# A WATER BALANCE AND HYDROLOGIC ANALYSIS ON CRUMARINE CREEK WATERSHED

JANET G. CHERRY
AGRICULTURAL ENGINEERING
APRIL 21, 1986

College of Agriculture
UNIVERSITY OF IDAHO
College of Engineering

A Water Balance and Hydrologic Analysis

on Crumarine Creek Watershed

A Thesis

Presented in Partial Fulfillment of the Requirements for the

DEGREE OF MASTER OF SCIENCE

with a

Major in Agricultural Engineering

in the

GRADUATE SCHOOL

UNIVERSITY OF IDAHO

by

JANET G. CHERRY

April 21, 1986

AUTHORIZATION TO PROCEED WITH THE FINAL DRAFT

This thesis of Janet G. Cherry for the Degree of Master of Science with a major in Agricultural Engineering, and titled "A Water Balance and Hydrologic Analysis on Crumarine Creek Watershed", was reviewed in rough draft form by each Committee member as indicated by the signatures and dates given below, and permission was granted to prepare the final copy incorporating suggestions of the Committee; permission was also given to schedule the final examination.

Major Professor Myron Molnau Date 4 Mar 86

Committee Members [signature] Date 4 Mar 86

[signature] Date MAR 5, 1986

Final Examination: By majority/unanimous vote of the candidate's Committee at the final examination held on the date of 18 Apr 86 Committee approval and acceptance were granted.

Major Professor Myron Molnau Date 22 Apr 86

GRADUATE COUNCIL FINAL APPROVAL AND ACCEPTANCE:

Graduate School Dean ______________________ Date __________

# ACKNOWLEDGEMENTS

My appreciation is expressed to the Idaho Agricultural Experiment Station for its financial support for this study. I would also like to express my appreciation to Dr. Myron Molnau for his help and guidance during my tenure at the University of Idaho. My other two committee members, Dr. Dale Ralston and Dr. George Bloomsburg, also deserve thanks for their review and suggestions for my thesis.

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# ABSTRACT

The hydrologic characteristics of Crumarine Creek watershed were observed. Crumarine Creek watershed (1570 acres) is located approximately eight miles northeast of Moscow, Idaho. The watershed is mostly forested with a small amount of winter wheat grown near the outlet. The objectives of this thesis were to determine the amount and monthly pattern of deep percolation within the watershed by use of a monthly water balance equation and to analyze hydrologic responses of the watershed to rainfall and snowmelt. The hydrologic responses were analyzed by separating hydrographs into direct runoff and baseflow. HEC-1, the Army Corps of Engineers' (1981) flood hydrograph model, was also applied to the watershed to examine the disposition of excess precipitation. An annual deep percolation value of 7.5 inches was found to occur on Crumarine Creek watershed based on data from the 1969 to 1973 water years. The hydrologic analysis indicated that the amount of baseflow increased during spring snowmelt events, comprising 80 percent or more of the total runoff during these events.

# CHAPTER 1

## INTRODUCTION

The city of Moscow, Idaho, and surrounding area obtain most of their water from ground-water sources. Concern has arisen whether these ground-water sources will continue to adequately supply water to the Moscow area. A portion of the aquifer recharge comes from Moscow Mountain and one of the watersheds contributing to this recharge is the Crumarine Creek watershed. Crumarine Creek is a small, perennial stream located on the south side of Moscow Mountain approximately eight miles northeast of Moscow. The majority of the watershed is forested but a fraction of the watershed is in winter wheat. Granite underlies all of Crumarine Creek watershed but basalt does begin to appear near the base of Moscow Mountain (Kaal, 1978).

Water supply for Moscow has been a concern since the beginning of the century. As early as 1923 a ground-water study was conducted on the Moscow basin by Laney and others (1923). The static water level had been drastically lowered from eight feet below the ground surface in 1897 to 44 feet below in 1927. The resulting report from the study indicated recharge to the ground-water aquifer was well in excess of the usage rate. By 1957 the water level had been lowered to 100 feet below the ground surface, which led to further investigation of the basin. Later studies by Stevens (1959), Ross (1965) and Lin (1967) on the Moscow basin showed that the pumpage had increased again, which led to a further drop in the static water level. Jones and Ross (1972) conducted a ground-water study on the

Moscow basin to determine if pumpage had exceeded the natural recharge of ground-water to the Moscow basin. They determined that the ground-water supply in Moscow basin was adequate to meet the expected demands through the year 2000 and perhaps longer. They also concluded that the ground-water would be supplied from either the present ground-water in storage or ground-water recharged to the basin. Crosthwaite (1972) conducted further studies on ground-water usage in the Moscow basin and determined that one billion gallons of ground-water was withdrawn from the basin in 1972. In 1979, Barker contended that vertical leakage from the upper aquifers was the most important source of recharge to the primary deep basalt aquifer in Moscow. He also predicted, with the use of a finite difference model, that a doubling of pumpage from 1975 to the year 2000 would cause a water level decline of 30 to 35 feet.

Water usage studies on the city of Moscow were soon accompanied by hydrologic studies on Moscow Mountain. Gaging stations were established on Gnat Creek and Crumarine Creek in 1956. Crumarine Creek is heavily forested and Gnat Creek is half forested and the remaining half is cropland and pasture. Bloomsburg (1958) performed a water balance analysis on both watersheds and concluded that both watersheds were an area of positive deep percolation. He computed that of the total annual precipitation entering the watersheds, 60 percent was lost to evapotranspiration, 25 percent was lost to runoff and 15 percent was lost to deep percolation. In 1971, Davis conducted a water balance on a small agricultural watershed located a half mile south of the Crumarine Creek drainage. He also found deep percolation to occur and that 27 percent of the incoming precipitation was lost to runoff, 57 percent to evapotranspiration and 16 percent to deep percolation.

Along with water balances performed on Moscow Mountain, other hydrologic analyses have been conducted near and on the north side of Moscow Mountain. Two significant hydrologic analyses were done by Churchill (1981) and Brooks (1982) on agricultural, forested and pastured watersheds. They observed baseflow and runoff pattern variations for different events. Little hydrologic work has been done on the south side of the mountain since 1971 and even less work has been done pertaining to forested areas of Moscow Mountain. In general, Morton (1984) observed that a forest provides an environment which promotes ground-water recharge. Therefore, it is important to examine the hydrologic properties of Crumarine Creek.

## Objectives

Because Crumarine Creek is a potential source of recharge to the Moscow Basin aquifers, the following main objectives were selected:

1) Determine if deep percolation occurs on the watershed and the monthly amount of deep percolation by use of a water balance equation.
2) Analyze hydrologic responses of the watershed to rainfall and snowmelt and observe monthly variations of the responses.

# CHAPTER 2

## METHOD

In order to determine the amount of deep percolation to the shallow aquifer a water balance was conducted on the watershed. Davis (1971) suggested the following water balance equation:

$$P=RO+ET+DP+SS+SM+ERR \qquad (1)$$

The equation was modified and applied to Crumarine Creek watershed:

$$P=RO+SM+ET+(DP+ERR)+SS+S+I \qquad (2)$$

P=precipitation
RO=surface runoff
SM=change in soil moisture
ET=evapotranspiration
DP=deep percolation
SS=change in snow storage
S=sublimation of snow
I=interception of precipitation
ERR=error term

Deep percolation to the shallow aquifer was used as the dependent variable in this equation. Hillel (1982) defined deep percolation as the internal drainage beyond the root zone. The amount of deep percolation that enters the deep Moscow aquifer, which the city of Moscow obtains its water from, was not determined. The deep percolation term also contains any residual or error terms. The precipitation data were obtained from recording gages located on Moscow Mountain. Runoff data were derived from gaging station records at the watershed outlet. Evapotranspiration was calculated by equations calibrated for forested catchments and utilizing local climatological data. Soil moisture was estimated from soil samples taken from the watershed and general soil moisture trends. Snow storage was also estimated from a generated equation based on snow surveys conducted on the watershed and other available climatological data. Interception and sublimation were determined from findings of other researchers.

The water balance was done on a monthly basis to examine fluctuations in the water balance components throughout the year. Data from water years 1969 to 1973 were used since these were years with concurrent data. On a yearly basis the change in soil moisture and snow storage should both be near zero since there will be times of recharge and discharge. All variables are serially correlated and will peak and nadir at different times of the year.

The hydrologic characteristics of the watershed were also examined. Hydrograph separation was performed on selected events to observe changes in baseflow throughout the year. The watershed's response to rainfall and snowmelt was also examined. The HEC-1 model (Army Corps of Engineers, 1981) was utilized to generate runoff hydrographs for different events and conditions to examine how excess precipitation is disposed of on the watershed.

# CHAPTER 3

## WATERSHED DESCRIPTION

Crumarine Creek is a small stream located on Moscow Mountain approximately eight miles northeast of Moscow. The watershed area is 1570 acres, with 88 percent forested and the remainder in winter wheat. These findings agree with Bloomsburg (1958). A map of the watershed appears in Figure 1. The gaging station is at an elevation of 2800 feet and the peak of the watershed is at 4975 feet. The mean elevation from the area-elevation curve in Figure 2 is 3670 feet. The watershed faces southwest with an aspect of 200 degrees and the slope varies from 3 percent to 50 percent. The steeper slopes are along the creek at the upper end of the watershed and the milder slopes are common near the gaging station. The small portion in crops is located at the watershed outlet. The principal crop grown is wheat. Bloomsburg (1958) found the forest to consist of ponderosa pine, spruce, Douglas fir, white fir, western larch, white pine and cedar, with a considerable amount of undergrowth.

The majority of the soil on the watershed is a silt loam (Soil Conservation Service, 1981). Loam and a rock outcrop complex can also be found on the watershed. The rock outcrop complex borders the channel banks on the steeper slopes upstream from the gaging station. This rock outcrop complex is composed of granite with numerous seeps into the creek being evident at these outcrops. Granite underlies the entire watershed (Kaal, 1978). The soils are of either hydrologic group B, indicating moderately low runoff potential, or C, indicating moderately high runoff potential.

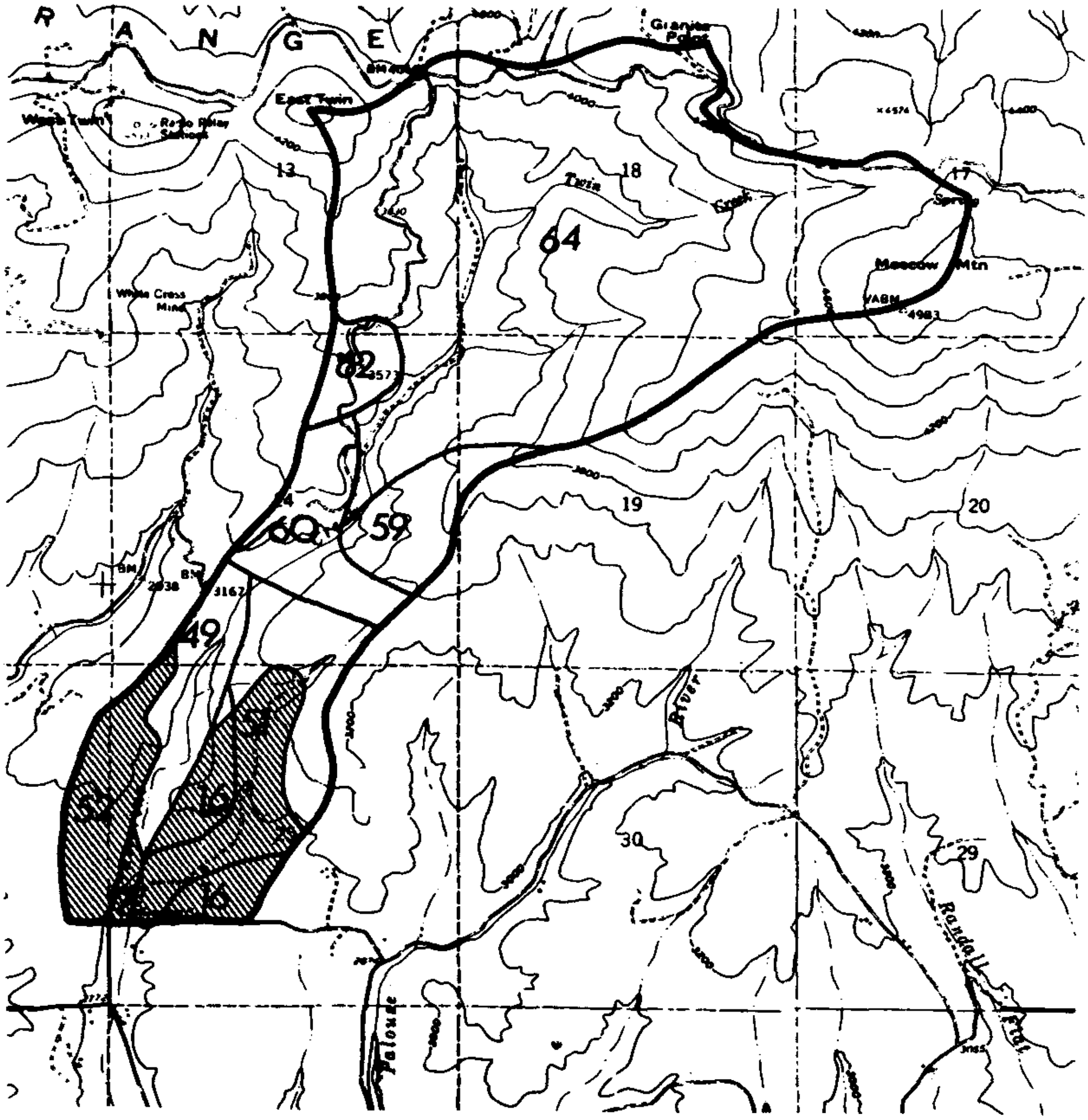


Figure 1. Crumarine Creek watershed. Backslashed area represents wheat and blank area represents forest. Numbers correspond to soil types.

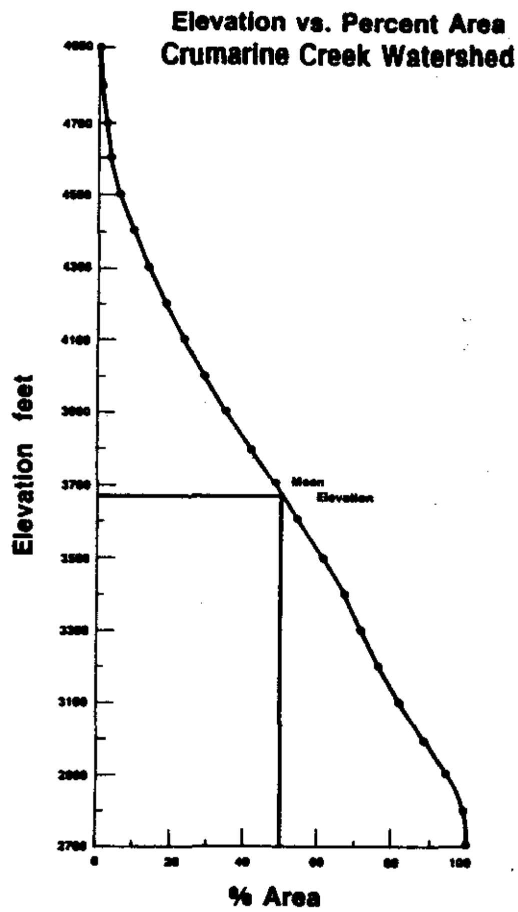


Figure 2. Area-elevation curve for Crumarine Creek watershed.

Figure 1 shows the soil type boundaries and the different soil types are listed in Table 1. The numbers in Table 1 correspond to the soil survey numbers as used by the Soil Conservation Service (1981).

Crumarine Creek is one of the few perennial streams on the south side of Moscow Mountain. It is fed by many small springs, which account for its perennial nature. These springs are especially prominent at the upper end of the watershed. Two tributaries, Twin Creek and an unnamed tributary, feed into Crumarine Creek at the upper end of the watershed. Both tributaries dry up in July and August but both have a high amount of snow storage in their respective basins.

Table 1. Soil types on Crumarine Creek watershed.

| No. | Name | Hydrologic Group | Percent of Watershed |
|---|---|---|---|
| 7 | Crumarine silt loam | B | 1 |
| 16 | Joel silt loam | B | 5 |
| 49 | Spokane rock outcrop complex | B | 5 |
| 51 | Taney silt loam (7-25% slope) | C | 11 |
| 52 | Taney silt loam (20-35% slope) | C | 4 |
| 59 | Uvi loam | B | 5 |
| 60 | Uvi-Spokane association loam | B | 5 |
| 62 | Vassar silt loam (5-20% slope) | B | 3 |
| 64 | Vassar silt loam (35-65% slope) | B | 61 |

# CHAPTER 4

# WATER BALANCE

In order to determine deep percolation to the shallow aquifer, the deep percolation term was solved for in Equation 2:

$$(DP+ERR)=P-RO-SM-ET-SS-S-I \qquad (2)$$

The deep percolation term is assumed to include any error or residual terms. Specific details on each water balance component are given in the following sections.

## Precipitation

The distribution of precipitation on the watershed was determined using data from four precipitation gages. The map in Figure 3 shows the location of the gages with respect to the watershed. Koster does not fall within the boundaries of the map but is located about one mile southwest of the Thompson rain gage.

