous year will provide information for a first approximation of these values.

Recession constants for use in routing the generated runoff through the drainage system were determined approximately and

FIGURE 2-3
 WRRI
 RESEARCH WATERSHEDS
 NASH FORK and LIBBY CREEK
 SEGMENTS



- LEGEND
- ▲ STREAMFLOW GAGING STATION
 - CLIMATOLOGICAL OBSERVATION STATION
 - ◇ SCS SNOW COURSE
 - ⑦ SEGMENT NUMBER

subsequently adjusted in the model tuning process. For the first approximations graphs with the flow on a given day as ordinates and the flow on the previous day as abscissas were plotted for recessions at each flowpoint having a streamflow record, and the slopes of the "best fit" lines through the points were determined (Garstka et al., 1958). No attempt was made to remove storm events or base flows from the streamflow data, and no attempt was made to fit the lines statistically. Two recession constants were selected per station with the approximate discharge at which they changed, and similar data were estimated for the flow points at which no records existed.

The physical data necessary for the model consist of slopes, aspects, elevations, and latitudes for each segment, the forest-covered areas and unforested areas within each segment, and estimations of a forest canopy density and a radiation factor for each segment. An overlay of forest cover was prepared for a base map, and the areas of forest cover and unforested areas for each segment were measured by planimeter. Lake and pond areas were also planimetered for each segment, with the provision that a lake on a boundary between two segments was considered to have one-half of its area in each segment. Forest canopy densities were estimated from an aerial photo mosaic and from the author's personal knowledge of the basin. These estimated densities are intended to represent the fraction of the forest area covered by projection of foliage onto the ground surface.

To determine the mean slope, the aspect of the mean slope, and the mean elevation for each segment within the basin, a grid was drawn on a basin map and the data were read for each grid point in a segment and then averaged for the segment. The grid lines were spaced about 375 ft (114 m) on the ground.

For each grid point the slope direction was taken as normal to the nearest contour line in the direction of drainage, measured as an azimuth angle to the right (clockwise) from north. The slope was measured as the angle with a tangent equal to the contour interval divided by the horizontal distance between the contour lines in the slope direction. The elevation of the grid point was interpolated between contours to the nearest 10 ft (3 m). When a grid point fell on a lake surface, only the elevation was determined.

The mean segment slope was obtained by finding the mean of all the slope tangents within the segment, and then the angle corresponding to the mean tangent. The angle was considered as a positive angle from a horizontal surface.

The aspect, or azimuth of the mean slope, was determined in two steps. The submeans of the azimuths of 180° or less and the azimuths greater than 180° were first determined. One of two calculation procedures was then applied: (1) When the smaller angle between the submeans did not include the north line (0° or 360°), the segment mean azimuth was considered as the arithmetic mean of all the segment azimuth observations; or (2) When the north line was included in the smaller angle between the submeans, each of the azimuths observed as less than 180° was increased by 360° , and an

arithmetic mean taken of all observed azimuths greater than 180° and all increased azimuths. If the resulting mean was greater than 360° , it was reduced by 360° . This mean was then considered the aspect of the segment.

The mean elevation of each segment was taken as the arithmetic mean of all elevations at grid intersections within the segment.

Latitudes were estimated from the map to one-tenth of a minute. The segment latitude was considered to pass through the estimated center of the segment area. Since the values were within a 2.2' range, all segments are essentially at the same latitude for the Nash Fork basin. A basin having a greater spread in segment latitudes would justify greater effort in latitude determinations.

The mean slopes, aspects, elevations, and latitudes of several of the original 28 segments were combined to describe the final scheme of 16 segments. The physical data are shown in Table 2-I.

The coefficients for the calculation of snowcovered areas in each segment are obtained outside of the model from a stepwise multiple linear regression procedure (Nie, Bent, and Hull, 1970). The procedure is discussed in detail in Chapter 4.

Solar radiation values for the snowcover regressions were taken directly as measured at Site 0108, without adjustment for slope or aspect (Smith and Swartz, 1971; Smith, 1973). Missing daily values of solar radiation were estimated from averages of totalized radiation at the 0108 site, which covered seven days or more between readings. A daily average was determined for the period of totalized record and considered as the daily values for the period of missing record.

TABLE 2-I

PHYSICAL DATA FOR NASH FORK BASIN BY SEGMENTS

SEGMENT NUMBER	OPEN AREA (AC)	FOREST AREA (AC)	TOTAL AREA (AC)	LAKE AREA (AC)	LATITUDE (DEG)	SLOPE (DEG)	SLOPE AZIMUTH (DEG)	MEAN ELEVATION (FT)	FOREST DENSITY (EST)
1	366.	73.	439.	39.	41.368	18.07	178.0	10930.	.55
2	405.	35.	440.	40.	41.360	10.68	62.2	10770.	.55
3	54.	23.	77.	7.	41.357	6.38	166.5	10460.	.55
4	82.	46.	126.	7.	41.353	5.89	62.5	10470.	.60
5	91.	32.	123.	2.	41.357	6.90	141.8	10220.	.60
6	13.	27.	40.	2.	41.353	5.99	75.7	10190.	.75
7	122.	90.	212.	19.	41.377	12.63	192.3	10780.	.55
8	199.	124.	327.	24.	41.373	14.33	129.9	10810.	.55
9	120.	230.	350.	3.	41.367	6.19	186.8	10420.	.75
10	224.	221.	445.	8.	41.362	7.59	80.4	10460.	.70
11	185.	153.	344.	1.	41.357	7.34	131.0	10120.	.80
12	18.	182.	200.	15.	41.347	10.57	42.1	10040.	.70
13	113.	237.	350.	0.	41.352	6.08	111.3	10260.	.65
14	30.	124.	154.	0.	41.348	7.44	38.6	10200.	.75
15	110.	291.	401.	1.	41.350	12.41	172.8	9750.	.75
16	76.	365.	441.	1.	41.344	11.41	48.3	9460.	.90

Wind data for snowcover distribution were based upon the continuous recorder at Station 0108 (Smith, 1972; 1973). Missing values were estimated directly either from the recorder set up for a short period at Station 0116 or from the averages from the totalizing anemometer at Station 0109. All three instrument sites have similar exposures, and data seem to be quite consistent among them. When 0109 and 0116 values were also missing, the 0108 values were estimated as the mean of the day preceding and the day following the missing data at 0108. Also, where only one or two days' data were missing from Site 0108, this approach was preferred over application of the mean (from a one- to four-week period) from Site 0109. The weekly, or longer, averages from the several totalizing anemometers in the basin gave poorer correlations with snow distribution than those obtained from the daily recorder at Site 0108; hence the decision to use daily wind runs from Site 0108 for all segments.

Temperature data requirements for the model operation are varied but may all be derived from the daily maximum and minimum temperatures. Ideally, each segment should have a source of temperature data obtained in, and representative of, the segment. Practical limitations of instrumentation and data collection reduced this ideal situation to consideration of seven data sources. Two of these, Sites 0101 and 0104, were out of the basin but suitable as backup stations when needed for estimation of missing records. A third, Site 0109, was in the basin but had excessive missing data. The four remaining sites in the basin, 0103, 0106,

0108, 0112, were operated throughout the 1970-72 water years for which the model was tested, and were accepted as temperature sites. The observed temperature data have been published by the University of Wyoming Water Resources Research Institute in the Water Resources Series (WRRRI 23, 1971; WRRRI 27, 1972; WRRRI 34, 1973).

The usual lapse-rate calculations for adjusting temperatures from one site to another were not satisfactory in this situation, probably due to vegetation and terrain effects overriding the comparatively small differences in elevations between sites. Scatter diagrams were plotted for available years of record for each site pair with sufficient overlapping records, and a line was estimated through the points parallel to a 1:1 line for each. The displacement of this line from the 1:1 line gave a lapse rate peculiar to each pair of sites. No attempt was made to fit a regression line to the data. Better estimates could be obtained from seasonal lapse rates derived in the same manner, or by a lapse rate continuously varied with time (Borovikova). This sophistication did not seem to be warranted for the present model.

Precipitation data should also be available from a representative site in each segment. In actuality, three sites were available with daily observed precipitation records for the study period. Precipitation data were continuously recorded at Site 0108 for the 1970, 1971, and 1972 water years. Recorders were in operation at Sites 0103 and 0106 for nearly all of the 1971 and 1972 water years (WRRRI 23, 1971; WRRRI 27, 1972; WRRRI 34, 1973).

In order to work with values obtained in the study area, rough estimations of missing precipitation values were made using an adaptation of the normal ratio method (Linsley, Kohler, and Paulhus, 1958, p. 33). The method is essentially a weighted average of the storm precipitation at three stations in the vicinity of the missing-record station, given as

$$P_x = \frac{1}{3} \left(\frac{N_x}{N_A} P_A + \frac{N_x}{N_B} P_B + \frac{N_x}{N_C} P_C \right) \quad (2-1)$$

where the subscript x refers to the missing-record station and subscripts A, B, and C refer to the index stations. Precipitation for the given storm at the appropriate station is denoted by P, and N refers to the normal annual precipitation at the subscript site.

Since only three usable stations were available, the equation was modified to approximate the precipitation at one station in terms of the other two, or

$$P_x = \frac{1}{2} \left(\frac{N_x}{N_A} P_A + \frac{N_x}{N_B} P_B \right). \quad (2-2)$$

When only one station with precipitation records was available, the other two were approximated from the normal annual precipitation ratios. For those periods when the recorder drive malfunctioned and gave only the total precipitation without a time indication, the total was proportioned over the time period in accord with the record at the other stations.

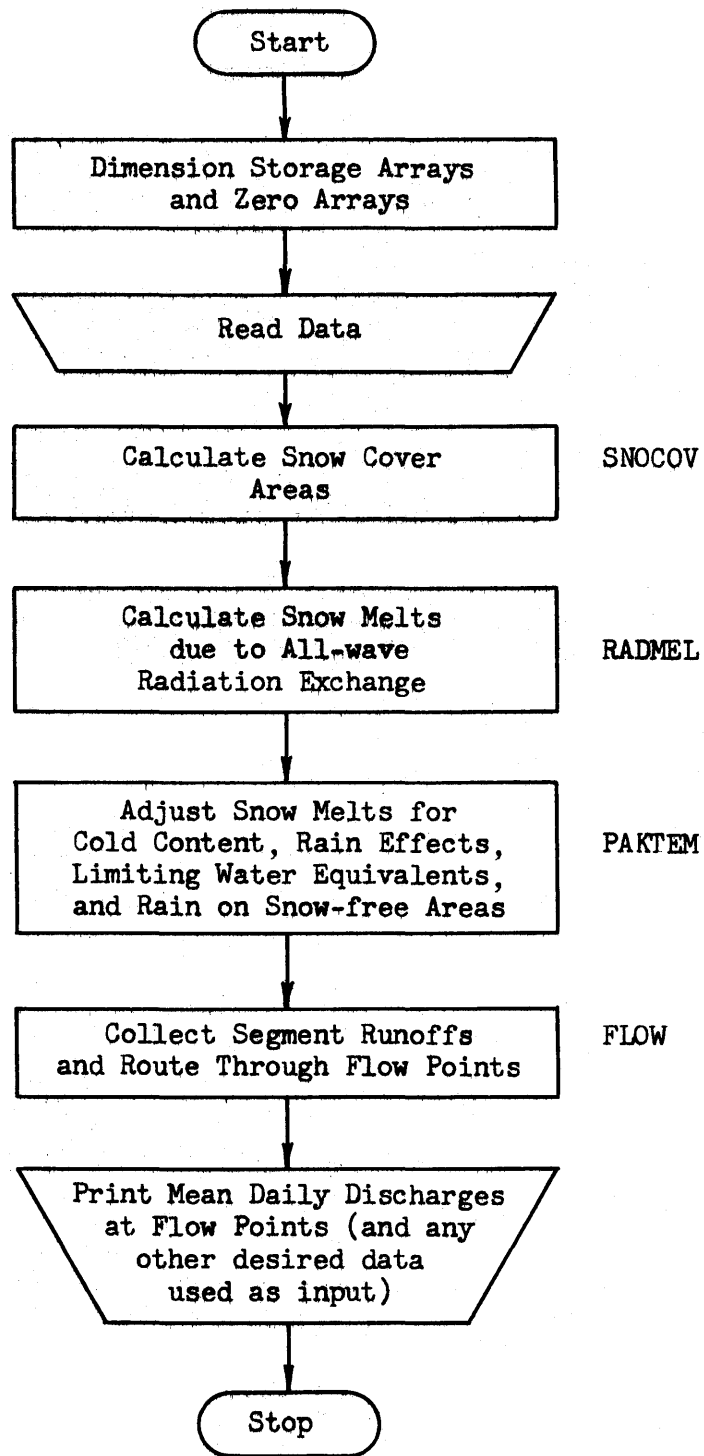


FIGURE 3-1

SNOWMELT RUNOFF MODEL FLOWCHART

CHAPTER 3

THE MODEL--AN OVERVIEW

The model program essentially processes the input data sequentially through a series of operations to transform them into the output of streamflows at several flow points. The flowchart, Figure 3-1, illustrates the model arrangement. The output of one operation becomes part of the input to the next operation. Decision criteria allow the bypassing of all or part of a particular section (except FLOW) under certain circumstances. The only subroutine operations are in connection with output, where they are used to rearrange data for printing in tables.

The model has been calibrated to the Nash Fork basin. Recession and routing constants, determined from 1970-72 data, were adjusted so as to bring the 1972 simulated hydrographs toward agreement with those observed for 1972. The flow points, as used in this model, may be considered as either actual or potential gaging station sites on the streams within the watershed to be modeled. In effect, they separate the streams into reaches through which the generated runoff may be routed.

The basic watershed subunit used in the model is a segment, or that portion of a drainage basin on one side of a stream reach and draining into the stream reach. The segment will normally contain an unforested area and a forested area, and the unforested area may include a water surface area if lakes or ponds are present.

A stream reach has a minimum of two segments (left and right sides) contributing to it, but could have more in multiples of two. There are 16 segments in the present model.

The model computation consists of: (1) calculating the snow-covered areas in the unforested and forested portions of each segment for each day (SNOCOV); (2) adjusting the solar radiation measured at the base site to the particular latitude, slope, and aspect of each segment, and calculating the resulting potential snowmelt from all-wave radiation exchange for the unforested and forested areas of each segment for each day (RADMEL); (3) modifying the potential snowmelt quantities for the effects of "cold content," excess precipitation as rain or snow, water equivalent limitations, or rain falling upon areas devoid of snowcover, as determined by the conditions existing on the calculation day (PAKTEM); and (4) routing of each day's snowmelt runoff (now including any rainfall runoff) through each flow point in the system (FLOW).

SNOCOV

SNOCOV is a multiple regression model used to describe the daily snowcover extent within a particular area from data representative of conditions in the area.

The snowcover for the unforested or forested portion of a given basin segment is calculated by an equation of the form

$$\begin{aligned} \text{SNOWCOVER} = & [(A + BX_1 + CX_2 + DX_3 + EX_4 + FX_5 \\ & + GX_6 + HX_7)/100](\text{AREA}) \end{aligned} \quad (3-1)$$

where X_1, X_2, \dots, X_7 are variables measured or determined daily

for the particular segment, and AREA is the unforested or forested area within the segment. The coefficients A through H are determined for the unforested and forested conditions of each segment by stepwise linear multiple regression, using the observed snowcover as the dependent variable and functions of certain meteorological variables for the seven "independent" variables. Snowcover was determined from oblique aerial photography taken periodically over the basin and transferred to maps for measurement of the areas.

In brief, the SNOCOV program section first assigns the appropriate temperature and precipitation stations to each segment, computes a mean temperature for the day, and calculates the degree-days above 32°F (0°C) for the day. If precipitation occurred on that day, a temperature criterion decides if it was in the form of rain or snow. If snow occurred, variables are reset and snowcover is calculated for each cover condition within each segment, using the applied form of Equation 3-1. If rain occurred it is a "no snow" condition; the variables are increased according to their respective values for the day, and the snowcover calculated as before. The calculated values of snowcover for each day are stored as inputs to subsequent program sections.

RADMEL

The RADMEL section is the heart of the model. The other sections are accessories to it, either supplying input or modifying its output. This section calculates the potential snowmelt from radiation exchange that could be derived from the forested and unforested areas of each segment in the watershed.

Insolation measured at a base station is adjusted to the latitude and the particular slope and aspect of each segment. These values of shortwave radiation are then adjusted to account for the albedo of any snowcover in the open area of each segment. The longwave radiation exchange in the unforested area of each segment is then calculated and combined with the effective shortwave radiation of the segment's open area. The sum is the net effective radiation exchange available to cause snowmelt in the unforested area of the segment for that day. The net longwave radiation exchanges in the forested areas of each segment are then calculated. These are considered the radiation energies available for causing snowmelt in the forested area of each segment for the day.

Potential snowmelts for the unforested and forested areas of each segment are finally calculated for the day, using the respective net radiation exchanges as energy sources. When no snowcover is indicated on a given day, the appropriate portions of the program are bypassed and a zero potential snowmelt value is stored. The snowmelts derived from this RADMEL section are those melts that could be expected from a ripe snowpack having a water equivalent in excess of the melt amount.

PAKTEM

The PAKTEM program section basically adjusts the potential snowmelt amounts from the previous section to reflect the actual conditions in the particular area under calculation. A submodel is contained within the PAKTEM section to estimate snowpack

densities in the open and forested portions of each segment as a function of snowpack age and elevation. For convenience, this submodel is referred to as DEN. The snowpack densities are required in the calculation of deep snowpack temperatures.

PAKTEM computes the snowpack temperatures, water equivalents, and cold contents, and adjusts the snowmelt amounts accordingly. It considers rainfall runoff and includes it with the adjusted snowmelt to get the total runoff from an area. Snowpack temperatures are considered for three water equivalent classes, less than 2 in (5 cm), 2 in to 4.5 in (5 cm to 11.4 cm), and greater than 4.5 in (11.4 cm). The first two classes use averaging schemes to estimate the temperatures at the center of the snowpack; the third class uses heat diffusion theory and requires the DEN results as well as temperatures for input.

Water equivalents are accumulated from day to day, starting from an initial value. The value at the start of a day is increased by precipitation occurring on that day as snow and a cold content is calculated from the water equivalent and the snowpack temperature. If precipitation occurred as rain, the cold content is reduced by the amount of the precipitation and a new pack temperature is calculated. If rain fell on bare ground, or if the amount of rain exceeded the cold content of the snowpack, the excess is considered runoff.

When the day's potential snowmelt is less than the cold content, it is used to reduce the cold content, and a new pack temperature is calculated. Once the cold content is satisfied,

the excess snowmelt is allowed to be runoff, up to the limit of the water equivalent of the snowpack. If the snowmelt does not deplete the snowpack water equivalent, the water equivalent is reduced by the amount of snowmelt in excess of that required to satisfy the cold content.

Any snowmelt appearing as runoff is multiplied by the snow-covered area for that day within the segment portion under consideration. This gives the day's runoff volume to be added to the day's runoff from any rain falling on snow-free ground. This sum retains the "snowmelt" identification so that the original snowmelt storage array can be utilized for storing the revised values. These are now input for the FLOW section of the model.

FLOW

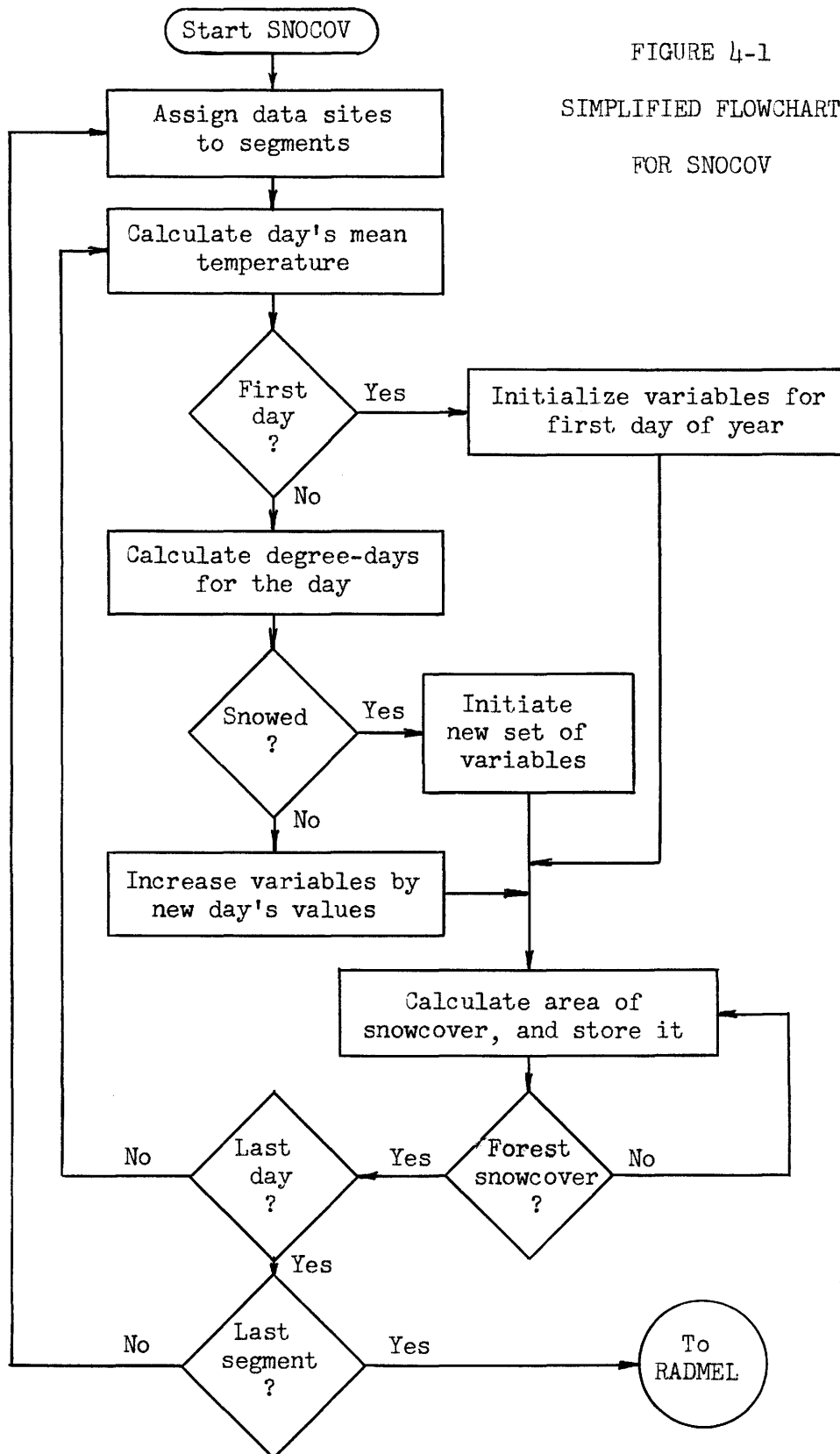
The FLOW section is the last calculation portion of the model program. The daily runoff volumes are combined to provide daily segment runoff volumes. The daily runoff volumes from each pair of segments on a stream reach are then combined, to become the flow entering that particular stream reach from its segments. These flows are then routed through the successive flow points to provide the calculated mean daily discharges at the flow points.

The routing operation is essentially the Muskingum method. Two storage constants for each reach are calculated from the recession constants provided in the input data. These are selected by the program at each flow point as required by the discharge magnitude, and the routing proceeds through the stream system for each day's runoff.

Program Documentation

The program detail documentation is essentially included in the Appendix, which contains a dictionary of all variable names used in the model program, model user instructions, input data coding and deck arrangement, an output discussion, and a listing of the program as run for the 1972 water year. The program documentation covers the pertinent topics recommended by the Office of Water Resources Research, although not necessarily in the order listed in their procedures memorandum (Office of Water Resources Research, 1973).

FIGURE 4-1
SIMPLIFIED FLOWCHART
FOR SNOCOV



CHAPTER 4

SNOCOV

Introduction

SNOCOV is used to estimate the area of snowcover on the unforested and forested portions of each segment. This is accomplished through a model equation relating snowcover to certain meteorological variables and time. The equation was derived through stepwise linear multiple regression, and the resulting coefficients of the variables were selected to maximize the coefficients of multiple correlation and minimize the standard errors of estimation. The calculation scheme is shown as a simplified flowchart in Figure 4-1.

Snow distributions in the study area are such that some portions of windswept subbasins are kept free of snowcover most of the year, while those portions that experience snow accumulation in drifts may retain snow all, or nearly all, year. Moreover, the areas that are generally snow-free during the winter are consistent from year to year and exhibit distinct shape patterns with time.

A study in Central Colorado by Leaf (1967) showed that the rates of snow depletion were highly correlated with seasonal runoff volumes and that "... annual patterns of snow depletion were also consistent, as was the snow-cover depletion on one watershed relative to another." Data were obtained from vertical aerial photos. He also found that each watershed studied had a

characteristic functional relationship between the extent of snowcover and the accumulated runoff during the melt season (Leaf, 1969). Further studies showed that this characteristic relationship was consistent, even though the amount of the snowpack and the weather conditions varied considerably each year (Leaf and Haeffner, 1971). A model of subalpine snowmelt runoff should apparently include some means of describing snow distribution patterns and their effect upon runoff.

Procedure

Oblique aerial snowcover photography for the period September 3, 1969, through March 12, 1973, was plotted on maps, one map for each flight. Percentages of the unforested and forested areas with snowcover were computed for each segment for each flight date. Intervals between flights varied from a few days to a month, depending upon season.

To begin the regression procedure, rough scatter diagrams, with percent snowcover as the dependent variable and segment variables that were felt suitable as independent variables, or their functions, were plotted for the unforested and forested portions of selected segments. From these scatter diagrams, the four independent variables and their three functions finally selected for regression were: (1) number of days, (2) accumulated wind run, (3) accumulated wind run to the 0.7 power, (4) accumulated measured insolation, (5) the square root of the accumulated insolation, (6) the accumulated degree-days above 32°F, and (7) the square root of the accumulated degree-days, all since snowfall.

Other variables were tested by scatter diagrams and regressions, and the above were selected as giving best fits to the observed data.

The actual regressions were performed by digital computer using the stepwise regression program of Statistical Package for the Social Sciences or SPSS (Nie, Bent, and Hull, 1970). The following criteria for selection of a particular regression equation were set up: (1) temperature and precipitation data must be from the same temperature or precipitation base station for the unforested and forested portions of a given segment; (2) the temperature base station must be in, or proximate to, the given segment; (3) the standard error of estimate should be less than 10 percent; and (4) the coefficient of multiple correlation, or multiple R, should be greater than 0.95 when possible. A fifth criterion, that the hypothesis that a relationship exists cannot be rejected by the analysis of variance F-test at the 0.01 level, was of no concern as none of the relationships tested could be rejected even at the 0.001 level. The regressions for some of the segments failed to satisfy the first four criteria, and the conclusion was reached that these segments were too small. The smaller segments were combined, where possible, to give the final 16-segment scheme. The result has one pair of segments (left and right) for each stream reach.

The regressions were tested for combinations of segment and data source sites that appeared to be compatible, and those combinations best satisfying the criteria given above were selected. It was felt that those segment and data site groupings determined

by the regressions, together with solar radiation and exposed site wind run from Site 0108, were "best combinations" to use in all sections of the snowmelt model.

Regression Results

The regression analysis on the 16-segment scheme gave very good statistical results for all but three of the 32 regressions. These three came near enough to criteria (3) and (4) to be usable, considering that the areas involved (all unforested) are still comparatively small and are affected by mechanical snow removal on highway and parking areas. The areas where snow is plowed are a significant part of the total unforested areas in these segments.

There does not appear to be any pattern regarding the number of regression steps required or in the independent variables used or not used in the several regressions. Therefore, it was felt advisable to use all seven variables and variable functions in the basic snowcover equation, entering zero as a coefficient when the variable or function was not used in a particular snowcover calculation.

The final form of the regression equation as used in the program is

$$\begin{aligned} \text{PCTSNO} = & (A(K,L) + B(K,L) * \text{DAY} + C(K,L) * \text{WIND} \\ & + D(K,L) * \text{WIND} ** 0.7 + E(K,L) * \text{ARAD} \\ & + F(K,L) * \text{SQRT}(\text{ARAD}) + G(K,L) * \text{ADD} \\ & + H(K,L) * \text{SQRT}(\text{ADD}))/100 \end{aligned} \quad (4-1)$$

where PCTSNO is the dependent variable expressing the snowcover as a decimal fraction for the area being calculated. A, B, C, ..., H

are the regression coefficients. The (K,L) pairs subscript the coefficients to identify the particular segment (K) and cover condition (L) being calculated. For the unforested condition, L = 1, and L = 2 for the forested condition. The variable names are defined in the Dictionary of Program Variables in the Appendix, and refer to elapsed time, wind run, accumulated solar radiation at the base site, and accumulated degree-days. PCTSNO is limited to values from zero to one, and is then multiplied by the appropriate area in acres to give the calculated snowcovered area for the day.

A summary of the SNOCOV stepwise multiple linear regression results is presented in Table 4-I. The statistics, except the critical F, were taken from the computer printout obtained by use of the SPSS stepwise regression program (Nie, Bent, and Hull, 1970). The critical F values were obtained from tables of the F-distribution as found in statistics texts. The equation coefficients are shown in Table 4-II. Figure 4-2 shows the calculated snowcover for the unforested portion of segment 8 for the three water years considered, along with the measured snowcovered areas for the flight dates.

The only snowcover observations that were not used in the snowcover regressions were those for successive zero values. Use of zero values beyond the first one would affect the regression equation and interfere with the equation's description of the snowcover. Test runs with and without these successive zero values supported this reasoning. A total of 37 flights for the 1970-72

TABLE 4-I
SUMMARY OF SNOWCOVER REGRESSIONS

Segment Number	Cover Condition ¹	Number of Regression Steps	Multiple R	Standard Error (percent)	F-Test (0.001 level)		
					Calculated F	Deg. of Freedom (num./denom.)	Critical F
1	1	6	0.992	4.31	276	6/27	5.31
	2	7	0.986	5.31	121	7/24	5.23
2	1	6	0.992	4.44	293	6/27	5.31
	2	4	0.983	6.07	202	4/28	6.25
3	1	3	0.967	8.11	128	3/27	7.27
	2	6	0.988	3.60	153	6/23	5.65
4	1	4	0.977	7.92	144	4/28	6.25
	2	5	0.994	3.53	440	5/26	5.80
5	1	5	0.968	8.04	71.1	5/24	5.98
	2	5	0.956	9.65	51.1	5/24	5.98
6	1	4	0.946	11.33	51.0	4/24	6.59
	2	6	0.966	7.12	51.6	6/22	5.76
7	1	6	0.990	5.29	228	6/27	5.31
	2	6	0.982	6.91	115	6/26	5.38
8	1	5	0.991	4.26	310	5/28	5.66
	2	5	0.977	7.04	111	5/26	5.80
9	1	6	0.981	6.88	101	6/24	5.55
	2	5	0.964	7.20	59.9	5/23	6.08
10	1	7	0.988	5.54	140	7/24	5.23
	2	7	0.991	4.12	181	7/23	5.33
11	1	3	0.960	9.91	101	3/26	7.38
	2	7	0.963	7.74	36.5	7/20	5.69
12	1	6	0.939	11.70	24.6	6/20	6.02
	2	5	0.963	9.62	61.7	5/24	5.98
13	1	5	0.986	5.86	175	5/25	5.88
	2	5	0.982	6.67	132	5/25	5.88
14	1	6	0.985	5.68	128	6/23	5.65
	2	4	0.968	9.19	95.6	4/26	6.41
15	1	4	0.974	7.17	109	4/24	6.59
	2	6	0.980	7.87	87.0	6/22	5.76
16	1	3	0.941	12.80	58.9	3/23	7.67
	2	5	0.972	7.84	71.4	5/21	6.32

¹1 = unforested, 2 = forested

TABLE 4-II

REGRESSION COEFFICIENTS FOR SNOW COVER CALCULATION
BY SEGMENT AND UNFORESTED OR FORESTED CONDITIONS

(COVER 1 = UNFORESTED, COVER 2 = FORESTED)

SEGMENT NUMBER	COVER CONDITION	COEFFICIENTS							
		A	B	C	D	E	F	G	H
1	1	96.49580	.51679	.00775	-.12763	-.00825	.31044	.07881	.00000
1	2	92.40771	1.19224	.01187	-.15952	-.01423	.53374	.07596	2.09220
2	1	99.21617	.00000	.00651	-.09098	-.00652	.21908	.09749	-1.18115
2	2	96.94980	1.63589	.00000	.00000	-.00959	.12556	.07877	.00000
3	1	100.56129	.00000	.00000	-.02389	.00000	-.34250	.00000	-.92713
3	2	92.44153	2.30232	.00001	-.04272	-.01409	.53803	.14484	.00000
4	1	100.57376	.00000	.00000	.00000	-.00286	-.01616	.09119	-2.99053
4	2	96.52200	1.99969	.00000	-.03385	-.01149	.39002	.08940	.00000
5	1	103.00629	3.64220	.00000	-.05566	.00000	-.65504	-.14918	-1.21219
5	2	97.01611	4.34543	-.00873	.00000	-.00947	.33438	.00000	-1.44525
6	1	106.05627	.00000	.00130	.00000	.00000	-.47136	.06233	-3.08811
6	2	87.09468	1.73253	-.04039	.43739	-.00303	.00000	.17716	-1.97675
7	1	95.62624	1.62603	.00000	-.03141	-.00766	.15061	.08419	-1.65669
7	2	89.72357	2.51558	-.00202	.00000	-.01153	.39489	.05945	-.02225
8	1	95.37137	1.94914	.00000	-.03217	-.01020	.35170	.07152	.00000
8	2	89.61599	2.67427	.00000	.00000	-.01689	.57771	.09924	1.96330
9	1	97.91016	2.59696	.00000	-.07027	-.00956	.31729	.10870	-2.84154
9	2	85.80324	5.35476	-.00619	.00000	-.02544	.95369	.20199	.00000
10	1	97.22443	1.14435	.00706	-.10633	-.00998	.29406	.11492	-1.35726
10	2	92.83530	3.07070	.00908	-.14062	-.01976	.76789	.12630	1.25637
11	1	101.12285	.00000	.00000	.00000	.00000	-.22525	.07214	-4.38859
11	2	99.25081	5.51219	.03538	-.47719	-.02500	1.11866	.05723	1.75172
12	1	116.68642	-3.71241	.04540	-.49683	.01069	.00000	-.31664	-2.62358
12	2	95.49484	2.60494	-.02383	.24379	.00000	-.28471	-.11393	.00000
13	1	94.86469	3.70001	-.00835	.07243	-.00699	.00000	.00000	-2.38748
13	2	93.86748	4.54981	-.00560	.00000	-.01336	.38854	.00000	.27322
14	1	102.81670	.59962	.00892	-.13519	-.00512	.24811	.00000	-1.51335
14	2	95.36990	5.33002	-.00739	.00000	-.01402	.36158	.00000	.00000
15	1	97.74364	.00000	.00000	.00000	.00984	-.79550	-.19185	-1.81641
15	2	113.28818	-2.78512	.00000	.05733	.02320	-1.26806	-.46450	.23063
16	1	103.53004	.00000	.00000	.05225	.00000	-.64106	.00000	-2.52931
16	2	112.41096	-4.34127	.00574	.00000	.02348	-.95063	-.45291	.00000

A = PCT OF SNOW COVER INTERCEPT, B = COEFF FOR DAYS SINCE SNOW, C = COEFF FOR WIND RUN, D = COEFF FOR 0.7POWER
OF WIND RUN, E = COEFF FOR ACCUM RADIATION, F = COEFF FOR SQ RT ACCUM RADIATION, G = COEFF FOR ACCUM DEGREE-
DAYS ABOVE 32F, H = COEFF FOR SQ RT ACCUM DEGREE-DAYS.

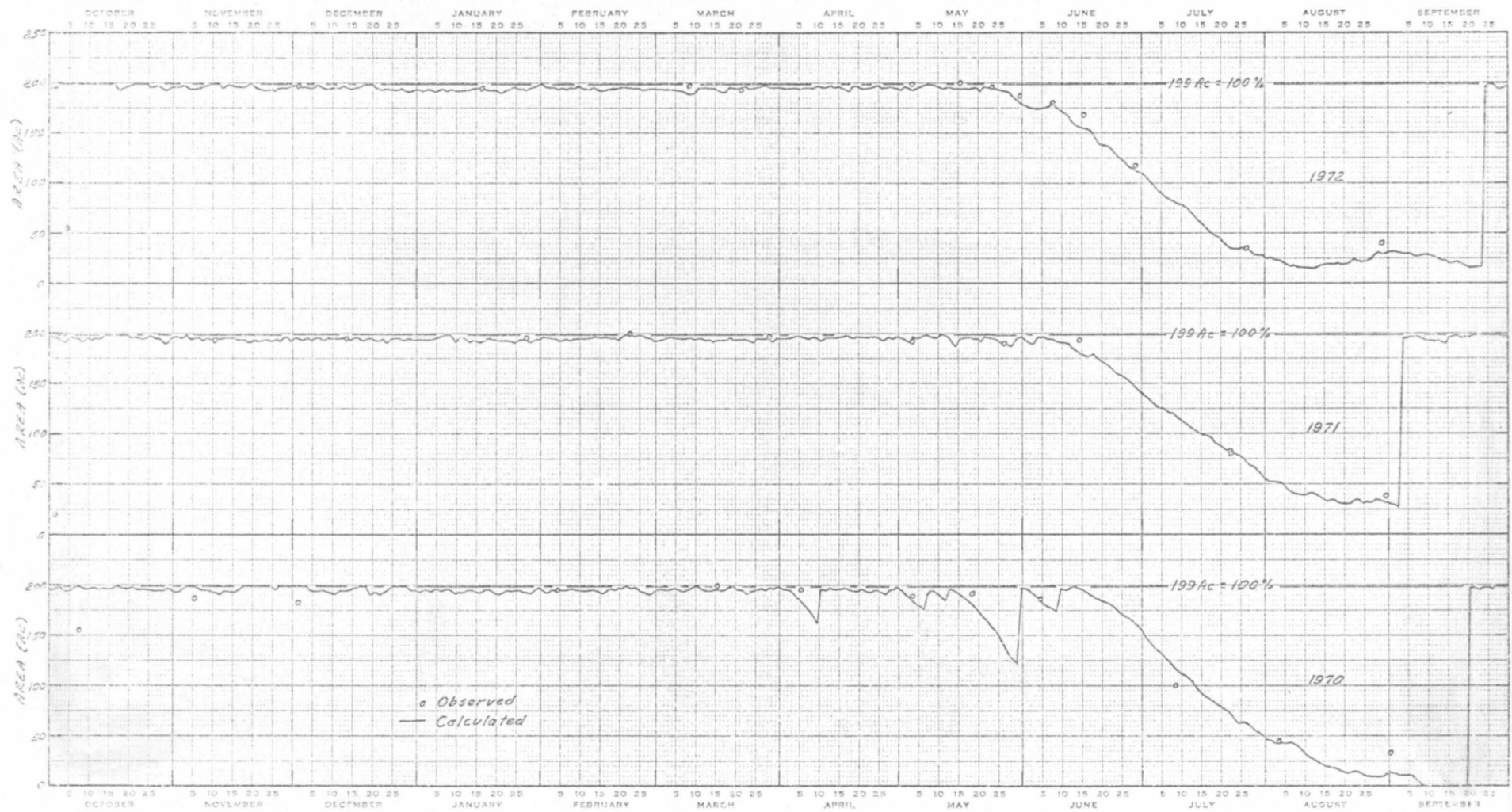


FIGURE 4-2

SNOWCOVER, SEGMENT 8, UNFORESTED

water years were available, of which some were not used for certain segments due to the above considerations.

Commentary

The regression equation for snowcover describes the observed data points quite well in most instances, except for the late September-early October period when the basin may experience light snows and the snowpack may start to build up. However, many times the new snow is depleted rapidly, and the SNOCOV model equation does not respond to this condition, since it is of empirical form and forced to describe the older, deeper snowpack situation.

One obvious approach to the problem would be another regression treatment for this period. Another approach would be to write an equation to describe the average shape of the snowcover curves with time. The best solution would seem to be one describing the snowcover in such a way that recalibration to another basin would require only physical data from the new basin.

The volumes of snowmelt occurring during the September-October period are normally small, as is the observed streamflow. The model, however, calculates excessive runoff for the period. The model does describe the peak flow months well, and the effort to refine the model for September and October was not felt justified at this stage.

CHAPTER 5

RADMEL

Introduction

Solar radiation has long been recognized as the ultimate energy source, or driving mechanism, for the various processes acting in the hydrologic cycle (Budyko, 1958). Federer (1968) observed that during melt periods the net solar radiation provided sufficient energy for snowmelt plus a small amount of evaporation. Dunne and Black (1971, p. 1160) found that "The melting of snow was extremely sensitive to solar radiation as modified by topography," and that daily surface runoff and daily radiation were related in a simple fashion. Cogley and McCann (1971) found that snowmelt runoff as stream discharge could be described in terms of incoming radiation as the generating process.

For snowmelt considerations, both shortwave and longwave radiation exchanges are necessary (Corps of Engineers, 1956). Smith (1966) suggests that direct solar radiation melts snow less rapidly than longwave radiation from tree trunks, and that this is longwave radiation from the tree itself rather than reradiation. The density of forest cover exerts an influence on all melt processes (Rantz, 1964). Night crusts, resulting from heat lost from the snow surface by longwave radiation, are less pronounced in forest areas than in open areas, as the radiation emitted from the snow surface is intercepted by the forest canopy and back-radiated to the snow (Anderson, 1963). The flux of radiation

entering or leaving the snowpack appears to be the major item to be considered when obtaining the energy available to produce snowmelt, particularly for the subalpine conditions of the Nash Fork basin.

The RADMEL, or radiation melt, section of the model was programmed to adjust insolation at a base station to incident radiation on the particular slope, aspect, and latitude of a subbasin (segment), to account for albedo effects, to include longwave radiation exchanges, and to calculate potential snowmelts from the open and forested areas of a segment. The calculated potential snowmelts may be positive, indicating potential runoff, zero, or negative, indicating an increase in heat deficit to be satisfied before runoff can occur. A simplified flowchart of the RADMEL program scheme is shown in Figures 5-1a and 5-1b.

Radiation Melt Derivations

Solar, or shortwave, radiation is directed toward the earth's surface as a positive flux and is reduced by surface albedo, or reflectivity, expressed as the ratio of the reflected to the incident shortwave radiation. The absorbed (or effective) shortwave radiation may then be estimated by

$$R_a = R_{in} (1 - \text{albedo}) \quad (5-1)$$

where R_a and R_{in} represent, respectively, the absorbed and the incoming shortwave radiation. Snow surface albedo generally ranges from about 0.80 for fresh snow to about 0.40 for wet snow or older, dirty snow (Corps of Engineers, 1956). Other albedo values

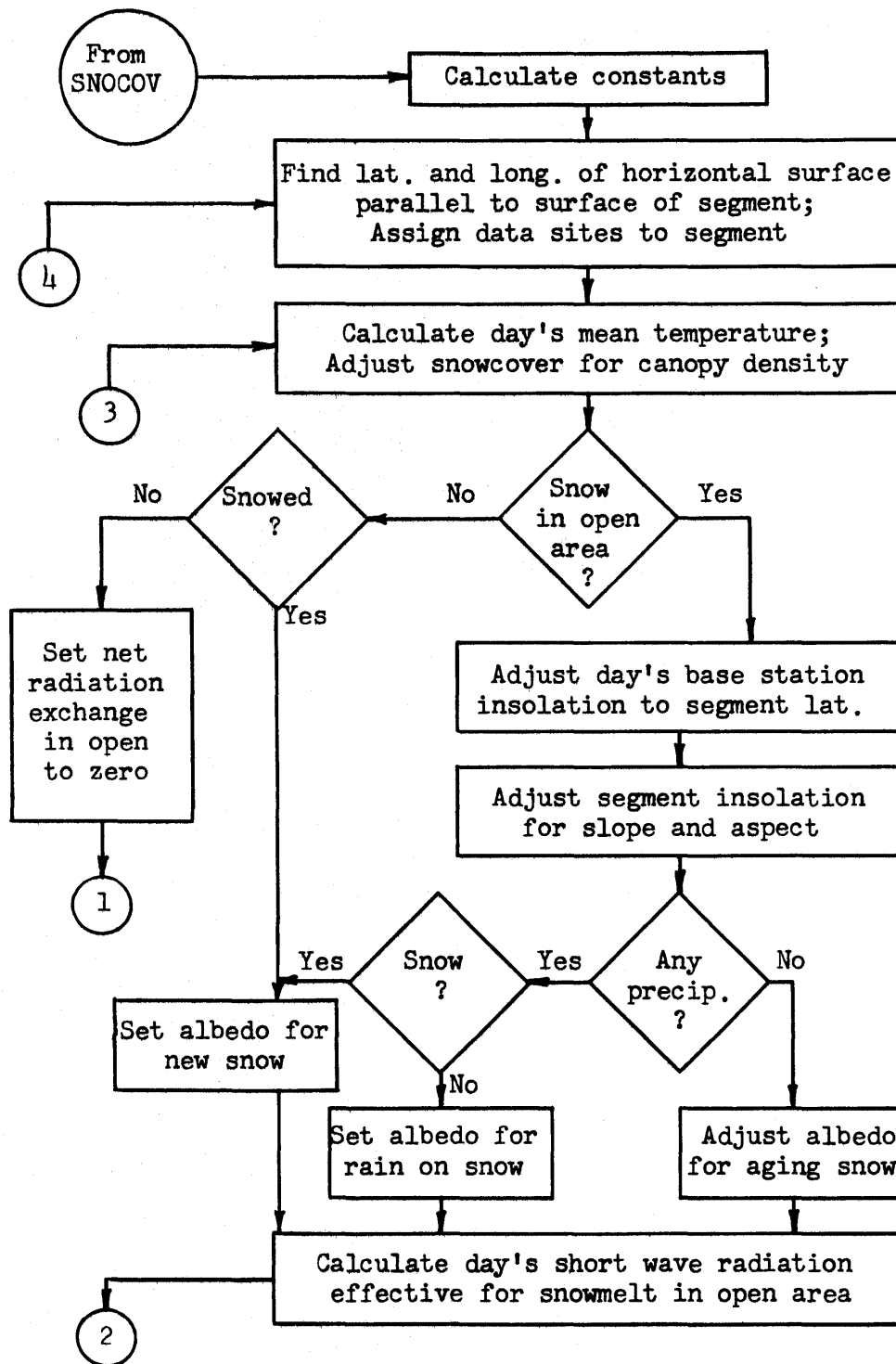


FIGURE 5-1a

SIMPLIFIED FLOWCHART FOR RADMEL
Short Wave Radiation Portion

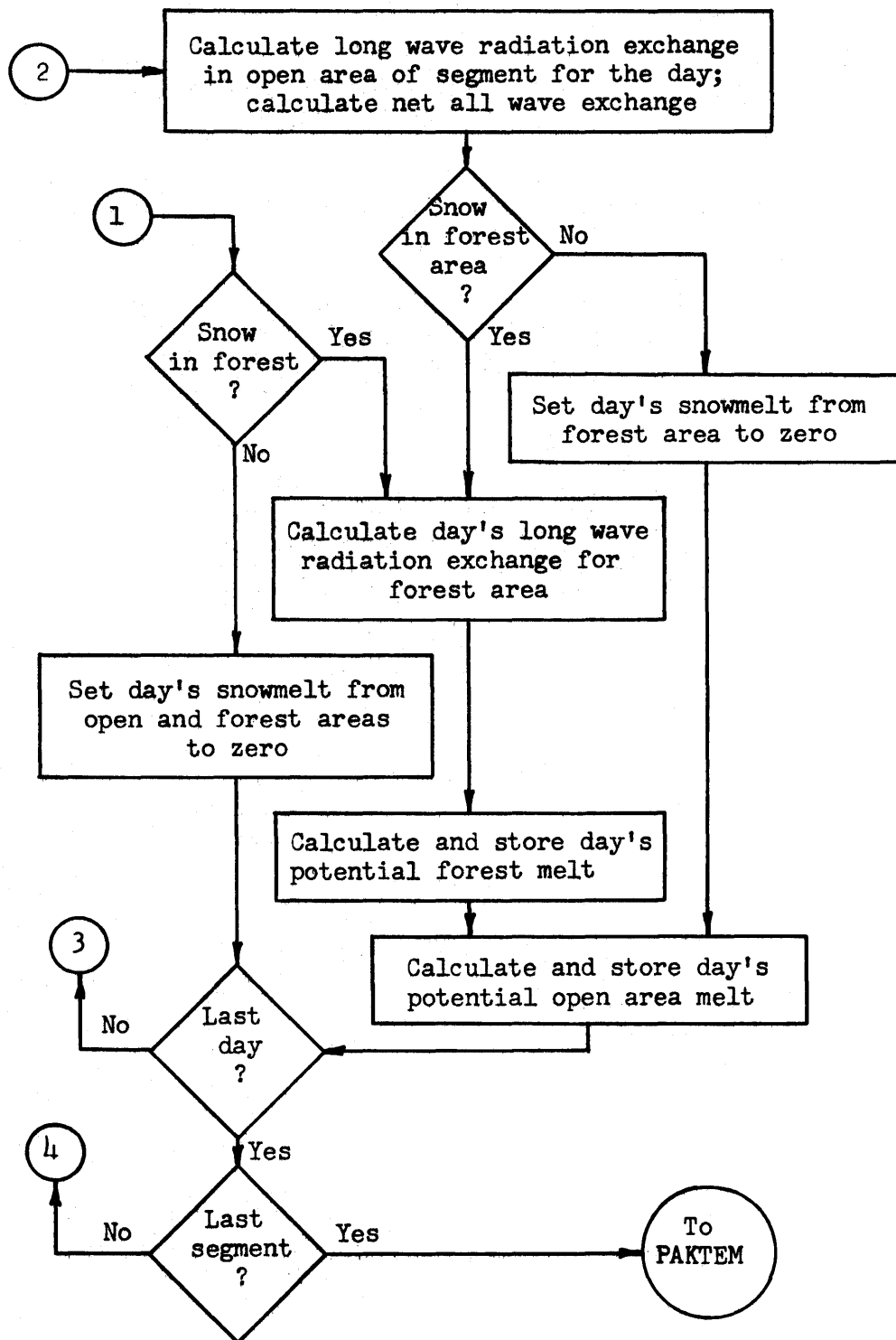


FIGURE 5-1b

SIMPLIFIED FLOWCHART FOR RADMEL
Long Wave Radiation and Potential Snowmelt

have been suggested. The Corps of Engineers (1956, Plate 5-2, Figure 4) indicates a nearly straight-line albedo decrease of about 1 percent per day over 20 days during the accumulation season, and a mean decrease of about 2 percent per day during the melt season. The melt season decrease is quite rapid, roughly 7 percent per day for the first three days, followed by a mean decrease of roughly 0.6 percent for 17 days. A mean decrease rate of 0.02 (2 percent) per day was selected for use in the model.

The value of R_{in} for the mean inclined surface of a particular subbasin (segment) varies from the radiation received on a horizontal surface as a function of the amount and direction of the surface inclination, latitude, and the solar declination. Continuous measurement of the incoming solar radiation upon a surface so inclined and oriented as to parallel the mean slope and slope direction of the area under consideration would eliminate the necessity of radiation corrections and adjustments. This situation is, however, rarely expected even in a research watershed. One approach to the problem of solar radiation received on inclined surfaces is to calculate the theoretical radiation upon a surface of the proper inclination located at the outer limits of the earth's atmosphere (Frank and Lee, 1966 ; Riley, Chadwick, and Bagley, 1966; Riley, Chadwick, and Eggleston, 1969). This potential solar radiation value would need to be reduced by atmospheric effects prior to application as a direct energy source for snowmelt.

"Only by actual measurement at the site can the true amount of daily insolation be accurately determined" (Corps of Engineers, 1956, p. 150). This idea is the basis of the approach taken in the present consideration, which presumes that daily insolation is measured within reasonable proximity to the subbasin under consideration.

The measured insolation (the solar radiation received on a horizontal surface) must be adjusted to the mean slope inclination and orientation of the subbasin to which it is to be applied and may require an adjustment for latitude difference as well. The adjustments are derived as a ratio of the potential inclined surface incoming radiation to the potential horizontal incoming radiation for the appropriate latitude and date. The potential radiation calculations essentially follow the procedure as described by Frank and Lee (1966), with some modifications to symbolism and extensions to provide a latitude adjustment and to develop the ratio concept.

The radiation received instantaneously upon a horizontal surface at the outer limit of the earth's atmosphere, I_s , is given by Milankovitch¹ as

$$I_s = \frac{I_o}{e^2} (\sin L \sin d + \cos L \cos d \cos \omega t) \quad (5-2)$$

where:

I_o = solar constant,

¹Milankovitch, M., Mathematische Klimalehre, Handbuch der Klim., Bank I, Teil A: 1-176, 1930 (Cited in Frank and Lee, 1966).

e = radius vector, ratio of the earth-sun distance at a particular time to its mean,
 L = terrestrial latitude,
 d = solar declination,
 w = angular velocity of the earth's rotation, 15 degrees per hour, or $\pi/12$ radians per hour, and
 t = time in hours from noon.

The times from solar noon to sunrise (t_1 , negative) and from solar noon to sunset (t_2 , positive) are equal for a horizontal surface at a given latitude. By setting $I_s = 0$, t may be found from Equation 5-2:

$$\cos wt = -\tan L \tan d \quad (5-3)$$

where $\cos wt$ must be between -1 and 1. For the maximum declination of $\pm 23.5^\circ$, the latitude would thus be restricted to the zone $66^\circ 30'$ south to $66^\circ 30'$ north, the Antarctic and Arctic Circles.

Equation 5-3 may be solved for t :

$$t = \frac{1}{w} \cos^{-1} (-\tan L \tan d) \quad (5-4)$$

It can be readily seen from Equation 5-4 that for a cosine of -1, at 23.5° maximum declination and a latitude of $66^\circ 30'$, the angle is 180° or π radians, and t is 12 hr. Thus for a latitude of $66^\circ 30'$ there is sunlight from midnight to midnight at maximum positive declinations (summer). At minimum declination, or -23.5° , the cosine is 1 and the angle is 0° or 0 (zero) radians, and t is zero so that there is no sunlight for the day at latitude $66^\circ 30'$ or greater. The total horizontal surface radiation for the period of one solar day, I_q , is obtained by integration of Equation 5-2 over

the interval t_1 to t_2 , actually $-t$ to $+t$:

$$I_q = \frac{I_0}{e} (2 t \sin L \sin d + 2 \frac{1}{w} \cos L \cos d \sin wt). \quad (5-5)$$

Slope inclination and slope orientation are accounted for by locating a horizontal surface that is parallel to the inclined surface. Following Okanoue,² the latitude of the equivalent surface, L' , is given by:

$$L' = \sin^{-1} (\sin k \cos h \cos L + \cos k \sin L) \quad (5-6)$$

where k = slope inclination and h = slope azimuth. A negative value of L' indicates that the equivalent latitude is on the opposite side of the equator from L . The change in longitude, a , between the inclined surface and its parallel horizontal surface is given by:

$$a = \tan^{-1} \frac{\sin h \sin k}{\cos k \cos L - \cos h \sin k \sin L} \quad (5-7)$$

where a is to the east for an easterly slope and to the west for a westerly slope.

Instantaneous radiation incident upon the inclined slope can be found by calculating the radiation incident upon the equivalent horizontal slope, I_{se} , by modification of Equation 5-2 to account for the "new" position:

$$I_{se} = \frac{I_0}{e} (\sin L' \sin d + \cos L' \cos d \cos wt') \quad (5-8)$$

where $wt' = wt + a$. Sunrise and sunset times for the inclined surface ($-t_1'$ from solar noon to sunrise, and t_2' from solar noon to sunset) are obtained from Equation 5-8 by setting $I_{se} = 0$ and

²Okanoue, M., "A Simple Method to Compute the Amount of Sunshine on a Slope," J. Jap. Forest, Nov. 1957, 435-437 (Cited in Frank and Lee, 1966).

solving for t' :

$$\cos wt' = -\tan L' \tan d \quad (5-9)$$

or

$$t' = \frac{1}{w} \cos^{-1} (-\tan L' \tan d) \quad (5-10)$$

noting that for a given latitude the maximum day-length is that for a horizontal surface, and the value of t from Equation 5-4 sets the maximum value that t' can assume.

The total potential radiation, I_{qe} , received on the inclined surface over the time period $(t_2' - t_1')$ is obtained by integrating Equation 5-8 over the interval t_1' to t_2' :

$$I_{qe} = \frac{I_0}{e^2} [(t_2' - t_1') \sin L' \sin d + \frac{1}{w} \cos L' \cos d (\sin wt_2' - \sin wt_1')]. \quad (5-11)$$

The solar declination, d , for each day is computed from

$$d = 0.4100 \sin N \quad (5-12)$$

where 0.4100 is the maximum declination angle (23.5°) expressed in radians, and N is the angle in radians the earth has swept out in its orbit since the spring equinox on March 21. For north latitudes this gives a positive declination for the half-year containing the summer solstice, and a negative declination for the half-year containing the winter solstice, with zero declination at the equinoxes.