Mean monthly precipitation values were computed for each station for the water years of 1969 to 1973. The Nutterville, Thompson and Koster gage had complete precipitation records for the years of concern. The Moscow Mountain precipitation gage had several months of missing data. In order

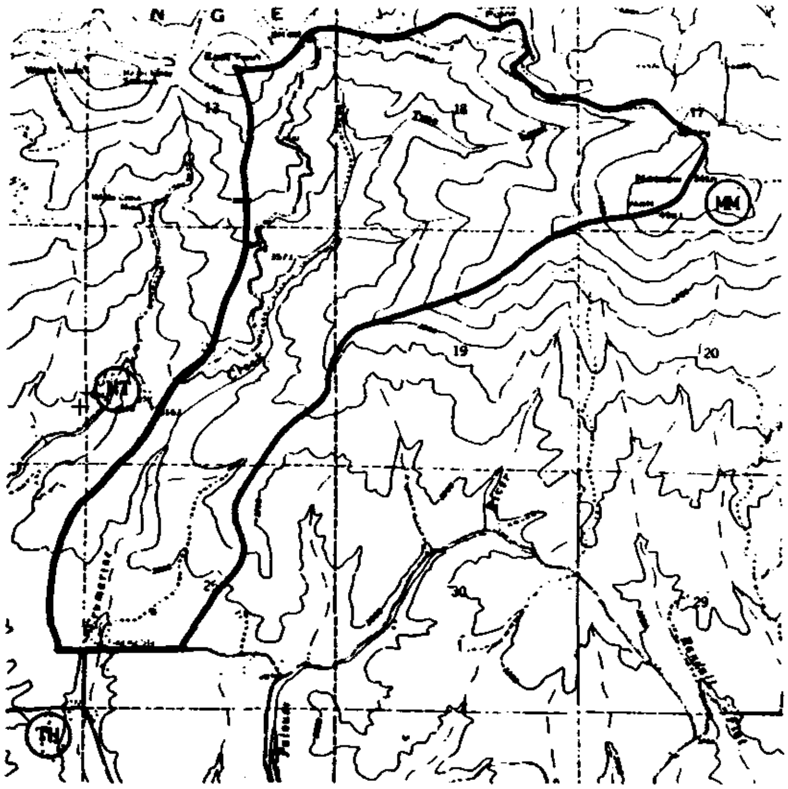


Figure 3. Location of precipitation gages on Crumarine Creek watershed. Koster is located about one mile southwest of the Thompson rain gage.

| Site | Elevation, ft |
|---|---|
| Moscow Mountain (MM) | 4968 |
| Nutterville (NT) | 3000 |
| Thompson (TH) | 2800 |
| Koster (KS) | 2740 |

Table 2. Mean monthly precipitation for four gages on Moscow Mountain for the 1969 to 1973 water years (inches).

| | Moscow Mountain | Nutterville | Thompson | Koster |
|---|---|---|---|---|
| Oct | 2.6 | 1.6 | 1.2 | 1.2 |
| Nov | 6.2 | 3.8 | 1.9 | 2.1 |
| Dec | 9.4 | 5.2 | 2.6 | 3.0 |
| Jan | 7.9 | 4.3 | 3.5 | 2.4 |
| Feb | 4.0 | 2.6 | 1.4 | 1.6 |
| Mar | 4.9 | 3.2 | 1.8 | 1.8 |
| Apr | 4.6 | 1.5 | 1.1 | 0.8 |
| May | 3.8 | 2.2 | 1.5 | 1.8 |
| Jun | 2.9 | 2.0 | 1.9 | 0.9 |
| Jul | 1.2 | 0.9 | 0.8 | 0.5 |
| Aug | 0.7 | 0.8 | 0.4 | 0.6 |
| Sep | 2.2 | 1.5 | 1.1 | 1.1 |
| Annual | 50.4 | 29.6 | 19.2 | 17.9 |

to estimate data for months with missing data, a correlation was developed between Nutterville and Moscow Mountain precipitation gages. A coefficient of determination of 0.863 was obtained based on 30 observations for the water years 1969 to 1973. Monthly precipitation values were used to develop the correlation. In his study of precipitation in Latah County, Idaho, Precht (1973) found a coefficient of determination of 0.934 between Moscow Mountain precipitation and Nutterville precipitation. His correlation was based on 29 storms for the water year of 1971. The following equation was used to generate Moscow Mountain monthly precipitation data:

$$MM=0.559+1.194(NUTT)+0.0527(NUTT^2) \quad (3)$$

Mean monthly precipitation values were then determined for the Moscow Mountain precipitation gage based on the generated and the actual values. Mean monthly precipitation values were determined for the other three gages based on the actual recorded data. The values are listed in Table 2.

Table 3. Mean monthly precipitation for Crumarine Creek watershed for 1969 to 1973 water years.

| Oct | Nov | Dec | Jan | Feb | Mar | |
|---|---|---|---|---|---|---|
| 1.9 | 4.7 | 6.9 | 5.4 | 3.1 | 3.8 | |
| Apr | May | Jun | Jul | Aug | Sep | Annual |
| 2.6 | 2.8 | 2.4 | 1.1 | 0.7 | 1.8 | 37.2 |

To calculate the mean monthly precipitation values for the entire watershed the isohyetal method was used. The mean monthly precipitation values from Table 2 were plotted on maps of the watershed and isohyetal lines were drawn on the maps. The area between each isohyetal line was planimetered and the watershed's monthly precipitation values were computed by weighting the precipitation values by area. Table 3 lists the monthly precipitation values for the entire watershed. The mean monthly precipitation values are assumed to be accurate within 15 percent. Error is introduced in the measurement of precipitation and also in the nonuniform distribution of precipitation on the watershed.

## Runoff

Runoff was determined from gage height records taken at the gaging station. A float-type recording gage is used to measure the water level. A culvert located immediately downstream of the gaging station serves as the control (Figure 4). The gaging station has been active since 1956.

Figure 4. Crumarine Creek gaging station.

A rating curve was developed for Crumarine Creek based on 58 discharge measurements taken from 1957 to 1985. The computed discharges ranged from a low of 0.10 cfs on many days in the summer to a maximum of 45.0 cfs during rain on snow events in February and March. Three definite shifts were evident on the rating curve due to physical changes in the stream throughout the years. The rating tables appear on Tables 4,5 and 6.

Table 4. Rating table #1 for Crumarine Creek for January 1957 to January 1977. All gage heights are in feet.

| | Flow in cfs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Gage Height | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
| 13.3 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 | 0.19 |
| 13.4 | 0.20 | 0.22 | 0.24 | 0.26 | 0.28 | 0.30 | 0.32 | 0.34 | 0.36 | 0.38 |
| 13.5 | 0.40 | 0.44 | 0.48 | 0.52 | 0.56 | 0.60 | 0.64 | 0.68 | 0.72 | 0.76 |
| 13.6 | 0.80 | 0.87 | 0.94 | 1.01 | 1.08 | 1.15 | 1.22 | 1.29 | 1.36 | 1.43 |
| 13.7 | 1.50 | 1.61 | 1.72 | 1.83 | 1.94 | 2.05 | 2.16 | 2.27 | 2.38 | 2.49 |
| 13.8 | 2.60 | 2.70 | 2.80 | 2.90 | 3.00 | 3.10 | 3.20 | 3.30 | 3.40 | 3.50 |
| 13.9 | 3.60 | 3.71 | 3.82 | 3.93 | 4.04 | 4.15 | 4.26 | 4.37 | 4.48 | 4.59 |
| 14.0 | 4.70 | 4.81 | 4.92 | 5.03 | 5.14 | 5.25 | 5.36 | 5.47 | 5.58 | 5.69 |
| 14.1 | 5.80 | 5.94 | 6.08 | 6.22 | 6.36 | 6.50 | 6.64 | 6.78 | 6.92 | 7.06 |
| 14.2 | 7.20 | 7.38 | 7.56 | 7.74 | 7.92 | 8.10 | 8.28 | 8.46 | 8.64 | 8.82 |
| 14.3 | 9.00 | 9.10 | 9.20 | 9.30 | 9.40 | 9.50 | 9.60 | 9.70 | 9.80 | 9.90 |
| 14.4 | 10.00 | 10.15 | 10.30 | 10.45 | 10.60 | 10.75 | 10.90 | 11.05 | 11.20 | 11.35 |
| 14.5 | 11.50 | 11.65 | 11.80 | 11.95 | 12.10 | 12.25 | 12.40 | 12.55 | 12.70 | 12.85 |
| 14.6 | 13.00 | 13.20 | 13.40 | 13.60 | 13.80 | 14.00 | 14.20 | 14.40 | 14.60 | 14.80 |
| 14.7 | 15.00 | 15.19 | 15.38 | 15.57 | 15.76 | 15.95 | 16.14 | 16.33 | 16.52 | 16.71 |
| 14.8 | 16.90 | 17.08 | 17.26 | 17.44 | 17.62 | 17.80 | 17.98 | 18.16 | 18.34 | 18.52 |
| 14.9 | 18.70 | 18.93 | 19.16 | 19.39 | 19.62 | 19.85 | 20.08 | 20.31 | 20.54 | 20.77 |
| 15.0 | 21.00 | 21.20 | 21.40 | 21.60 | 21.80 | 22.00 | 22.20 | 22.40 | 22.60 | 22.80 |
| 15.1 | 23.00 | 23.25 | 23.50 | 23.75 | 24.00 | 24.25 | 24.50 | 24.75 | 25.00 | 25.25 |
| 15.2 | 25.50 | 25.75 | 26.00 | 26.25 | 26.50 | 26.75 | 27.00 | 27.25 | 27.50 | 27.75 |
| 15.3 | 28.00 | 28.25 | 28.50 | 28.75 | 29.00 | 29.25 | 29.50 | 29.75 | 30.00 | 30.25 |
| 15.4 | 30.50 | 30.75 | 31.00 | 31.25 | 31.50 | 31.75 | 32.00 | 32.25 | 32.50 | 32.75 |
| 15.5 | 33.00 | 33.30 | 33.60 | 33.90 | 34.20 | 34.50 | 34.80 | 35.10 | 35.40 | 35.70 |
| 15.6 | 36.00 | 36.30 | 36.60 | 36.90 | 37.20 | 37.50 | 37.80 | 38.10 | 38.40 | 38.70 |
| 15.7 | 39.00 | 39.30 | 39.60 | 39.90 | 40.20 | 40.50 | 40.80 | 41.10 | 41.40 | 41.70 |

The gaging station has an inner recording gage and an outer staff gage. The two gages are linearly related. The bottom lip of the culvert is at 7.16 feet on the staff gage, which corresponds to 13.34 feet on the inner gage. The culvert begins to control the flow at a gage height of 14.40 feet with a discharge of 10.0 cfs. The stage of flow at which the culvert controls was determined by a USGS method presented by Bodhaine (1968).

Table 5. Rating table #2 for Crumarine Creek for January 1977 to March 1979 and August 1981 to November 1982. All gage heights are in feet.

Flows in cfs

| Gage Height | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 13.2 | | | | | | | 0.01 | 0.04 | 0.07 | 0.10 |
| 13.3 | 0.10 | 0.11 | 0.13 | 0.14 | 0.15 | 0.16 | 0.18 | 0.19 | 0.21 | 0.22 |
| 13.4 | 0.24 | 0.26 | 0.27 | 0.29 | 0.31 | 0.33 | 0.36 | 0.38 | 0.41 | 0.44 |
| 13.5 | 0.46 | 0.49 | 0.52 | 0.56 | 0.59 | 0.62 | 0.67 | 0.72 | 0.76 | 0.81 |
| 13.6 | 0.86 | 0.93 | 1.01 | 1.08 | 1.16 | 1.23 | 1.31 | 1.39 | 1.48 | 1.56 |
| 13.7 | 1.64 | 1.74 | 1.84 | 1.94 | 2.04 | 2.14 | 2.25 | 2.35 | 2.45 | 2.55 |
| 13.8 | 2.65 | 2.78 | 2.90 | 3.02 | 3.15 | 3.28 | 3.40 | 3.52 | 3.65 | 3.78 |
| 13.9 | 3.90 | 4.02 | 4.13 | 4.24 | 4.36 | 4.48 | 4.59 | 4.70 | 4.82 | 4.94 |
| 14.0 | 5.05 | 5.16 | 5.28 | 5.40 | 5.51 | 5.62 | 5.74 | 5.86 | 5.97 | 6.08 |
| 14.1 | 6.20 | 6.32 | 6.44 | 6.56 | 6.68 | 6.80 | 6.92 | 7.04 | 7.16 | 7.28 |
| 14.2 | 7.40 | 7.56 | 7.72 | 7.88 | 8.04 | 8.20 | 8.36 | 8.52 | 8.68 | 8.84 |
| 14.3 | 9.00 | 9.10 | 9.20 | 9.30 | 9.40 | 9.50 | 9.60 | 9.70 | 9.80 | 9.90 |
| 14.4 | 10.00 | 10.15 | 10.30 | 10.45 | 10.60 | 10.75 | 10.90 | 11.05 | 11.20 | 11.35 |
| 14.5 | 11.50 | 11.65 | 11.80 | 11.95 | 12.10 | 12.25 | 12.40 | 12.55 | 12.70 | 12.85 |
| 14.6 | 13.00 | 13.20 | 13.40 | 13.60 | 13.80 | 14.00 | 14.20 | 14.40 | 14.60 | 14.80 |
| 14.7 | 15.00 | 15.19 | 15.38 | 15.57 | 15.76 | 15.95 | 16.14 | 16.33 | 16.52 | 16.71 |
| 14.8 | 16.90 | 17.08 | 17.26 | 17.44 | 17.62 | 17.80 | 17.98 | 18.16 | 18.34 | 18.52 |
| 14.9 | 18.70 | 18.93 | 19.16 | 19.39 | 19.62 | 19.85 | 20.08 | 20.31 | 20.54 | 20.77 |
| 15.0 | 21.00 | 21.20 | 21.40 | 21.60 | 21.80 | 22.00 | 22.20 | 22.40 | 22.60 | 22.80 |
| 15.1 | 23.00 | 23.25 | 23.50 | 23.75 | 24.00 | 24.25 | 24.50 | 24.75 | 25.00 | 25.25 |
| 15.2 | 25.50 | 25.75 | 26.00 | 26.25 | 26.50 | 26.75 | 27.00 | 27.25 | 27.50 | 27.75 |
| 15.3 | 28.00 | 28.25 | 28.50 | 28.75 | 29.00 | 29.25 | 29.50 | 29.75 | 30.00 | 30.25 |
| 15.4 | 30.50 | 30.75 | 31.00 | 31.25 | 31.50 | 31.75 | 32.00 | 32.25 | 32.50 | 32.75 |
| 15.5 | 33.00 | 33.30 | 33.60 | 33.90 | 34.20 | 34.50 | 34.80 | 35.10 | 35.40 | 35.70 |
| 15.6 | 36.00 | 36.30 | 36.60 | 36.90 | 37.20 | 37.50 | 37.80 | 38.10 | 38.40 | 38.70 |
| 15.7 | 39.00 | 39.30 | 39.60 | 39.90 | 40.20 | 40.50 | 40.80 | 41.10 | 41.40 | 41.70 |

Table 6. Rating table #3 for Crumarine Creek for April 1979 to July 1981 and December 1982 to present. All gage heights are in feet.

Flow in cfs

| Gage Height | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 13.3 | 0.14 | 0.15 | 0.16 | 0.18 | 0.20 | 0.21 | 0.22 | 0.24 | 0.26 | 0.27 |
| 13.4 | 0.28 | 0.32 | 0.35 | 0.39 | 0.42 | 0.45 | 0.49 | 0.52 | 0.55 | 0.59 |
| 13.5 | 0.62 | 0.69 | 0.77 | 0.84 | 0.91 | 0.98 | 1.06 | 1.13 | 1.20 | 1.28 |
| 13.6 | 1.35 | 1.46 | 1.56 | 1.67 | 1.77 | 1.88 | 1.98 | 2.09 | 2.19 | 2.30 |
| 13.7 | 2.40 | 2.51 | 2.62 | 2.73 | 2.84 | 2.95 | 3.06 | 3.17 | 3.28 | 3.39 |
| 13.8 | 3.50 | 3.61 | 3.72 | 3.83 | 3.94 | 4.05 | 4.16 | 4.27 | 4.38 | 4.49 |
| 13.9 | 4.60 | 4.70 | 4.80 | 4.90 | 5.00 | 5.10 | 5.20 | 5.30 | 5.40 | 5.50 |
| 14.0 | 5.60 | 5.72 | 5.84 | 5.96 | 6.08 | 6.20 | 6.32 | 6.44 | 6.56 | 6.68 |
| 14.1 | 6.80 | 6.90 | 7.00 | 7.10 | 7.20 | 7.30 | 7.40 | 7.50 | 7.60 | 7.70 |
| 14.2 | 7.80 | 7.92 | 8.04 | 8.16 | 8.28 | 8.40 | 8.52 | 8.64 | 8.76 | 8.88 |
| 14.3 | 9.00 | 9.10 | 9.20 | 9.30 | 9.40 | 9.50 | 9.60 | 9.70 | 9.80 | 9.90 |
| 14.4 | 10.00 | 10.15 | 10.30 | 10.45 | 10.60 | 10.75 | 10.90 | 11.05 | 11.20 | 11.35 |
| 14.5 | 11.50 | 11.65 | 11.80 | 11.95 | 12.10 | 12.25 | 12.40 | 12.55 | 12.70 | 12.85 |
| 14.6 | 13.00 | 13.20 | 13.40 | 13.60 | 13.80 | 14.00 | 14.20 | 14.40 | 14.60 | 14.80 |
| 14.7 | 15.00 | 15.19 | 15.38 | 15.57 | 15.76 | 15.95 | 16.14 | 16.33 | 16.52 | 16.71 |
| 14.8 | 16.90 | 17.08 | 17.26 | 17.44 | 17.62 | 17.80 | 17.98 | 18.16 | 18.34 | 18.52 |
| 14.9 | 18.70 | 18.93 | 19.16 | 19.39 | 19.62 | 19.85 | 20.08 | 20.31 | 20.54 | 20.77 |
| 15.0 | 21.00 | 21.20 | 21.40 | 21.60 | 21.80 | 22.00 | 22.20 | 22.40 | 22.60 | 22.80 |
| 15.1 | 23.00 | 23.25 | 23.50 | 23.75 | 24.00 | 24.25 | 24.50 | 24.75 | 25.00 | 25.25 |
| 15.2 | 25.50 | 25.75 | 26.00 | 26.25 | 26.50 | 26.75 | 27.00 | 27.25 | 27.50 | 27.75 |
| 15.3 | 28.00 | 28.25 | 28.50 | 28.75 | 29.00 | 29.25 | 29.50 | 29.75 | 30.00 | 30.25 |
| 15.4 | 30.50 | 30.75 | 31.00 | 31.25 | 31.50 | 31.75 | 32.00 | 32.25 | 32.50 | 32.75 |
| 15.5 | 33.00 | 33.30 | 33.60 | 33.90 | 34.20 | 34.50 | 34.80 | 35.10 | 35.40 | 35.70 |
| 15.6 | 36.00 | 36.30 | 36.60 | 36.90 | 37.20 | 37.50 | 37.80 | 38.10 | 38.40 | 38.70 |
| 15.7 | 39.00 | 39.30 | 39.60 | 39.90 | 40.20 | 40.50 | 40.80 | 41.10 | 41.40 | 41.70 |