The adjustment of measured radiation (R_m) from the latitude of the base site (L_b) to the latitude of the subbasin (L) to which it is to be applied could be accomplished by computing the theoretical insolation for both latitudes, I_{q_b} and I_{q_z} for the base site and the segment of application, respectively, and multiplying the

measured radiation by the ratio Iq_z/Iq_b , or

$$Rz = Rm (Iq_z/Iq_b) \quad (5-13)$$

where Rz represents the radiation that would presumably have been measured on a horizontal surface in the subbasin. Iq_z and Iq_b are calculated from Equation 5-5, using Equation 5-4 for time, and the appropriate latitudes. This adjustment procedure should probably be used if the difference in latitude between the base site and the subbasin is greater than one or two degrees.

An approximate adjustment may be made that is simpler to compute and sufficiently accurate for most purposes for the smaller latitude differences. The basic premise is that the intensity of radiation upon a surface is proportional to the cosine of the angle of incidence of the radiation to the surface (Frank and Lee, 1966). The angle of incidence varies throughout the day, but at solar noon on a given day it can be taken as the difference, latitude minus solar declination, where the declination as obtained from Equation 5-12 will be positive, zero, or negative depending upon the day of the year counted from March 21. The total daily insolation at a given latitude is also proportional to the time of irradiation (sunrise to sunset), or $2t$. Since in ratio form the factor 2 will occur in both numerator and denominator and divide out, it may be ignored at this point. The radiation at the base site may be approximated by

$$Rm = c t_b \cos (Lb - d) \quad (5-14)$$

and at the subbasin by

$$R_z = c' t_z \cos (L - d) \quad (5-15)$$

where t_b and t_z are the values of t from Equation 5-4 for their respective latitudes and c and c' are proportionality constants. Both c and c' can be considered as corrections for their respective latitudes for the assumption that the angle of incidence is $L - d$ for the entire day, and hence should be very nearly equal for small latitude differences. The adjustment for latitude may then be expressed as

$$R_z = R_m [t_z \cos (L - d)] / [t_b \cos (L_b - d)] \quad (5-16)$$

in which R_z approximates very closely the insolation that would be expected in the application subbasin as a function of that measured at a base site within one or two degrees latitude from the zone. In the event that base site and segment latitudes differ by no more than about one-half degree they can be considered as equal (or $L_b = L$), so that $R_z = R_m$.

The radiation, R_z , that has either been adjusted to or measured at the subbasin latitude, is the amount of solar radiation received on a horizontal surface. A further adjustment is necessary to arrive at the incoming solar radiation for the particular mean slope and mean slope aspect of the subbasin. This daily radiation quantity has been referred to as R_{in} in Equation 5-1, and is obtained by multiplying the day's value of R_z by the ratio of the theoretical slope irradiation to the theoretical horizontal irradiation for that day:

$$R_{in} = R_z (I_{qe}/I_q) \quad (5-17)$$

where R_z is the result of Equation 5-16, I_q is calculated from Equation 5-5, and I_{qe} is given by Equation 5-11. The value of I_0/e^2 found in Equations 5-5 and 5-11 need not be computed since it divides out of the ratio considerations. Equation 5-17 then becomes

$$R_{in} = \frac{R_z (t_2' - t_1') \sin L' \sin d}{2 (t \sin L \sin d + \frac{1}{w} \cos L \cos d \sin wt)} + \frac{\frac{R_z}{w} \cos L' \cos d (\sin wt_2' - \sin wt_1')}{2 (t \sin L \sin d + \frac{1}{w} \cos L \cos d \sin wt)}. \quad (5-18)$$

The azimuth angle, h , describing the down-slope orientation (aspect) of the segment inclination is measured clockwise from north. The total hours of irradiation are the same for corresponding easterly and westerly aspects, but sunrise and sunset will occur later for the westerly slopes than for corresponding easterly slopes.

The calculation of the ratio I_{qe}/I_q in Equation 5-17, or its equivalent form in Equation 5-18, can give a negative value for some northerly slopes during the winter months, indicating a flux of shortwave radiation away from the earth. Since the shortwave emissivity of the earth, especially at snow surface temperatures, is so small as to be considered essentially zero (Lowry, 1969, Ch. 3; Corps of Engineers, 1956, Plate 5-3, Figure 1), the value of R_{in} must be restricted to zero or positive values. A zero value, however, eliminates the possibility of diffuse and reflected short-wave radiation being considered as reaching the surface, while it is actually part of the measured radiation considered for those surfaces touched by direct solar radiation. The Corps of Engineers

presents data for a 25° north slope in the Alps in which theoretical solar radiation becomes zero from mid-November to early February, but "diffuse sky radiation" is shown for this period as a straight line at about 17 percent of the horizontal-surface radiation (Corps of Engineers, 1956, Plate 5-1, Figure 6). It seems reasonable that some allowance should be made for diffuse and reflected radiation. The magnitude of this allowance is open to question, and would certainly vary as a function of terrain features and clouds that could reflect solar radiation onto the surface. An arbitrary lower limit for slope radiation was selected as 5 percent of the measured horizontal radiation in the zone, or 0.05 R_z, such that R_{in} from Equation 5-18 has this constraint placed upon it:

$$R_{in} \geq 0.05 R_z. \quad (5-19)$$

Longwave radiation exchange analysis is based upon Stefan's law, which describes the total radiant energy in all wavelengths per unit time and unit area emitted by a black body as a function of the fourth power of the absolute temperature of the body. Treatment of longwave radiation herein essentially follows that given in Snow Hydrology (Corps of Engineers, 1956, pp. 146-163), with modifications to adapt to the requirements and data base of the model situation.

Stefan's law (also referred to as the Stefan-Boltzmann law, and sometimes as the Stephan-Boltzmann law) is expressed as

$$E = \sigma T^4 \quad (5-20)$$

where E is the total all-wave radiation emitted, σ is Stefan's constant, and T is the absolute temperature of the emitting body.

For heat units of calories, T would be expressed in degrees Kelvin ($^{\circ}\text{K}$) and the constant σ is given as 0.826×10^{-10} langley/min/ $^{\circ}\text{K}^4$ ($\text{ly}/\text{min}/^{\circ}\text{K}^4$) where one langley represents one calorie per square centimeter (cal/cm^2). The radiation E is then in units of ly/min , or $\text{cal}/\text{cm}^2/\text{min}$.

Longwave radiation exchanges between snowpack and sky, cloud cover, forest canopy, and exposed rock or other surfaces, are very complex, with each "body" exchanging radiation with all other "bodies" that it "sees." The complexity is further increased by selective absorption of certain wavelengths by various substances, such as carbon dioxide and water vapor, and re-emission of the energy at other wavelengths. The model computation of radiation exchange requires a simple treatment, which is aided by the close approximation of black-body radiation conditions by snow, sky, and forest canopy.

Observed temperatures near ground (or snow) level tend to respond to radiation effects, and thus become useful indices for longwave radiation computations. Calculation of radiation exchange between two "bodies," such as the snow surface and the atmosphere or the forest canopy, can be accomplished by finding the difference in emissions of the two "bodies," using Stefan's law with the appropriate temperatures:

$$\Delta E = \sigma T_1^4 - \sigma T_2^4 \quad (5-21)$$

where ΔE is the radiation exchange. Since the radiation transfer to the snow surface is considered positive, the temperature T_2 should apply to the snow surface, or $T_2 = T_S$. Equation 5-21 may

then be written as

$$\Delta E = \sigma T_1^4 - \sigma TS^4. \quad (5-22)$$

Temperature T_1 can be used to represent the atmospheric temperature, the forest canopy temperature, or the temperature of any other body of concern.

For lack of observed snow surface temperatures, TS is assumed to be represented by either 32°F (0°C , or 273°K) or by the mean daily air temperature, TM , whichever is lower. Temperature T_1 is assigned to mean air temperatures for each 12-hour period of the day, $TM1$ for the first 12 hours and $TM2$ for the second 12 hours. $TM1$ and $TM2$ are defined as the "lower average" air temperature and the "upper average" air temperature, respectively, for the day in question. Thus,

$$TM1 = (T_{\min} + T_{\text{mean}})/2 \quad (5-23a)$$

$$TM2 = (T_{\max} + T_{\text{mean}})/2 \quad (5-23b)$$

and Equation 5-22 can now be written as

$$\Delta E = \sigma(TM1^4 + TM2^4) - 2\sigma TS^4 \quad (5-24)$$

where σ is now $594.72 \times 10^{-10} \text{ ly/12hr/}^\circ\text{K}^4$, and all temperatures are in $^\circ\text{K}$. The temperature of the lower portion of the forest canopy will approach the observed temperature of the air.

Corps of Engineers measurements of back radiation (R_d) from the atmosphere in unforested areas with melting snowcover indicate a nearly constant ratio of $R_d/\sigma T_a^4$ (Corps of Engineers, 1956). The value of this constant ratio is given as 0.757, and is used in the Stanford Model IV as 0.76 (Crawford and Linsley, 1966). The

0.76 value will be used in the present discussion, so that, for clear weather,

$$R_d = 0.76 \sigma T_a^4 \quad (5-25)$$

or, upon substituting into Equation 5-24,

$$\Delta E = 0.76 \sigma (TM1^4 + TM2^4) - 2 \sigma TS^4 \quad (5-26)$$

for unforested areas.

The segment or subbasin is considered to have some fraction of its area forested, with some canopy density ≤ 1.00 , and some fraction of its area unforested, or open. The canopy density may be defined as the ratio of the actual forest canopy area to the area enclosed by the boundaries of the forested portion of the segment. If the area of the segment that is forested, FA, is multiplied by the canopy density, FD, the actual forest canopy area of the segment, Fact, may be estimated. Then the unforested or open area of the segment, OA, may be increased by the reduction in forested area, FA - Fact, to obtain Oact, the estimate of the total area not covered by forest canopy. Thus,

$$\text{Fact} = \text{FA} \cdot \text{FD} \quad (5-27a)$$

and

$$\text{Oact} = \text{OA} + \text{FA} - \text{Fact} \quad (5-27b)$$

or

$$\text{Oact} = \text{OA} + \text{FA}(1 - \text{FD}). \quad (5-27c)$$

The forested and unforested areas are kept distinct to facilitate the calculation of snowmelt from each cover condition due to long-wave radiation exchange.

Longwave radiation exchange in the forest may be described by Equation 5-24, and in the open by Equation 5-26. Working with Equation 5-24, designating ΔE to be RLF, the longwave radiation

exchange for forested areas, and factoring out σ , we have

$$RLF = \sigma(TM1^4 + TM2^4 - 2TS^4). \quad (5-28)$$

If $(273^\circ K)^4$ is now factored out of the temperature terms,

$$RLF = 273^4 \sigma [(TM1/273)^4 + (TM2/273)^4 - 2(TS/273)^4]. \quad (5-29)$$

Since σ , as used here for a 12-hour interval, has a value of 595×10^{-10} ly/12hr/ $^\circ K^4$, multiplying it by $(273^\circ K)^4$ gives 330 ly/12hr.

Equation 5-29 can now be written in convenient form for computer calculation as

$$RLF = 330 [(TM1/273)^4 + (TM2/273)^4 - 2(TS/273)^4], \quad (5-30)$$

which sums the forest longwave radiation exchange over the two 12-hour periods for the day.

Similarly for Equation 5-26, with ΔE now designated to be RLO for longwave radiation exchange in open areas

$$RLO = 0.76 \sigma(TM1^4 + TM2^4 - 2.63TS^4). \quad (5-31)$$

Factoring $(273^\circ K)^4$ and multiplying $\sigma(273)^4$ out, as before,

Equation 5-31 becomes

$$RLO = 0.76(330) [(TM1/273)^4 + (TM2/273)^4 - 2.63(TS/273)^4], \quad (5-32)$$

which sums the open area longwave radiation exchange over the two 12-hour periods for the day.

The net radiation exchange for the open or nonforested portion of the area, RO , is obtained by summing the effective shortwave radiation, R_{in} , from Equation 5-18, and the longwave open area radiation exchange, RLO , from equation 5-32. Thus:

$$RO = R_{in} + RLO \quad (5-33)$$

giving RO in ly/day.

With RO and RLF determined, the potential melt contributions from the open area may be computed. RO and RLF have energy (heat) units of ly/day, or $\text{cal}/\text{cm}^2/\text{day}$, and it is convenient to convert this to inches (or cm) of melt water.

Assuming the snow to be ice only (no liquid water) at 32°F (0°C), one gram of ice can be melted by supplying 80 cal of heat, since the latent heat of fusion of ice is very nearly 80 cal/gm. For water or ice near 0°C (32°F), one gram has a volume of one cm^3 , and the heat of fusion may then be expressed as $80 \text{ cal}/\text{cm}^3$. Dividing the heat available by the heat of fusion,

$$\text{RMO} = \text{RO}/80 \quad (5-34)$$

for cm of melt per day. To convert to units of inches per day, divide RMO by 2.54 cm/in:

$$\text{RMO} = \text{RO}/203.2, \quad (5-35)$$

which is the potential snowmelt generated in an unforested area by radiation exchange. Similarly, for the potential radiation melt in inches per day in the forested area of the zone,

$$\text{RMF} = \text{RLF}/203.2. \quad (5-36)$$

Some conditions may generate a "negative melt" value for the day, which must be satisfied before actual snowmelt runoff can occur.

Program Development

In the model, melt due to radiation fluxes is computed for each day for a given segment open-area condition and for the segment forest-area condition before computing melt for successive segments. The radiation flux directed to the snowpack is considered positive.

Input data necessary for the radiation melt portion, RADMEL, are: RASWM(I), SRADF(K), TMAX(J,I), TMIN(J,I), P(M,I), SNOCOV(K,I,L), SLAT(K), SLOPE(K), AZ(K), BLAT, and FDEN(K). These are defined in the Dictionary of Program Variables in the Appendix.

Due to the difficulties of measuring canopy densities in forested areas and in determining the fractional areas of each density class, the forested areas are considered to have a uniform canopy density within a given segment, FDEN(K), estimated from vertical aerial photos as the fraction of the forest area covered by foliage projected to the ground surface.

The segment radiation factor, SRADF(K), for adjusting short-wave radiation from its point of measurement to the segment of application is quite subjective. It involves primarily the consideration of pertinent items such as relative general cloud cover patterns, measurement site exposure conditions, large differences in elevation, and relative air "clearness" to radiation penetration. Initial runs were made with SRADF(K) = 1.0 for all segments.

Upon entering the melt computation loops, the year is tested for a leap year, and an angle in radians (DAYANG) is calculated to approximate the earth's orbital movement about the sun for each day of a 365 or a 366 day year, as appropriate, assuming a circular orbit and a uniform angular movement. The sun's declination follows very closely the sine of this accumulated angle when March 21 is used as day one.

Each segment is assigned its appropriate temperature and precipitation data source, and the snowcover in the open and

forested areas of each segment is adjusted for forest density as each day is examined during the run. A day counter from March 21 is set, with consideration of whether or not the year is a leap year.

The computation within the melt loop begins with a decision based on whether or not the open area in the segment has any snow-cover. If there is no snow in the segment open area for the day, processing bypasses calculations for radiation melt in the open, since without snow there can be no melt.

For the condition where there is snow in the segment open area, shortwave radiation effects will be considered first. The angle of the earth's orbital movement (ANGL) since the spring equinox (March 21) for the day in question is calculated from DAYANG and the number of days (NDAY) elapsed since March 21. The declination of the sun (DELT) above or below the equinox position is obtained as a function of the sine of ANGL. With DELT, and the latitudes of the base radiation observation station (BLAT) and the application segment (SLAT(K)), a factor (ADLAT) is computed when necessary to adjust the measured daily horizontal surface radiation (RASWM(I)) to daily horizontal surface radiation at the segment latitude, RASWMS.

A second factor (RADJ) is obtained from the ratio of calculated theoretical solar radiation on the segment mean slope (RTHSLO) to the calculated theoretical solar radiation on a horizontal surface in the segment (RTHHOR). Duration of radiation cannot exceed that for a horizontal surface, and is so limited in

the computation. To account somewhat for diffuse solar radiation, the minimum value of RADJ is limited to 0.05. The horizontal surface segment radiation, RASWMS, is multiplied by RADJ and by SRADF(K) to obtain an estimate of the solar radiation received on the segment surface (RASWS) for those days when the open area of the segment has at least some snowcover.

If $I = 1$ (the first day of the computation period) the day counter since snowfall is set equal to five ($N = 5$) arbitrarily, since it is not generally known how many days have elapsed since snowfall. Errors from considering $N = 5$ should be minor, and would pertain only for those days until the next precipitation event occurred, the albedo dropped to 0.40, or the snow disappeared, whichever occurred first.

The day's data are checked to see if precipitation occurred on that day. If not ($P(M,I) = 0.0$), control moves to set the day counter to $N = N + 1$, and the day's albedo ratio is calculated from

$$ALB = 0.82 - 0.02 * FLOAT(N). \quad (5-37)$$

The starting value of 0.82 is chosen so that on day $N = 1$, the calculated albedo will be 0.80 for new snow.

If precipitation occurred ($P(M,I) > 0.0$), the mean temperature, TMEAN, is used to decide if the precipitation would be expected in the form of rain or snow. Snow is considered to occur if TMEAN is 34°F (1.1°C) or less, in which case control moves to set the day counter N to zero and ALB to 0.80 for new snow. If rain is considered to occur ($TMEAN > 34^{\circ}\text{F}$ or 1.1°C), N is set to 16, the value required to lower the albedo to 0.50, and ALB is set to 0.50

for rain on snow, after which control passes to an albedo check and then calculation of effective shortwave radiation, RASWE.

If control has followed the path for no snow in the open, the data are also tested for precipitation on that day. If precipitation did not occur, RASWE is set to 0.0 and control moves into the longwave radiation portion of the program. If precipitation did occur, the decision as to rain or snow is made as described above, and if snow occurred, N is set to zero and ALB to 0.80. For rain, the program follows the "no snow" path to the longwave portion, with RASWE = 0.0.

Processing paths for snow in the open area converge on an albedo test where its value is set equal to 0.40 if its computed value is less than 0.40, followed by calculation of RASWE, the day's effective shortwave radiation for producing snowmelt in the open portion of the segment,

$$\text{RASWE} = \text{RASWS} * (1.0 - \text{ALB}), \quad (5-38)$$

The longwave radiation portion of the program is entered by either of two paths: (1) the no-snow-in-the-open path, or (2) the path with snow in the open area. Path (1) tests for snow in the forested area. If there is none, the net radiation factors for open areas (RANETO) and forested areas (RANETF) are set to zero and control moves to the end of the section for calculation of radiation melts, which become zero for segment K on day I. This total path (no snow in the segment) effectively bypasses the radiation program, touching it only to test for snow.

If the test indicates snow in the forested portion of the segment, a temperature manipulation is made to facilitate calculation of longwave radiation exchange. An "upper average" (TMUPP) is the mean of the day's maximum and mean temperatures, and a "lower average" (TMLOW) is the mean of the day's minimum and mean temperatures. These upper and lower averages are converted to absolute temperatures ($^{\circ}\text{K}$) for use in calculating longwave radiation exchange in the forest area of segment K on day I, RANETF, and finally the potential snowmelt's due to radiation, SM(K,I,1) and SM(K,I,2) are calculated. This route will also give a zero value of SM(K,I,1), since there is no snow in the open area.

Entry on path (2) is brought about by the fact that there is snow in the open area. The absolute upper and lower average temperatures ($^{\circ}\text{K}$) are calculated as above, the longwave radiation exchange in the open (RALWO) is calculated, and RASWE and RALWO are summed to give the net radiation exchange in the open area (RANETO). The program then tests for snow in the forest area. If none, control moves to set RANETF = 0.0 and then to calculate SM(K,I,1) and SM(K,I,2) (which is zero in this event). With snow in the forest area, control shifts to calculate the longwave radiation exchange with the forest, RANETF, and finally SM(K,I,1) and SM(K,I,2) for the day I segment K melt in inches from the open area and the forested area, from

$$\text{SM}(\text{K}, \text{I}, 1) = \text{RANETO} / 203.2 \quad (5-39\text{a})$$

$$\text{SM}(\text{K}, \text{I}, 2) = \text{RANETF} / 203.2 \quad (5-39\text{b})$$

where division by 203.2 converts radiation energy to inches of

potential melt. Division by 80 rather than 203.2 would give the results as centimeters of potential melt.

The values of $SM(K,I,1)$ and $SM(K,I,2)$ may be zero (and will be zero for no snow), positive for snow present and melt occurring, or negative if snow is present but net radiation flux is directed away from the snowpack. A negative value indicates the so-called "negative melt," and represents a heat deficit which must be satisfied before actual melt may occur from the area.

Commentary

Initial runs with the model, including the PAKTEM adjustments to runoff, indicated that the radiation considerations could describe the snowmelt runoff quite well. In view of these results, and the limited project time available, no attempt was made to add additional sections. Adding other melt and loss considerations should improve the model response.

CHAPTER 6

PAKTEM

Introduction

The results of the potential snowmelt calculations described in Chapter 5 could be translated directly into streamflow. They would then represent runoff from a ripe snowpack that always had a sufficient water equivalent to supply the day's melt whenever snow was present in the area being calculated. The PAKTEM section of the model takes into account that the snowpack may not be ripe, that the water equivalent may be less than the potential melt amount, that the amount of runoff may be augmented by an excess of rainfall, and that the area being calculated may have only partial snowcover.

The interior of a snowpack may have a temperature considerably below the 32°F (0°C) melting point of snow. This represents a heat deficit, or cold content, which must be satisfied before liquid water can leave the snowpack (Corps of Engineers, 1956; Leaf and Brink, 1973). The source of heat supply to satisfy this cold content is primarily liquid water, which may come either from melt generated near the snowpack surface, or from rainfall (Rantz, 1964). The release of the latent heat of fusion as this liquid refreezes serves to warm the snowpack. Other heat sources are the condensation and subsequent freezing of water vapor transferred within the snowpack, conduction from the ground surface, and sensible heat carried by rain (Corps of Engineers, 1956). These appear to be

minor compared to the melt- and rainwater latent heat sources, and are not modeled here. The ground warming is considered, since this provides a small amount of melt near the bottom of the snowpack which helps to prime the ground and influences the snowpack temperature by virtue of being a snowpack boundary.

The consideration of rainfall effects upon the snowpack is important. Once the heat deficit has been satisfied, and drainage channels established in the snowpack, any excess rainfall (plus melt) is transmitted through the snowpack at essentially the same rate that the liquid water enters the snowpack (Gerdel, 1954; Corps of Engineers, 1956; Rantz, 1964). Gerdel also indicates that the higher transmission rates are associated with snowpacks of higher density. The high transmission rates can result in rainwater arriving at stream channels rapidly and little diminished in volume, as the ground surface will be at, or near, its field capacity from ground melt. The rain-on-snow situation can result in serious flooding.

Heat transmission through a medium is described by heat diffusion theory (Jakob and Hawkins, 1942; Lowry, 1969; Leaf and Brink, 1973; Riley et al., 1969). The heat diffusion through a medium, and hence the temperature at some internal point, is a function of the density of the medium. The determination of the snowpack density in the model is accomplished through a submodel, DEN, which is included within the PAKTEM program.

The PAKTEM program also limits the snowmelt runoff to the water equivalent in the snowpack, after correcting the snowmelt

for the amount needed to satisfy the cold content of the snowpack. Final runoff volumes are computed from the net snowmelt and the area of snowcover on that portion of the segment under consideration.

Figures 6-1a, b, and c show a simplified flowchart of the PAKTEM section of the model. It is a lengthy program owing to the number of decisions required and the possible interactions resulting from the decisions.

Snow Density Model (DEN)

Snow sampling data in the study area were inadequate for a formal regression technique to obtain a snow density model. The sampling periods did not begin until December at the earliest, and as late as February in some years, and were generally terminated around mid-June or earlier while considerable snow still existed in the higher portion of the basin. Furthermore, the sampling scheme involved zones that did not coincide with the basin segments, but did roughly coincide with groups of segments. Available sample sets included both point samples and random sampling sets. The observed densities include data from two S.C.S. snow courses in the basin (Peak and Clagett, 1972).

The first step in arriving at the density model was to plot the observed snow densities against the sample date, combining observations from sample zones with similar elevations and conditions. The sample dates were adjusted for plotting so that observed densities from different years could be compared on

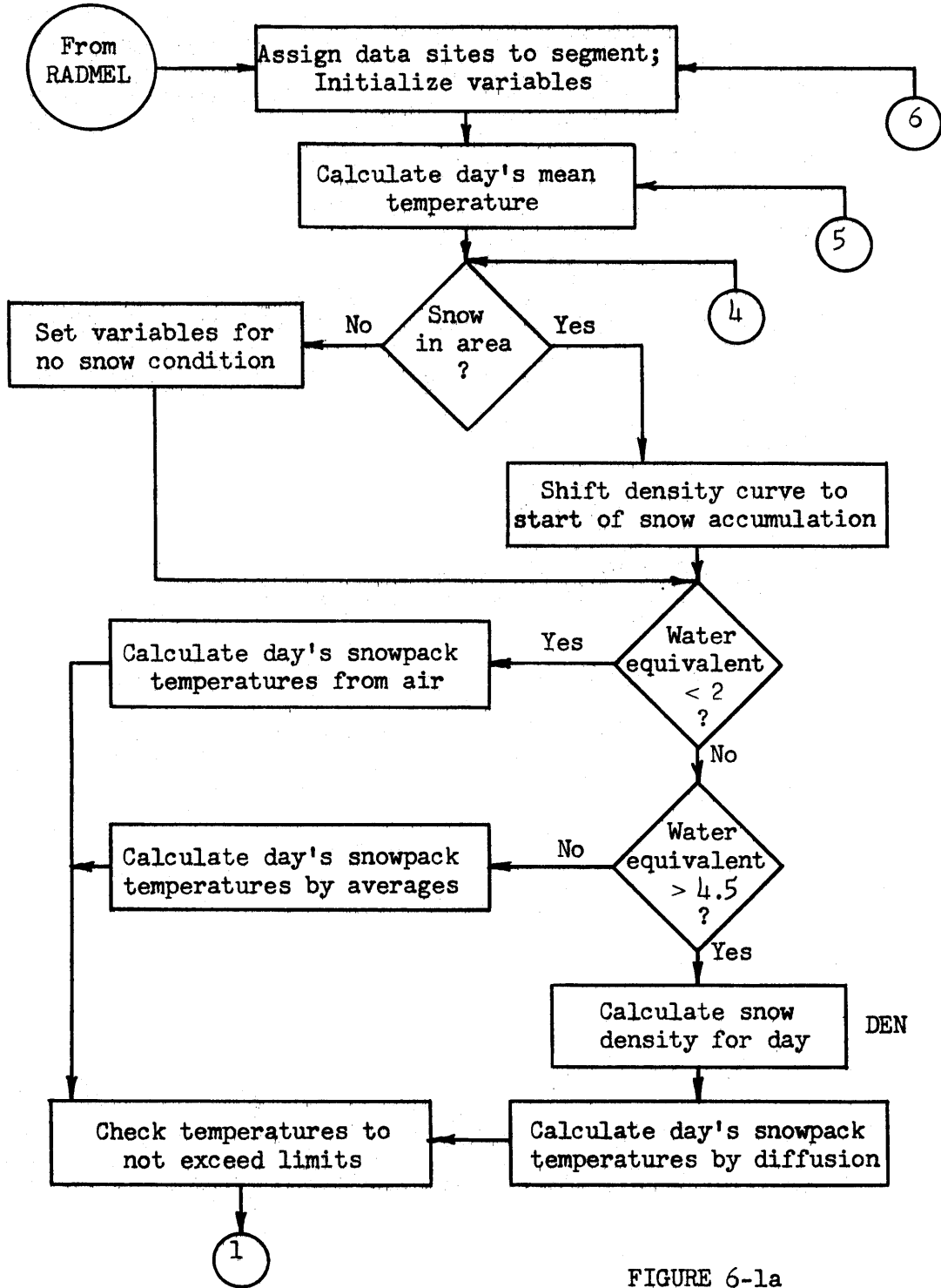


FIGURE 6-1a

SIMPLIFIED FLOWCHART FOR PAKTEM
Calculation of Snowpack Temperatures

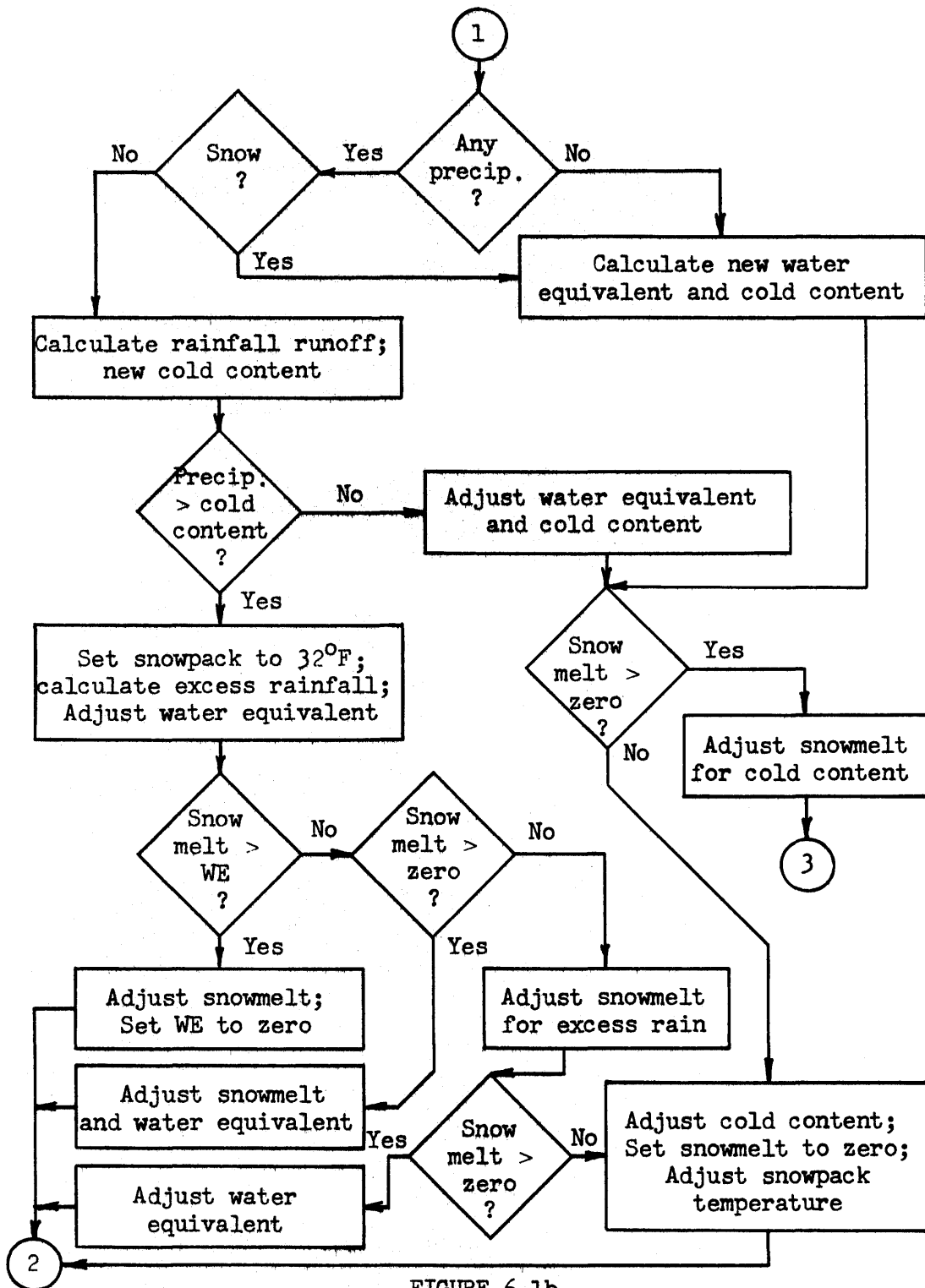


FIGURE 6-1b

SIMPLIFIED FLOWCHART FOR PAKTEM
First Adjustments for Precipitation

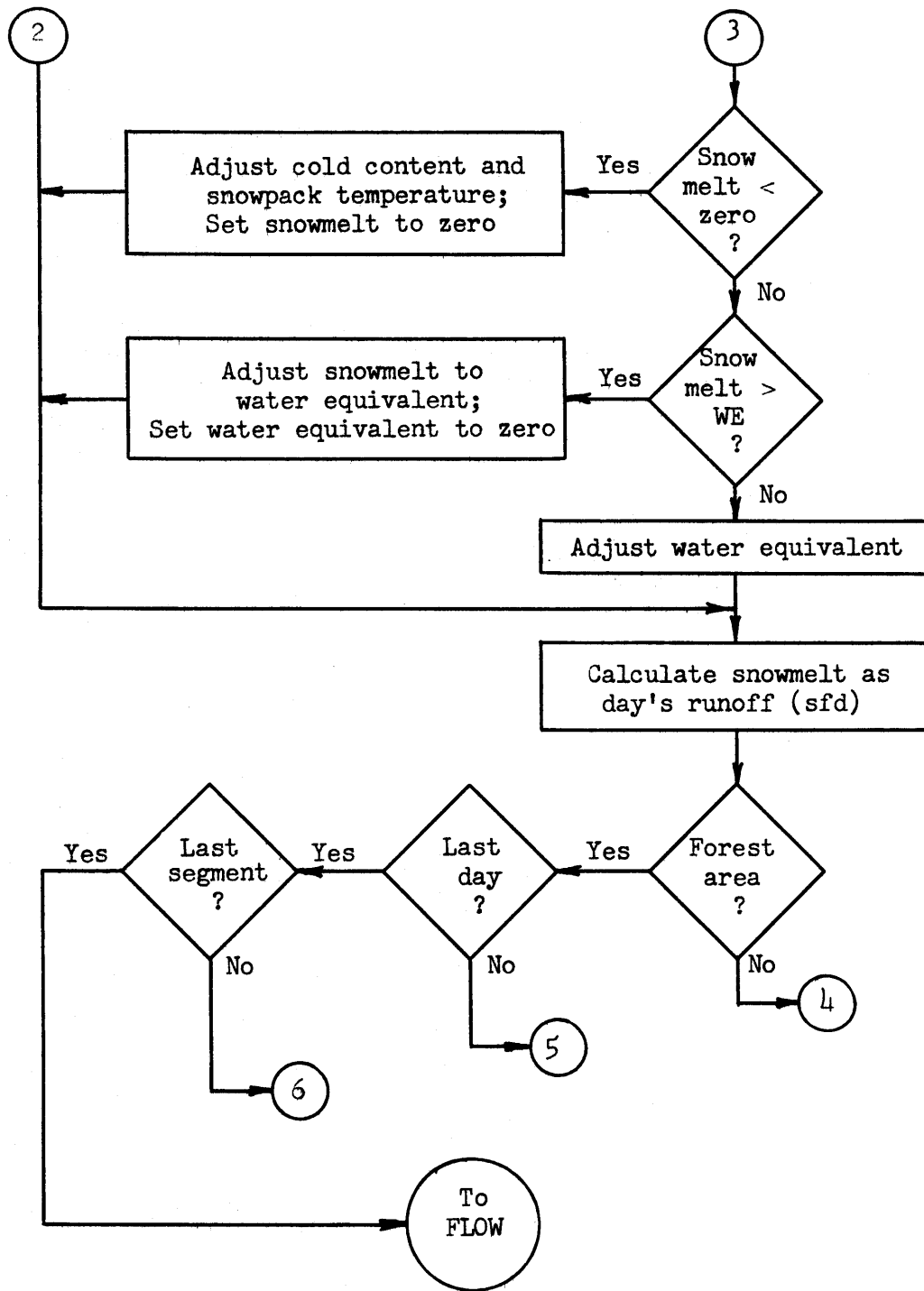


FIGURE 6-1c

SIMPLIFIED FLOWCHART FOR PAKTEM
Final Adjustments and Runoff

the basis of snowpack age. Since the snowpack buildup in the study area normally begins about the first of October, the October 1 date was assumed as the beginning date for snowpack ages. Sampling dates for a given water year were moved ahead and back the number of days that the actual pack buildup began before or after October 1. Plots of forest samples and open area samples were kept separate, and the pertinent segments noted on each graph. There was no apparent distinction between the years, so all years were considered together. Examination of the plots indicated the density increasing with time in a parabolic curve, with an additional increase superimposed beginning around the 230th day of the water year, or about mid-May. The curve tended to flatten again to a near parabola after about 30 days, or by mid-June. The density, as expected, continued to increase (but at varying rates) throughout the period of sampling. It would further be expected to increase until the snowpack became shallow under the effects of active melt. An example of the density versus time plots is shown in Figure 6-2 for the forested and unforested areas pertinent to segments 11-14. The calculated density curves for this segment group are also shown in the figure.

The plotted density curves were similar in shape to those shown for the Central Sierra Snow Laboratory (Corps of Engineers, 1956, Plate 5-6, Figure 6). The plotted curves exhibited a response to elevation, and the density model was therefore considered to be a function of elevation as well as snowpack age.

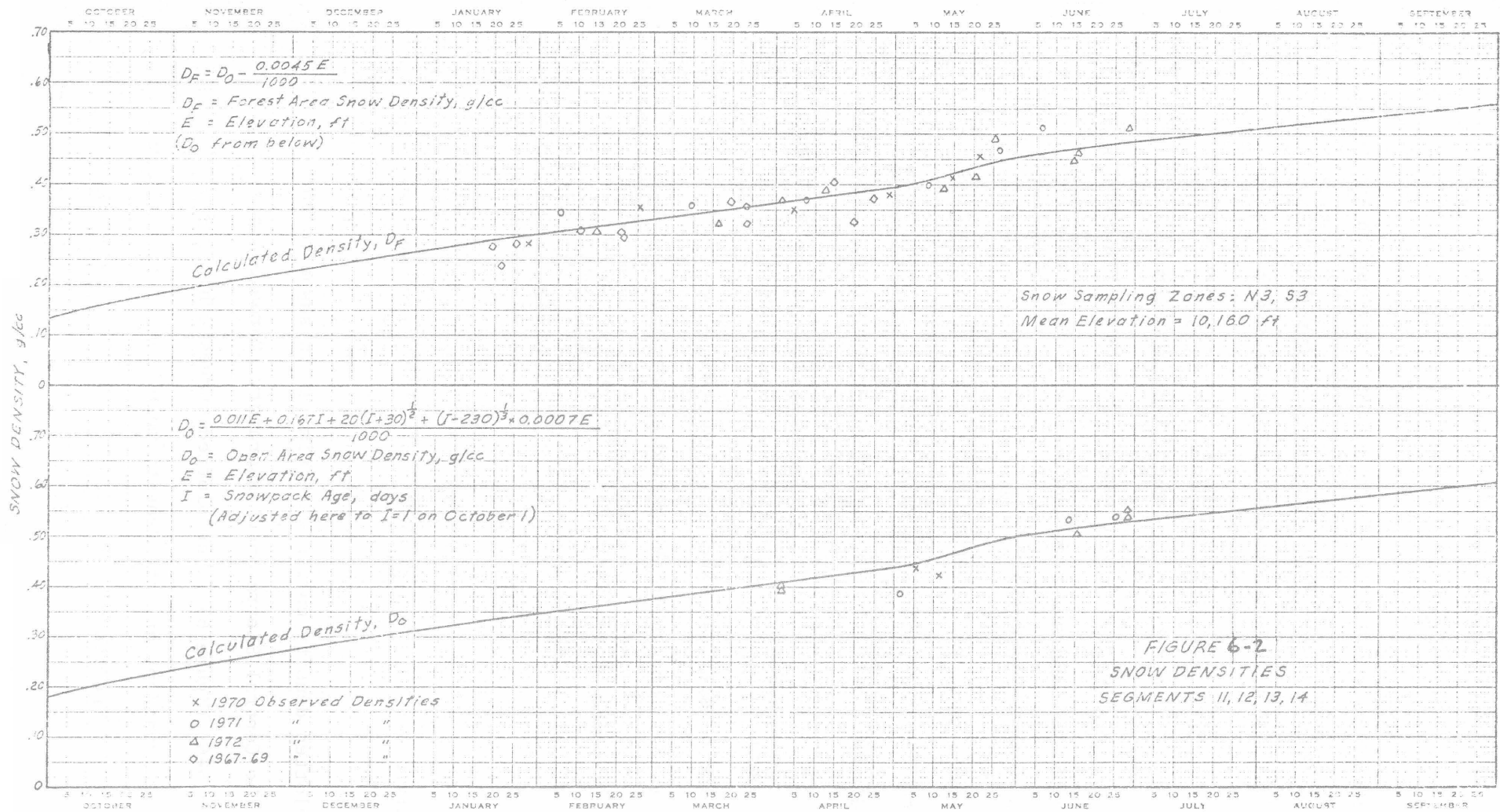


FIGURE 6-2

SNOW DENSITIES, SEGMENTS 11, 12, 13, 14

Data were not sufficient for an analysis of individual storm effects, early season densities, or densities after sampling was halted with significant snowpack yet in existence.

Smith (1966) and Bartos and Rechar (1973) found snow density uniform over smaller study areas, although snow depths were highly variable. Work in a subalpine area in Canada indicated densities to be "... remarkably similar from year to year so that it is reasonable to suggest the character of the density at a specific time in the climatic calendar" (McKay and Findlay, 1971, p. 16). They also suggest that snow compaction by wind has a major influence on snowpack density. Gerdel (1954) attributes crusts in the snowpack to wind action or to alternate freezing and thawing at the snow surface between storms, and suggests that these crusts are so thin that they have little effect on the measured snow density. Observations in the Nash Fork basin indicate that these crusts, or ice layers, do affect the density measurements. They can commonly be as much as 0.5 in (1.3 cm) in thickness with very close spacing at times, usually much less than 2 in (5 cm) in snow more than 2-3 weeks old.

Examination of the observed data showed several densities exceeding 0.40 at the lower elevations (around 9,600 ft or 2,900 m) and one of 0.485. Readings from the higher elevations (10,850 ft or 3,310 m, mean) show a low of 0.425 in mid-March, and a high of 0.622 near the end of May (this value was the average of several samples taken across a drift, one of which exceeded 0.72). Gerdel (1954) reports values between 0.25 and 0.56 for ripe

snowpacks. The observed densities may be somewhat high, as most were obtained with a Mt. Rose type snow sampler which tends to read high in some conditions. Comparisons with densities obtained from snow pits on several occasions did not indicate this, however (Bartos and Rechar, 1973).

In view of the above considerations it was felt that a general density model responsive to elevation changes and snowpack age, allowing for changes in the rates of density increase at approximately the proper times, would be adequate. A parabolic curve was consequently fitted by approximation to give the basic increase with time, and which varied as a function of the mean segment elevation:

$$\text{DEN} = (0.011 * \text{ELEV}(K) + 20. * \text{SQRT}(\text{SDAY})) / 1000 \quad (6-1)$$

where DEN is the calculated snowpack density in g/cm^3 , ELEV(K) is the elevation of segment K in feet above sea level, and SDAY is a counter to indicate snowpack age.

SDAY is determined in such a way that it allows for consideration of snowpack accumulation prior to the start of the water year (by initializing at the start of calculation), or for snowpack accumulation beginning after the start of the water year. The curve described by Equation 6-1 exhibited the abrupt rise at the start of the calculation period which is characteristic of a parabola. This was reduced by adding 30 days to SDAY, so that calculations were begun on a flatter portion of the curve. (Computer notation is used in these derivations to simplify transfer of the equation to the model.)

Since curvature was still too pronounced to give a realistic density at the end of the season, a straight line term was added to raise the density values as the water year progressed. Equation 6-1 thus appeared as

$$\begin{aligned} \text{DEN} = & (0.011 * \text{ELEV}(K) + 0.167 * \text{SDAY} \\ & + 20. * \text{SQRT}(\text{SDAY} + 30.))/1000. \end{aligned} \quad (6-2)$$

The increasing rate of density change in late May followed by a decrease in the rate of change in early June was entered using a cube root expression in such a way that negative values were obtained prior to $\text{SDAY} = 230$, and positive values thereafter. It was apparent that elevation should also be considered, so that the density model in its final form became

$$\begin{aligned} \text{DEN} = & (0.011*\text{ELEV}(K) + 0.167*\text{SDAY} + 20.*\text{SQRT}(\text{SDAY} + 30.) \\ & + ((\text{SDAY} - 230)**0.33333)*0.0007*\text{ELEV}(K))/1000 \end{aligned} \quad (6-3)$$

for elevations in feet. For elevations in meters, the elevation coefficients would be divided by 0.3048.

Snow densities observed in the forested portions of each segment were generally less than in the unforested portions, probably due to reduced wind action and crust formation. For forested areas, the density is computed as

$$\text{DEN} = \text{DEN} - (0.0045*\text{ELEV}(K)/1000) \quad (6-4)$$

for elevations in feet. The 0.3048 divisor is required for elevations in meters. The results of the DEN model calculated for the mean elevations of the sample zone groupings at selected snowpack ages are shown in Table 6-I. The calculated curves applicable to segments 11-14 were shown in Figure 6-2.

TABLE 6-I

SNOW DENSITIES CALCULATED WITH MODEL
FOR SELECTED ELEVATIONS AND SNOWPACK AGES

Age of Snowpack (days)	Densities: Open Area, D_o , and Forest Area, D_F (g/cc) ¹											
	Elevation 7,000 ft		Elevation ² 9,590 ft		Elevation ³ 10,160 ft		Elevation ⁴ 10,410 ft		Elevation ⁵ 10,850 ft		Elevation 13,000 ft	
	D_o	D_F	D_o	D_F	D_o	D_F	D_o	D_F	D_o	D_F	D_o	D_F
1	.159	.127	.176	.133	.180	.134	.181	.134	.184	.136	.199	.140
30	.208	.177	.226	.183	.230	.184	.232	.185	.235	.186	.250	.191
70	.262	.231	.281	.238	.285	.239	.286	.240	.290	.241	.305	.247
110	.308	.276	.328	.284	.332	.286	.333	.287	.337	.288	.353	.295
150	.349	.318	.370	.327	.374	.329	.376	.329	.380	.331	.397	.339
190	.388	.357	.411	.368	.416	.370	.418	.371	.422	.373	.440	.382
230	.438	.406	.466	.423	.473	.427	.475	.428	.480	.432	.504	.445
270	.485	.454	.520	.477	.528	.482	.531	.484	.537	.488	.566	.507
310	.519	.487	.555	.512	.563	.517	.566	.520	.573	.524	.603	.544
365	.561	.529	.598	.555	.607	.561	.610	.564	.617	.568	.648	.590

¹ Open area density, $D_o = [0.011E + 0.167I + 20(I + 30)^{1/2} + (I - 230)^{1/3} (0.0007E)] / 1000$, and Forest area density, $D_F = D_o - (0.0045E) / 1000$; where E = elevation, ft, and I = age of snowpack, days. Model assumes open areas are subject to frequent high winds.

² Mean elevation of segments 15 and 16.

⁴ Mean elevation of segments 3, 4, 5, 6, 9, and 10.

³ Mean elevation of segments 11, 12, 13, and 14. ⁵ Mean elevation of segments 1, 2, 7, and 8.

PAKTEM, Derivations and Programming

The derivations for PAKTEM are presented in computer form, for the most part. Some are developed from basic mathematical relationships and are transitioned into the program notation as they are derived. The Dictionary of Program Variables in the Appendix should be consulted for more complete definitions.

PAKTEM is initialized by assigning temperature and precipitation measurement sites, an XDAY value, and an existing water equivalent value (WE) to each of the basin segments. XDAY represents the number of days prior to the end of the previous water year that the current snowpack has been accumulating, and is initialized as either zero or a negative number. When no previous snowpack exists, the program accumulates XDAY as a positive number until the snowpack accumulation begins. This allows SDAY, for density determination, to adjust for the actual age of the snowpack by the expression

$$SDAY = \text{FLOAT}(I) - XDAY. \quad (6-5)$$

Snowpack temperature calculation procedures are determined from the value of WE existing at the beginning of the calculation day. For a shallow snowpack ($WE < 2$ in, or 5 cm), the temperatures of the snow surface (TSNO), the snowpack (TPAK), and the ground (TGR) are all set equal to the mean air temperature (TMEAN), with the constraints that $TGR \leq 33^{\circ}\text{F}$ (0.6°C), and $TSNO$ and $TPAK \leq 32^{\circ}\text{F}$ (0°C).

Thus,

$$TSNO = TMEAN, \quad TMEAN \leq 32 \quad (6-6a)$$

$$TPAK = TMEAN, \quad TMEAN \leq 32 \quad (6-6b)$$

$$TGR = TMEAN, \quad TMEAN \leq 33. \quad (6-6c)$$

For a snowpack such that $2 \leq WE \leq 4.5$ in ($5 \leq WE \leq 11.4$ cm), TGR is taken as the mean of the previous day's TGR and the current day's TSNO values, where TSNO is determined as in Equation 6-6a, and all are subject to the above constraints. Thus TSNO is given by Equation 6-6a and

$$TGR = (TGR + TSNO)/2, TGR \leq 33 \quad (6-7a)$$

$$TPAK = (TSNO + TGR)/2, TPAK \leq 32. \quad (6-7b)$$

Although Equations 6-7a and 6-7b appear the same, the card sequence is such that the previous day's TGR is used in Equation 6-7a, while the current value of TGR calculated from Equation 6-7a is used in Equation 6-7b.

When the snowpack accumulates so that $WE > 4.5$ in (11.4 cm), TPAK is calculated from heat flow, or diffusion, theory. This portion of the model parallels the work of Leaf and Brink (1973), whose treatment was almost directly applicable to the present development.

The basic heat flow equation for heat flow in any direction is:

$$\frac{\partial t}{\partial \tau} = \alpha \left(\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2} \right) \quad (6-8)$$

where α = the thermal diffusivity, $k/\rho c_p$ (Jakob and Hawkins, 1942). In a snowpack considered very large in lateral extent (x and y) compared to its vertical dimension, z, the heat transfer in the x and y directions can be considered zero except near the pack edges, leaving the z direction as the one of interest. Equation 6-8 thus becomes:

$$\frac{\partial t}{\partial \tau} = \frac{k}{\rho c_p} \left(\frac{\partial^2 t}{\partial z^2} \right) \quad (6-9)$$

where α is replaced by $k/\rho c_p$. Replacing the temperature symbol t by T , and the time symbol τ by t ,

$$\frac{\partial T}{\partial t} = \frac{k}{\rho c_p} \left(\frac{\partial^2 T}{\partial z^2} \right) \quad (6-10)$$

as given by Lowry (1969, p. 53), and, upon rearranging,

$$k \left(\frac{\partial^2 T}{\partial z^2} \right) = \rho c_p \left(\frac{\partial T}{\partial t} \right) \quad (6-11)$$

as given by Leaf and Brink (1973). Definitions of terms, in metric units to facilitate computation, are:

k = thermal conductivity, cal/°C/cm/sec,

c_p = specific heat at constant pressure, cal/g/°C,

ρ = snowpack density, g/cm³,

T = snowpack temperature, °C,

z = depth from surface of snowpack, cm, and

t = time, sec.

Replacing $k/\rho c_p$ by K , the thermal diffusivity in cm²/sec,

Equation 6-11 becomes

$$\frac{\partial^2 T}{\partial z^2} = \frac{1}{K} \left(\frac{\partial T}{\partial t} \right) \quad (6-12)$$

which corresponds to the form of Equation (3) of Leaf and Brink

(1973). Schwerdtfeger¹ assumed the thermal diffusivity, K , to vary with density:

$$K = \frac{2k_i}{(3\rho_i - \rho_s)c_i} \quad (6-13)$$

¹Schwerdtfeger, P., "Theoretical Derivation of the Thermal Conductivity and Diffusivity of Snow," U.G.G.I. Int. Assoc. Sci. Hydrol. Comm. Pub. 61, 1963, p. 75-81 (Cited in Leaf and Brink, 1973).

where:

k_i = thermal conductivity of ice, cal/°C/cm/sec,

ρ_i = density of ice, g/cm³,

ρ_s = density of snow, g/cm³, and

c_i = specific heat of ice at constant pressures, cal/g/°C.

Rewriting Equation 6-12 as

$$\frac{\partial T}{\partial t} = K \left(\frac{\partial^2 T}{\partial z^2} \right) \quad (6-14)$$

a finite difference solution is given by Leaf and Brink (1973), following work by Smith² and by Richtmyer and Morton,³ as follows.

The nondimensional form of Equation 6-14 can be represented by

$$\frac{\partial u}{\partial t} = \sigma \left(\frac{\partial^2 u}{\partial x^2} \right) \quad (6-15)$$

where σ is a constant such that $\sigma > 0$. Leaf and Brink (1973) note that the number representing the depth of the snowpack is unity in this expression. The approximate solution of Equation 6-15 by central differences is given by

$$\frac{u_{i,j+1} - u_{i,j}}{m} = K \frac{u_{i+1,j} - 2u_{i,j} + u_{i-1,j}}{h^2} \quad (6-16)$$

where mK/h^2 corresponds to σ , and

$$x = ih \quad (i = 0, 1, 2, \dots)$$

$$t = jm \quad (j = 0, 1, 2, \dots).$$

²Smith, G. D., Numerical Solution of Partial Differential Equations, Oxford Univ. Press, N.Y., 1965 (Cited in Leaf and Brink, 1973).

³Richtmyer, R. D., and K. W. Morton, Difference Methods for Initial-Value Problems, 2nd ed., Intersci. Pub., John Wiley and Sons, N.Y., 1967, (Cited in Leaf and Brink, 1973).

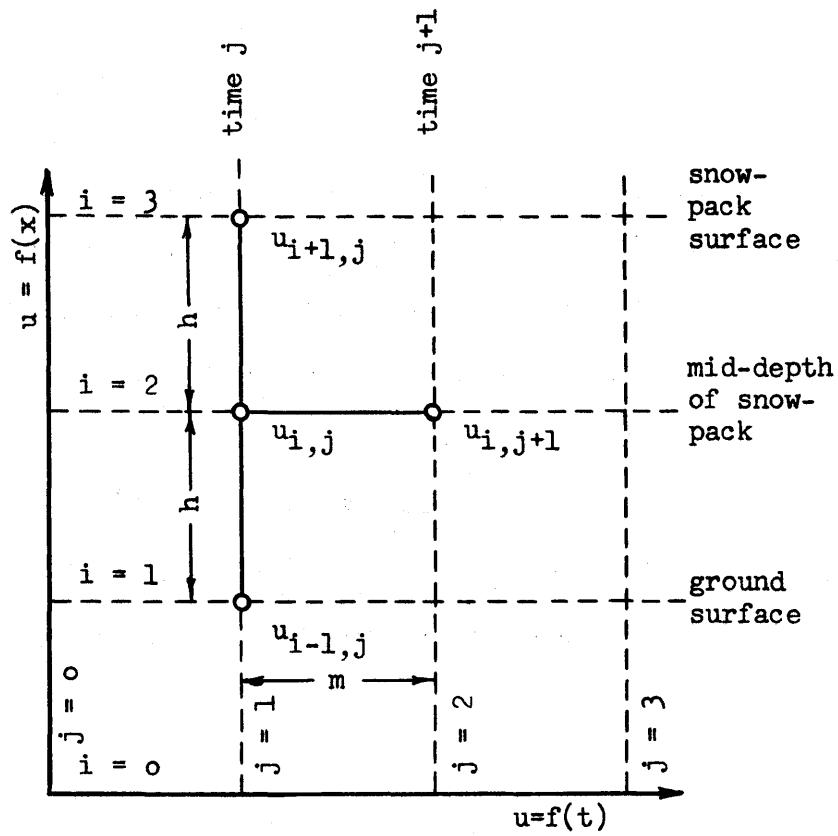
Solving Equation 6-16 for $u_{i,j+1}$,

$$u_{i,j+1} = u_{i,j} + \frac{mK}{h^2} (u_{i-1,j} - 2u_{i,j} + u_{i+1,j}), \quad (6-17)$$

gives the unknown temperature for depth i and time $j+1$ in terms of known previous temperatures at time j , as shown in Figure 6-3. Thus, if the temperatures of the ground surface, the snowpack, and the snow surface are known along the line of time = j , the snowpack temperature for time line $j+1$ may be computed, knowing the time interval, m , and the depth to the mid-point of the snowpack, h .

Leaf and Brink (1973) divide each day into two 12-hour periods for computation of the snowpack temperature, and average the results, in order to obtain stability. The first 12-hour period is controlled by a snow surface temperature, TSN01C (the "upper average" air temperature), which is the average of the maximum air temperature and the mean air temperature for the day. The second 12-hour period uses the "lower average" air temperature for the snow surface temperature TSN02C, the average of the minimum and the mean air temperatures for the day. (Temperatures are converted to °C for computation purposes, designated by a suffix C on the variable names.) The time increment, m , becomes 12 hours or 43,200 seconds for the diffusion calculation.