Occasional disruptions occur at the gaging station. At such times, the data recorded at the gaging station are inaccurate. The most common cause of these disruptions were ice jams in the culvert, which result in backwater in the stream. Some data were also missing due to mechanical failures of the recording gage or freezing of the float during the winter. In order to determine the flow during these ice jams and other disruptions, a correlation was computed between flows on Crumarine Creek and Missouri Flat Creek. Missouri Flat Creek's gage is located in Pullman, Washington, and the watershed drains an area of 27.1 square miles. Monthly correlations were determined with Missouri Flat Creek flows as the independent variable and Crumarine Creek flows as the dependent variable. The correlations were based on 21 years of daily streamflow data from 1959 to 1979. The equations used to generate the data appear in Appendix A. Some months exhibited a strong positive correlation and some months, especially the summer months and early fall months, had low positive correlations (Table 7). Low correlations during the summer are expected since Crumarine Creek has very low flows in the summer with little fluctuations unlike Missouri Flat Creek. During periods of no rain in the summer the discharge of the two streams is nearly the same. During periods of rain in the summer, Missouri Flat Creek carries a much larger flow than Crumarine Creek since Missouri Flat Creek drains a much larger area. Missouri Flat Creek flows are usually five to ten times larger than Crumarine Creek flows during a rain event. This larger increase in flows carried by Missouri Flat Creek during a summer rain event causes the poor correlation between the two streams.

Data were generated for missing daily streamflow values based on the regression equations in Appendix A. Once the data were generated, mean monthly runoff values were computed using recorded and generated streamflow

Table 7. Coefficients of determination of daily streamflow between Crumarine Creek and Missouri Flat Creek.

| Month | $r^2$ |
|---|---|
| Oct | 0.2162 |
| Nov | 0.6474 |
| Dec | 0.4170 |
| Jan | 0.3473 |
| Feb | 0.5817 |
| Mar | 0.1981 |
| Apr | 0.4378 |
| May | 0.4252 |
| Jun | 0.5386 |
| Jul | 0.0000 |
| Aug | 0.0000 |
| Sep | 0.1642 |

All are significant at the 90% level

values for the water years of 1969 to 1973. Table 8 lists the mean monthly runoff values for the watershed for both the years of interest and the long term average. The long-term average for annual runoff for Crumarine Creek based on data from 1956 to 1985 was 8.9 inches. As can be seen, the 1969 to 1973 water years were above the long term average runoff. The mean annual runoff values are assumed to be accurate within 10 percent. The source of error lies in the measurement of runoff and localized shifts in the rating curve.

Table 8. Mean monthly streamflow for Crumarine Creek.

| | 1969 to 1973 Water Years | | 1959 to 1979 Long term average | |
|---|---|---|---|---|
| Month | cfs-days | inches | cfs-days | inches |
| Oct | 8.8 | 0.1 | 7.4 | 0.1 |
| Nov | 10.0 | 0.2 | 10.1 | 0.2 |
| Dec | 12.0 | 0.2 | 19.9 | 0.3 |
| Jan | 81.2 | 1.2 | 35.2 | 0.5 |
| Feb | 77.2 | 1.2 | 80.6 | 1.2 |
| Mar | 175.0 | 2.6 | 122.5 | 1.9 |
| Apr | 159.4 | 2.4 | 140.7 | 2.1 |
| May | 141.3 | 2.1 | 108.3 | 1.6 |
| Jun | 43.1 | 0.6 | 38.8 | 0.6 |
| Jul | 13.0 | 0.2 | 15.0 | 0.2 |
| Aug | 6.7 | 0.1 | 6.5 | 0.1 |
| Sep | 6.5 | 0.1 | 5.8 | 0.1 |
| Annual | 734.2 | 11.0 | 590.8 | 8.9 |

## Soil Moisture

The amount of soil moisture available to the vegetation varies from month to month but remains relatively constant on an annual basis. Zahrer and Stage (1966) found that in upland coniferous and hardwood forests of the United States and Canada the majority of water available to tree roots is that water held in storage by the soil particles themselves. Additional sources, such as lateral underground seepage or shallow water tables, are often absent. Therefore, in order to calculate soil moisture in the ground, compensation for ground-water seepage is not necessary. Copeland

(1956) and Gardner (1958) both suggested using the top three feet of soil to determine the amount of soil moisture available in a forest.

The amount of water available to the tree roots is that water held between 15 bars (the wilting point) and 1/3 bar (the field capacity). Hillel (1982) defined the wilting point as the water content at which roots can no longer extract water and the field capacity as the water content at which internal drainage by gravity has ceased.

The soils of the watershed are either a loam or silt loam. The following information was obtained from the Latah County Soil Survey (Soil Conservation Service, 1981). A Vassar silt loam and an Uvi loam are located on the upper end of the watershed and cover approximately 74 percent of the total watershed. Both soils are highly permeable, well drained and are common on steep slopes. The lower part of the creek is lined with a Spokane rock outcrop complex accounting for five percent of the total area. This soil is of the loam textural class, well drained, has medium permeability and contains residuum from granite. The Spokane, Uvi and Vassar series are all of hydrologic group B. The lower end of the watershed, approximately 15 percent of the total area, contains a Taney silt loam. This soil is well drained, has low permeability and the dominant cover is wheat. The remaining ten percent of the watershed has various silt and silt loam soil series.

Three sites were chosen on the watershed to conduct infiltration tests and collect soil samples. Figure 5 shows the location of these sites. A two ring infiltrometer test was done and soil samples were taken on each site in June and September. The results from these tests are in Table 9.

In September, 1985, 3.75 inches of rain were received while the normal for September is 1.10 inches. All 3.75 inches were received prior to September 27. Therefore, the soil moisture values obtained for the

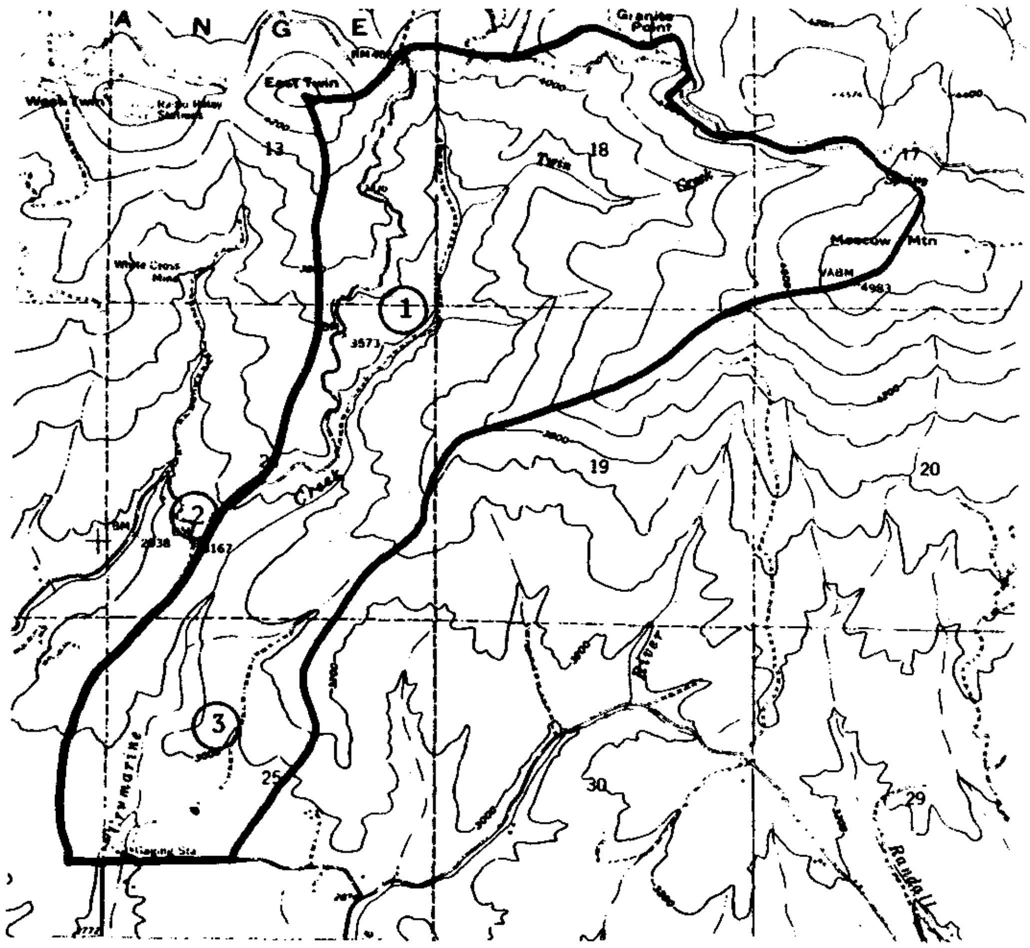


Figure 5. Location of soil sampling and infiltrometer test sites.

watershed in September were most likely above normal. In June, 1985, 2.05 inches of rain were received and the normal for June is 1.65 inches. All 2.05 inches were received prior to June 15. Since the precipitation received prior to June 15, 1985, was above the normal for June, then it is believed that the soil moistures obtained in June are probably slightly above normal.

Definite fluctuations in soil moisture occur throughout the year. Daubenmire (1968) conducted soil moisture tests under cedar, fir and pine forest habitats near Moscow, Idaho. The lower elevation sites (2700 feet

Table 9. Soil sampling and infiltrometer results results for Crumarine Creek.

| Site | Date of Sampling | Infiltration in/hr[1] | Soil Moisture[2] |
|---|---|---|---|
| 1 | 6/15/85 | 2.4 | 51% |
| 2 | 6/18/85 | 1.4 | 21% |
| 3 | 6/16/85 | 0.5 | 16% |
| 1 | 9/25/85 | 3.8 | 37% |
| 2 | 9/27/85 | 7.1 | 17% |
| 3 | 9/27/85 | -- | 14% |

Site 1- Vassar silt loam
Site 2- Spokane rock outcrop complex
Site 3- Taney silt loam

[1] Represents constant infiltration rates

[2] Represents average soil moisture over 2.0 foot depth

and 2800 feet) were near Troy and the higher elevation site (3300 feet) was on Moscow Mountain. His results are shown in Figure 6. The precipitation for 1942, when Daubenmire performed his soil moisture measurements, was slightly below the normal precipitation for the Moscow area. The actual precipitation recorded for 1942 was 17.3 inches. The normal precipitation for the Moscow area, based on data prior to 1942, was 18.5 inches. Since the precipitation was near normal then Daubenmire's soil moisture fluctuations were assumed to be representative of normal soil moisture fluctuations.

In order to predict representative soil moisture values and the amount of available water for the watershed, the bulk density, field capacity and

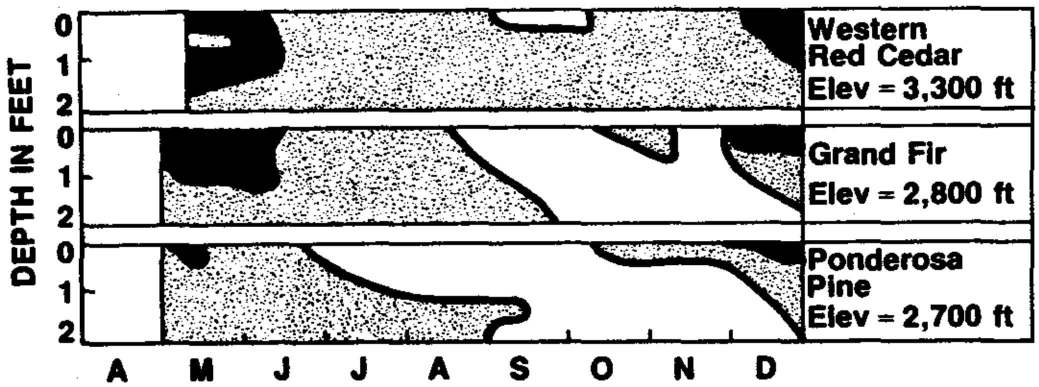


Figure 6. Daubenmire's soil moisture results for Moscow and Troy area for 1942. Black areas indicate soil moisture at or in excess of the field capacity. Stippled areas indicate water content between the field capacity and the wilting point. Unshaded areas indicate the soil moisture is at or below the wilting point.

wilting point must be known. These three variables have been determined by other researchers for soils found on Crumarine Creek watershed. Peterson (1981) determined soil properties of deep loess soils in Latah County under forest canopies. Two of his soils, a Taney silt loam and a Joel silt loam, were identical to those soils found on Crumarine Creek watershed. Also, the soils had the same forest canopies as those found on the watershed. Dechert and others (1981) described a soil (unnamed fine sandy loam, 76-Ida-29109), which has been unofficially classified as a Vassar silt loam.* An unnamed loam, 77-Ida-2999, described by Falen and others (1983) was classified as an Uvi loam by Fosberg.* The bulk density, field capacity and wilting point of each soil are listed in Table 10. Each soil type was weighted by area to determine a representative bulk density, field capacity and wilting point for the entire watershed.

Table 10. Soil moisture properties for Crumarine Creek watershed.

| Soil type | Forest type | Field Capacity* | Wilting Point* | Bulk Density* | Percent Area |
|---|---|---|---|---|---|
| Taney silt loam | Grand fir | 34.2 | 8.3 | 1.46 | 16 |
| Joel silt loam | Douglas fir | 31.7 | 16.9 | 1.58 | 5 |
| Vassar silt loam | Western hemlock | 26.6 | 7.0 | 1.17 | 68 |
| Uvi loam | Douglas fir | 19.8 | 5.3 | 1.12 | 11 |
| Weighted watershed values | | 27.3 | 7.5 | 1.23 | |

*Percent by weight and weighted over the top three feet of soil

Schauer (1976) observed soil moisture during the summer of 1974 and 1975 near Coeur D'Alene, Idaho. A portion of his results illustrates soil moisture fluctuations during the summer (Table 11). Site 1 is a Douglas fir forest habitat and the underlying soil has an average field capacity of 15.5 percent and wilting point of 5.1 percent. Site 2 is a grand fir forest habitat and the underlying soil has an average field capacity of 32.1 percent and wilting point of 8.8 percent. Soil moistures were averaged over a three foot depth. Schauer's (1976) data show a definite decline in soil moisture during the summer. In July the soil moisture is

*Personal communication with Dr. Maynard Fosberg, Professor of Plant, Soil and Entomological Sciences ,University of Idaho, November 26, 1985.

well above the wilting point and by late summer has declined to near or below the wilting point.

Table 11. Percent soil moisture by weight near Coeur D'Alene, Idaho.

1974

| Site | 7/24 | 7/30 | 8/5 | 8/14 | 8/21 | 8/24 | 9/12 | 9/27 |
|---|---|---|---|---|---|---|---|---|
| 1 | 13.0 | 11.1 | 10.7 | 9.0 | 7.9 | 7.7 | 7.6 | 6.7 |
| 2 | 20.4 | 18.0 | 15.9 | 14.5 | 12.8 | 10.5 | 10.2 | 8.5 |

1975

| Site | 7/12 | 7/22 | 7/28 | 8/5 | 8/12 | 8/17 | 8/26 |
|---|---|---|---|---|---|---|---|
| 1 | 15.6 | 14.1 | 11.6 | 10.4 | 8.0 | 9.1 | 8.2 |
| 2 | 23.0 | 20.1 | 18.6 | 16.4 | 14.7 | 14.4 | 16.5 |

Since Daubenmire (1968) conducted his study of soil moisture during a year where precipitation was close to normal, his results were used as a guideline in predicting soil moisture patterns on Crumarine Creek. The months of December, January, February and March were assumed to have soil moistures near or in excess of the field capacity of 27.3 percent. This is a safe assumption since evapotranspiration is relatively low in these months and precipitation is high. Also, the snow covering the ground is melting during these months and infiltrating into the ground, which would account for soil moistures above the field capacity. The months of August, September and October will have soil moistures approaching the wilting point of 7.5 percent. The remaining months will have soil moistures between 27.3 percent and 7.5 percent. As seen from the soil moisture data taken on the watershed, a definite decline in soil water content occurred between June and September. It was assumed that the summer months will follow a soil moisture trend similar to Schauer's (1976) findings. Based on the above assumptions, the soil moisture values shown in Table 12 were obtained for the top three feet of soil.