The depth increment, h , is taken as the depth from the snow surface to the mid-point of the snowpack, so that the snowpack depth is equal to $2h$. This value of h is computed from the water equivalent and the density of the snowpack, and designated as DEP2 in the program. Since the water equivalent is in inches, and centimeters are desired for computation, the depth calculation becomes



$$u_{i,j+1} = u_{i,j} + \frac{mK}{h^2} (u_{i-1,j} - 2u_{i,j} + u_{i+1,j})$$

FIGURE 6-3

COMPUTATION SCHEME FOR SNOWPACK
TEMPERATURE BY DIFFUSION THEORY

$$\text{DEP2} = 2.54 * (\text{WE}/\text{DEN}) * 0.5 \quad (6-18)$$

which simplifies to

$$\text{DEP2} = 1.27 * \text{WE}/\text{DEN}. \quad (6-19)$$

The thermal diffusivity, K, as defined in Equation 6-9, would require day-by-day ice data for thermal conductivity, density, and specific heat. Since these vary only over a small range average values have been used in the model, so that the variability of K is treated as a function of snowpack density only. The values used herein for k_i , ρ_i , and c_i are as follows:⁴

$$k_i = 0.0058 \text{ cal}/^\circ\text{C}/\text{cm}/\text{sec} \text{ (average value),}$$

$$\rho_i = 0.9167 \text{ g}/\text{cm}^3 \text{ (average value), and}$$

$$c_i = 0.48 \text{ cal}/\text{g}/^\circ\text{C} \text{ (average value).}$$

The expression for K, Equation 6-13, can then be written as

$$K = \frac{2(0.0058)}{[3(0.9167) - \rho_s](0.48)} \quad (6-20)$$

or, approximately, since average values are used,

$$K = 0.025/(2.75 - \rho_s) \quad (6-21)$$

where ρ_s is the daily value of DEN as calculated by the model.

With DEP2, K, and the time increment of 43,200 seconds, the coefficient mK/h^2 in Equation 6-17 can be determined for each day. Designating this coefficient as TCOEF,

$$\text{TCOEF} = 43200 (0.025)/(2.75 - \text{DEN})(\text{DEP2}^2) \quad (6-22)$$

or

$$\text{TCOEF} = 1080./((2.75 - \text{DEN}) * (\text{DEP2} ** 2.)) \quad (6-23)$$

⁴Smithsonian Meteorological Tables, 6th rev. ed., Washington, D.C., 1966; k_i and ρ_i from Table 120, p. 404, compiled by Dorsey; c_i from Table 92, p. 343.

as used in the model. According to Leaf and Brink (1973), this value must be limited to no more than 0.5 for mathematical stability. It is so limited in the present model.

To calculate the snowpack temperature for day I, the values of TGRC, TPAKC, and TSN01C or TSN02C for the previous day are used in Equation 6-17 for $u_{i-1,j}$, $u_{i,j}$, and $u_{i+1,j}$, respectively. Thus, for the first 12-hour snowpack temperature, TPAK1C, based on the "upper average" snow surface temperature,

$$\text{TPAK1C} = \text{TPAKC} + \text{TCOEF} * (\text{TGRC} - 2.*\text{TPAKC} + \text{TSN01C}) \quad (6-24)$$

and for the second 12-hour snowpack temperature, TPAK2C, based on the "lower average" snow surface temperature,

$$\text{TPAK2C} = \text{TPAKC} + \text{TCOEF} * (\text{TGRC} - 2.*\text{TPAKC} + \text{TSN02C}). \quad (6-25)$$

Finally, TPAK1C and TPAK2C are averaged to give TPAKC, the desired snowpack temperature in °C. TPAKC is then converted to TPAK, the snowpack temperature in °F, and TGR is increased by 0.03 °F (0.017°C) for the next calculation of TPAK.

The remainder of the PAKTEM portion of the program is used to determine the cold content of the snowpack, to follow water equivalent changes, and to correct snowmelt values for cold content effects, for rain-on-snow events, and for rainfall on snow-free areas. The value of TPAK is also corrected when warranted by changes in cold content through melt or rain effects. The program can follow any of several paths, depending upon the outcomes of the various decisions based upon precipitation, mean temperature, and interrelations between calculated snowmelt, water equivalent, and cold content.

For the case when precipitation on day I is zero or falls as snow, the water equivalent, WE, is incremented by the precipitation amount

$$WE = WE + P(M,I) \quad (6-26)$$

and the cold content, WC in inches, is determined from the relationship

$$WC = WE * (32. - TPAK)/288 \quad (6-27)$$

adapted from Equation 8-2, p. 298 in Snow Hydrology (Corps of Engineers, 1956). If $SM(K,I,L) \geq 0.$, the snowmelt is reduced by WC,

$$SM(K,I,L) = SM(K,I,L) - WC \quad (6-28)$$

and if this results in a negative snowmelt, a new value of WC is set equal to the negative melt and $SM(K,I,L)$ becomes zero. A new value of TPAK is then computed, using the solution of Equation 6-27 for TPAK:

$$TPAK = 32. - (288. * WC/WE). \quad (6-29)$$

If, however, the original value of $SM(K,I,L)$ for the day is negative, then WC is increased,

$$WC = WC - SM (K,I,L), \quad (6-30)$$

$SM(K,I,L)$ is set to zero, and TPAK is recalculated by Equation 6-29.

In the case of rain-on-snow, WC is computed as in Equation 6-27, and this WC value is compared to the rainfall for the day. When the rainfall is less than WC, $P(M,I) < WC$, the value of WE is increased using Equation 6-26 and WC is reduced by $P(M,I)$:

$$WC = WC - P(M,I). \quad (6-31)$$

Any runoff volume resulting from rainfall on snow-free areas (RRUN) is calculated at this time from

$$RRUN = (P(M,I) - 0.21) * (AREA(K,L) - SNOCOV(K,I,L)) \quad (6-32)$$

where RRUN is in acre-inches. The constant 0.21 has been selected to represent an initial index of infiltration and other losses, or ϕ index (Linsley, Kohler, and Paulhus, 1958, p. 180). This value seems reasonable in view of the soil conditions, forest litter, and foliage conditions found in the basin, and the generally small, less than 0.30 in (0.8 cm), amounts of rainfall that occur. The calculated value of RRUN is restricted from being negative. The path then returns to Equation 6-28, adjusting SM(K,I,L), WC (if necessary), and TPAK. When $P(M,I) \geq WC$, TPAK is set equal to 32°F (0°C); the excess precipitation, XP, is determined from

$$XP = P(M,I) - WC; \quad (6-33)$$

and WE is increased by WC,

$$WE = WE + WC, \quad (6-34)$$

to account for the ice formed in satisfying WC. If the original daily value of $SM(K,I,L) > WE$, $SM(K,I,L)$ becomes

$$SM(K,I,L) = WE + XP \quad (6-35)$$

and WE is set to zero. If, however, $SM(K,I,L)$ is less than WE but is positive, $0 \leq SM(K,I,L) < WE$, the value of WE is reduced by $SM(K,I,L)$,

$$WE = WE - SM(K,I,L) \quad (6-36)$$

and the snowmelt amount is augmented by the excess precipitation,

$$SM(K,I,L) = SM(K,I,L) + XP \quad (6-37)$$

to approximate the day's available runoff.

In the event that $SM(K,I,L)$ is negative at the beginning of the calculation for the day, $SM(K,I,L) < 0$, the value of $SM(K,I,L)$ is

increased by XP as in Equation 6-37. If SM(K,I,L) is now positive, a new WE is obtained from Equation 6-36 for carryover to the next day. If, after application of Equation 6-37, SM(K,I,L) is still negative, WC is increased by using Equation 6-30 and SM(K,I,L) is subsequently set to zero. TPAK is recalculated by Equation 6-29.

The value of SM(K,I,L) is prepared for the flow routing operation by combining it with RRUN and expressing the sum in second-foot days (sfd):

$$SM(K,I,L) = (SM(K,I,L) * SNOCOV(K,I,L) + RRUN)/(12.*1.98). \quad (6-38)$$

The result multiplied by 0.028 would give second-meter days.

The generated snowmelt runoffs plus the rainfall runoffs are now ready for routing in the FLOW portion of the program, Chapter 7.

Commentary

The corrections to the potential snowmelts by the PAKTEM program seem to bring the generated runoffs, or streamflows, at the flow points to reasonable values. This would indicate that the model concept is correct in assuming radiation to be the principal energy source for snowmelt, and that the PAKTEM corrections include the major items to be considered. The model's sensitivity could be improved.

Future work on the PAKTEM section might encompass the inclusion of evaporation from snow and open water surfaces, transpiration, and convection melt effects. Refinement of infiltration of rainfall on snow-free areas should be undertaken. A lag, with its attendant increased losses, might be applied to the runoff as the snowcover recedes from the main drainage channel in a given segment.

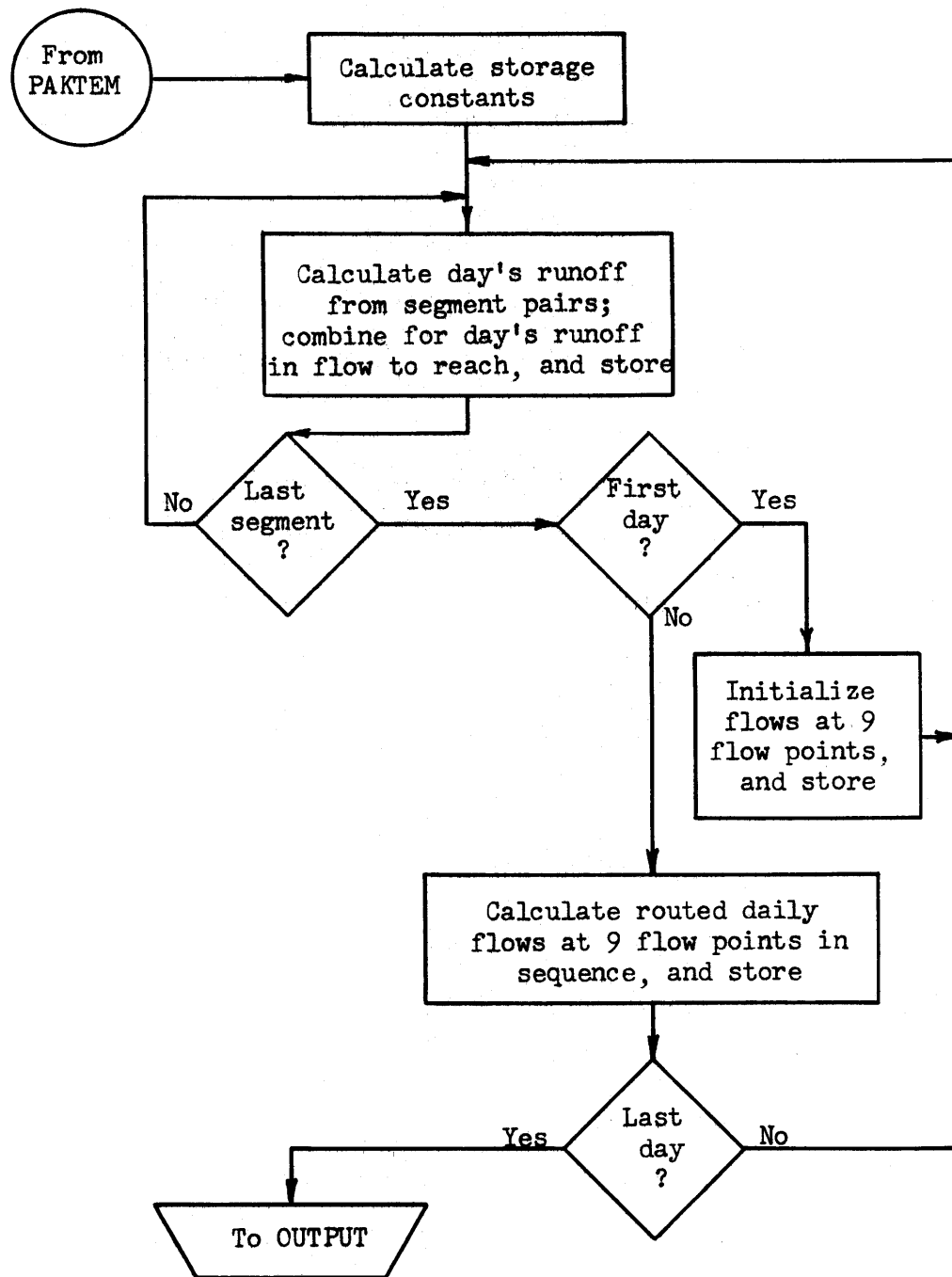


FIGURE 7-1
SIMPLIFIED FLOWCHART FOR FLOW

CHAPTER 7

FLOW

Introduction

The FLOW program in the snowmelt runoff model provides the means for bringing the runoff calculated by RADMEL and modified by PAKTEM into the stream system, and routing it through the flow points. The output of PAKTEM is runoff volume in second-foot days (sfd) for the unforested and forested areas of each segment for each day. FLOW first combines the runoff volumes from the unforested and forested areas of each segment for each day. This gives the calculated daily segment contribution to channel inflow. The segment contributions are then combined by the pairs bordering a stream reach so that the runoff inflow to each stream reach is obtained for each day. These inflows are then routed through the flow points located at the outlet of each reach. Figure 7-1 shows a simplified flowchart for the FLOW section of the model.

The model, as arranged for the Nash Fork basin, utilizes nine flow points, six of which coincide with established gaging stations. The other three are considered potential gaging stations. One of the potential gaging stations is "located" at the mouth of Telephone Creek, and another just below the confluence of Telephone Creek with Nash Fork. The one below the confluence is used only to combine the flows in the two streams. The third potential station is used to obtain an intermediate flow point on the relatively long section

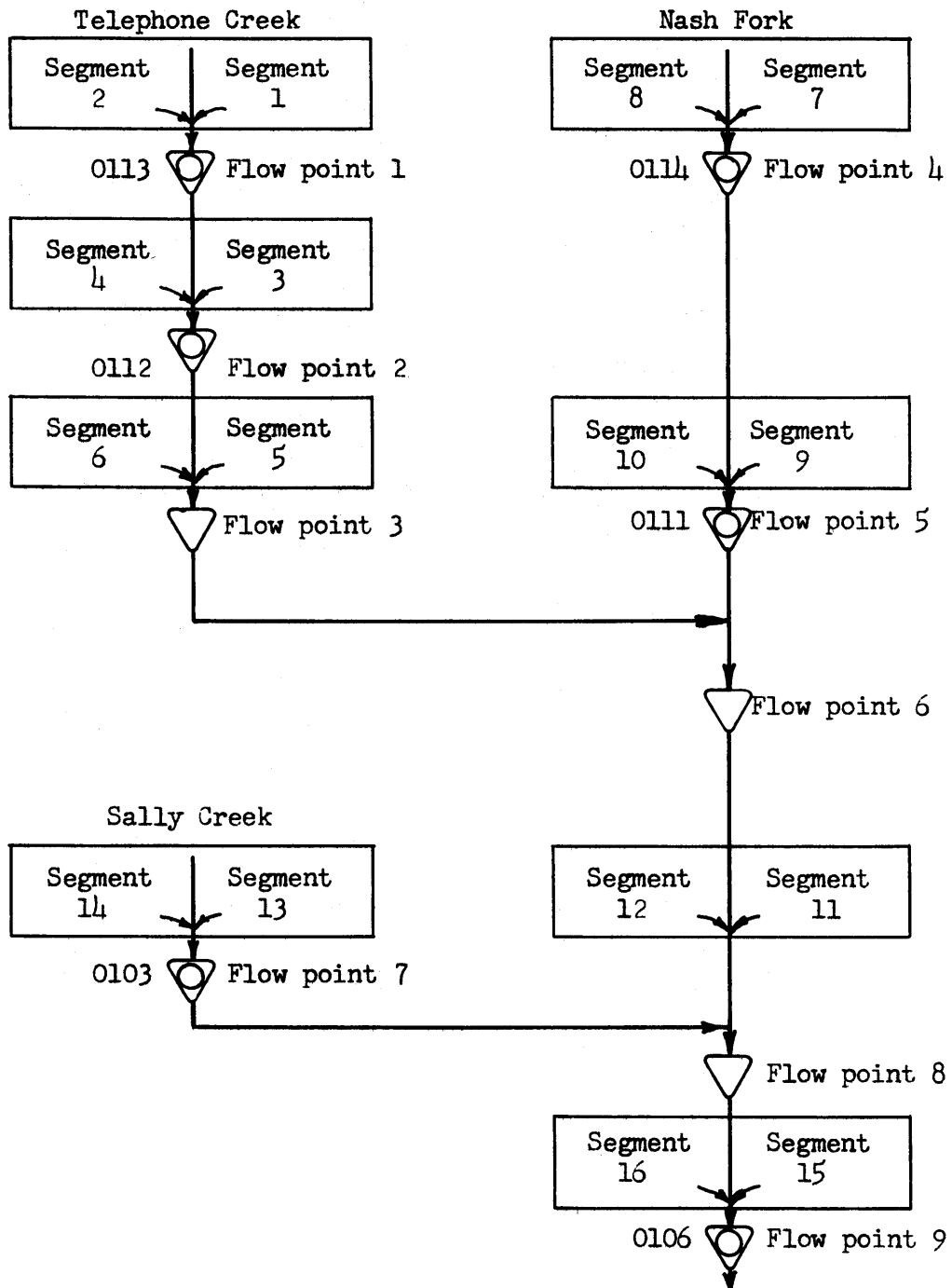


FIGURE 7-2

SCHMATIC DIAGRAM OF STREAM SYSTEM
AND FLOW ROUTING SEQUENCE

of Nash Fork from Telephone Creek to the study area outlet gage, 0106. It is "located" at the Green Rock Picnic Area, a short distance below the mouth of Sally Creek. A schematic diagram of the segment and flow point system is shown in Figure 7-2.

Derivations and Programming

Preparation for use of the FLOW program section includes the determination of flow travel time through the channel system, and, if greater than one day, the consideration of appropriate lag times. Storage constants are needed for the routing operation, and were determined in this instance through streamflow recession constants obtained from observed flow data. The Muskingum routing constants for proportioning flows are also required, as are initializing estimates for the beginning of the routing. A minimum flow limit for the reaches based upon observed data is also used such that the flow must equal or exceed zero.

A time-of-travel study was made on the Nash Fork proper on July 8, 1969, during the snowmelt runoff recession with the discharge at approximately one-half of the year's maximum daily discharge (Zimmerman, 1970). The travel time was determined by monitoring the fluorescence of stream samples at various sites along the study reach following injection of a known quantity of fluorescent dye at the upstream end of the reach. The study indicated that about five hours were required for the peak of the dye cloud to pass from the outlet of Little Brooklyn Lake to the gaging station below the Medicine Bow Ski Area (Station 0106). About eleven hours were required for the entire dye cloud to pass through the reach.

The information available indicates that a total travel time of less than one day is a valid assumption for all significant discharges.

Base flows were estimated subjectively by examination of observed streamflows at gaging stations in the study basin. An initial flow value for day one for each actual and potential gaging site was selected, and read in with the data as BFLOK. Flow recession constants were estimated from observed streamflow records following the method given by Garstka et al. (1958, Ch. 7). The observed daily discharges were plotted against the observed discharge of the previous day for each station, and lines drawn by eye to fit the plots. Two recession constants were determined for each station from these line slopes. Routing is accomplished in the model through the Muskingum method (Linsley, Kohler, and Paulhus, 1958).

The basic routing equation is the continuity equation in the form

$$\frac{I_1 + I_2}{2} t - \frac{O_1 + O_2}{2} t = S_2 - S_1 \quad (7-1)$$

where $\frac{I_1 + I_2}{2}$ and $\frac{O_1 + O_2}{2}$ are the average inflow and outflow, respectively, during the routing period, t , for the particular stream reach and $S_2 - S_1$ represents the change in storage during the same routing period. The routing period, t , is taken as one day in the model. The inflows and outflows are in cubic feet per second (cfs), and when multiplied by $t = 1$ day, become volume inflows and outflows in second-foot days (sfd). Storage must then be expressed

in sfd for Equation 7-1 to be dimensionally homogeneous. The subscripts 1 and 2 refer to the previous day and the current day, respectively. There are two unknowns, O_2 and S_2 , to be determined in Equation 7-1, and use is made of the Muskingum equation for storage,

$$S = K[xI + (1 - x)O] \quad (7-2)$$

where K is a storage constant with the dimension of time (Linsley et al., 1958, p. 228). With K in days, the inflow and outflow in cubic feet per second (cfs), the storage, S , will be in sfd. The dimensionless constant x is used to indicate the relative importance of the inflow and the outflow in determining storage. For a natural stream reach, $0 < x < 0.5$, and generally $0 < x \leq 0.3$. Initial estimates of x were made, and then adjusted during tuning runs of the model. An approximation of K may be obtained from

$$K = -1/\log_e K_r \quad (7-3)$$

where K_r is the recession constant for the reach at the gaging station under consideration (Linsley et al., 1958, p. 240).

The inflow to a reach can be considered a combination of the channel inflow from an upstream reach and local inflow entering along the reach. In the situation of the model, the generated snow-melt runoff can be considered local inflow entering the channel essentially along the entire reach length. A scheme was used for proportioning local inflow so that a percentage is considered with inflow for the storage calculation and routing, and the balance added to the outflow after routing (Linsley et al., 1958, p. 223). Let y represent the fraction of the local inflow, I_r , that is to

be routed through the reach. Equation 7-2 may then be written as

$$S = K[x(I + yI_r) + (1 - x) O] \quad (7-4)$$

with the understanding that the balance of the local inflow, $(1-y)I_r$, is to be added to the reach outflow following the routing calculation.

The channel inflow to the reach, I in Equation 7-1, must also be increased by the amount yI_r to obtain the total inflow to be routed. Adding this amount to I , substituting Equation 7-4 for S , and multiplying both sides by two, Equation 7-1 becomes

$$I_1 + yI_{r1} + I_2 + yI_{r2} - O_1 - O_2 = 2K[x(I_2 + yI_{r2}) + (1 - x)O_2 - x(I_1 + yI_{r1}) - (1 - x)O_1] \quad (7-5)$$

which may now be solved for O_2 by algebraic manipulation. The solution for O_2 becomes the basic routing equation,

$$O_2 = \frac{Kx + .5}{K - Kx + .5} (I_1 + yI_{r1}) - \frac{Kx - .5}{K - Kx + .5} (I_2 + yI_{r2}) + \frac{K - Kx - .5}{K - Kx + .5} O_1 \quad (7-6)$$

to which the removed portion of the local inflow must still be returned. The coefficient fractions in Equation 7-6 may be described as

$$CK1 = \frac{Kx + .5}{K - Kx + .5} \quad (7-7a)$$

$$CK2 = \frac{Kx - .5}{K - Kx + .5} \quad (7-7b)$$

$$CK3 = \frac{K - Kx - .5}{K - Kx + .5} \quad (7-7c)$$

following the development given by Linsley et al. (1958, p. 229).

Upon substitution of Equations 7-7 into Equation 7-6, the basic routing equation becomes

$$O_2 = CK1(I_1 + yI_{r1}) - CK2(I_2 + yI_{r2}) + CK3(O_1) \quad (7-8)$$

which describes the reach outflow for the current day in terms of the inflow and outflow of the previous day and the inflow of the current day. The removed portion of the local inflow must now be added to Equation 7-8 to give

$$O_2 = CK1(I_1 + yI_{r1}) - CK2(I_2 + yI_{r2}) + CK3(O_1) + (1 - y)(I_{r1} + I_{r2}) \quad (7-9)$$

for the outflow of the reach.

The "tuning" of the flow routing portion of the model consists of first selecting the best x and y combination for the reach at the head of a subbasin where there is no channel inflow to the reach, and then proceeding downstream to the second reach, and so on, until reasonable agreement with the observed hydrographs is obtained. The tuning process also involves adjustment of the recession constants. The final values of the flow routing constants as used in the model are given in Table 7-I. Constants are not required for the potential station Nash Fork below Telephone Creek, except that in entering the recession constant data, two K_r values for this station must be entered to preserve the numbering scheme.

Programming for the model is basically a day by day inflow-outflow accounting procedure. Once the storage constants have been calculated and the segment runoffs have been combined by reaches, the first day's flows are calculated. Flows for the succeeding days

TABLE 7-I
CONSTANTS FOR FLOW ROUTING

Flow Point (Station)	Muskingum x	Fraction of Local Inflow Routed (y)	Recession Constants (K _r)	Flow Range for K _r (Q in cfs)	Minimum Flow Allowed (cfs)
0113	0.2	0.8	0.95 0.74	Q < 6 Q ≥ 6	0.7
0112	0.1	0.7	0.98 0.72	Q < 2.5 Q ≥ 2.5	0.5
Telephone Cr. at Mouth	0.2	0.6	0.92 0.70	Q < 2 Q ≥ 2	0.4
0114	0.0	0.8	0.94 0.78	Q < 5 Q ≥ 5	0.3
0111	0.1	0.8	0.97 0.74	Q < 5 Q ≥ 5	0.7
Nash Fork below Telephone Cr. ¹	---	---	----	-----	0.4
0103	0.2	0.9	0.96 0.75	Q < 1.5 Q ≥ 1.5	0.0
Nash Fork at Green Rock	0.1	0.4	0.88 0.62	Q < 5 Q ≥ 5	0.8
0106	0.1	0.4	0.90 0.62	Q < 5 Q ≥ 5	0.5

¹Nash Fork below Telephone Cr. was not routed; the discharge was taken as the sum of 0111 and Telephone Cr. at Mouth. Two K_r entries are required, but they may have any value.

are calculated by an application of Equation 7-9 for each of the flow points for each day.

The general scheme is to set the value of the Muskingum x and the value of y for the reach, XFLO and YFLO, respectively, and then select the appropriate storage constant according to the flow magnitude on the previous day. The Kx products in Equations 7-7 are calculated from the storage constant and XFLO, and then the CK1, CK2, and CK3 values are obtained from Equations 7-7. Equation 7-9 is then used to calculate the new day's routed flow at the flow point. The flow is then checked to see if it exceeds the minimum. As Equation 7-9 is adapted to each flow point, terms are dropped or added as required by the situation above the flow point.

Sample hydrographs for the 1972 water year are shown in Figure 7-3 for the 0111 flow point, Nash Fork at Brooklyn Lodge. These include the observed hydrograph and the hydrograph as calculated by the model. A hydrograph is also shown for a model development step in which the segment runoffs were collected and combined in proper sequence, but not routed.

Commentary

Further tuning of the model with respect to the FLOW section to achieve a greater agreement with observed data does not seem justified. Water losses to the ground and evapotranspiration need to be accounted for, and melt due to other sources, principally advected energy, need to be incorporated into the model before any tuning process can be effective. The routing scheme is basically valid.

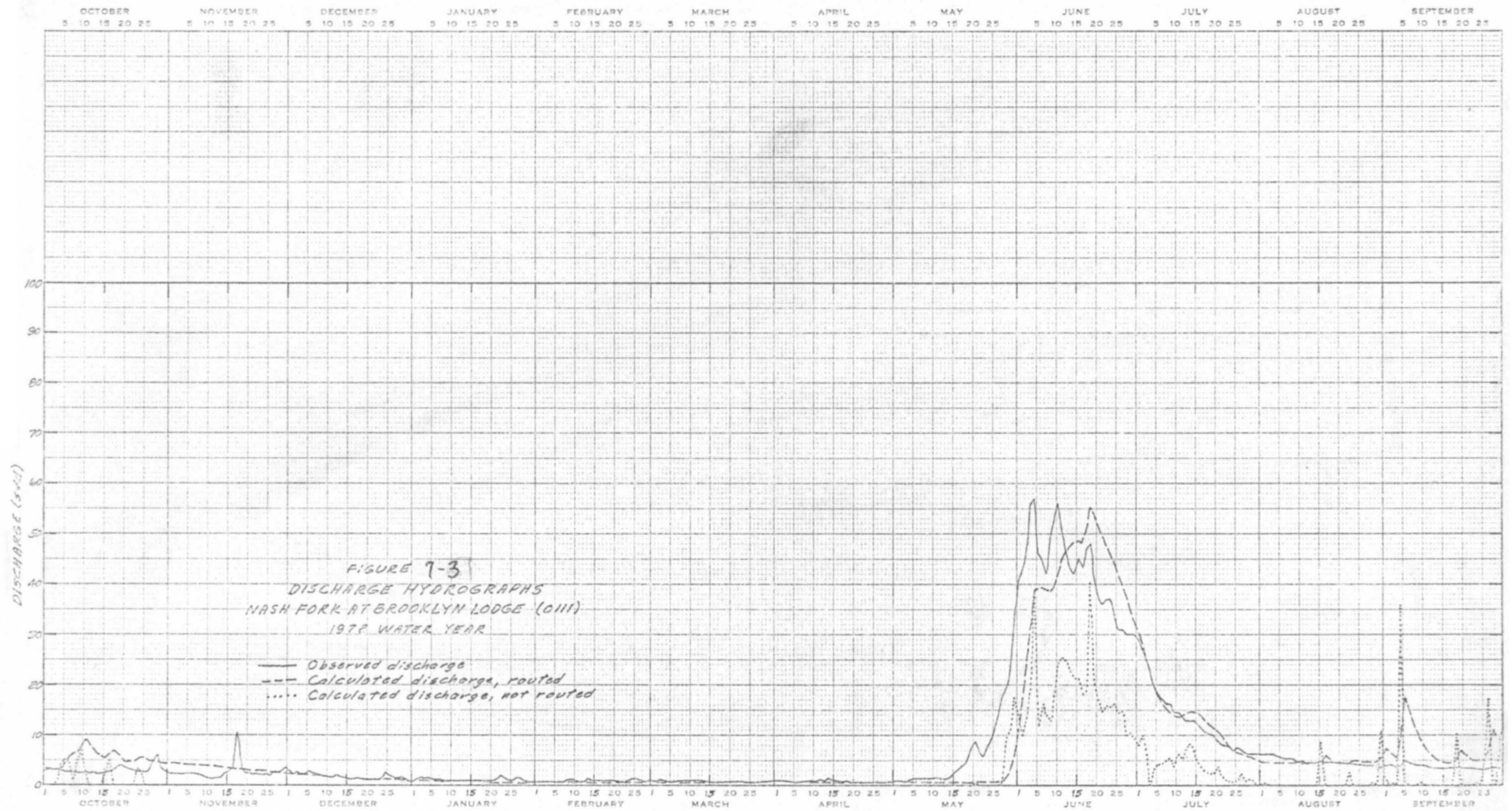


FIGURE 7-3

DISCHARGE HYDROGRAPHS, NASH FORK AT BROOKLYN LODGE (0111), 1972 WATER YEAR

CHAPTER 8

RESULTS

The model results of most concern are the simulated streamflows, the output of the FLOW section. Examination of the hydrographs shows that the simulated flows are in general agreement with the observed flows. They are quite consistent in starting the spring rise (snowmelt runoff) several days later than the observed rises, and in showing a generally corresponding delay in recession flows. Some stations, particularly the lower ones, exhibit a rise at the proper time, but do not peak at the same time as the observed flows. The upper stations particularly show simulated peak discharges that tend to be high.