Table 12. Soil moisture for Crumarine Creek watershed.

| Month | Percent soil moisture* | Amount of water, in | Change in water content, in |
|---|---|---|---|
| Oct | 10.0 | 4.4 | 1.3 |
| Nov | 16.0 | 7.1 | 2.7 |
| Dec | 24.0 | 10.6 | 3.5 |
| Jan | 29.0 | 13.3 | 2.7 |
| Feb | 36.0 | 15.5 | 2.2 |
| Mar | 31.0 | 14.6 | -0.9 |
| Apr | 26.0 | 12.4 | -2.2 |
| May | 20.0 | 10.2 | -2.2 |
| Jun | 16.0 | 7.5 | -2.7 |
| Jul | 12.0 | 5.3 | -2.2 |
| Aug | 9.0 | 4.0 | -1.3 |
| Sep | 7.0 | 3.1 | -0.9 |

*Percent soil moisture by weight for top three feet of soil

Moisture content on a volumetric basis and the amount of water were computed by the following equations from Armson (1977):

$$\text{Vol M.C.} = \text{M.C. by weight} \times \text{B.D.} \quad (4)$$

$$\text{Depth of water} = \text{Vol M.C.} \times \text{Depth} \quad (5)$$

Change in water content=Amount(i)-Amount(i-1) (6)

Soil moisture recharge occurs from October to February, which is represented by positive values. March through September is a period of soil moisture depletion, which is represented by negative values. The final soil moisture values are assumed to be accurate within 20 percent since these are not actual monthly soil moisture values but those assumed to exist in some nearly normal year.

Evapotranspiration

Two types of evapotranspiration (ET) equations exist- one predicts potential ET and the other predicts actual ET. Penman (page 9, 1956) defined potential ET as "the amount of water transpired in a unit time by a short green crop, completely shading the ground, of uniform height and never short of water." Potential ET (PET) is said to be independent of plant or soil type provided the albedo remains constant. Penman (1956) also stated that PET is determined by the prevailing weather and the rate of PET cannot exceed the rate of evaporation from an open water surface exposed to similar environmental conditions. Actual ET is either less than or equal to PET. ET for the watershed was calculated separately for both the winter wheat and the forest and the final ET values were weighted by area.

ET from the winter wheat was estimated from existing ET data. Since the winter wheat only comprises 12 percent of the total watershed and the final ET values were multiplied by 0.12 as a weighting factor, an average value of ET from the winter wheat was sufficient. ET from the winter wheat was estimated from data presented by Allen and Brockway (1983). They calculated average monthly reference ET for alfalfa. Reference ET represents a standard on which crop ET can be based. In order to obtain actual ET from the winter wheat the reference ET must be multiplied by a crop coefficient. Crop coefficients for winter wheat have been determined by Wright (1981) in Kimberly, Idaho, based on data taken from 1968 to 1978. The crop coefficient is a function of the growing stage of the crop and is the ratio of actual ET to potential ET. Allen and Brockway (1983) determined that winter wheat in Moscow, Idaho, usually begins to transpire February 25, has 100 percent effective cover by June 15 and is harvested by August 15. The crop coefficient peaks at 100 percent effective cover, which is approximately the time of heading. Crop coefficients, reference ET and actual ET are listed in Table 13.

Many factors influence ET in a forest. At one time it was believed that net radiation was the major driving force in ET. Morton (1984) found under dry-canopy conditions the stomatal response to radiation, temperature, vapor pressure deficit and carbon-dioxide concentration to be the controlling factor. In their study of a Douglas fir forest, McNaughton and Black (1973) noticed that peak ET rates consistently occurred two to three hours after solar noon. This result further indicated that forest ET is not directly driven by net radiation. Tan and Black (1976) continued investigations on a Douglas fir forest to further examine stomatal resistance. Their results showed that stomatal resistance increases more in response to increases in the daytime mean vapor pressure deficit than to a decrease in daily soil-water content. An increase in vapor pressure deficit would increase transpiration which in turn would reduce internal leaf water content, which causes the stomata to contract. Under wet canopy

Table 13. Average ET for the winter wheat on Crumarine Creek watershed.

| Month | Crop Coefficient* | Reference ET, inches** | Actual ET, inches |
|---|---|---|---|
| Feb | 0.30 | 0.0 | 0.0 |
| Mar | 0.46 | 1.6 | 0.7 |
| Apr | 0.90 | 4.5 | 4.0 |
| May | 1.00 | 6.0 | 6.0 |
| Jun | 1.00 | 6.8 | 6.8 |
| Jul | 0.71 | 9.3 | 6.6 |
| Aug | 0.24 | 7.4 | 1.8 |
| Annual | | | 25.9 |

*Obtained from Wright (1981)
**Obtained from Allen and Brockway (1983)

conditions, Morton (1984) found ET to be constrained primarily by the frequency and duration of rainfall.

Many equations exist to predict ET but few are applicable to forested watersheds. The Penman equation, for instance, provides a practical method for estimating losses from grasses and short crops. However, Calder (1977) found the equation unfit for tall crops, such as forests, whose aerodynamic and surface resistance are very different than grasses. Monteith (1965) modified the Penman equation to give accurate estimates of actual evapotranspiration from any crop. This equation is:

$$LE=\frac{\Delta r_a(R_n-G)+C_p\rho(e_s-e_a)}{(\Delta+\gamma)r_a+\gamma r_c} \quad (7)$$

L=latent heat of vaporization
E=potential evaporation flux density
$\Delta$=slope of saturation vapor pressure curve
$\gamma$=psychrometric constant
$R_n$=net radiation
G=soil heat flux
$C_p$=heat capacity of air
$\rho$=density of air
$e_s$=saturation vapor pressure at air temperature
$e_a$=actual vapor pressure of the air
$r_a$=aerodynamic or boundary layer resistance
$r_c$=canopy resistance

The availability of the necessary climatological data makes this equation attractive. The biggest problem in utilizing this equation is obtaining the proper value for the aerodynamic resistance. A value of 0.06 s/cm for the aerodynamic resistance, $r_a$, was found by McNaughton and Black (1973) on a Douglas fir forest and Stewart and Thom (1973) on a pine forest. Calder (1977) found $r_a$ from April to June for a spruce forest to be 0.035 s/cm. The aerodynamic resistance is a function of wind and is therefore subject to variability (Calder, 1977). A value of 1.0 s/cm is suggested by Federer (1975) for the canopy resistance. In the Monteith equation, the soil heat flux is of minor importance and can be ignored (McCaughey, 1978).

Another equation widely used to predict ET in a forest is the Priestley-Taylor (1972) equation.

$$PET = \frac{\alpha\,(R_n - G)}{L(1+\gamma/\Delta)} \qquad (8)$$

PET=potential evapotranspiration
$\alpha$=dimensionless coefficient of conductivity
L=latent heat of vaporization
$R_n$=net radiation
G=soil heat flux
$\gamma$=psychrometric constant
$\Delta$=slope of saturation vapor pressure curve

Priestley and Taylor (1972) assigned $\alpha$ a mean value of 1.26 for a variety of well-watered terrestial surfaces. McCaughey (1978) noticed $\alpha$ to vary with volumetric soil moisture in his study of balsam firs. When the volumetric moisture content was in excess of 32 percent, PET conditions prevailed. Below 32 percent soil moisture was limiting and PET no longer occurred. Also, when the volumetric soil moisture was 32 percent or less, $\alpha$ decreased as the soil moisture decreased. McCaughey (1978) found $\alpha$ to reach a minimum of 0.67. McNaughton and Black (1973) found $\alpha$ to be 1.05 for a Douglas fir forest under PET conditions. Stewart and Thom (1973) found $\alpha$ was 0.7 for a pine forest under nonpotential conditions. Attempts have been made by others to relate $\alpha$ to soil moisture to predict actual ET.

The Priestley-Taylor equation has been modified by other researchers. McNaughton and Black (1973) used the following form of the equation to predict PET on a Douglas fir watershed.

$$PET = \frac{\alpha\,(R_n - G)}{L\,(1+\gamma/\Delta)} + 0.17I \qquad (9)$$

PET=potential evapotranspiration over 24 hours
α=dimensionless coefficient of conductivity=1.05
I=gross canopy interception

Once again, the soil heat flux term can be ignored. This version of the Priestley-Taylor equation takes into account canopy interception unlike the orginal form of the equation (Equation 8). McNaughton and Black (1973) assumed that only 17 percent of the intercepted precipitation evaporates.

Actual evapotranspiration from the watershed is the final value needed in the water balance equation, not PET. Shuttleworth and Calder (1979) suggested another form of the Priestley-Taylor equation to predict actual ET.

$$ET = \frac{(0.72 \pm 0.07)}{L} \frac{(R_n - G)}{(1+\gamma/\Delta)} + (0.27 \pm 0.08)P \qquad (10)$$

ET=actual evapotranspiration
$\alpha = 0.72 \pm 0.07$
$(0.27 \pm 0.08)P$=gross canopy interception
P=mean monthly precipitation

Equation 10 assumes a larger part of the intercepted precipitation is evaporated than Equation 9. Equation 10 also accounts for variation in α based on studies by Clark and McCulloch (1976) and Stewart and Thom (1973) on coniferous forests. The Shuttleworth and Calder form of the Priestley-Taylor equation was chosen to predict actual ET from the watershed. The reason for choosing equation 10 is that the necessary climatological data was available and a definite range of α values was defined in Equation 10 by Shuttleworth and Calder (1979), unlike the other forest ET equations.

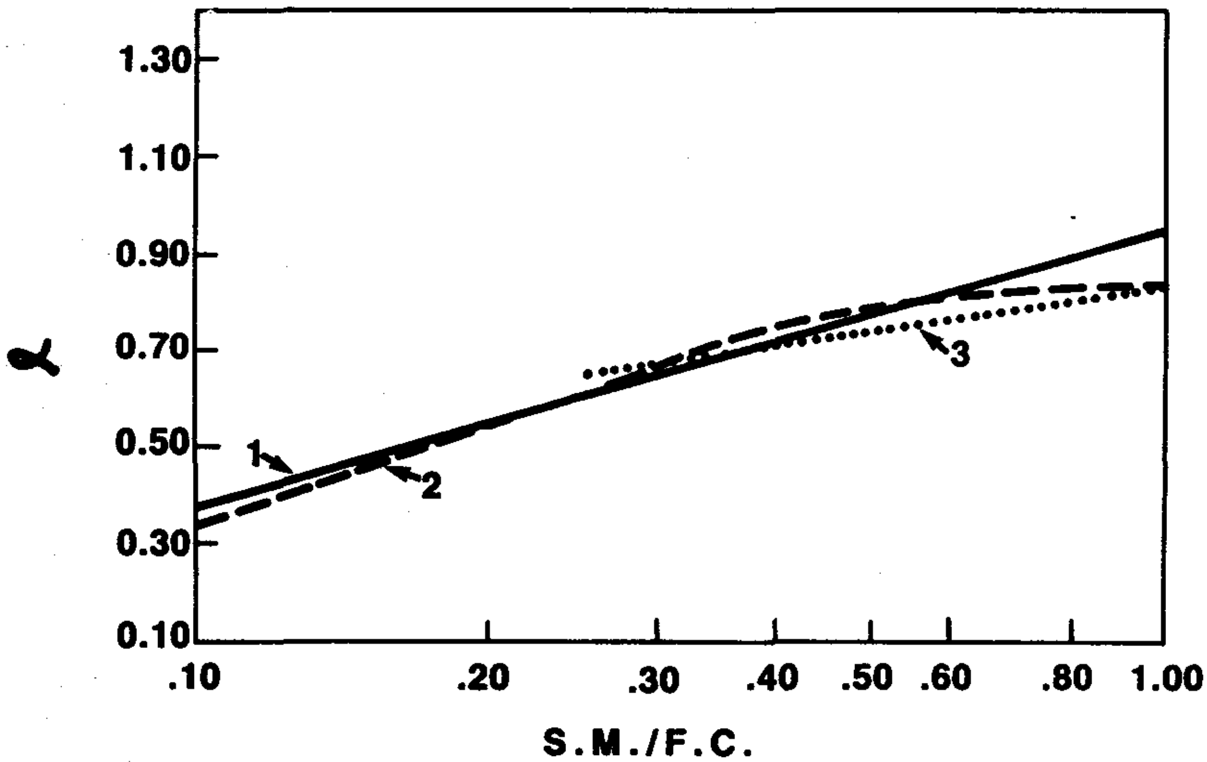


Figure 7. Variation of α with soil moisture. α is the dimensionless coefficient of conductivity, S.M.=soil moisture and F.C.=field capacity.

In order to derive the actual ET from the watershed the α coefficient must be varied in accordance with soil moisture. The relationship between soil moisture and α has been found to be nonlinear. Davies and Allen (1973), Williams and others (1978) and Barton (1979) described the relationship as exponential. The results of Williams and others (1978) are represented by Lines 1 and 2 in Figure 7. As seen in Figure 7, the lines are nearly straight. It was assumed a similar relationship existed between $\alpha$ and soil moisture for the watershed. A plot of $\alpha$ versus soil moisture divided by field capacity was made with $\alpha$ on the arithmetic axis. The soil moisture and field capacity were taken over the top three feet of soil and are listed in Table 12. A field capacity of 27.3 percent and a wilting point of 7.5 percent were found. Any soil moistures equal to or in excess of the field capacity will correspond to an $\alpha$ of 0.79. Any soil moisture values at or below the wilting point corresponded to an $\alpha$ of 0.65. In other words, when the soil moisture divided by the field capacity equals 1.0, $\alpha$ equals 0.79. When the soil moisture is at the wilting point, the soil moisture over the field capacity equals 0.27 (7.5/27.3). This ratio corresponds to an $\alpha$ value of 0.65. These two points were plotted on semilog paper and a straight line was drawn between the points. This line is shown in Figure 7 as Line 3. The equation of the line is:

$$\alpha=0.79+0.25\log(S.M./F.C.) \qquad (11)$$

The $\alpha$ values in Table 14 were determined based on mean monthly soil moisture values in Table 12.

ET was calculated by Equation 10 for all months except December, January and February. Sublimation occurs during these months, which was calculated separately. Interception was also excluded from the equation since this too was calculated separately. Net radiation values used in calculating actual ET were determined by the following equation suggested by Schwab and others (1981):

$$R_n=(1.0-a)R_s-R_b \qquad (12)$$

Table 14. Monthly average ET from the forest for Crumarine Creek Watershed.

| Month | % SM | SM/FC | α | ET, inches |
|---|---|---|---|---|
| Oct | 10.0 | 0.36 | 0.69 | 0.6 |
| Nov | 16.0 | 0.59 | 0.73 | 0.1 |
| Dec | 24.0 | 0.88 | 0.78 | 0.0 |
| Jan | 29.0 | 1.00 | 0.79 | 0.0 |
| Feb | 36.0 | 1.00 | 0.79 | 0.0 |
| Mar | 31.0 | 1.00 | 0.79 | 1.0 |
| Apr | 26.0 | 0.95 | 0.78 | 2.0 |
| May | 20.0 | 0.73 | 0.76 | 2.4 |
| Jun | 16.0 | 0.59 | 0.73 | 2.7 |
| Jul | 12.0 | 0.44 | 0.70 | 2.4 |
| Aug | 9.0 | 0.33 | 0.67 | 1.4 |
| Sep | 7.0 | 0.25 | 0.65 | 0.5 |
| Annual | | | | 13.1 |

$R_n$=net radiation
a=albedo
$R_s$=incoming solar radiation
$R_b$=net outgoing longwave radiation on a clear day

Appendix B contains more information on the calculation of net radiation. Calculations for actual ET are also shown in Appendix B. Table 14 lists the final results for actual ET. Climatological data from 1969 to 1973 water years were used to calculate ET (Appendix C). As seen from the results, June exhibits the most ET but after June ET decreases due to decreasing amounts of available soil-water and declining temperatures. As temperatures increase in March, ET also begins to increase and peaks in June.

Table 15. ET values for Crumarine Creek for 1969 to 1973 water years (inches).

| | Winter Wheat | | Forest | | Weighted |
|---|---|---|---|---|---|
| Month | Actual | Weighted | Actual | Weighted | Total |
| Oct | 0.0 | 0.0 | 0.6 | 0.5 | 0.5 |
| Nov | 0.0 | 0.0 | 0.1 | 0.9 | 0.9 |
| Dec | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Jan | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Feb | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mar | 0.7 | 0.1 | 1.0 | 0.9 | 1.0 |
| Apr | 4.0 | 0.5 | 2.0 | 1.8 | 2.3 |
| May | 6.0 | 0.7 | 2.4 | 2.1 | 2.8 |
| Jun | 6.8 | 0.8 | 2.7 | 2.4 | 3.2 |
| Jul | 6.6 | 0.8 | 2.4 | 2.1 | 2.9 |
| Aug | 1.8 | 0.2 | 1.4 | 1.2 | 1.4 |
| Sep | 0.0 | 0.0 | 0.5 | 0.4 | 0.4 |
| Annual | 25.9 | 3.1 | 13.1 | 12.3 | 15.4 |

Since the winter wheat occupies only 12 percent of the total watershed, the monthly ET values for the winter wheat were multiplied by 0.12 to obtain weighted ET values. The final ET from the winter wheat when weighted by area was actually 3.1 inches. The same process was applied to the forest. Monthly ET values from the forest were multiplied by 0.88 since 88 percent of the watershed is forested. The final ET value from the forest when weighted was 12.3 inches. Table 15 lists the actual and weighted ET values for the watershed. The total annual ET from the watershed based on data from 1969 to 1973 water year and average estimates of monthly ET for wheat was 15.4 inches. The mean monthly evapotranspiration values are assumed to have a maximum error of 20 percent, with the largest amount of error in the prediction of the monthly $\alpha$ values.

## Snow Storage

Snow distribution is a function of climate, physiography and vegetative cover. The major climatological factors influencing snow cover are precipitation, temperature and wind. The physiographic features which have the most prominent effect on the snow distribution are elevation, slope and aspect. Gray and Male (1981) observed that elevation is the most important factor affecting snow cover distribution in a mountainous region. A linear relationship between snow accumulation and elevation usually exists. The major influence of vegetative cover on snow distribution is whether or not the area is forested or in an open area. Forested areas tend to accumulate less snow than open areas due to interception.

In order to determine snow distribution on Crumarine Creek watershed, a snow survey was conducted. Snow surveys were done twice, once in February and once in April, at designated areas on the watershed. To develop a proper relationship between snow sites, consistency of procedure, equipment and location is important. Depth, density and snow water equivalent of the snow were determined from the snow survey. Viessman and others (1977) defined the water equivalent as the depth of water that would weigh the same amount as that of the sample. Density is the percentage of snow volume that would be occupied by its water equivalent. A standard

Federal snow tube was used to obtain snow samples. The depth of the snow and weight of the sample and tube were directly measured at the site. From these data the water content and density can be determined by the following equations:

$$WC=WTC-WT \qquad (13)$$

WC=water content, inches
WTC=weight of tube and core sample
WT=weight of empty tube

$$D=WC/Depth \qquad (14)$$

D=density
Depth=depth of snow, inches

Three different snow survey sites were chosen on the watershed (Figure 8). Each site consisted of five sampling points. Depth, water equivalent and density were averaged over these five points. Site 1 is at an elevation of 2920 feet and is an open area. Site 2 is at an elevation of 3180 feet and is within 10 feet of trees. Site 3 is at an elevation of 3750 feet and is in a dense stand of pines. Two snow surveys were conducted- one in February and one in April. The results of the snow surveys appear in Table 16.

The Soil Conservation Service (SCS) in Moscow, Idaho, also conducted snow surveys on Moscow Mountain (Figure 8). Their sites are Moscow Mountain (at an elevation of 4410 feet), East Twin (at an elevation of 4220 feet) and West Twin (at an elevation of 4130 feet). The SCS surveys are conducted around the first of each month beginning with February. Their results for February, March and April of 1985 are listed in Table 17. These values give further information about snow distribution on the mountain.

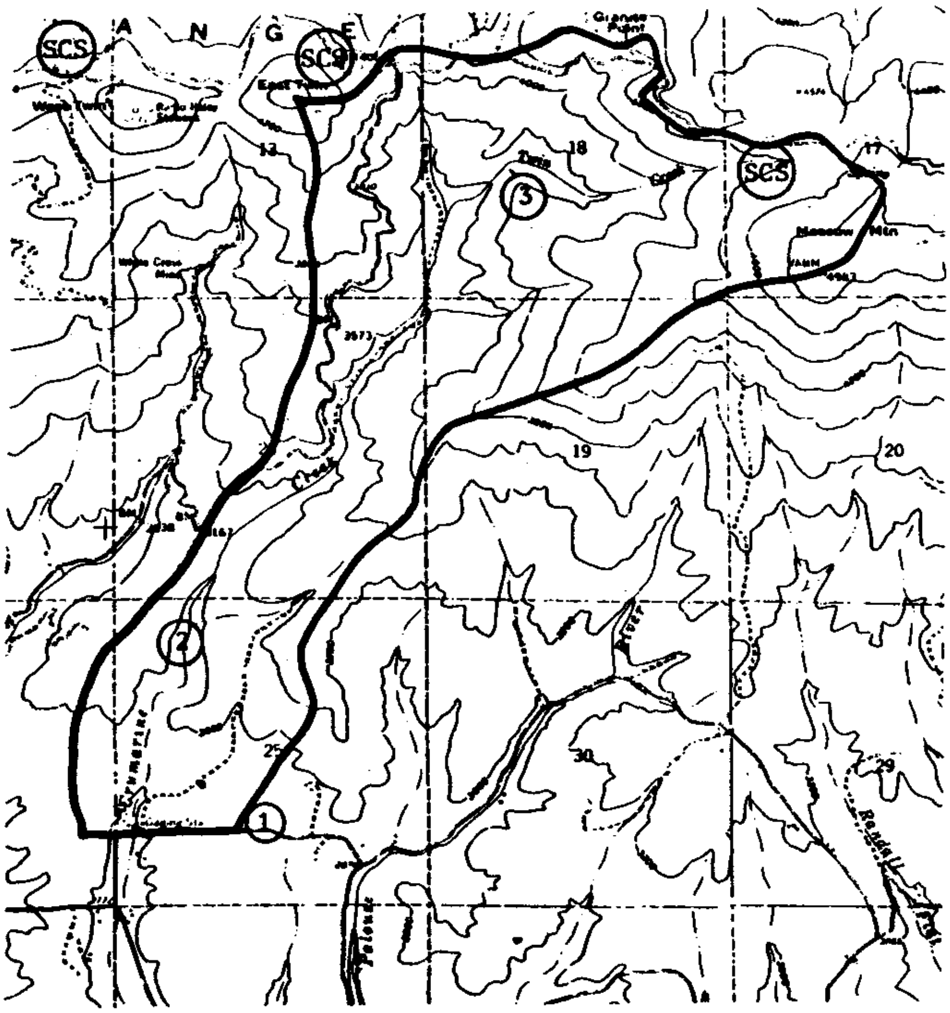


Figure 8. Location of Crumarine Creek and SCS snow survey sites.

Site 3 has a markedly higher depth and water equivalent than the other two sites. This difference is partially due to Site 3 being at a higher elevation but mostly due to the dense forest and the location of the site. Site 3 is in the Twin Creek drainage. This basin is situated such that it accumulates and retains snow longer than any other part of the watershed. Also, this area receives little direct sunlight due to the heavy forest and basin orientation, which slows the melting process.

Table 16. Crumarine Creek snow survey data.

| Site | Date | Depth, in | Water Equivalent, in | Density |
|---|---|---|---|---|
| 1 | 2/21/85 | 19.6 | 6.2 | 0.32 |
| 2 | 2/19/85 | 30.5 | 8.5 | 0.28 |
| 3 | 2/19/85 | 49.8 | 15.0 | 0.31 |
| 1 | 4/6/85 | 2.7 | 1.2 | 0.44 |
| 2 | 4/2/85 | 12.5 | 5.4 | 0.43 |
| 3 | 4/2/85 | 50.4 | 20.0 | 0.40 |

A noticeable correlation between depth and elevation and between water equivalent and elevation exists. Density appears to be uniform over the watershed on a monthly basis and increases with time as temperatures rise. In general, Gray and Male (1981) observed that higher density values occur at lower elevations due to warmer temperatures. The SCS sites also follow a similar trend as the sites on Crumarine Creek watershed. The Moscow Mountain site, being at a higher elevation, has much higher water equivalent values and depths than the lower sites at East Twin and West Twin. Also, density appears to be uniform on a given date at each of these sites. The Crumarine Creek densities are larger than the SCS densities for April, showing that density increases as elevation declines.

The snow surveys taken in 1985 give some indication of snow distribution on the watershed but little can be concluded about mean monthly snow water equivalents. In order to predict the mean monthly snow

Table 17. SCS snow survey data.

| Site | Date | Depth, in | Water Equivalent, in | Density |
|---|---|---|---|---|
| Moscow Mountain | 2/15/85 | 67.0 | 20.7 | 0.31 |
| East Twin | 2/15/85 | 50.0 | 14.2 | 0.28 |
| West Twin | 2/15/85 | 52.0 | 14.4 | 0.28 |
| Moscow Mountain | 3/1/85 | 64.0 | 22.6 | 0.35 |
| East Twin | 3/1/85 | 50.0 | 14.8 | 0.30 |
| West Twin | 3/1/85 | 49.0 | 16.6 | 0.34 |
| Moscow Mountain | 3/29/85 | 76.0 | 27.6 | 0.36 |
| East Twin | 3/29/85 | 50.0 | 17.2 | 0.34 |
| West Twin | 3/29/85 | 40.0 | 14.4 | 0.36 |

water equivalents, an equation was developed. Snow water equivalent, temperature and precipitation data from the Moscow Mountain snow site at an elevation of 4968 feet were used. All of the data were recorded on a continuous basis from 1969 to 1972. Snow water equivalents (SWE) were measured with a snow pillow. Some of the precipitation data and temperature data were missing and had to be generated based on the Nutterville site at 3000 feet. Only the months of November through April were used to develop the equation since the first snow usually occurs in November and normally leaves by the end of April. Correlations between

Moscow Mountain and Nutterville were determined for both precipitation and temperature. Monthly precipitation and mean monthly temperatures were used to develop the relationship. A coefficient of determination of 0.925 was found between Moscow Mountain and Nutterville precipitation based on 16 observations. This compares with Precht's (1973) coefficient of determination of 0.934 between Moscow Mountain precipitation and Nutterville precipitation based on 29 storms for the 1971 water year. A coefficient of determination of 0.953 was found between Moscow Mountain and Nutterville temperatures based on 18 observations. The Nutterville and Moscow Mountain data used to develop the equations appear in Table 18.

Table 18. Nutterville and Moscow Mountain data.

| | Nutterville Data | | Moscow Mountain Snow Site | | |
|---|---|---|---|---|---|
| Date | Precipitation inches | Temperature °F | Precipitation inches | Temperature °F | Snow Water Equivalent inches |
| 11/69 | 0.75 | 37.4 | 1.17 | 34.0* | 0.8 |
| 12/69 | 3.35 | 30.5 | 6.00* | 26.0* | 3.5 |
| 01/70 | 5.30 | 29.5 | 9.68 | 25.0* | 11.2 |
| 02/70 | 2.57 | 37.0 | 3.48 | 33.0* | 18.5 |
| 03/70 | 2.79 | 35.7 | 4.03 | 32.0* | 21.2 |
| 04/70 | 1.58 | 37.9 | 3.51 | 34.0* | 20.8 |
| 11/70 | 3.40 | 35.9 | 4.66 | 31.0 | 0.8 |
| 12/70 | 2.71 | 26.9 | 4.03 | 22.1 | 4.8 |
| 01/71 | 4.23 | 29.7 | 7.50* | 24.7 | 12.5 |
| 02/71 | 2.30 | 31.8 | 4.10* | 27.2 | 14.9 |
| 03/71 | 3.42 | 32.1 | 6.10* | 24.9 | 20.1 |
| 04/71 | 2.02 | 40.6 | 3.60* | 35.7 | 17.2 |
| 11/71 | 3.67 | 33.0 | 6.50* | 29.2 | 0.6 |
| 12/71 | 7.53 | 24.4 | 13.40* | 20.6 | 12.2 |
| 01/72 | 5.00 | 21.6 | 8.90* | 20.0 | 20.0 |
| 02/72 | 4.18 | 28.9 | 7.80 | 23.2 | 24.9 |
| 03/72 | 4.35 | 36.3 | 7.70* | 32.9 | 29.1 |
| 04/72 | 1.83 | 36.6 | 5.43 | 30.7 | 25.0 |

*Estimated from Nutterville data

Linear regressions were computed on the Moscow Mountain snow site data. Data from the months of November through April were used. It was assumed that the snow water equivalent peaked in the month of March on the watershed. This assumption is not always true at higher elevations, such as Site 3 and the Moscow Mountain site. Higher elevation sites will peak later in the spring. Sites 1 and 2 exhibit a decrease in snow water equivalent from February to April, which is more representative of the actual situation on the watershed than Site 3.

Snow water equivalent was first related to mean monthly temperature and the summation of mean monthly precipitation starting with November. The generated equation resulted in a coefficient of determination of 0.927. This equation predicted acceptable snow water equivalent values (within 25 perent of the actual values) for the months of November through March but not for the month of April. Instead of predicting a decrease in snow water equivalent from March to April, the equation predicted the snow water equivalent increased from March to April. Therefore, another equation was developed using the same procedure as before except April data were excluded. The following equation was derived:

$$SWE=-4.617+0.129(Temp)+0.750(Precip) \quad (15)$$

$r^2=0.947$

$n=15$

Another equation had to be generated to estimate snow water equivalents for April. A similar regression was performed relating snow water equivalent to temperature and precipitation but only March and April data were used. Also, the actual monthly precipitation values were used instead of the cumulative precipitation. The following equation was derived:

$$SWE=-143.69+10.790(Temp)-0.176(Temp^2) -0.802(Precip)+0.245(Precip^2) \quad (16)$$

$r^2=0.978$
n=6

Figure 9 illustrates generated and actual snow water equivalents at the Moscow Mountain snow site. The actual snow water equivalent values from 1969 to 1970 were plotted. Data at the Moscow Mountain snow site from 1969 to 1970 were used in the equations to generate data. Equation 15 was used to generate snow water equivalents from November to March and Equation 16 was used to generate April's snow water equivalents. As seen from Figure 9, the equations predict the actual situation quite well.

The equations were used to predict snow water equivalents for the entire watershed. Again, Equation 15 was used to generate snow water equivalents for the months of November through March and Equation 16 was used to generate a snow water equivalent value for the month of April. Using the above equations and the mean monthly temperature and precipitation values for the watershed from 1969 to 1973 water year (Appendix C), snow water equivalent values were generated for the Crumarine Creek watershed. The results appear in Table 19.

The change in snow water equivalent represents the change in snow storage on the watershed. The positive values represent periods of accumulation while the negative numbers represent periods of snow melt. As seen, November through March are periods of accumulation, with December as the peak month. April and May represent periods when the snow storage is lost to either soil moisture or runoff. The snow water equivalent values

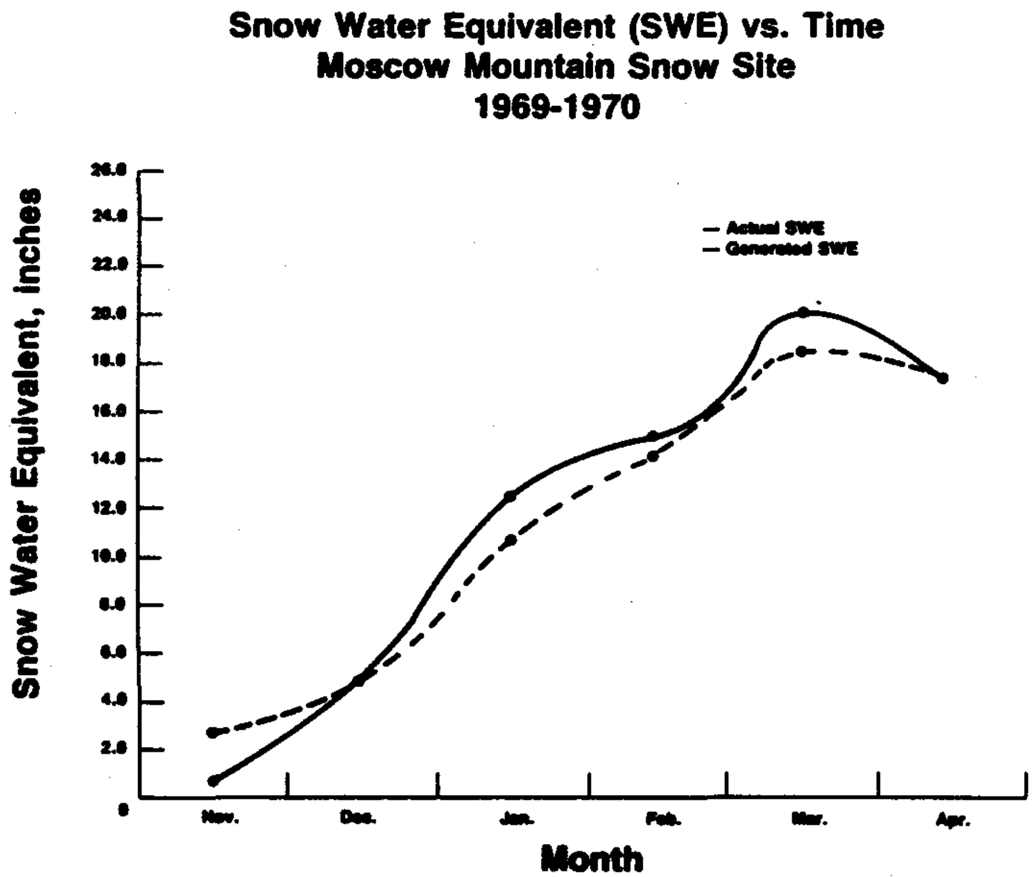


Figure 9. Generated and actual snow water equivalents (SWE) at Moscow Mountain snow site for 1969 to 1970.

are assumed to have an error of 15 percent since these values were predicted from an equation and not directly measured.

## Interception and Sublimation

A significant portion of the precipitation is lost to interception by the trees and winter wheat. Viessman and others (1977) defined interception as that segment of the gross precipitation which wets and

Table 19. Average monthly snow water equivalent (SWE) for Crumarine Creek for 1969 to 1973 water years.

| Month | Temperature °F | Precipitation inches | SWE, in | Change in SWE, in |
|---|---|---|---|---|
| Nov | 31.8 | 4.7 | 3.0 | 3.0 |
| Dec | 24.3 | 6.9 | 7.2 | 4.2 |
| Jan | 24.0 | 5.4 | 11.2 | 4.0 |
| Feb | 29.9 | 3.1 | 14.3 | 3.1 |
| Mar | 32.3 | 3.8 | 17.4 | 3.1 |
| Apr | 39.0 | 2.6 | 9.0 | -8.4 |
| May | | | | -9.0 |

adheres to above-ground objects until it is returned to the atmosphere. Interception was calculated separately for both the winter wheat and the forest. Again, the final values were weighted by area.