The annual runoff volumes for the water year at each station seem to be simulated fairly well. Comparisons were made between the generated and observed flows for several periods, expressing the variation as a percent of the observed streamflow according to the relation

$$\text{Variation} = \frac{\text{Generated Flow} - \text{Observed Flow}}{\text{Observed Flow}} (100). \quad (8-1)$$

These variations for the annual, May-August, May-July, June-August, and June-July periods are shown in Table 8-I.

Comparisons with observed data on a monthly basis show some very large variations, as well as some good agreement. These are shown in Table 8-II. It should be noted that the larger variations occur in the low-flow months. Thus a very large variation may be

TABLE 8-I

COMPARISON OF CALCULATED TO OBSERVED STREAMFLOW VOLUMES

Station	Variation from Observed Volumes as Percent of Observed Volumes					
	W.Y.	Annual	May - Aug	May - Jul	Jun - Aug	Jun - Jul
0113	'70	37	31	33	19	20
	'71	-3	-10	-11	-9	-10
	'72	0	-6	-8	1	0
0112	'70	16	24	23	26	25
	'71	-11	-22	-27	-20	-25
	'72	-1	-7	-11	4	0
0114	'72	0 ¹	-6	-5	3	5
0111	'70	30	32	33	32	32
	'71	-9	-6	-10	0	-4
	'72	0	-10	-10	-2	-2
0103	'70	-7	-16	-18	-17	-20
	'71	-36	-45	-46	-41	-43
	'72	28	14	14	3	4
0106	'70	83 ²	72	67	69	64
	'71	10	-6	-11	-5	-11
	'72	27	10	9	16	15

¹No record prior to December of 1972 water year, comparison for 10 months.

²No record January 1970, comparison for 11 months.

TABLE 8-II

COMPARISON OF CALCULATED TO OBSERVED MONTHLY STREAMFLOW VOLUMES

Station	W.Y.	Variation from Observed Volumes as Percent of Observed Volumes											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
0113	'70	4	-42	189	456	3820	7133	4100	306	4	38	12	113
	'71	115	-32	-51	-71	-26	83	5	-49	-45	22	-6	150
	'72	33	11	-27	-29	-23	-15	-22	-70	4	-8	12	111
0112	'70	16	-62	-36	-49	-52	-42	-50	4	12	37	29	108
	'71	58	18	-4	-29	-22	-31	-30	-75	-68	23	12	170
	'72	14	-19	-30	-1	-10	56	35	-83	-6	15	52	169
0114 ¹	'72	---	----	-5	-4	12	0	-25	-71	1	16	-13	117
0111	'70	142	97	-19	-77	-62	-35	-30	41	2	76	27	84
	'71	45	-25	-59	-80	-74	-71	-75	-85	-60	78	33	124
	'72	84	35	-8	-25	-29	-15	-12	-84	-3	3	-2	108
0103	'70	395	81	8	0	0	-100 ³	-100 ³	-7	-45	50	56	361
	'71	503	35	-71	-38 ₄	0 ₄	-100 ³	-100 ³	-100 ³	-52	-25	4	361
	'72	459	2205	3600	-- ₄	-- ₄	-100 ³	-86	65	-1	37	-22	330
0106	'70 ²	174	77	268	--	66	82	53	97	22	128	136	388
	'71	189	108	176	90	104	-47	-35	-18	-49	45	51	266
	'72	213	148	26	33	32	0	10	-24	0	79	40	285

¹No record prior to December of 1972 water year, comparison for 10 months.

²No record January 1970, comparison for 11 months.

³Calculated value of zero.

⁴Observed value of zero, percent of error is infinitely positive.

based on very small discharges where the inherent errors in determining discharges could contribute to the large variation. Large negative variations in May and June could be attributed in part to the delay in the rise of the simulated hydrograph. The large positive variations in July and August are due in part to the delayed recession. The large variations in October and September are probably due to the SNOCOV section, in that it does not seem to respond well at the beginning of the snow accretion season. A statistical analysis of the FLOW results was not deemed justifiable at this time.

With regard to annual flows, average annual precipitation at Little Brooklyn Lake, Site 0108, is about 52 in (132 cm). Average annual runoff at Nash Fork at Brooklyn Lodge (0111) is about 46 in (117 cm). For Sally Creek (0103), where precipitation is measured near the lower end of the watershed, an annual precipitation amount of 33 in (84 cm) results in 28.7 in (73 cm) of runoff. The basin outlet gage (0106) indicates an average runoff of 26.2 in (67 cm). The figures are in general agreement with Ffolliott and Hansen (1968), who found that over 90 percent of the snowpack left the watershed as runoff.

The delay in the rise of the simulated hydrographs may be due to the inadvertent "double-indexing" of the cold content under certain conditions in the PAKTEM section. The computation scheme calculates a snowpack temperature as a function of the snow surface temperature, which is in turn a function of radiation exchange. When the day's snowmelt from RADMEL enters the computation, the

program recalculates the cold content and a new snowpack temperature.

Since the calculated snowmelt from RADMEL is a function of radiation exchange also, the cold content may be increased beyond what it should be from its functional relationship. Subsequent recalculation of the snowpack temperature drives it below that indicated as a function of the snow surface temperature. The effect is that spring melt that should be contributing to the hydrograph rise must remain in the pack as ice after giving up its heat of fusion to satisfy the excessive cold content, and then must be remelted to produce runoff. Allotted project time did not allow for corrections to be made and tested after the discovery of this situation.

The calculated hydrograph peaks tend to be high in the upper reaches of the basin. These are the windswept areas, and apparently sublimation losses should be taken into account, as they can be quite large where the wind fetch is long (Tabler, 1973). Consideration of other losses, such as lake evaporation, evapotranspiration, and infiltration, should be made. These would have the effect of reducing the simulated hydrograph volumes. The accounting for sublimation losses of windblown snow, mentioned above, should be sufficient to account for intercepted snow losses.

Advected energy, especially in the higher windswept areas, should be important in producing melt for an earlier rise. Convection-condensation melt should be a relatively small contributor, but could be important to the model sensitivity in following the

small rises and recessions that are superimposed on the general hydrograph trend.

The variations between the simulated and observed flows in September and October seem to be due primarily to the SNOCOV model. A SNOCOV model more sensitive to early season snowpack conditions is needed.

CHAPTER 9

DISCUSSION AND CONCLUSIONS

Discussion

The subalpine snowmelt runoff model, as described in the preceding chapters, seems to satisfy the project objective for which it was developed. It is a basic model designed to simulate streamflows in the Nash Fork basin with reasonable accuracy and sensitivity. Its theoretical base should be valid in any high-altitude subalpine watershed situation, and probably in other watersheds as well, where snowmelt is the principal source of streamflow. Calibration to other watersheds should present difficulties only in determining the snowcover relationships.

The programming scheme, where the calculation moves in series through the several computing operations, seems advantageous where the snowpack must be considered all year in some basin segments. The individual sections could be readily adapted to a set of subroutines, to be called as needed by a main program. More efficient programming, either in the present form or through a subroutine approach, could certainly be achieved.

It is intended that this model will at least partially answer the plea of Cawood, Thunvik, and Nilsson (1971, p. 79), who state "... it is strongly felt that a major effort to develop a good snowmelt routine is warranted in the next stage of modeling work."

Evaporation and transpiration effects were not included in the model because the allotted project time was limited. Parmele

(1972) suggests that an estimate of potential evapotranspiration to +20 percent may be sufficient for a basin with 40 to 50 inches of water yield when fitting a hydrologic model to a watershed. The Nash Fork basin would approximate the 40 to 50 inches of water yield, so great sophistication in estimate of potential evapotranspiration may not be required.

The largest obstacle to use of the model in other basins appears to be in the snowcover modeling technique. Obtaining snowcover data for determining coefficients in the snowcover equation is an expensive process and requires several years. The technique itself is valid for any basin with snowcover. An alternative approach, modeling snowcover as a function of readily available data from a given basin, would be preferred.

Brink and Leaf (1973) suggest that response units, or sub-watersheds, for a model of this type should average about 10 percent of the total watershed area. This would imply approximately 10 segment pairs, or 20 segments, where 16 segments are presently used in the model. Terrain, basin shape, drainage pattern, forest distribution, and data sources would all influence this choice. Many small segments are desirable for sensitivity but require many sources of accurate data. A few large segments simplify calculation but sacrifice sensitivity.

The RADMEL program section could be used "as is," with the exception of the statements assigning temperature and precipitation data sites to each segment. The PAKTEM section could also be used directly, with the exception of the data source assignments and

changes to eliminate the "double-indexing" of the cold content. FLOW would need to be written for the particular routing sequence encountered in the new basin. The equations and the procedure would be similar to the present situation.

Within the framework outlined above, the model should have general applicability to any basin where snowmelt is the main source of streamflow. The RADMEL section should be adaptable to any basin where adjusted radiation data are desired, provided the bypass features used when a "no-snow" condition is encountered are modified.

There are many projects that could be done toward improving the model itself, and in extending its use. Some of these are suggested, not necessarily in any order of priority.

An evaluation procedure through statistical analysis should be developed, either within the program or as a separate operation, to give a rapid objective measure of "how good" the results are. A major effort should be invested in revising the SNOCOV model. An approach that did not require several seasons of aerial photography would facilitate the adaptation of the model to other watersheds.

The reciprocal distance squared method for estimating missing precipitation records should be examined to see if the method is valid for snowfall in mountainous areas (Wei and McGuinness, 1973). If so, it could be useful for estimating precipitation records lost from the data sites, and possibly for synthesizing additional precipitation sites from observed data.

Provision should be made to include the effects of evapotranspiration in the model. A section should also be added for consideration of advected energy as a melt source.

The proof of the model would be in its performance with data from another basin. It should be tested in this manner if basins with the necessary data sources are available.

Conclusions

1. A first-generation base model describing subalpine snowmelt runoff has been developed for the Nash Fork basin. The importance of solar and longwave radiation has been demonstrated by the fact that it is used as the mechanism to produce potential snowmelt in the model with reasonable success. The importance of the snowpack conditions, such as areal extent of snowcover, cold content, and water equivalent, in modifying the potential snowmelt into runoff has also been demonstrated. The inclusion of additional melt sources, as well as loss considerations, is needed for greater sensitivity.

2. There do not appear to be any theoretical reasons to prevent the model from being applied in other high-altitude watersheds where streamflow is predominately derived from snowmelt. Since rainfall has been considered primarily as a modifier of the snowpack condition and of snowmelt runoff, the model should not be applied to basins where rainfall is a large contributor to runoff without modification of the rainfall runoff treatment.

3. The model is probably not well suited to very small basins where finer time increments would be preferred. Adaptation to larger basins should not present major difficulties.

4. The concept of using segments, one (or more) on each side of a stream reach, appears to make the model more sensitive to the effects of land slope and aspect on the incident solar radiation. When the land forms on the two sides of a stream reach are averaged the aspect effects, in particular, tend to "wash out." Slopes and their aspects are quite important in controlling the amount of solar radiation that can be received on a given surface to provide energy for snowmelt.

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A P P E N D I X

DICTIONARY OF PROGRAM VARIABLES

The alpha-numeric variable names encountered in the model program are defined in alphabetical order in the following listing. Comment cards within the program in conjunction with the first use of many of the variables also carry definitions. Certain names used only for data manipulation in the output subroutines are listed together at the end of the dictionary. These are used only to rearrange the data into the proper arrays for output, and do not enter into the model computations.

A(K,L), B(K,L), C(K,L), D(K,L), E(K,L), F(K,L), G(K,L), H(K,L) =
coefficients for snow cover equation, K for segment number, L = 1
or 2 for open or forested areas, respectively.

AA = computation device.

ADD = accumulated degree-days above 32°F since snowfall.

ADLAT = ratio for adjusting observed horizontal surface radiation from
base latitude to segment latitude.

AKON = computation device, the product of the assigned SKON(N) and
XFLO, used with STORK to calculate CK1, CK2, and CK3 values for
a particular routing computation.

ALB = daily value of snow albedo for segment, decimal fraction.

ALPH = change in longitude to a horizontal surface parallel to the
mean slope of the segment, radians.

ANGL = angle of orbital translation of earth since March 21, radians.

ARAD = accumulated measured insolation (RASWM) since snowfall,
langleys.

AREA(K,L) = segment area, unforested (L = 1) or forested (L = 2), for
K segments, acres.

ATABLE = subroutine for printing water year data, months by columns,
days by rows, no decimal places.

AZ(K) = azimuth of mean down slope direction of segment, clockwise
from north, degrees and decimal parts when entered, radians in
calculations.

BB = computation device.

BFLOK(NN) = the initializing values of FLOW for each of the stream
reaches, NN, where NN = 1,2,3,...,9.

BLAT = base latitude, latitude of base site where solar radiation is
measured, degrees and decimal parts when entered, radians in
calculations.

BTABLE = subroutine for printing water year data, months by columns
(two data columns each month), days by rows, no decimal
places.

CB = computation device.

CC = computation device.

CK1, CK2, CK3 = routing coefficients for streamflow.

CTAB(I) = name device for printing TMIN(KJ,I) and SNOCOV(KJ,I,2) with
BTABLE subroutine.

CTABLE = subroutine for printing water year data, months by columns,
days by rows, two decimal places.

CZ = computation device.

CZS = computation device.

DAY = number of days since snowfall.

DAYANG = constant, average angle of earth orbital movement in 24 hrs,
radians.
= $2\pi/IX$.

DAZ = segment azimuth converted to degrees for output.

DDAY = degree-days above 32°F for day I, limited to zero or positive values.

DELTA = declination of sun as function of orbital position since March 21, radians.

DEN = calculated snow pack density, g/cc.

DEP2 = calculated depth to mid-point of snow pack, cm.

DLAT = segment latitude converted to degrees for output.

DSLO = segment slope converted to degrees for output.

DTAB(I) = name device for printing TMAX(KJ,I) and SNOCOV(KJ,I,1) with BTABLE subroutine, and P(KI,I) and FLOW(NK,I) with CTABLE subroutine.

DWIND(I) = measured daily wind run, for day I, miles.

DYR = days in year, obtained from IX.

ELAT = latitude of a horizontal surface parallel to the mean slope of the segment, radians.

ELEV(K) = mean elevation of segment, feet above sea level.

FDEN(K) = forest density for segment K, decimal fraction.

FF = constant, angular rotation rate of earth, radians per hour.
 = $\pi / 12$, or $1/\text{TIC}$.

FL = computation device to hold SRO from an odd numbered segment to
 combine with SRO from the next even numbered segment.

FLO(KF,I) = combined runoff for a pair of segments identified by KF
 on day I, sfd.

FLOW(KF,I) = channel flow past a flow point or gaging station (either
 actual or potential), sfd. Since each reach requires a
 special calculation, KF here is entered by the actual
 number, rather than by "DO" loop indexing.

I = day of water year.

IX = number of days in water year to be considered, usually 365, or
 366 for leap years.

IYEAR = water year for computations, ending September 30 of IYEAR.

J = temperature site (1 = 0108, 2 = 0112, 3 = 0103, 4 = 0106).

K = segment number.

KF = counter for identification of stream reach based on segment pairs.

KI = counter for stations in output of precipitation data.

KJ = counter for stations in output of temperature and snowcover data.

KX = number of segments to be considered.

L = cover condition in segment, 1 = open, 2 = forested.

M = precipitation site (1 = 0108, 2 = 0103, 3 = 0106).

N = day counter, after precipitation event in segment, for albedo adjustment. Also used as recession constant identifier in FLOW section.

NDAY = day counter from spring equinox; March 21 = 1.

NK = counter for stream reaches (or flow points) in output of FLOW data.

P(M,I) = precipitation for segment K on day I, in, from site M.

PCTSNO = percent snow covered area in segment, for open or forested condition, on day of calculation, decimal fraction.

RADJ = factor for adjusting daily horizontal solar radiation in the segment to the mean slope and mean azimuth of the segment.

RALWO = daily value for long wave radiation exchange in unforested portion of segment, langleys.

RANETF = daily value of net radiation in forested portion of segment, langleys.

RANETO = daily value of net radiation in unforested portion of segment, langleys.

RASWE = daily value of effective short wave radiation in segment, langleys.

RASWM(I) = measured short wave radiation for day I, langleys.

RASWMS = short wave radiation measured at base latitude, adjusted to latitude of segment, langleys.

RASWS = calculated daily incoming solar radiation adjusted to slope and orientation of segment, langleys.

RKON(N) = flow recession constants. There are two recession constants for each reach, assigned by the value of N.

RRUN = runoff due to rain falling upon snow-free areas, ac-in, later converted to sfd for routing.

RTHHOR = theoretical horizontal irradiation factor for segment, langleys.

RTHSLO = theoretical irradiation factor for particular slope and azimuth of segment, langleys.

SB = computation device.

SDAY = counter based on XDAY for aging of snow pack for snow density model.

SKON(N) = storage constants, two for each reach, calculated from the appropriate value of RKON(N).

SLAT(K) = mean segment latitude, degrees and decimal parts when entered, radians in calculations.

SLOPE(K) = mean slope of segment, positive angle, degrees and decimal parts when entered, radians in calculation.

SM(K,I,L) = water available for runoff from segment K, cover L, on day I, from all sources and losses previously considered, in.

SNOCOV(K,I,L) = acres of snow covered area in segment K, for open (L = 1) or forested (L = 2) condition, on Day I.

SNOFOR = SNOCOV(K,2,I) reduced by FDEN(K) to actual (estimated) canopy area, acres.

SNOWOP = SNOCOV(K,1,I) increased by fraction of forest snow cover that is "open" due to forest canopy cover less than complete, acres.

SRADF(K) = segment radiation factor to adjust observed solar radiation between observation site and segment (generally for elevation and atmospheric differences).

SRO = segment runoff, the combined runoff from open and forested portions of a segment, sfd.

STORK = computation device to assign the appropriate value of SKON(N) to a particular routing computation.

SZ = computation device.

SZS = computation device.

TA,TB,TC = computation devices.

TAREA = total segment area, acres.

TCOEF = coefficient for calculating TPAK by thermal diffusion, based on thermal diffusivity as a function of thermal conductivity, densities of ice and snow, and specific heat of ice, and on time (1/2 day in seconds), snow pack density, and mid-point depth of snow pack; dimensionless.

TGR = calculated temperature of ground surface under snow pack, °F.

TGRC = TGR expressed as °C.

TIBH = similar to TIZH, except for latitude of base station.

TIC = constant, average hours for one radian of earth rotation.
= $12/\pi$.

TIZH = time, hours, before or after noon for solar radiation on horizontal surface, considering latitude and declination, for segment. Also sets limits for time of radiation on inclined surfaces.

TIZS1 = time, hours, before noon for sunrise on inclined segment surface, not earlier than -TIZH.

TIZS2 = time, hours, after noon for sunset on inclined segment surface, not later than TIZH.

TMAX(J,I) = maximum temperature for segment K on day I, from site J, °F.

TMAXC = maximum temperature for the day preceding the calculation day, °C.

TMC = mean temperature for the day preceding the calculation day, °C.

TMEAN = mean temperature for segment calculated from TMAX(J,I) and TMIN(J,I), °F.

TMIN(J,I) = minimum temperature for segment K on day I, from site J, °F.

TMINC = minimum temperature for the day preceding the calculation day, °C.

TMLOK = TMLOW expressed in °K.

TMLOW = daily lower average temperature in segment, °F, $(TMIN + TMEAN)/2$.

TMUPK = TMUPP expressed in °K.

TMUPP = daily upper average temperature in segment, °F, $(TMAX + TMEAN)/2$.

TPAK = calculated temperature at mid-point of snow pack depth, °F.

TPAKC = TPAK expressed as °C.

TPAK1C = snow pack temperature from diffusion calculation, based on "upper" average snow surface temperature for day preceding the calculation day, °C.

TPAK2C = snow pack temperature from diffusion calculation, based on "lower" average snow surface temperature for day preceding the calculation day, °C.

TS = snow surface temperature, °F, limited to maximum of 32°F, in RADMEL section.

TSK = TS expressed as °K.

TSNO = temperature of snow surface, based on mean air temperature for the day, in PAKTEM section, °F, limited to maximum of 32°F.

TSNO1C = temperature of snow surface for 1/2 day, based on "upper average" air temperature, °C.

TSNO2C = temperature of snow surface for 1/2 day, based on "lower average" air temperature, °C.

TXEL = computation device.

WAREA(K) = water area of segment K, acres.

WC = "cold content" of snow pack, the inches of water which, upon freezing, would warm the snow pack to 32°F.

WE = water equivalent of snow pack, in.

WIND = accumulated wind run since snowfall, miles.

XALPH = computation device.

XDAY = counter for (1) initializing snow density model for days of snow cover at end of previous water year (XDAY is zero or negative in this case), or (2) counting days of no snow cover at beginning of water year, or in late summer prior to accumulation of snow late in water year.

XEL = computation device.

XFLO = Muskingum x, proportioning constant to indicate the relative importance of inflow and outflow in determining reach storage for routing.

XP = precipitation as rain, in excess of that required to satisfy the "cold content," in.

YALPH = computation device.

YFLO = proportion of the local inflow to the reach that is to be routed, where $(1 - YFLO)$ is the proportion of the local inflow to be added after the routing computation.

DAYS, ICOL, IDAY, INDX, JJ, MONTH, NN, TAB, TAB1, TAB2, TAB3, TAB4, TABN, TABX = variable names and counters used for manipulating data arrays in the output subroutines to give the desired output format.

MODEL USER INSTRUCTIONS

General

The subalpine snowmelt runoff model discussed herein was developed for the University of Wyoming Xerox Data System Sigma 7 computer system. The program is in Fortran IV language, H-level, compatible with the UTS system under which the Computer Center operated at the conclusion of the model development.

An operating core of approximately 64K bits was available, and the model requirements were 19K bits of core. The Computer Center partitions the available core, and the present form of the model requires nearly all of the core available in its operating partition. The total CPU time was 2.77 minutes for the 1972 water year run, broken down to 1.35 minutes of processor execution time, 0.10 minutes of processor service time, 1.26 minutes of user execution time, and 0.06 minutes of user service time. Other water year runs were comparable. The program was run with a time limit of three minutes. The usual output was on the order of 61 pages for complete output.

The model does not use any tapes or disc packs, other than those internal to the computer system. The input data are read into the computer along with the program deck. Figure A-1 shows the card deck arrangement for program operation on the University of Wyoming system. It should be noted that the symbol "!" (bang) preceding the entry on these cards is not printed on the program listing; it is punched in space 1 of each card on which it occurs.

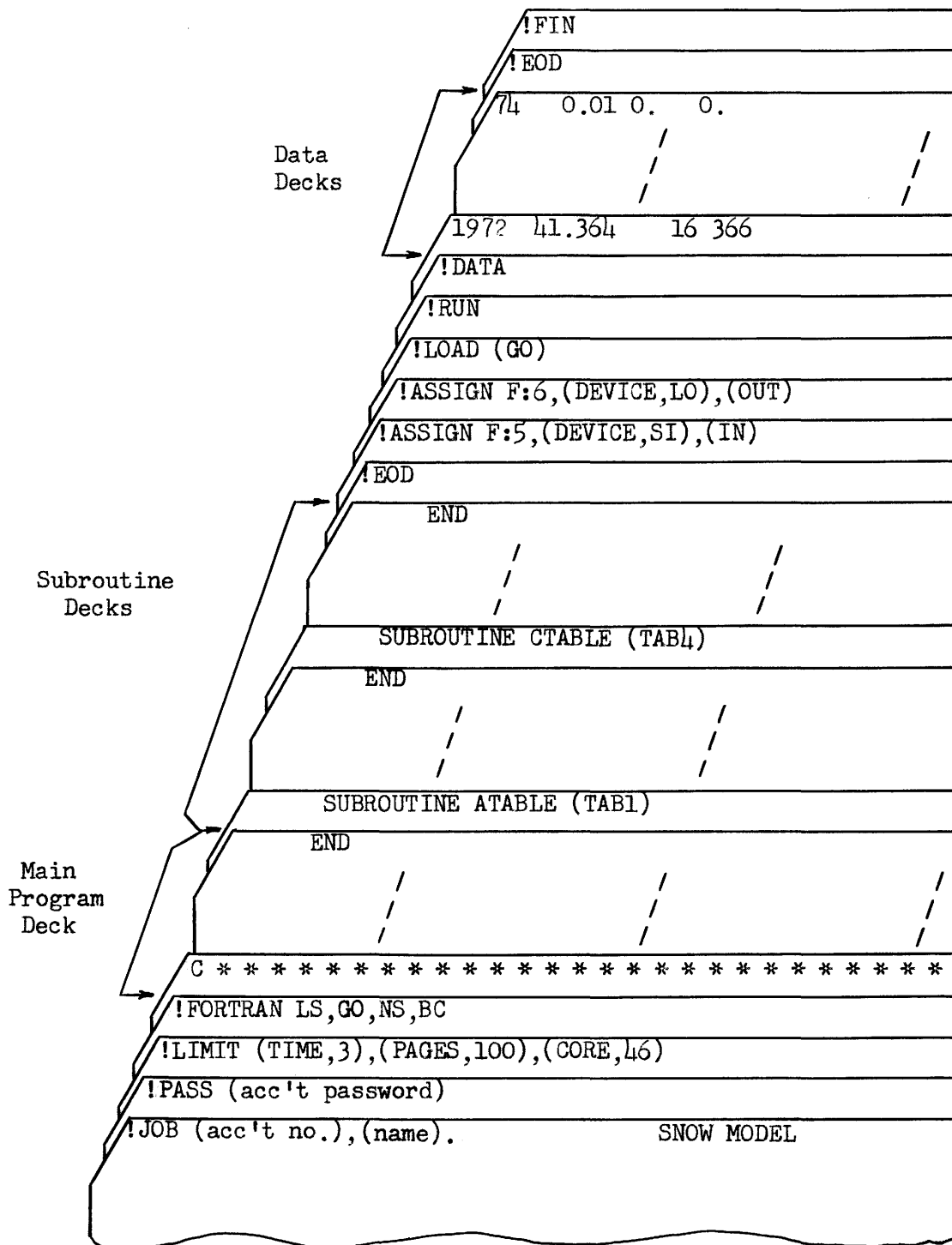


FIGURE A-1

CARD DECK ARRANGEMENT FOR PROGRAM OPERATION

Figure A-8 illustrates the temperature data coding. The data are paired so that the first number is the maximum temperature and the second number is the minimum temperature for the same site on the same day. An "X" is marked on the coding form of Figure A-8 to indicate the change from one temperature site to another. This data set requires 209 cards, with 210 cards for a leap year, and is the largest set in the data deck.

IBM FORTRAN Coding Form GPO: 75274-01 MC5577 Printed in U.S.A.

DATE		STATION ID		ELEVATION		LATITUDE		LONGITUDE		TIME		MOON		WIND		WEATHER		CLOUDS		VISIBILITY		REMARKS	
FORTRAN STATEMENT																							
1	1	72	38	10	18	12	36	14	47	19	50	25	54	23	50	26							
1	2	40	27	50	27	54	28	48	36	40	28	46	33	52	30								
1	3	46	28	45	28	43	26	23	17	32	21	41	22	38	26								
1	4																						
1	5																						
1	51																						
1	52	52	33	48	33	45	31	34	23	45	29	50	30	36	22								
1	2	135	21	50	32	X 37	16	21	15	41	18	45	25	49	27								
2	2	56	25	49	27	41	27	50	28	54	34	53	33	40	27								
2	3																						
2	5																						
2	52																						
2	3	151	34	37	26	36	21	51	32	X 34	19	24	18	43	20								
3	2	49	22	53	27	59	21	53	25	46	27	54	29	58	29								
3	3																						
3	5																						
3	52																						
3	4	138	27	48	25	56	34	38	29	40	23	55	30	X 40	23								
4	2	34	22	53	20	59	20	60	25	68	23	61	25	54	26								
4	3																						
4	5																						
4	53																						
4	54	60	31																				

**Number of lines per page may vary slightly.

FIGURE A-8
 CODING FOR TEMPERATURES
 (Data Cards 138 through 347)

The eighth, and last, data set consists of daily precipitation amounts in inches from three sites, P(M,I), where M identifies the site and I is the day of the water year. These data are coded in triplets, precipitation for sites 1, 2, and 3 for each day, with

cards), and 72-1180, 72-1190, 72-1200, and 72-1210 which initialize DAY, WIND, ARAD, and ADD for the snowcover calculation. The other group of values initialized within the program is in the PAKTEM section. Card number 72-6020 is a comment card. Cards numbered 72-6021 through 72-6026 assign the appropriate values of XDAY and WE to the particular combinations of segment, temperature site, and precipitation site for the water year. Certain other values are put into the calculation as constants, and would not normally be changed.

Output

The model program has options for printing out tables of the input data, the calculated snowcover, and the calculated streamflows. The output instructions are arranged so that groups of tables can be omitted as desired by removing the proper sets of cards. Output format cards are grouped at the end of the program. With the exceptions of the table of snowcover coefficients and the table of physical data, all output tables require the use of a formulating subroutine, either ATABLE, BTABLE, or CTABLE. These subroutines rearrange the data to the desired array forms for printing.

Cards numbered 8000 through 8016, together with the ATABLE subroutine, print the observed radiation table for the particular water year. The observed wind run table is printed from cards numbered 8020 through 8030, again using the ATABLE subroutine. Maximum and minimum temperatures for each day at each site for a given water year are printed from cards numbered 8040 through

8063. The BTABLE subroutine is utilized for these tables to provide a double column under each month. Observed precipitation for each day at each of three sites is printed with cards numbered 8070 through 8084, using the CTABLE subroutine.

The physical data for each segment are printed by the cards numbered 8090 through 8115. The angles, which were converted to radians within the program, are returned to the form of degrees for printout by cards 8106, 8107, and 8108. The segment areas are obtained by summing the unforested and forested areas within the segment, card number 8109. The coefficients for the snowcover submodel are printed by cards 8120 through 8146.

The calculated snowcovered areas within each segment are printed from the cards numbered 8150 through 8167, and with the BTABLE subroutine to provide a double entry for each date. The tables of mean daily flows at the nine flow points are the desired outputs of the model. Cards 8170 through 8201, with the CTABLE subroutine, provide this printout.

Removal of a particular print section, as the model is presently arranged, does not remove the format cards associated with it. These cards are numbered in sequence, in general, with the cards in their print section, but some are used by several of the print sections. They are placed at the end of the main program and left undisturbed. The subroutines contain their own format cards.

Operation Instructions

There are no particular operation instructions that are unique to this model program. The general requisites of accurate coding and card-punching, and of keeping program and data cards in their proper order, are essential.

PROGRAM LISTING

The program listing shown on the following pages is essentially page by page as received from the computer printer. As previously noted, those cards beginning with a "!" (bang) do not have the bang printed, and certain of the bang cards are not printed at all (!EOD, !DATA, and !FIN). Comparison of Figure A-1 with the following printout would be advantageous, for the cards as shown in Figure A-1 are essential. The computer supplies certain other statements which are not a part of the card deck. Semicolons (;) are not printed.

The page of printout following the SUBROUTINE CTABLE printout is a composite of several computer printout pages. The final page contains the run summary.

54.	A(K,L)=0.0	0300
55.	B(K,L)=C.0	0310
56.	C(K,L)=0.0	0320
57.	D(K,L)=0.0	0330
58.	E(K,L)=0.0	0340
59.	F(K,L)=0.0	0350
60.	G(K,L)=0.0	0360
61.	10 H(K,L)=0.0	0370
62.	DO14 K=1,16	0380
63.	DO14 I=1,366	0390
64.	DO14 L=1,2	0400
65.	SNOCOV(K,I,L)=0.0	0410
66.	14 SM(K,I,L)=0.0	0420
67.	DO 11 I=1,366	0430
68.	RASWM(I)=0.0	0440
69.	CTAB(I)=0.	0441
70.	DTAB(I)=0.	0442
71.	11 DWIND(I)=0.0	0450
72.	DO 12 J=1,4	0460
73.	DO 12 I=1,366	0470
74.	TMAX(J,I)=0.0	0480
75.	12 TMIN(J,I)=0.0	0490
76.	DO 13 M=1,3	0500
77.	DO 13 I=1,366	0510
78.	13 P(M,I)=0.0	0520
79.	DO 15 N=1,18	0521
80.	SKON(N)=0.0	0522
81.	15 RKON(N)=0.0	0523
82.	DO 16 NN=1,9	0524
83.	16 BFLOK(NN)=0.0	0525
84.	C	
85.	C READ INPUT DATA INTO ARRAYS	0530
86.	C	
87.	C READ WATER YEAR, RADIATION OBSERVATION BASE LATITUDE, NO. OF SEGMENTS	0531
88.	C NO. OF DAYS IN YEAR, THEN READ FLOW INITIALIZATION, THEN READ FLOW	0532
89.	C RECESSION CONSTANTS.	0533
90.	READ(5,100)IYEAR,BLAT,KX,IX	0540
91.	READ(5,170)BFLOK	72A0540
92.	READ(5,160)RKON	0541
93.	DO50 K=1,KX	0550
94.	C READ PHYSICAL DATA FOR SEGMENTS IN WATERSHED.	0551
95.	50 READ(5,110) SLAT(K),AZ(K),SLOPE(K),ELEV(K),WAREA(K),FOEN(K),	0560
96.	ISRADF(K)	0561
97.	DO51 K=1,KX	0590
98.	DO 51 L=1,2	0600
99.	C READ AREAS AND SNOW COVER EQ. COEFFICIENTS FOR OPEN AND FORESTED	0601
100.	C PORTIONS OF EACH SEGMENT.	0602
101.	51 READ(5,120)AREA(K,L),A(K,L),B(K,L),C(K,L),D(K,L),E(K,L),F(K,L),	0610
102.	IG(K,L),H(K,L)	0611
103.	C READ WATER YEAR DATA FOR RADIATION, WIND, TEMPERATURES, PRECIPITATION	0612
104.	READ(5,130)(RASWM(I),DWIND(I),I=1,IX)	0650
105.	READ(5,140)((TMAX(J,I),TMIN(J,I),I=1,IX),J=1,4)	0700
106.	READ(5,150)((P(M,I),M=1,3),I=1,IX)	0750
107.	100 FORMAT(14,F10.3,214)	0780

108.	110	FORMAT(5X,4F10.0,3F5.0)	0790
109.	120	FORMAT(5X,7F10.0/5X,2F10.0)	0800
110.	130	FORMAT(5X,14F5.0)	0810
111.	140	FORMAT(5X,14F5.0)	0820
112.	150	FORMAT(5X,15F5.0)	0830
113.	160	FORMAT(5X,14F5.0/5X,4F5.3)	0831
114.	170	FORMAT(5X,9F5.1)	0832
115.	C		
116.	C	CONVERT ANGLES FROM DEGREES TO RADIANS	0840
117.	C		
118.		BLAT = BLAT * 0.0174533	0850
119.		DO 55 K=1,KX	0860
120.		SLAT(K)= SLAT(K) * 0.0174533	0880
121.		IF(ABS(SLAT(K)-BLAT).LT.0.00873)SLAT(K)=BLAT	0890
122.		SLOPE(K)=SLOPE(K)* 0.0174533	0900
123.		55 AZ(K)= AZ(K)* 0.0174533	0910
124.	C	* *	
125.	C	SNOCOV	1000
126.	C	* *	
127.	C		
128.	C	COMPUTES AREAL SNOW COVER IN EACH SEGMENT (K) ON EACH DAY (I) FOR	1001
129.	C	OPEN AND FORESTED AREAS (L) TO GIVE SNOCOV(K,I,L) IN ACRES.	1002
130.	C		
131.	C	VARIABLES DAY, WIND, ARAD, ADD, ARE INITIALIZED TO START PARTICULAR	1003
132.	C	WATER YEAR.	1004
133.	C		
134.	C	FOR WATER YEAR 1972	72-1005
135.	C		
136.	C	ASSIGN TEMPERATURE AND PRECIPITATION STATIONS TO EACH SEGMENT.	1006
137.		DO 200 K=1,KX	1010
138.		IF(K.LE.4)J=1 M=1 GO TO 211	1020
139.		IF(K.LE.6)J=2 M=1 GO TO 211	1030
140.		IF(K.LE.11)J=1 M=1 GO TO 211	1040
141.		IF(K.LE.12)J=3 M=2 GO TO 211	1050
142.		IF(K.LE.14)J=2 M=2 GO TO 211	1060
143.		J=4	1070
144.		M=3	1071
145.	C	ABOVE 7 CARDS USED TO CALL TEMPS FROM 4X366 (J,I) ARRAY AND PRECIP	1080
146.	C	FROM 3X366 (M,I) ARRAY--USED TO SAVE DIMENSION STORAGE SPACE.	1081
147.		211 DO 212 I=1,IX	1090
148.		TMEAN=(TMAX(J,I) + TMIN(J,I))/2.0	1110
149.		IF(I.EQ.1)GO TO 203	1120
150.		DDAY=TMEAN - 32.0	1130
151.		IF(DDAY.LE.0.0)DDAY=0.0	1140
152.		IF(P(M,I).GT.0.0)GO TO 204	1150
153.		GO TO 205	1160
154.	C		
155.	C	FOLLOWING FOUR CARDS, 203, 208, 209, 210, INITIALIZE SNOCOV FOR	1170
156.	C	1972	72-1173
157.	C		
158.		203 DAY=1.	72-1180
159.		208 WIND=408.	72-1190
160.		209 ARAD=206.	72-1200
161.		210 ADD=0.	72-1210

216.	IF(K.LE.11)J=1 M=1 GO TO 626	4190
217.	IF(K.LE.12)J=3 M=2 GO TO 626	4200
218.	IF(K.LE.14)J=2 M=2 GO TO 626	4210
219.	J=4	4220
220.	M=3	4221
221.	626 DO 627 I=1,IX	4230
222.	TMEAN=(TMAX(J,I) + TMIN(J,I))/2.0	4250
223.	C ADJUST OPEN AND FOREST SNOW AREAS FOR FOREST DENSITY	4260
224.	SNOWOP=SNOCOV(K,I,1)+ SNOCOV(K,I,2)* (1.0- FDEN(K))	4270
225.	SNOFOR=SNOCOV(K,I,2) * FDEN(K)	4280
226.	IF(SNOWOP.EQ.0.0)GO TO 604	4290
227.	C DECISION AS TO LEAP YEAR, THEN APPROPRIATE CALCULATION FOR ANGLE OF	4300
228.	C ORBITAL TRANSLATION SINCE MARCH 21, THEN CALC. OF DECLINATION (DELTA)	4301
229.	C FOR DAY I.	4302
230.	IF(CYR.EQ.366.0)GO TO 628	4310
231.	IF(1.GE.173)GO TO 629	4320
232.	NDAY=I-172	4330
233.	GO TO 606	4340
234.	628 IF(1.GE.174)GO TO 605	4350
235.	NDAY=I+193	4360
236.	GO TO 606	4370
237.	629 NDAY=I+192	4380
238.	GO TO 606	4390
239.	605 NDAY=I-173	4400
240.	606 ANGL=DAYANG * FLOAT(NDAY)	4410
241.	DELTA=0.4109* SIN(ANGL)	4420
242.	C CALCULATE TIME OF NOON TO SUNRISE OR SUNSET ON HOR. SURFACE IN SEG. K	4430
243.	C ON DAY I (TIZH), AND SAME AT OBSERVATION (BASE) LAT. (TIBH), THEN	4431
244.	C CALC. LATITUDE ADJUSTMENT FOR OBS. RADIATION (ADLAT) FOR DAY I.	4432
245.	IF(DELTA.LT.0.0001)TIZH=6.0 GO TO 619	4440
246.	CZ=-TAN(SLAT(K)) * TAN(DELTA)	4450
247.	SZ=SQRT(1.0 - CZ**2.0)	4460
248.	TIZH=TIC * ATAN2(SZ,CZ)	4470
249.	IF(TIZH.LT.0.0)TIZH=0.0 GO TO 619	4480
250.	IF(TIZH.GT.12.0)TIZH=12.0	4490
251.	619 IF(SLAT(K).EQ.BLAT)ADLAT=1.0 GO TO 609	4500
252.	IF(DELTA.LT.0.0001)TIBH=6.0 GO TO 620	4510
253.	CB=-TAN(BLAT) * TAN(DELTA)	4520
254.	SB=SQRT(1.0 - CB**2.0)	4530
255.	TIBH=TIC * ATAN2(SB,CB)	4540
256.	IF(TIBH.LT.0.0)TIBH=0.0 GO TO 621	4550
257.	IF(TIBH.GT.12.0)TIBH=12.0	4560
258.	620 ADLAT=(TIZH * COS(SLAT(K) - DELTA))/(TIBH * COS(BLAT - DELTA))	4570
259.	GO TO 609	4580
260.	621 ADLAT=COS(SLAT(K) - DELTA)/COS(BLAT - DELTA)	4590
261.	609 RASWMS=RASWM(I) * ADLAT	4600
262.	C	
263.	C RASWMS IS MEASURED SOLAR RADIATION ADJUSTED TO SEGMENT K LAT., DAY I.	4610
264.	C	
265.	C NEXT, RADIATION ADJUSTMENT IN SEGMENT K ON DAY I FOR SEGMENT SLOPE	4611
266.	C AND AZIMUTH. USES HOR. SURFACE PARALLEL TO SLOPE AT ANOTHER LATITUDE	4612
267.	C AND LONGITUDE. ELAT IS OTHER LAT., ALPH IS DIFFERENCE IN LONG. TO	4613
268.	C ELAT. RADJ IS RATIO, THEORET. RAD. AT PARALLEL HOR. SURFACE TO SAME	4614
269.	C ON HOR. SURFACE IN SEGMENT.	4615

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270. C
271. IF(SLOPE(K).LT.0.0003)RADJ=1.0 GO TO 610 4620
272. IF(RELT.LT.0.0001)GO TO 622 4630
273. CZS=-TAN(ELAT) * TAN(DELT) 4640
274. SZS=SQRT(1.0 - CZS**2.0) 4650
275. TIZS1=-TIC *(ATAN2(SZS,CZS) + ALPH) 4660
276. GO TO 623 4670
277. 622 TIZS1=-6.0 + ALPH 4680
278. 623 IF(TIZS1.LT.-TIZH)TIZS1=-TIZH 4690
279. IF(DELT.LT.0.0001)GO TO 624 4700
280. TIZS2=TIC *(ATAN2(SZS,CZS) - ALPH) 4710
281. GO TO 625 4720
282. 624 TIZS2=6.0 - ALPH 4730
283. 625 IF(TIZS2.GT.TIZH)TIZS2=TIZH 4740
284. CC=SIN(FF * TIZH) 4750
285. AA=SIN(FF * TIZS2) - SIN(FF * TIZS1) 4760
286. BB=TIZS2 - TIZS1 4770
287. RTHSLO=BB * SIN(ELAT) * SIN(DELT) + TIC*AA* COS(ELAT) * COS(DELT) 4780
288. RTHHOR=2.0*(TIZH * SIN(SLAT(K)) * SIN(DELT) + TIC*CC *COS(SLAT(K)) 4790
289. * COS(DELT)) 4791
290. RADJ=RTHSLO/RTHHOR 4800
291. IF(RADJ.LT.0.05)RADJ=0.05 4810
292. 610 RASWS=RASWMS * RADJ * SRADF(K) 4820
293. C
294. C RASWS IS MEASURED INSOLATION ADJUSTED FOR LATITUDE, SLOPE, AZIMUTH TO 4830
295. C SEGMENT K ON DAY I. SRADF(K) IS A GENERAL FACTOR FOR CLOUDS, HAZE, 4831
296. C ETC. 4832
297. C
298. C NEXT, DETERMINE ALBEDO AND EFFECTIVE SHORT WAVE RADIATION. DAY I=1 IS 4833
299. C ARBITRARILY SET WITH N=5 DAYS SINCE SNOWFALL FOR ALBEDO. (IF THERE 4834
300. C IS NO SNOW IN THE OPEN ON DAY I, ALBEDO CALC. IS BYPASSED). 4835
301. C
302. IF(I.EQ.1)N=5 4840
303. IF(P(M,I).EQ.0.0)GO TO 611 4850
304. IF(TMEAN.LE.34.0)N=0 ALB=0.80 GO TO 612 4860
305. C WHEN PRECIP. OCCURS AND TMEAN IS 34 DEG. F OR LESS, SNOW. IF GREATER 4861
306. C ALBEDO IS SET FOR RAIN-DN-SNOW. 4862
307. N=16 4870
308. ALB=0.50 4880
309. GO TO 612 4890
310. 611 N=N + 1 4900
311. ALB=0.82 - 0.02 * FLOAT(N) 4910
312. GO TO 613 4920
313. 604 IF(P(M,I).EQ.0.0)RANETO=0.0 GO TO 614 4930
314. IF(TMEAN.LE.34.0)N=0 ALB=0.80 GO TO 612 4940
315. RANETO=0.0 4950
316. GO TO 614 4960
317. 613 IF(ALB.LT.0.40)ALB=0.40 4970
318. 612 RASWE=RASWS * (1.0 - ALB) 4980
319. C
320. C RASWE IS EFFECTIVE SHORT WAVE RADIATION FOR SEGMENT K ON DAY I, IF 4990
321. C SNOW COVER EXISTED IN THE OPEN PORTION ON DAY I. 4991
322. C
323. C NEXT, LONG WAVE RADIATION EXCHANGE FOR OPEN AND FOREST. USE UPPER 4992

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324.	C	AVERAGE AND LOWER AVERAGE TEMPERATURES.	4993
325.	C	SUFFIX K INDICATES KELVIN TEMPERATURES.	4994
326.	C		
327.		IF (TMEAN.GE.32.0)TS=32.0 TSK=273.0 GO TO 630	5000
328.		TS=TMEAN	5010
329.		TSK=0.557 *(TS - 32.0)+ 273.0	5020
330.	630	TMUPP=(TMAX(J,I)+ TMEAN)/2.0	5030
331.		TMLOW=(TMIN(J,I)+ TMEAN)/2.0	5040
332.		TMLOK=0.557 *(TMLOW- 32.0)+ 273.0	5050
333.		TMUPK=0.557 *(TMUPP- 32.0)+ 273.0	5060
334.		TA=(TMLOK/273.0)**4.0	5070
335.		TB=(TMUPK/273.0)**4.0	5080
336.		TC=(TSK/273.0)**4.0	5090
337.	C		
338.	C	LONG WAVE RADIATION EXCHANGE IN OPEN, RALWO	5100
339.	C		
340.		RALWO=330.0* 0.76 *(TA+TB-2.63*TC)	5110
341.		IF(RALWO.LT.-660.0)RALWO=-660.0 GO TO 515	5120
342.		IF(RALWO.GT.660.0)RALWO=660.0	5130
343.	615	RANETO=RASWE+ RALWO	5140
344.	C		
345.	C	RANETO IS NET ALL WAVE RADIATION EXCHANGE IN OPEN FOR SEG. K ON DAY I	5150
346.	C		
347.		IF(SNOFOR.EQ.0.0)SM(K,I,2)=0.0 GO TO 616	5160
348.		GO TO 617	5170
349.	614	IF(SNOFOR.EQ.0.0)SM(K,I,1)=0.0 SM(K,I,2)=0.0 GO TO 627	5180
350.	C	SUFFIX K INDICATES KELVIN TEMPERATURES.	5181
351.		IF (TMEAN.GE.32.0)TS=32.0 TSK=273.0 GO TO 631	5190
352.		TS=TMEAN	5200
353.		TSK=0.557 *(TS- 32.0)+ 273.0	5210
354.	631	TMUPP=(TMAX(J,I)+ TMEAN)/2.0	5220
355.		TMLOW=(TMIN(J,I)+ TMEAN)/2.0	5230
356.		TMLOK=0.557 *(TMLOW- 32.0)+ 273.0	5240
357.		TMUPK=0.557 *(TMUPP- 32.0)+ 273.0	5250
358.		TA=(TMLOK/273.0)**4.0	5260
359.		TB=(TMUPK/273.0)**4.0	5270
360.		TC=(TSK/273.0)**4.0	5280
361.	617	RANETF=330.0 *(TA+TB-2.0*TC)	5290
362.		IF(RANETF.LT.-660.0)RANETF=-660.0 GO TO 618	5300
363.		IF(RANETF.GT.660.0)RANETF=660.0	5310
364.	C		
365.	C	RANETF IS NET LONG WAVE RADIATION EXCHANGE IN FOREST FOR SEG. K ON	5320
366.	C	DAY I. (SHORT WAVE NOT TREATED AS SUCH IN FOREST).	5321
367.	C		
368.		618 SM(K,I,2)=RANETF/203.2	5330
369.		616 SM(K,I,1)=RANETO/203.2	5340
370.		627 CONTINUE	5350
371.		603 CONTINUE	5360
372.	C		
373.	C	SM(K,I,1) AND SM(K,I,2) ARE POTENTIAL SNOWMELTS IN INCHES DUE TO THE	5370
374.	C	RADIATION EXCHANGE IN OPEN AND FOREST AREAS RESPECTIVELY FOR SEGMENT	5371
375.	C	K ON DAY I.	5372
376.	C	(SM'S ARE LATER CONVERTED TO AC-IN, THEN LATER TO SFD.)	5373
377.	C		

432.	DEN=DEN - (.0045*ELEV(K)/1000.)	6180
433.	C CALC HALF DEPTH OF SNOW (DEP2) FROM WE AND DEN. CALCS ARE DDNE IN SI	6181
434.	C UNITS TO FACILITATE USE OF CONSTANTS, THEN CONVERTED TO ENGLISH UNIT	6182
435.	705 DEP2=1.27*WE/DEN	6190
436.	TCOEF=1080./((2.75-DEN)*(DEP2**2.))	6200
437.	C FOR STABILITY TCOEF LIMITED TO .5 MAX.	6201
438.	IF(TCOEF.GT.0.5)TCOEF=.5	6210
439.	IF(1.GT.1)GOTO 706	6220
440.	TSNO=TMEAN	6230
441.	IF(TSNO.GT.32.)TSNO=32.	6240
442.	TSNO1C=.556*(TSNO-32.)	6250
443.	TSNO2C=TSNO1C	6260
444.	GOTO 707	6270
445.	C CALC TPAK USING UPPER AND LOWER AVERAGES JF TSNO, 12-HR EACH, AND	6271
446.	AVERAGE RESULTING VALUES FOR TPAK. DONE FOR STABILITY.	6272
447.	C SUFFIX C INDICATES CENTIGRADE TEMPERATURES.	6273
448.	706 TMAXC=.556*(TMAX(J,I-1)-32.)	6280
449.	TMINC=.556*(TMIN(J,I-1)-32.)	6290
450.	TMC=(TMAXC + TMINC)/2.	6300
451.	TSNO1C=(TMAXC + TMC)/2.	6310
452.	TSNO2C=(TMINC + TMC)/2.	6320
453.	707 TGRC=.556*(TGR-32.)	6330
454.	TPAKC=.556*(TPAK-32.)	6340
455.	C SOLUTION OF DIFFUSION EQ. FOR EACH HALF-DAY PACK TEMP., THEN AVERAGE	6341
456.	C FOR THE DAY AND CONVERT TO DEG. F.	6342
457.	TPAK1C=TPAKC + TCOEF*(TGRC -2.*TPAKC + TSNO1C)	6350
458.	TPAK2C=TPAKC + TCOEF*(TGRC -2.*TPAKC + TSNO2C)	6360
459.	TPAKC=(TPAK1C + TPAK2C)/2.	6370
460.	TPAK=(TPAKC/.556) + 32.	6380
461.	TGR=TGR+.03	6390
462.	C GROUND ALLOWED TO WARM UNDER SNOW AT 0.03 DEG. F PER DAY.	6391
463.	703 IF(TGR.GT.33.)TGR=33.	6400
464.	IF(TPAK.GT.32.)TPAK=32.	6410
465.	IF(TSNO.GT.32.)TSNO=32.	6420
466.	C NEXT ADJUST SM FOR PRECIP, COLD CONTENT, LIMITED WE, AND ADJUST TPAK.	6421
467.	RRUN=0.	6422
468.	C RRUN IS RUNOFF FROM RAIN ON SNOW-FREE AREA, AC-IN, INDEXED TO ZERO	6423
469.	C BEFORE NEW VALUE CALCULATED.	6424
470.	IF(P(M,I).EQ.0.)GOTO 708	6430
471.	IF(TMEAN.GT.34.)GOTO 709	6440
472.	C PRECIP. OCCURRED AND TMEAN EXCEEDS 34 DEG. F, RAINED.	6441
473.	708 WE=WE + P(M,I)	6450
474.	WC=WE *(32.-TPAK)/288.	6460
475.	GOTO 710	6470
476.	709 WC=WE *(32.-TPAK)/288.	6480
477.	RRUN=(P(M,I)-.21)*(AREA(K,L)-SNOCOV(K,I,L))	6481
478.	IF(RRUN.LT.0.)RRUN=0.	6482
479.	IF(P(M,I).GE.WC)GOTO 711	6490
480.	WE=WE + P(M,I)	6500
481.	WC=WC - P(M,I)	6510
482.	GOTO 710	6520
483.	711 TPAK=32.	6530
484.	XP=P(M,I)-WC	6540
485.	C XP IS RAIN IN EXCESS OF COLD CONTENT, PRESUMED AVAILABLE TO INCREASE	6541

540.	FLOW(6,1)=FLOW(3,1)+FLOW(5,1)+BFLOK(6)	7130
541.	FLOW(7,1)=FLO(7,1)+BFLOK(7)	7140
542.	FLOW(8,1)=FLOW(6,1)+FLOW(7,1)+FLO(6,1)+BFLOK(8)	7150
543.	FLOW(9,1)=FLOW(8,1)+FLO(8,1)+BFLOK(9)	7160
544.	IF(FLOW(9,1).LT.0.2)FLOW(9,1)=0.2	B7160
545.	GO TO 900	7160A
546.	C AFTER DAY 1, CALCULATE FLOWS BY MUSKINGUM ROUTING. XFLO IS MUSKINGUM	7161
547.	C X, YFLO IS FRACTION OF LOCAL INFLOW TO BE ROUTED, REST ADDED LATER.	7162
548.	C	
549.	C CALCULATE FLOW ON DAY I AT STA. 0113, TEL. CR. AB. TOWNER LK.	A7162
550.	902 XFLO=0.2	7163
551.	YFLO=0.8	7164
552.	IF(FLOW(1,I-1).GE.6.)STORK=SKON(2) AKON=SKON(2)*XFLO GO TO 903	7170
553.	AKON=SKON(1)*XFLO	7171
554.	STORK=SKON(1)	7180
555.	903 CK1=(AKON+0.5)/(STORK-AKON+0.5)	7181
556.	CK2=(AKON-0.5)/(STORK-AKON+0.5)	7182
557.	CK3=(STORK-AKON-0.5)/(STORK-AKON+0.5)	7183
558.	FLOW(1,I)=CK1*YFLO*FLO(1,I-1)-CK2*YFLO*FLO(1,I)+CK3*FLOW(1,I-1)+{(1	7184
559.	*.-YFLO)*(FLO(1,I-1)+FLO(1,I))	7185
560.	IF(FLOW(1,I).LT.0.7)FLOW(1,I)=0.7	7190
561.	C CALCULATE FLOW ON DAY I AT STA. 0112, TEL. CR. BEL. MIDDLE POND.	7191
562.	XFLO=0.1	7192
563.	YFLO=0.7	7193
564.	IF(FLOW(2,I-1).GE.2.5)STORK=SKON(4) AKON=SKON(4)*XFLO GO TO 904	7200
565.	AKON=SKON(3)*XFLO	7201
566.	STORK=SKON(3)	7210
567.	904 CK1=(AKON+0.5)/(STORK-AKON+0.5)	7211
568.	CK2=(AKON-0.5)/(STORK-AKON+0.5)	7212
569.	CK3=(STORK-AKON-0.5)/(STORK-AKON+0.5)	7213
570.	FLOW(2,I)=CK1*(FLOW(1,I-1)+YFLO*FLO(2,I-1))-CK2*(FLOW(1,I)+YFLO*FL	7214
571.	*O(2,I))+CK3*FLOW(2,I-1)+(1.-YFLO)*(FLO(2,I-1)+FLO(2,I))	7215
572.	IF(FLOW(2,I).LT.0.5)FLOW(2,I)=0.5	7221
573.	C CALCULATE FLOW ON DAY I AT TEL. CR. AB. MOUTH (NO GAGE).	A7221
574.	XFLO=0.2	7222
575.	YFLO=0.6	7223
576.	IF(FLOW(3,I-1).GE.2.)STORK=SKON(6) AKON=SKON(6)*XFLO GO TO 905	7230
577.	AKON=SKON(5)*XFLO	7231
578.	STORK=SKON(5)	7240
579.	905 CK1=(AKON+0.5)/(STORK-AKON+0.5)	7241
580.	CK2=(AKON-0.5)/(STORK-AKON+0.5)	7242
581.	CK3=(STORK-AKON-0.5)/(STORK-AKON+0.5)	7243
582.	FLOW(3,I)=CK1*(FLOW(2,I-1)+YFLO*FLO(3,I-1))-CK2*(FLOW(2,I)+YFLO*FL	7244
583.	*O(3,I))+CK3*FLOW(3,I-1)+(1.-YFLO)*(FLO(3,I-1)+FLO(3,I))	7245
584.	IF(FLOW(3,I).LT.0.4)FLOW(3,I)=0.4	7251
585.	C CALCULATE FLOW ON DAY I AT STA. 0114, NASH FK. AT BROOKLYN LK. OUTLET	A7251
586.	XFLO=0.0	7252
587.	YFLO=0.8	7253
588.	IF(FLOW(4,I-1).GE.5.)STORK=SKON(8) AKON=SKON(8)*XFLO GO TO 906	7260
589.	AKON=SKON(7)*XFLO	7261
590.	STORK=SKON(7)	7270
591.	906 CK1=(AKON+0.5)/(STORK-AKON+0.5)	7271
592.	CK2=(AKON-0.5)/(STORK-AKON+0.5)	7272
593.	CK3=(STORK-AKON-0.5)/(STORK-AKON+0.5)	7273