Interception by the winter wheat is a function of the growing stage. Lull (1964) reported on interception of various crops. He presented interception values for oats, which were adopted for this study to estimate interception on winter wheat since they are both small grain crops. Lull (1964) determined that during the oat's low-vegetation development three percent of the precipitation was intercepted and during the growing season seven percent was intercepted. These values were applied to the winter wheat on Crumarine Creek watershed. Low-vegetation development was assumed to be in March and April. The months of May through August were assumed to be the growing and maturing season. Based on the above assumptions the interception values for the winter wheat were determined (Table 20). Mean monthly precipitation values from 1969 to 1973 water years were used and a total of 0.7 inches of precipitation was intercepted by the winter wheat.

Table 20. Interception for winter wheat on Crumarine Creek for 1969 to 1973 water years.

| Month | Precipitation inches | Percent Interception | Intercepted Precipitation inches |
|---|---|---|---|
| Mar | 3.8 | 3 | 0.1 |
| Apr | 2.6 | 3 | 0.1 |
| May | 2.8 | 7 | 0.2 |
| Jun | 2.4 | 7 | 0.2 |
| Jul | 1.1 | 7 | 0.1 |
| Aug | 0.7 | 7 | 0.0 |
| Annual | 13.4 | | 0.7 |

Interception on a coniferous forest is a function of precipitation type. Rutter and others (1972) determined 20 to 40 percent of the precipitation on a coniferous forest was intercepted. Shuttleworth and Calder (1979) suggested using an annual average of 27 percent. These average interception values are acceptable for estimating annual interception but are not acceptable for predicting monthly interception. For a coniferous forest, more snowfall is intercepted than rainfall (Dunne and Leopold, 1978). In order to compute monthly interception it was necessary to define summer and winter months. The months of April through October were assumed to be summer and November through March were defined as winter.

During the summer months, all the intercepted precipitation eventually evaporates. Dunne and Leopold (1978) compiled data from North America and Europe and determined 22 percent of the rainfall on a coniferous forest was intercepted. They also suggested that 28 percent of the rain and snow received on a coniferous forest during the winter time is intercepted. Again, their value was based on data from coniferous forests in North America and Europe. Intercepted precipitation during winter months with mean monthly temperatures below freezing will sublimate rather than evaporate. Sublimation occurs on the Crumarine Creek watershed during December, January and February since these months had mean monthly temperatures below freezing. Beaty (1975) stated that sublimation occurs when the temperature is below freezing and the humidity is less than 100 percent. Satterlund and Haupt (1967) determined that more than 80 percent of the snow initially caught by the crowns of trees ultimately reaches the ground and the remaining snow sublimates under the conditions described by Beaty (1975). A conservative estimate of 20 percent was used to represent the amount of snow sublimated. November and March had mean monthly temperatures above freezing so all intercepted precipitation evaporated during these months. Table 21 lists the amount of interception on Crumarine Creek's forest based on mean monthly precipitation from 1969 to 1973 water years.

The intercepted precipitation values on the winter wheat and forest were weighted by area. Again, the winter wheat values were multiplied by 0.12 and the forest values were multiplied by 0.88. Table 22 lists the final interception values on Crumarine Creek watershed. As seen from the results, the winter wheat had no influence on the final interception values for the watershed. An annual average of 5.6 inches of precipitation were intercepted based on data from 1969 to 1973 water years. Of the 5.6 inches

Table 21. Interception for the forest on Crumarine Creek watershed for 1969 to 1973 water years.

| Month | Precipitation inches | Percent Intercepted | Percent Sublimated | Intercepted Precipitation inches |
|---|---|---|---|---|
| Oct | 1.9 | 22 | 0 | 0.4 |
| Nov | 4.7 | 28 | 0 | 1.3 |
| Dec | 6.9 | 28 | 20 | 0.4* |
| Jan | 5.4 | 28 | 20 | 0.3* |
| Feb | 3.1 | 28 | 20 | 0.2* |
| Mar | 3.8 | 28 | 0 | 1.1 |
| Apr | 2.6 | 22 | 0 | 0.6 |
| May | 2.8 | 22 | 0 | 0.6 |
| Jun | 2.4 | 22 | 0 | 0.5 |
| Jul | 1.1 | 22 | 0 | 0.2 |
| Aug | 0.7 | 22 | 0 | 0.2 |
| Sep | 1.8 | 22 | 0 | 0.4 |
| Annual | 37.2 | | | 6.2 |

*Intercepted and sublimated

intercepted, 0.9 inch was sublimated and 4.7 inches were evaporated. The final interception values probably have an error of 15 percent.

Table 22. Interception and sublimation on Crumarine Creek watershed for 1969 to 1973 water years.

| | Winter Wheat | | Forest | | |
|---|---|---|---|---|---|
| Month | Actual | Weighted | Actual | Weighted | Total |
| Oct | 0.0 | 0.0 | 0.4 | 0.4 | 0.4 |
| Nov | 0.0 | 0.0 | 1.3 | 1.1 | 1.1 |
| Dec | 0.0 | 0.0 | 0.4 | 0.4 | 0.4* |
| Jan | 0.0 | 0.0 | 0.3 | 0.3 | 0.3* |
| Feb | 0.0 | 0.0 | 0.2 | 0.2 | 0.2* |
| Mar | 0.1 | 0.0 | 1.1 | 1.0 | 1.0 |
| Apr | 0.1 | 0.0 | 0.6 | 0.5 | 0.5 |
| May | 0.2 | 0.0 | 0.6 | 0.5 | 0.5 |
| Jun | 0.2 | 0.0 | 0.5 | 0.4 | 0.4 |
| Jul | 0.1 | 0.0 | 0.2 | 0.2 | 0.2 |
| Aug | 0.0 | 0.0 | 0.2 | 0.2 | 0.2 |
| Sep | 0.0 | 0.0 | 0.4 | 0.4 | 0.4 |
| Annual | 0.7 | 0.0 | 6.2 | 5.6 | 5.6 |

*Intercepted and sublimated

## Results of the Water Balance

Deep percolation was determined using the following equation and the results calculated in the previous sections based on data from 1969 to 1973 water years (Table 23). Any error or residual terms that occurred in the water balance components were included in the final deep percolation values.

(DP+ERR)=P-RO-SM-ET-SS-S-I (2)

DP=deep percolation
P=precipitation
RO=runoff
SM=change in soil moisture
ET=evapotranspiration
SS=change in snow storage
S=sublimation
I=interception
ERR=error term

Table 23. Water balance results for Crumarine Creek watershed for 1969 to 1973 water years. All values are in inches.

| Month | P | RO | SM | ET | SS | I+S | (DP+ERR) |
|---|---|---|---|---|---|---|---|
| Oct | 1.9 | 0.1 | 1.3 | 0.6 | 0.0 | 0.4 | -0.5 |
| Nov | 4.7 | 0.2 | 2.7 | 0.1 | 3.0 | 1.1 | -2.4 |
| Dec | 6.9 | 0.2 | 3.5 | 0.0 | 4.2 | 0.4* | -1.4 |
| Jan | 5.4 | 1.2 | 2.7 | 0.0 | 4.0 | 0.3* | -2.8 |
| Feb | 3.1 | 1.2 | 2.2 | 0.0 | 3.1 | 0.2* | -3.6 |
| Mar | 3.8 | 2.6 | -0.9 | 1.0 | 3.1 | 1.0 | -3.0 |
| Apr | 2.6 | 2.4 | -2.2 | 2.0 | -8.4 | 0.5 | 8.3 |
| May | 2.8 | 2.1 | -2.2 | 2.4 | -9.0 | 0.5 | 9.0 |
| Jun | 2.4 | 0.6 | -2.7 | 2.7 | 0.0 | 0.4 | 1.4 |
| Jul | 1.1 | 0.2 | -2.2 | 2.4 | 0.0 | 0.2 | 0.5 |
| Aug | 0.7 | 0.1 | -1.3 | 1.4 | 0.0 | 0.2 | 0.3 |
| Sep | 1.8 | 0.1 | -0.9 | 0.5 | 0.0 | 0.4 | 1.7 |
| Annual | 37.2 | 11.0 | 0.0 | 13.1 | 0.0 | 5.6 | 7.5 |

*Sublimated

As seen from the results (Table 23), some months have negative deep percolation values. These numbers do not physically mean that water is moving upward from the root zone to the ground surface. Instead, they indicate that the water lost to deep percolation is temporarily stored below the root zone and it is later released as baseflow into the stream or it permanently leaves the watershed. Also, positive error in the other water balance terms could result in negative deep percolation values. Because the depth of the soils on the watershed are deeper than the assumed three feet, some water is stored below the three foot depth. If it is assumed that up to 1.5 inches can be stored in this manner, then any deep percolation values greater than -1.5 inches can be attributed to error.

On an annual basis an average of 7.5 inches of the incoming precipitation is lost to deep percolation based on data from 1969 to 1973 water years. Of the total annual precipitation entering the watershed, 30 percent is lost to runoff, 35 percent is lost to evapotranspiration, 15 percent is lost to interception and sublimation and 20 percent enters the underlying shallow aquifer as deep percolation. May had the largest amount of deep percolation, which is mostly influenced by the large amount of snowmelt. The months of October through March experience little, if any, deep percolation, which is mostly influenced by snow storage on the watershed.

The final results of the water balance study on Crumarine Creek over the five year period of 1969 to 1973 agree fairly well with previous findings. Bloomsburg (1958) performed a water balance study on Crumarine Creek and determined that 25 percent of the incoming precipitation was lost to runoff, 60 percent was lost to evapotranspiration and 15 percent was lost as deep percolation on an annual basis. Davis (1971) conducted a water balance study on an agricultural watershed near Crumarine Creek. He

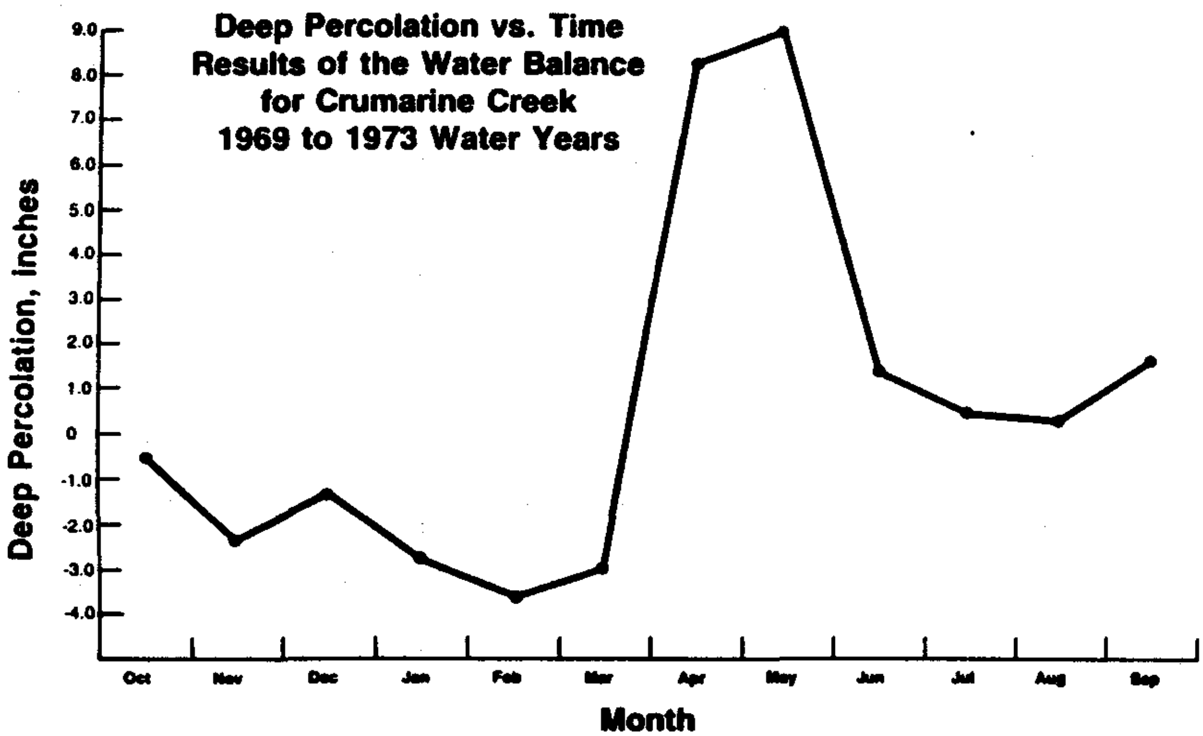


Figure 10. Deep percolation on Crumarine Creek Watershed for 1969 to 1973 water years.

determined that of the total annual precipitation entering the watershed, 27 percent was lost to runoff, 57 percent was lost to evapotranspiration and 16 percent was lost as deep percolation. All three studies agree quite well in their final percentage of deep percolation to the underlying aquifer and other water balance components (Table 24). It has been shown that deep percolation does occur on Crumarine Creek watershed and based on five years of data (1969 to 1973 water years), 20 percent of the incoming

Table 24. Summary of water balance results done on Moscow Mountain (all values are percentages).

| Water Balance Component | Bloomsburg | Davis | Present |
|---|---|---|---|
| Runoff | 25 | 27 | 30 |
| Evapotranspiration | 60 | 57 | 35+15=50 |
| Deep percolation | 15 | 16 | 20 |

precipitation entered the shallow aquifer as deep percolation. The amount of deep percolation that may enter the deep Moscow aquifer is unknown.

## Error Analysis

The percent error in the annual deep percolation value was estimated by three different methods. An exact percent error on the final deep percolation value could not be calculated due to the nature of the monthly values. Some of the values were measured (precipitation and runoff), some were calculated (evapotranspiration and snow storage) and some were estimated (soil moisture, interception and sublimation). Therefore, not every water balance term had monthly values for each of the five years (1969 to 1973). Without a monthly value for each term for the five year period, a proper error analysis could not be conducted. The three methods used to estimate the percent error are described in the following paragraphs.

The first method utilized the mean monthly values for each term. Equation 17 was used to calculate the percent error (Beers, 1958):

$$\% \text{ Error} = \frac{2.0\ (S_x/\sqrt{n})}{\bar{x}} \qquad (17)$$

$S_x$=standard deviation of x
n=number of observations
$\bar{x}$=mean of x

In order to use Equation 17, the standard deviation of the annual deep percolation value must be known. Equation 18 (Beers, 1958) was used to calculate the standard deviation for the monthly deep percolation. All the water balance terms were assumed to be independent to use Equation 18, which is not necessarily true.

$$S_{DP}=(S^2{}_P+S^2{}_{RO}+S^2{}_{SM}+S^2{}_{ET}+S^2{}_{SS}+S^2{}_{(S+D)})^{0.5} \qquad (18)$$

The standard deviation for each monthly term was calculated by rearranging Equation 17, using n as five and the monthly values as the mean. Percent error of all terms except deep percolation were given at the end of each section and these values were used in Equation 17. To obtain the standard deviation of the annual deep percolation term, the sum of the squares of the monthly deep percolation standard deviations were divided by five (Equation 19).

$$S_{DP}=(S^2{}_{DP1}+S^2{}_{DP2}+\ldots+S^2{}_{DP12}/5)^{0.5} \qquad (19)$$

Table 25. Error analysis of deep percolation based on monthly values

| Month | Standard Deviation of Deep Percolation |
|---|---|
| Oct | 46 inches |
| Nov | 113 inches |
| Dec | 156 inches |
| Jan | 129 inches |
| Feb | 90 inches |
| Mar | 91 inches |
| Apr | 164 inches |
| May | 177 inches |
| Jun | 94 inches |
| Jul | 75 inches |
| Aug | 44 inches |
| Sep | 38 inches |
| Annual | 172 inches |

Table 25 summarizes the results. An annual error of 20 percent was calculated for the mean annual value of deep peroclation. The annual deep percolation value of 7.5 inches was used in Equation 17 as the mean.

The second method used was based on the annual values instead of the monthly values. The same equations were used and all water balance terms were assumed to be independent. Since change in soil moisture and snow storage are zero on an annual basis these terms did not enter the error analysis. Table 26 summarizes the results. By this method, an error of 84 percent was calculated for the annual value of deep percolation.

The third method used was a method proposed by Davis (1971). He weighted each term as a percentage of precipitation and determined the

Table 26. Error analysis of deep percolation based on annual values.

| Term | Standard Deviation inches | Percent Error |
|---|---|---|
| P | 624 | 15 |
| RO | 123 | 10 |
| ET | 293 | 20 |
| (I+S) | 94 | 15 |
| DP | 706 | 84 |

Table 27. Error analysis of deep percolation based on magnitude of other water balance terms.

| Term | Annual Value, inches | Relative Magnitude | Percent Error | Magnitude of Error, inches |
|---|---|---|---|---|
| P | 37.2 | 100% | 15 | 5.6 |
| RO | 11.0 | 30% | 10 | 1.1 |
| SM | 0.0 | 0% | 20 | 0.0 |
| ET | 13.1 | 35% | 20 | 2.6 |
| SS | 0.0 | 0% | 15 | 0.0 |
| (S+I) | 5.6 | 15% | 15 | 0.8 |
| DP | 7.5 | 20% | 75 | 5.6 |

probable error in each term. The deep percolation will then have an error at least as large as the largest error of any other term. Table 27 summarized the results. The error in the deep percolation by this method is 5.6 inches, or 75 percent.

As seen, each method results in a different percent error- 20 percent, 84 percent and 75 percent. The first two methods only apply to independent variables, which is not the case here but these errors will depend upon the degree of dependence exhibited by the variables. Some of the water balance terms are very dependent on another term, such as runoff is dependent on the amount of precipitation. The validity of the third method is totally dependent upon the accuracy with which the percent error of each term was estimated.

# CHAPTER 5

## HYDROGRAPH ANALYSIS

The long time span of a month used for the water balance does not allow any inference about the manner in which the watershed behaves with regard to individual runoff events. An analysis of individul events can be used to examine changes in baseflow and deep percolation throughout the year. Thus, event hydrograph analysis can be used to determine the correctness of the broad outline of deep percolation patterns obtained from the water balance.

Hydrologic analyses have been performed on nearby watersheds but none of these watersheds were heavily forested. Churchill (1981) observed runoff patterns on Cow Creek (located five miles southeast of Moscow) and Little Potlatch Creek (adjacent to Cow Creek). Both watersheds are agricultural watersheds. He noticed that curve numbers changed throughout the year with respect to ground cover conditions and soil moisture. He also concluded that rain on snow events had higher curve numbers than rain on bare ground. Brooks (1982) conducted a hydrologic analysis on Rock Creek watershed located four miles south of Potlatch, Idaho, and about two miles north of Crumarine Creek. This watershed is partly pastured and partly forested. His results for the 1977, 1978 and 1979 water year showed that baseflow comprised 38 percent or less of the total runoff on an annual basis. Both studies indicate that the land use and time of year effect the hydrologic response of the watershed.

In order to further investigate hydrologic characteristics of the watershed, hydrograph separation of selected runoff events was done. The objective of the hydrograph separation process was to observe how ground-water is released from the shallow aquifer during different runoff events. Also, variation in the recession curve duration and shape was of interest. In his study of streams, Warnick (1947) noticed variations in the recession curve with seasons. Hydrograph separation techniques have been applied to Crumarine Creek before along with a stream near Bovill, Idaho (Davis, 1967).

A hydrograph has three components: overland flow, interflow and ground-water, or baseflow. Figure 11 illustrates a separated hydrograph. Overland flow is surface water which originated in small detentions and flows on the watershed surface. Viessman and others (1977) defined interflow as that part of subsurface flow which moves at shallow depths and reaches the surface channels in a relatively short period of time. Overland flow and interflow both comprise direct runoff. The baseflow represents the discharge of ground-water from subsurface storage. Kunkle (1962) divided the baseflow into bank storage and basin storage discharge. Basin storage results from the infiltration of precipitation. Ground-water in bank storage is derived from influent stream runoff during high river stages. The water is temporarily stored in the banks and quickly released as the river stage falls.

The recession curves of 74 runoff hydrographs from Crumarine Creek from 1979 to 1985 were observed. Bethlahmy (1972) stated that the recession curve begins at the lower inflection point on the falling limb of the hydrograph where direct runoff ceases. The end of the recession curve was designated as the point where the falling limb flattens out or becomes horizontal. The location of this point is somewhat subjective. The

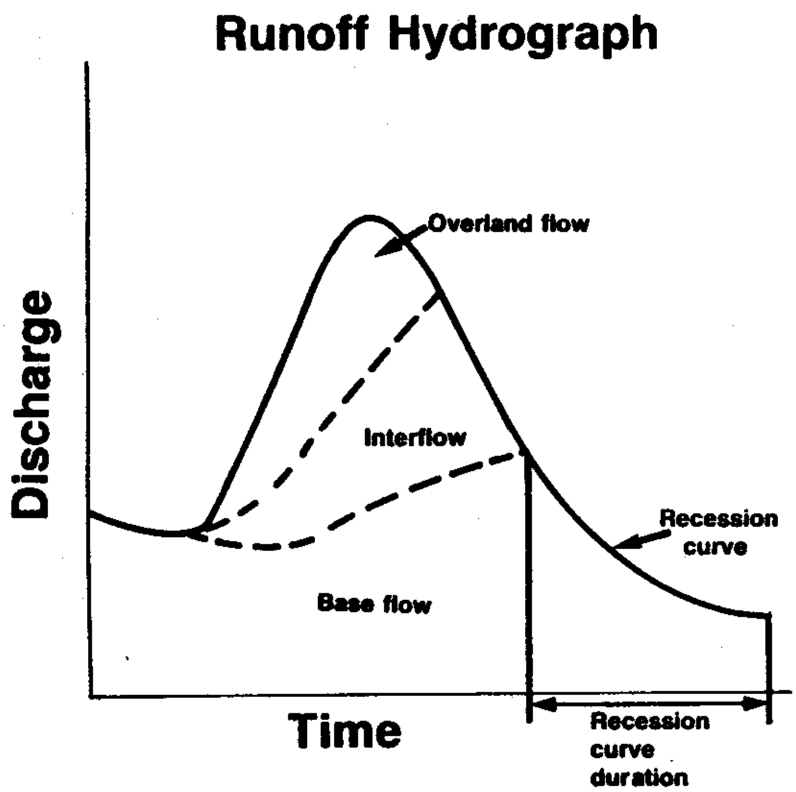


Figure 11. Separated runoff hydrograph.

recession curves from Crumarine Creek were found to vary throughout the year. The months of June through November were dominated by recession curves with durations under 24 hours. The remaining months had recession curves with durations spanning from one to four days, depending on the storm intensity and the amount of snow storage. Seasonal variations in recession curves have been explained by Singh and Stall (1971). They attributed the steep, rapid recession curves during June to October to evapotranspiration, when the stream may become influent. On the other hand, the water released from shallow aquifers causes the flattening of recession curves in the other months.

Hydrograph separation was performed on the same 74 runoff events from 1979 to 1985 to examine monthly baseflow. A computer program developed by

Bethlahmy (1972) was used to perform the separation. This program was developed for forested areas in eastern Idaho and western Montana but has been used all over the United States. The program separates the hydrograph into baseflow, interflow and overland flow. The computations in the program are based on a few assumptions. One is that both the increment of baseflow and the ratio of surface runoff to interflow depend essentially on the hydrograph's rate of rise. In other words, a rapid rising limb indicates a small baseflow increment and the ratio of surface runoff to interflow is large. Bethlahmy (1972) also assumed that surface runoff and interflow end at the first inflection point following the peak flow. The data required to run the program are hydrograph ordinates, time increment of the ordinates and the number of ordinates. The program is somewhat sensitive to the time increment used but this was not believed to be a serious problem in this study.

The percent of total runoff as baseflow, direct runoff, interflow and overland flow were examined once the hydrographs were separated. These results are listed in Appendix D. Figure 12 illustrates the monthly variation of percent baseflow of the total runoff for the 74 selected runoff events. Baseflow was found to comprise 50 percent or more of the total streamflow in most events. In the months of March, April and May, baseflow accounted for 80 percent or more of the total runoff for a runoff event. A high amount of baseflow is expected during these months due to the release of water from snow storage. Snow melting from the snowpack infiltrates into the ground, enters the underlying shallow aquifer and is eventually released into the stream as baseflow. Other researchers have also studied snowmelt events on watersheds and have come to similar conclusions. Davis (1967) noticed diurnal fluctuations in the ground-water level during snowmelt events, indicating that ground-water is released from temporary storage in the shallow aquifer and soon appears as baseflow. As stated previously, Singh and Stall (1971) determined much water is released from basin storage during winter and spring runoff events. Kobayashi (1985) determined in his study of snowmelt in Japan that as a snowmelt hydrograph recedes, all of the flow is subsurface in origin. He also found that surface runoff only accounted for 15 to 20 percent of the total streamflow in a snowmelt event. Baseflow usually ranged from 0.20 to 0.90 cfs for June through November for Crumarine Creek. The baseflow for the remaining months was as small as 0.20 cfs upwards to 7.0 cfs. The higher baseflows are more prominent during spring snowmelt events.

Table 28. Hydrograph separation results of selected events.

| Date of Event | Type of Event | Amount of Runoff, in | Recession Curve Duration, hrs | Baseflow, cfs | Percent Baseflow |
|---|---|---|---|---|---|
| 10/07/81 | Rain | 0.0062 | 14 | 0.24 | 58 |
| 11/21/80 | Rain | 0.0097 | 20 | 0.32 | 52 |
| 01/23/81 | Rain | 0.0479 | 32 | 1.35 | 46 |
| 03/15/79 | Rain on Snow | 0.2030 | 32 | 5.28 | 81 |
| 06/17/83 | Rain | 0.0117 | 9 | 0.88 | 68 |
| 07/29/84 | Rain | 0.0059 | 22 | 0.49 | 50 |

When comparing Figure 12 to the deep percolation results (Figure 10), it can be seen that the two curves coincide. When percent baseflow is at a low in November, December and January, so is the deep percolation. This coincidence explains the negative deep percolation values during these

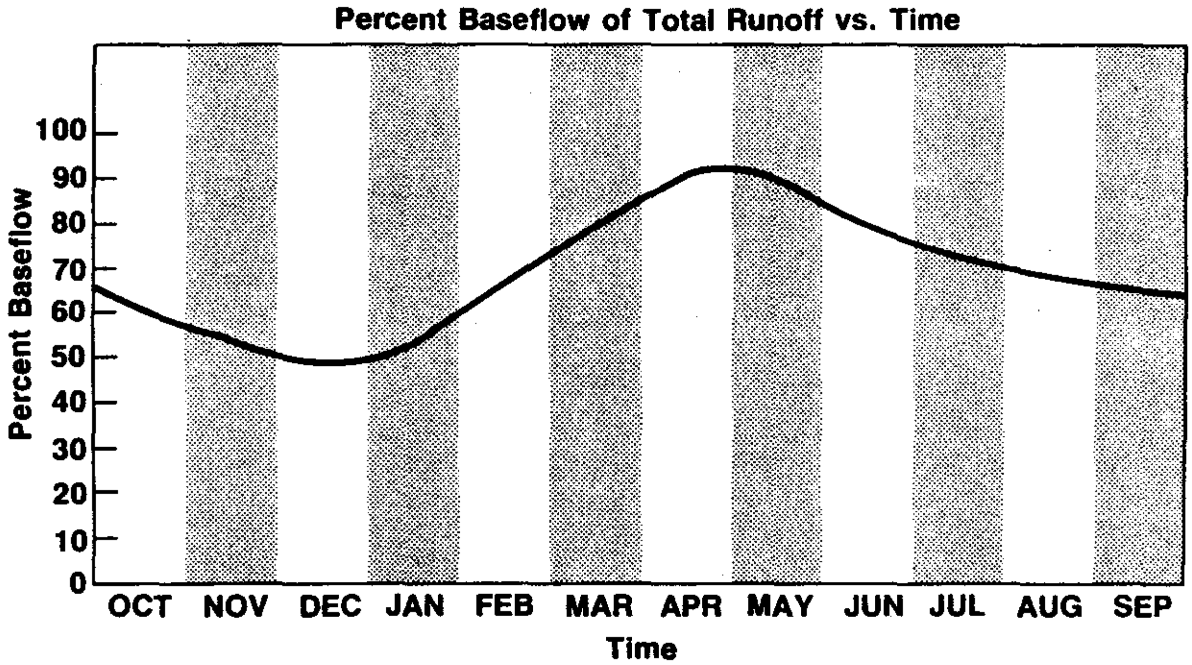


Figure 12. Monthly variations of percent baseflow of total runoff for selected runoff events.

months. As stated earlier, the negative deep percolation values indicate that water is being stored below the root zone and is later released. The fact that percent baseflow is low during these months indicates that the infiltrated water is being stored instead of appearing as baseflow in the stream.

Six runoff events on Crumarine Creek watershed were examined in detail to further illustrate seasonal variations in runoff patterns. The hydrographs were separated by the program developed by Bethlahmy (1972) and

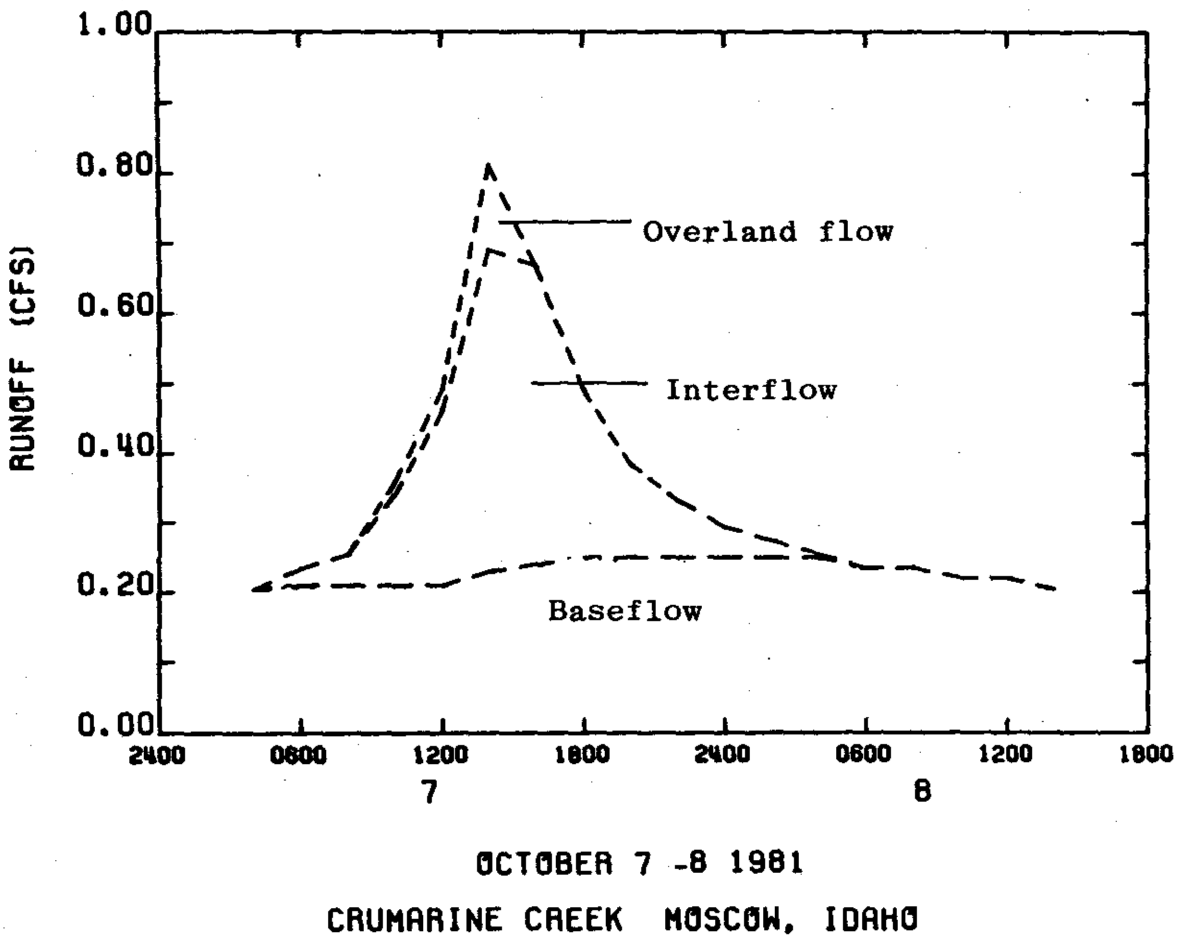


Figure 13. Separated hydrograph for October 7-8, 1981.

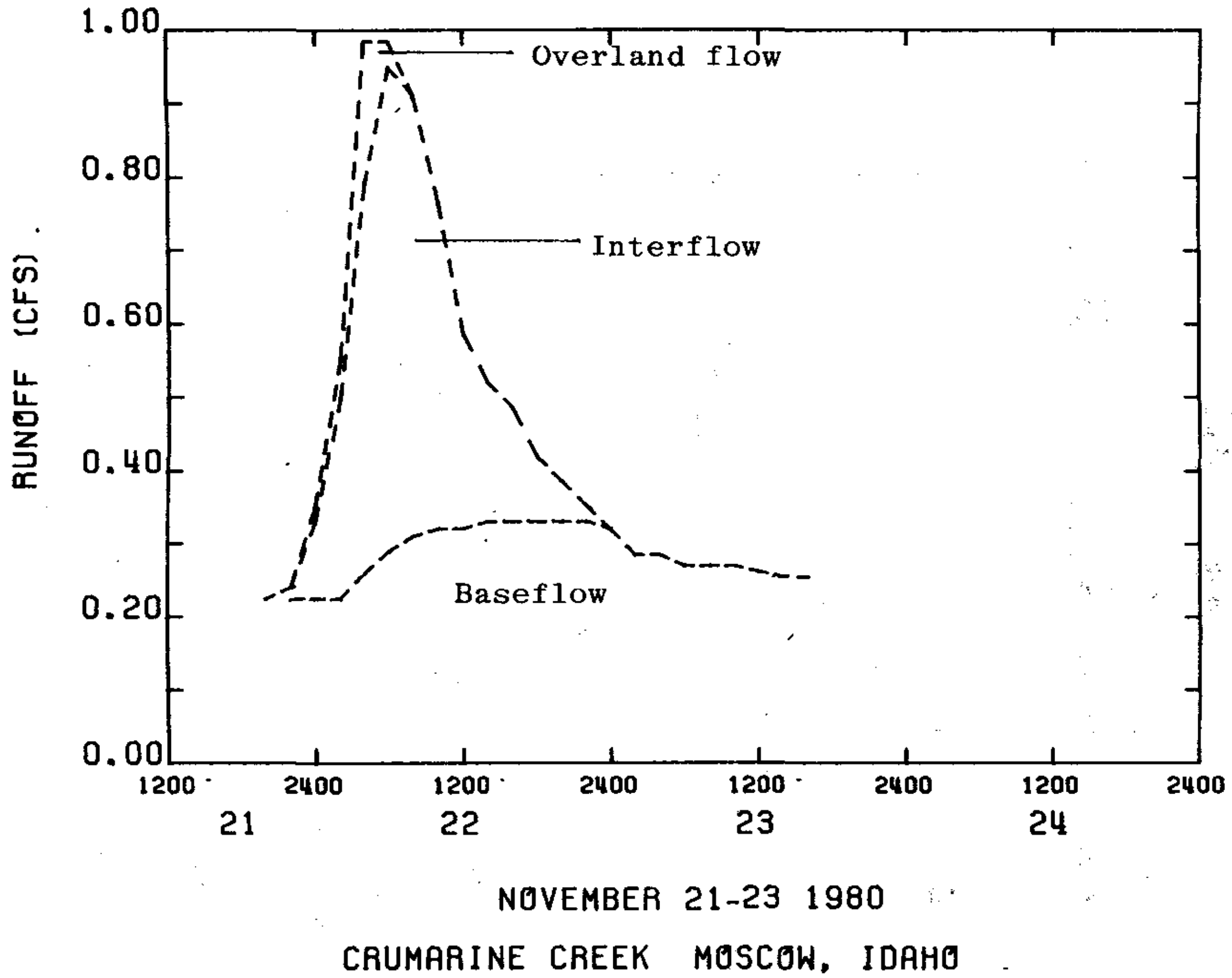


Figure 14. Separated hydrograph for November 21-23, 1980.