594.	FLOW(4,I)=CK1*YFLO*FLO(4,I-1)-CK2*YFLO*FLO(4,I)+CK3*FLOW(4,I-1)+(1	7274
595.	*.-YFLO)*(FLO(4,I-1)+FLO(4,I))	7275
596.	IF(FLOW(4,I).LT.0.3)FLOW(4,I)=0.3	7280
597.	C CALCULATE FLOW ON DAY I AT STA. 0111, NASH FK. AT BROOKLYN LODGE.	7281
598.	XFLO=0.1	7282
599.	YFLO=0.8	7283
600.	IF(FLOW(5,I-1).GE.5.)STORK=SKON(10) AKON=SKON(10)*XFLO GO TO 907	7290
601.	AKON=SKON(9)*XFLO	7291
602.	STORK=SKON(9)	7300
603.	907 CK1=(AKON+0.5)/(STORK-AKON+0.5)	7301
604.	CK2=(AKON-0.5)/(STORK-AKON+0.5)	7302
605.	CK3=(STORK-AKON-0.5)/(STORK-AKON+0.5)	7303
606.	FLOW(5,I)=CK1*(FLOW(4,I-1)+YFLO*FLO(5,I-1))-CK2*(FLOW(4,I)+YFLO*FL	7304
607.	*O(5,I))+CK3*FLOW(5,I-1)+(1.-YFLO)*(FLO(5,I-1)+FLO(5,I))	7305
608.	IF(FLOW(5,I).LT.0.7)FLOW(5,I)=0.7	7310
609.	C ADD FLOWS FOR TEL. CR. AB. MOUTH AND STA. 0111 FOR DAY I FLOW AT NASH	7311
610.	C FK. BEL. TEL. CR.(BEL. CONFLUENCE) (NO GAGE).	7312
611.	FLOW(6,I)=FLOW(3,I)+FLOW(5,I)	7334
612.	IF(FLOW(6,I).LT.0.4)FLOW(6,I)=0.4	7341
613.	C CALCULATE FLOW ON DAY I AT STA. 0103, SALLY CR. AT MOUTH.	A7341
614.	XFLO=0.2	7342
615.	YFLO=0.9	7343
616.	IF(FLOW(7,I-1).GE.1.5)STORK=SKON(14) AKON=SKON(14)*XFLO GO TO 909	7350
617.	AKON=SKON(13)*XFLO	7351
618.	STORK=SKON(13)	7360
619.	909 CK1=(AKON+0.5)/(STORK-AKON+0.5)	7361
620.	CK2=(AKON-0.5)/(STORK-AKON+0.5)	7362
621.	CK3=(STORK-AKON-0.5)/(STORK-AKON+0.5)	7363
622.	FLOW(7,I)=CK1*YFLO*FLO(7,I-1)-CK2*YFLO*FLO(7,I)+CK3*FLOW(7,I-1)+(1	7364
623.	*.-YFLO)*(FLO(7,I-1)+FLO(7,I))	7365
624.	IF(FLOW(7,I).LT.0.)FLOW(7,I)=0.	7371
625.	C CALCULATE FLOW ON DAY I AT NASH FK. AT GREEN ROCK (NO GAGE).	A7371
626.	XFLO=0.1	7372
627.	YFLO=0.4	7373
628.	IF(FLOW(8,I-1).GE.5.)STORK=SKON(16) AKON=SKON(16)*XFLO GO TO 910	7380
629.	AKON=SKON(15)*XFLO	7381
630.	STORK=SKON(15)	7390
631.	910 CK1=(AKON+0.5)/(STORK-AKON+0.5)	7391
632.	CK2=(AKON-0.5)/(STORK-AKON+0.5)	7392
633.	CK3=(STORK-AKON-0.5)/(STORK-AKON+0.5)	7393
634.	FLOW(8,I)=CK1*(FLOW(6,I-1)+FLOW(7,I-1)+YFLO*FLO(6,I-1))-CK2*(FLOW(7394
635.	*6,I)+FLOW(7,I)+YFLO*FLO(6,I))+CK3*FLOW(8,I-1)+(1.-YFLO)*(FLO(6,I-1	7395
636.	*)+FLO(6,I))	7396
637.	IF(FLOW(8,I).LT.0.3)FLOW(8,I)=0.8	7400
638.	C CALCULATE FLOW ON DAY I AT STA. 0106, NASH FK. BEL. SKI AREA (OUTLET	7401
639.	C OF STUDY BASIN).	A7401
640.	XFLO=0.1	7402
641.	YFLO=0.4	7403
642.	IF(FLOW(9,I-1).GE.5.)STORK=SKON(18) AKON=SKON(18)*XFLO GO TO 911	7410
643.	AKON=SKON(17)*XFLO	7411
644.	STORK=SKON(17)	7420
645.	911 CK1=(AKON+0.5)/(STORK-AKON+0.5)	7421
646.	CK2=(AKON-0.5)/(STORK-AKON+0.5)	7422
647.	CK3=(STORK-AKON-0.5)/(STORK-AKON+0.5)	7423

648.	FLOW(9,I)=CK1*(FLOW(8,I-1)+YFLO*FLC(8,I-1))-CK2*(FLOW(8,I)+YFLO*FL	7424
649.	*D(8,I))+CK3*FLOW(9,I-1)+(1.-YFLO)*(FLO(8,I-1)+FLO(8,I))	7425
650.	IF(FLOW(9,I)-LT.0.5)FLOW(9,I)=0.5	7430
651.	900 CONTINUE	7440
652.	C	
653.	C START PRINTOUT OF TABLES	7999
654.	C	
655.	C CARDS NO. 8000 THROUGH 8016 PRINT OBSERVED RADIATION TABLE	
656.	WRITE(6,1005)	8000
657.	WRITE(6,1000)	8002
658.	WRITE(6,1001)	8004
659.	WRITE(6,1002)	8006
660.	WRITE(6,1003)IYEAR	8008
661.	WRITE(6,1000)	8010
662.	WRITE(6,1004)	8011
663.	WRITE(6,1000)	8014
664.	CALL ATABLE (RASWM)	8015
665.	WRITE(6,1000)	8016
666.	C	
667.	C CARDS NO. 8020 THROUGH 8030 PRINT OBSERVED WIND RUN TABLE	
668.	WRITE(6,1005)	8020
669.	WRITE(6,1000)	8021
670.	WRITE(6,1006)	8022
671.	WRITE(6,1002)	8024
672.	WRITE(6,1003)IYEAR	8025
673.	WRITE(6,1000)	8026
674.	WRITE(6,1004)	8027
675.	WRITE(6,1000)	8028
676.	CALL ATABLE (DWIND)	8029
677.	WRITE(6,1000)	8030
678.	C	
679.	C CARDS NO. 8040 THROUGH 8053 PRINT MAX AND MIN TEMPS FOR 4 STATIONS	
680.	DO 1013 KJ=1,4	8040
681.	WRITE(6,1005)	8041
682.	WRITE(6,1000)	8042
683.	WRITE(6,1007)	8043
684.	IF(KJ.EQ.1)WRITE(6,1002)	8046
685.	IF(KJ.EQ.2)WRITE(6,1008)	8047
686.	IF(KJ.EQ.3)WRITE(6,1009)	8049
687.	IF(KJ.EQ.4)WRITE(6,1010)	8051
688.	WRITE(6,1003)IYEAR	8053
689.	WRITE(6,1000)	8054
690.	WRITE(6,1011)	8055
691.	WRITE(6,1012)	8058
692.	WRITE(6,1000)	8060
693.	DO 1027 I=1,IX	A8060
694.	DTAB(I)=TMAX(KJ,I)	B8060
695.	1027 CTAB(I)=TMIN(KJ,I)	C8060
696.	CALL BTABLE (DTAB,CTAB)	8061
697.	WRITE(6,1000)	8062
698.	1013 CONTINUE	8063
699.	C	
700.	C CARDS NO. 8070 THROUGH 8084 PRINT PRECIPITATION FOR 3 STATIONS	
701.	DO 1014 KI=1,3	8070

702.	WRITE(6,1005)	8071
703.	WRITE(6,1000)	8072
704.	WRITE(6,1015)	8073
705.	IF(KI.EQ.1)WRITE(6,1002)	8075
706.	IF(KI.EQ.2)WRITE(6,1009)	8076
707.	IF(KI.EQ.3)WRITE(6,1010)	8077
708.	WRITE(6,1003)IYEAR	8078
709.	WRITE(6,1000)	8079
710.	WRITE(6,1004)	8080
711.	WRITE(6,1000)	8081
712.	DO 1028 I=1,IX	8081
713.	1028 DTAB(I)=P(KI,I)	8081
714.	CALL CTABLE (DTAB)	8082
715.	WRITE(6,1000)	8083
716.	1014 CONTINUE	8084
717.	C	
718.	C CARDS NO. 8090 THROUGH 8115 PRINT PHYSICAL DATA FOR EACH SEGMENT	
719.	WRITE(6,1005)	8090
720.	WRITE(6,1000)	8091
721.	WRITE(6,1016)	8092
722.	WRITE(6,1000)	8094
723.	WRITE(6,1017)	8095
724.	WRITE(6,1018)	8098
725.	WRITE(6,1019)	8101
726.	WRITE(6,1000)	8104
727.	DO 1020 K=1,16	8105
728.	DLAT=SLAT(K)/0.0174533	8106
729.	DSLO=SLOPE(K)/0.0174533	8107
730.	DAZ=AZ(K)/0.0174533	8108
731.	TAREA=AREA(K,1)+AREA(K,2)	8109
732.	WRITE(6,1021)K,AREA(K,1),AREA(K,2),TAREA,WAREA(K),DLAT,DSLO,DAZ,EL	8110
733.	*EV(K),FDEN(K)	8111
734.	1020 CONTINUE	8114
735.	WRITE(6,1000)	8115
736.	C	
737.	C CARDS NO. 8120 THROUGH 8146 PRINT COEFFICIENTS FOR SNOWCOVER EQUATION	8120
738.	WRITE(6,1005)	8121
739.	WRITE(6,1000)	8122
740.	WRITE(6,1022)	8123
741.	WRITE(6,1000)	8127
742.	WRITE(6,1023)	8128
743.	WRITE(6,1000)	8132
744.	DO 1024 K=1,KX	8133
745.	DO 1024 L=1,2	8134
746.	WRITE(6,1025)K,L,A(K,L),B(K,L),C(K,L),D(K,L),E(K,L),F(K,L),G(K,L),	8135
747.	*H(K,L)	8136
748.	1024 CONTINUE	8138
749.	WRITE(6,1000)	8139
750.	WRITE(6,1026)	8140
751.	WRITE(6,1000)	8146
752.	C	
753.	C CARDS 8150 THROUGH 8167 PRINT SNOW COVER TABLES FOR EACH SEGMENT	8150
754.	DO 1030 KJ=1,KX	8151
755.	WRITE(6,1005)	8152

756.	WRITE(6,1000)	8153
757.	WRITE(6,1031)KJ,IYEAR	8154
758.	WRITE(6,1000)	8157
759.	WRITE(6,1011)	8158
760.	WRITE(6,1032)	8159
761.	WRITE(6,1000)	8161
762.	DO 1033 I=1,IX	8162
763.	DTAB(I)=SNOCOV(KJ,I,1)	8163
764.	1033 CTAB(I)=SNOCOV(KJ,I,2)	8164
765.	CALL BTABLE (DTAB,CTAB)	8165
766.	WRITE(6,1000)	8166
767.	1030 CONTINUE	8167
768.	C	
769.	C CARDS 8170 THROUGH 8201 PRINT MEAN DAILY FLOWS (SFD) FOR 9 FLOWPOINTS	8170
770.	DO 1034 NK=1,9	8171
771.	WRITE(6,1005)	8172
772.	WRITE(6,1000)	8173
773.	WRITE(6,1035)	8174
774.	IF(NK.EQ.1)WRITE(6,1036)	8176
775.	IF(NK.EQ.2)WRITE(6,1037)	8177
776.	IF(NK.EQ.3)WRITE(6,1038)	8178
777.	IF(NK.EQ.4)WRITE(6,1039)	8179
778.	IF(NK.EQ.5)WRITE(6,1040)	8180
779.	IF(NK.EQ.6)WRITE(6,1041)	8181
780.	IF(NK.EQ.7)WRITE(6,1042)	8182
781.	IF(NK.EQ.8)WRITE(6,1043)	8183
782.	IF(NK.EQ.9)WRITE(6,1010)	8184
783.	WRITE(6,1003)IYEAR	8194
784.	WRITE(6,1000)	8195
785.	WRITE(6,1004)	8196
786.	WRITE(6,1000)	8197
787.	DO 1044 I=1,IX	8198
788.	1044 DTAB(I)=FLOW(NK,I)	8199
789.	CALL CTABLE (DTAB)	8200
790.	1034 WRITE(6,1000)	8201
791.	C	
792.	1005 FORMAT(1H1,130X)	8001
793.	1000 FORMAT(130*' '/')	8003
794.	1001 FORMAT(53X,'OBSERVED SOLAR RADIATION'/56X,'(LANGLEYS PER DAY)')	8005
795.	1002 FORMAT(48X,'LITTLE BROOKLYN LAKE, STATION 0108')	8007
796.	1003 FORMAT(57X,14,' WATER YEAR')	8009
797.	1004 FORMAT(9X,'DAY',7X,'OCT',6X,'NOV',6X,'DEC',6X,'JAN',6X,'FEB',6X,'M	8012
798.	*AR',6X,'APR',6X,'MAY',6X,'JUN',6X,'JUL',6X,'AUG',6X,'SEP')	8013
799.	1006 FORMAT(56X,'OBSERVED WIND RUN'/57X,'(MILES PER DAY)')	8023
800.	1007 FORMAT(44X,'OBSERVED MAXIMUM AND MINIMUM TEMPERATURES'/56X,'DEGREE	8044
801.	*S FAHRENHEIT')	8045
802.	1008 FORMAT(41X,'TELEPHONE CREEK BELOW MIDDLE POND, STATION 0112')	8048
803.	1009 FORMAT(48X,'KNIGHT SCIENCE CAMP, STATION 0103')	8050
804.	1010 FORMAT(46X,'NASH FORK BELOW SKI AREA, STATION 0106')	8052
805.	1011 FORMAT(12X,'DAY',5X,'OCT',7X,'NOV',7X,'DEC',7X,'JAN',7X,'FEB',7X,'M	8056
806.	*AR',7X,'APR',7X,'MAY',7X,'JUN',7X,'JUL',7X,'AUG',7X,'SEP')	8057
807.	1012 FORMAT(7X,12(' MAX MIN '))	8059
808.	1015 FORMAT(54X,'OBSERVED PRECIPITATION'/61X,'(INCHES)')	8074
809.	1016 FORMAT(42X,'PHYSICAL DATA FOR NASH FORK BASIN BY SEGMENTS'/)	8093

810.	1017	FORMAT(7X,'SEGMENT',5X,'OPEN',6X,'FOREST',6X,'TOTAL',6X,'LAKE',6X,	8096
811.		*'LATITUDE',6X,'SLOPE',7X,'SLOPE',9X,'MEAN',9X,'FOREST')	8097
812.	1018	FORMAT(7X,'NUMBER',7X,'AREA',7X,'AREA',7X,'AREA',7X,'AREA',31X,'AZ	8099
813.		*IMUTH',6X,'ELEVATION',6X,'DENSITY')	8100
814.	1019	FORMAT(20X,'(AC)',7X,'(AC)',7X,'(AC)',7X,'(AC)',7X,'(DEG)',8X,'(DE	8102
815.		*G)',7X,'(DEG)',9X,'(FT)',10X,'(EST)')	8103
816.	1021	FORMAT(1H ,I10,9X,4(F4.0,7X),F6.3,7X,F5.2,7X,F5.1,8X,F6.0,10X,F3.2	8112
817.		*)	8113
818.	1022	FORMAT(40X,'REGRESSION COEFFICIENTS FOR SNOW COVER CALCULATION'/41	8124
819.		*X,'BY SEGMENT AND UNFORESTED OR FORESTED CONDITIONS'//44X,'(COVER	8125
820.		*1 = UNFORESTED, COVER 2 = FORESTED)')	8126
821.	1023	FORMAT(10X,'SEGMENT',5X,'COVER',38X,'COEFFICIENTS'/32X,88*'//10X,'	8129
822.		*NUMBER',4X,'CONDITION',8X,'A',10X,'B',10X,'C',10X,'D',10X,'E',10X,	8130
823.		*'F',10X,'G',10X,'H')	8131
824.	1025	FORMAT(1H ,I13,I11,6X,8F11.5)	8137
825.	1026	FORMAT(10X,'A = PCT OF SNOW COVER INTERCEPT, B = COEFF FOR DAYS SI	8141
826.		*NCE SNOW, C = COEFF FOR WIND RUN, D = COEFF FOR 0.7POWER'/12X,'OF	8142
827.		*WIND RUN, E = COEFF FOR ACCUM RADIATION, F = COEFF FOR SQ RT ACCUM	8143
828.		* RADIATION, G = COEFF FOR ACCUM DEGREE-'//12X,'DAYS ABOVE 32F, H =	8144
829.		*COEFF FOR SQ RT ACCUM DEGREE-DAYS.')	8145
830.	1031	FORMAT(45X,'CALCULATED SNOW COVER, ACRES, SEGMENT',13/57X,14,' WAT	8155
831.		*ER YEAR')	8156
832.	1032	FORMAT(6X,12(* OPEN FOR.))	8160
833.	1035	FORMAT(51X,'CALCULATED DAILY STREAMFLOWS'/57X,'SECOND-FOOT DAYS')	8175
834.	1036	FORMAT(41X,'TELEPHONE CREEK ABOVE TOWNER LAKE, STATION 0113')	8185
835.	1037	FORMAT(41X,'TELEPHONE CREEK BELOW MIDDLE POND, STATION 0112')	8186
836.	1038	FORMAT(41X,'TELEPHONE CREEK ABOVE MOUTH, (POTENTIAL STATION)')	8187
837.	1039	FORMAT(41X,'NASH FORK AT BROOKLYN LAKE OUTLET, STATION 0114')	8188
838.	1040	FORMAT(44X,'NASH FORK AT BROOKLYN LODGE, STATION 0111')	8189
839.	1041	FORMAT(39X,'NASH FORK BELOW TELEPHONE CREEK, (POTENTIAL STATION)')	8190
840.	1042	FORMAT(36X,'SALLY CREEK NEAR MOUTH AT KNIGHT SCIENCE CAMP, STATION	8191
841.		* 0103')	8192
842.	1043	FORMAT(43X,'NASH FORK AT GREEN ROCK, (POTENTIAL STATION)')	8193
843.	1050	FORMAT(40X,'CALCULATED RUNOFF FROM PAIRED SEGMENTS ON REACH',12/48	8217
844.		*X,'SECOND-FOOT DAYS, WATER YEAR ',14)	8218
845.	1051	FORMAT(56X,'ABOVE STATION 0113')	8220
846.	1052	FORMAT(50X,'BETWEEN STATIONS 0113 AND 0112')	8222
847.	1053	FORMAT(40X,'BETWEEN STATION 0112 AND MOUTH OF TELEPHONE CREEK')	8224
848.	1054	FORMAT(56X,'ABOVE STATION 0114')	8226
849.	1055	FORMAT(50X,'BETWEEN STATIONS 0114 AND 0111')	8228
850.	1056	FORMAT(22X,'BETWEEN CONFLUENCE OF TELEPHONE CR. WITH NASH FORK AND	8230
851.		* GREEN ROCK, EXCLUDING SALLY CR.')	8231
852.	1057	FORMAT(49X,'SALLY CREEK, ABOVE STATION 0103')	8233
853.	1058	FORMAT(47X,'BETWEEN GREEN ROCK AND STATION 0106')	8235
854.		END	8202

1.	SUBROUTINE ATABLE(TAB1)	9000
2.	DIMENSION TAB(31,12),DAYS(12),TAB1(366)	9002
3.	COMMON DYS	9001
4.	DATA DAYS/31,28,31,30,31,30,31,31,30,31,30,31/	9006
5.	DO 2000 NN=1,31	9003
6.	DO 2000 JJ=1,12	9004
7.	2000 TAB(NN, JJ)=0.	9005
8.	IDAY=0	9007
9.	MONTH=10	9008
10.	DO 2001 ICOL=1,12	9009
11.	INDX=DAYS(MONTH)	9010
12.	IF(MONTH.EQ.2.AND.DYS.EQ.366.)INDX=INDX+1	9011
13.	DO 2002 NN=1,INDX	9012
14.	IDAY=IDAY+1	9013
15.	2002 TAB(NN,ICOL)=TAB1(IDAY)	9014
16.	2001 MONTH=MOD(MONTH,12)+1	9015
17.	DO 2003 I=1,28	9016
18.	2003 WRITE(6,2004)I,(TAB(I,J),J=1,12)	9017
19.	2004 FORMAT(1H ,I10,3X,12F9.0)	9018
20.	I=29	9019
21.	IF(DYS.EQ.366.)WRITE(6,2004)I,(TAB(I,J),J=1,12)	9020
22.	IF(DYS.EQ.365.)WRITE(6,2005)I,(TAB(I,J),J=1,4),(TAB(I,J),J=6,12)	9021
23.	2005 FORMAT(1H ,I10,3X,4F9.0,9X,7F9.0)	9022
24.	I=30	9023
25.	WRITE(6,2005)I,(TAB(I,J),J=1,4),(TAB(I,J),J=6,12)	9024
26.	I=31	9025
27.	WRITE(6,2006)I,TAB(I,1),TAB(I,3),TAB(I,4),TAB(I,6),TAB(I,8),TAB(I,	9026
28.	*10),TAB(I,11)	9027
29.	2006 FORMAT(1H ,I10,3X,F9.0,9X,2F9.0,9X,2(F9.0,9X),2F9.0)	9028
30.	RETURN	9029
31.	END	9030

1.	SUBROUTINE BTABLE (TAB2,TAB3)	9040
2.	DIMENSION TABX(31,12),TABN(31,12),DAYS(12),TAB2(366),TAB3(366)	9042
3.	COMMON DYC	9041
4.	DATA DAYS/31,28,31,30,31,30,31,31,30,31,30,31/	9047
5.	DO 2010 NN=1,31	9043
6.	DO 2010 JJ=1,12	9044
7.	TABX(NN,JJ)=0.	9045
8.	2010 TABN(NN,JJ)=0.	9046
9.	IDAY=0	9048
10.	MONTH=10	9049
11.	DO 2011 ICOL=1,12	9050
12.	INDX=DAYS(MONTH)	9051
13.	IF(MONTH.EQ.2.AND.DYC.EQ.366.)INDX=INDX+1	9052
14.	DO 2012 NN=1,INDX	9053
15.	IDAY=IDAY+1	9054
16.	TABX(NN,ICOL)=TAB2(IDAY)	9055
17.	2012 TABN(NN,ICOL)=TAB3(IDAY)	9056
18.	2011 MONTH=MOD(MONTH,12)+1	9057
19.	DO 2013 I=1,28	9058
20.	2013 WRITE(6,2014)I,((TABX(I,J),TABN(I,J)),J=1,12)	9059
21.	2014 FORMAT(1H ,I3,2X,12(2F5.0))	9060
22.	I=29	9061
23.	IF(DYC.EQ.366.)WRITE(6,2014)I,((TABX(I,J),TABN(I,J)),J=1,12)	9062
24.	IF(DYC.EQ.365.)WRITE(6,2015)I,((TABX(I,J),TABN(I,J)),J=1,4),((TABX	9063
25.	*(I,J),TABN(I,J)),J=6,12)	9064
26.	2015 FORMAT(1H ,I3,2X,4(2F5.0),10X,7(2F5.0))	9065
27.	I=30	9066
28.	WRITE(6,2015)I,((TABX(I,J),TABN(I,J)),J=1,4),((TABX(I,J),TABN(I,J)	9067
29.	*),J=6,12)	9068
30.	I=31	9069
31.	WRITE(6,2016)I,((TABX(I,1),TABN(I,1)),(TABX(I,3),TABN(I,3)),(TABX(I	9070
32.	*,4),TABN(I,4)),(TABX(I,6),TABN(I,6)),(TABX(I,8),TABN(I,8)),(TABX(I	9071
33.	*,10),TABN(I,10)),(TABX(I,11),TABN(I,11))	9072
34.	2016 FORMAT(1H ,I3,2X,2F5.0,10X,2(2F5.0),10X,2(2F5.0,1CX),2(2F5.0))	9073
35.	RETURN	9074
36.	END	9075

1.	SUBROUTINE CTABLE (TAB4)	9080
2.	DIMENSION TAB(31,12),DAYS(12),TAB4(366)	9082
3.	COMMON DYC	9081
4.	DATA DAYS/31,28,31,30,31,30,31,31,30,31,30,31/	9086
5.	DO 2020 NN=1,31	9083
6.	DO 2020 JJ=1,12	9084
7.	2020 TAB(NN,JJ)=0.	9085
8.	IDAY=0	9087
9.	MONTH=10	9088
10.	DO 2021 ICOL=1,12	9089
11.	INDX=DAYS(MONTH)	9090
12.	IF(MONTH.EQ.2.AND.DYC.EQ.366.)INDX=INDX+1	9091
13.	DO 2022 NN=1,INDX	9092
14.	IDAY=IDAY+1	9093
15.	2022 TAB(NN,ICOL)=TAB4(IDAY)	9094
16.	2021 MONTH=MOD(MONTH,12)+1	9095
17.	DO 2023 I=1,28	9096
18.	2023 WRITE(6,2024)I,(TAB(I,J),J=1,12)	9097
19.	2024 FORMAT(1H ,I10,2X,12F9.2)	9098
20.	I=29	9099
21.	IF(DYC.EQ.366.)WRITE(6,2024)I,(TAB(I,J),J=1,12)	9100
22.	IF(DYC.EQ.365.)WRITE(6,2025)I,(TAB(I,J),J=1,4),(TAB(I,J),J=6,12)	9101
23.	2025 FORMAT(1H ,I10,2X,4F9.2,9X,7F9.2)	9102
24.	I=30	9103
25.	WRITE(6,2025)I,(TAB(I,J),J=1,4),(TAB(I,J),J=6,12)	9104
26.	I=31	9105
27.	WRITE(6,2026)I,TAB(I,1),TAB(I,3),TAB(I,4),TAB(I,6),TAB(I,8),TAB(I,	9106
28.	*10),TAB(I,11)	9107
29.	2026 FGRMAT(1H ,I10,2X,F9.2,9X,2(F9.2),9X,2(F9.2,9X),2F9.2)	9108
30.	RETURN	9109
31.	END	9110