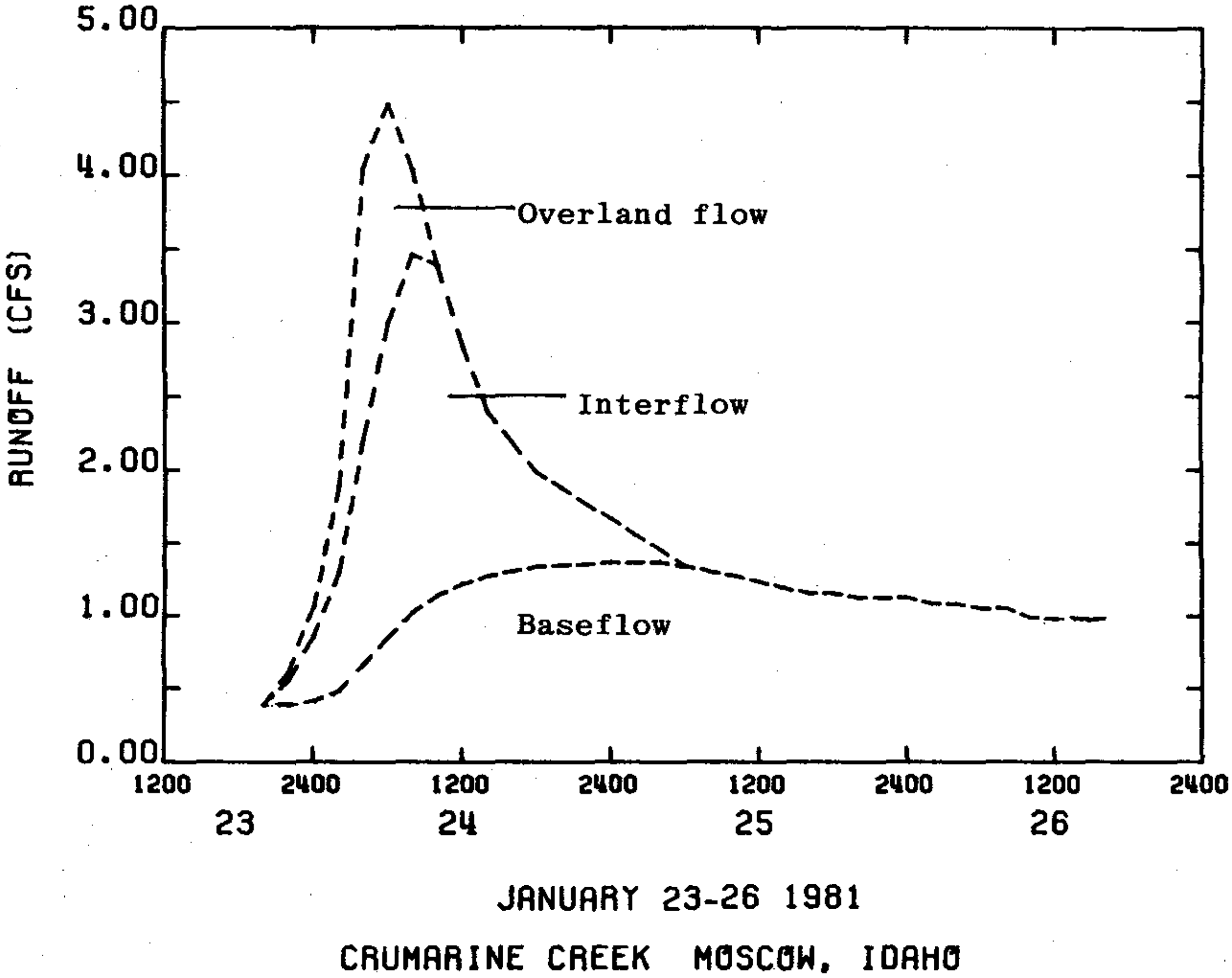


Figure 15. Separated hydrograph for January 23-26, 1981.

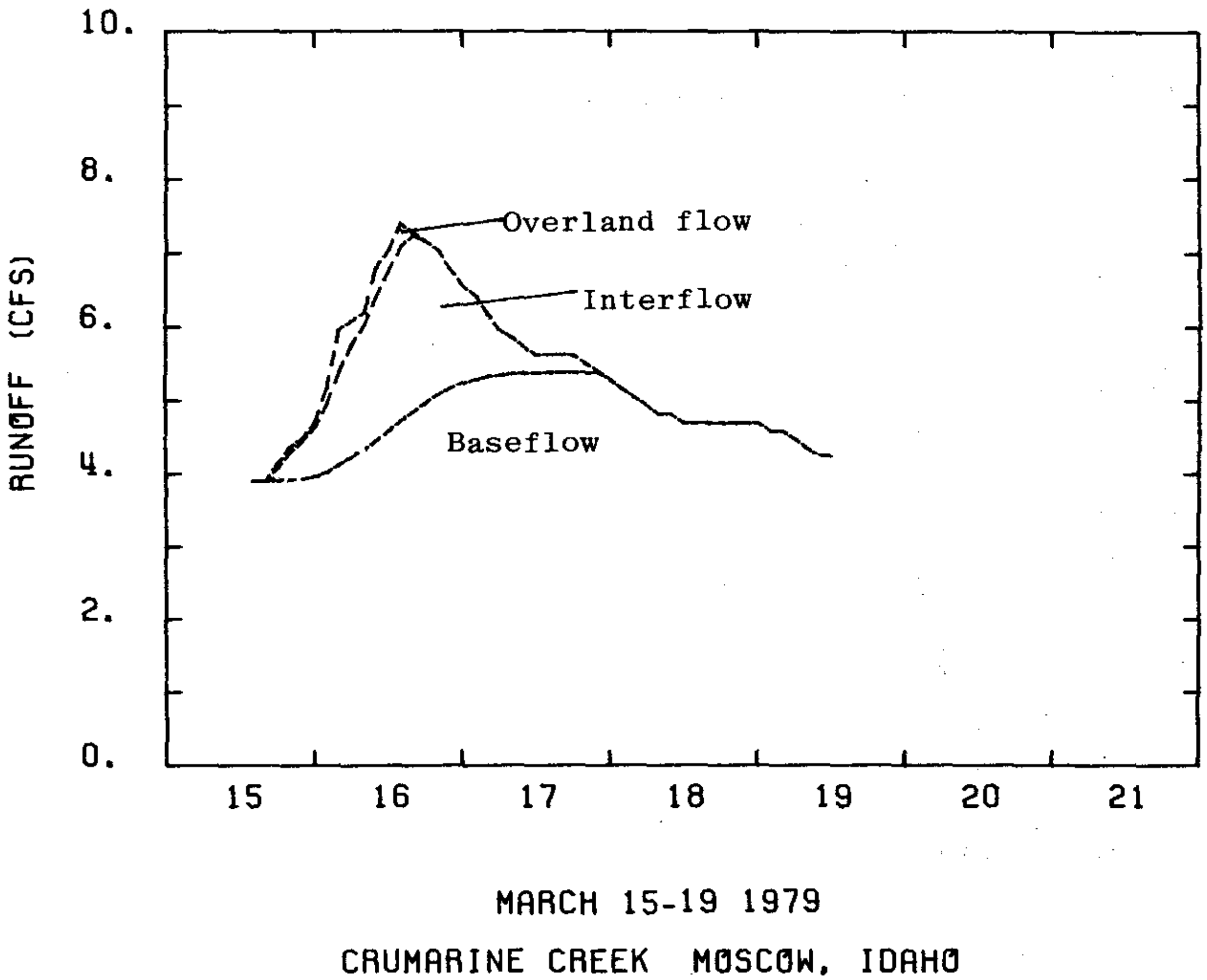


Figure 16. Separated hydrograph for March 15-19, 1979.

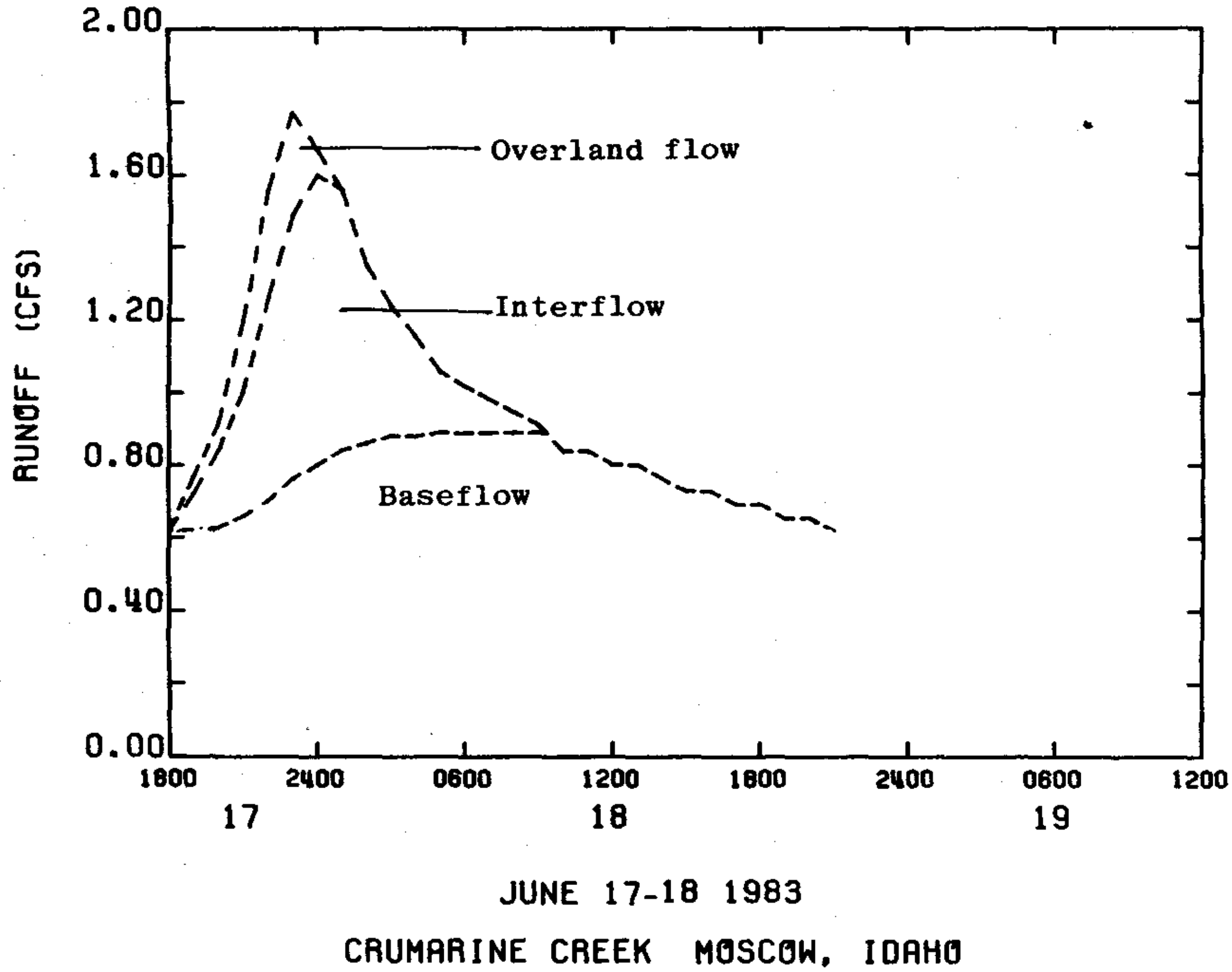


Figure 17. Separated hydrograph for June 17-18, 1983.

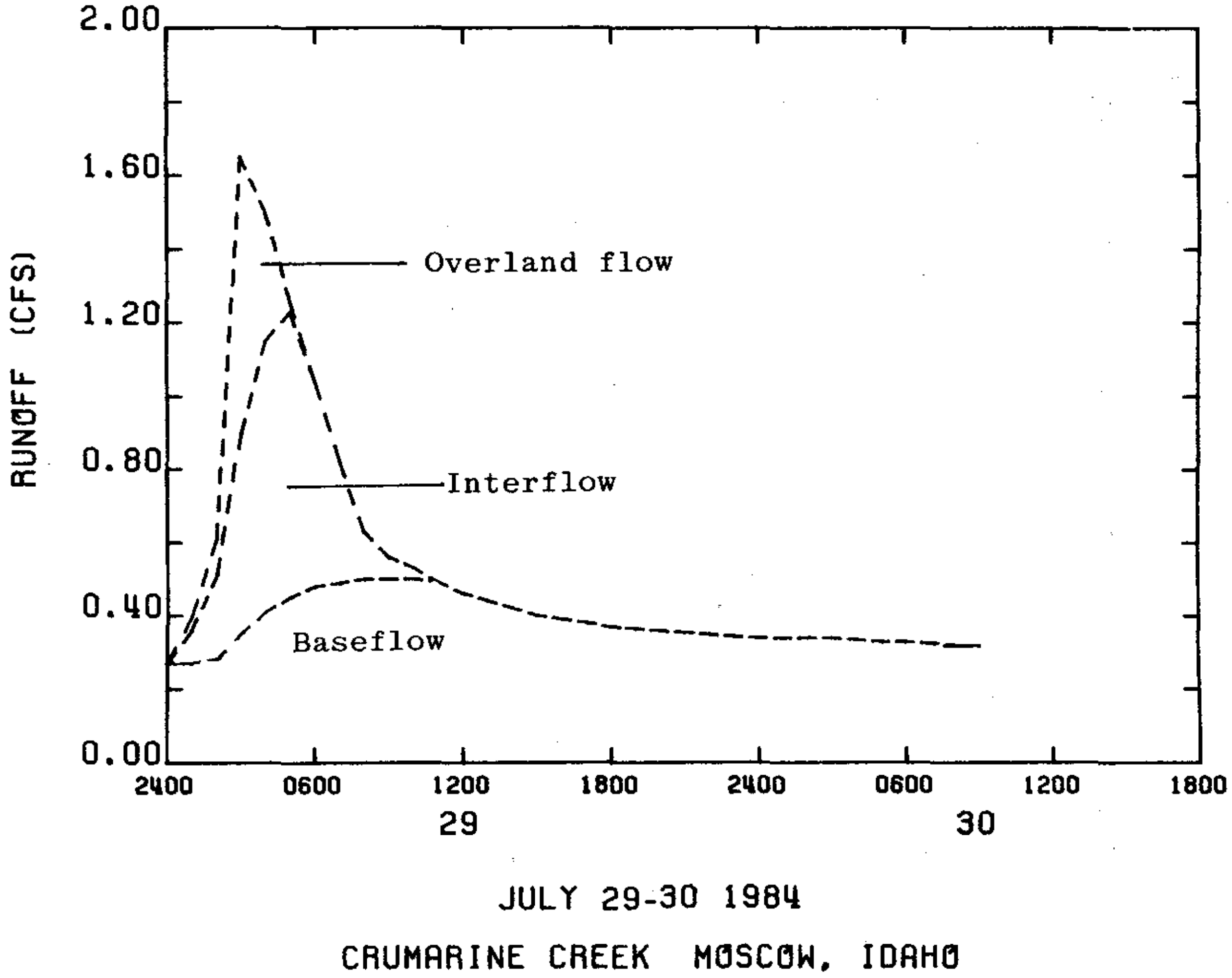


Figure 18. Separated hydrograph for July 29-30, 1984.

appear in Figures 13 through 18. Table 28 summarizes the results. The separated hydrographs are listed in sequence by months instead of years beginning with October, the first month of the water year.

The duration of the recession curve was determined as the time between where direct runoff ceases to the point where the recession curve flattens out or baseflow becomes constant. The baseflow amounts listed were the baseflow values that existed when direct runoff ceased, which was where the recession curve began. As seen from the results, the events in October, November, June and July had recession durations under 24 hours and baseflows between 0.20 cfs and 0.90 cfs. The short duration of these recession curves was due to evapotranspiration during these months (Singh and Stall, 1971). These traits are quite typical of Crumarine Creek runoff events during the months of June through October. The runoff events in January and March exhibited a recession curve duration of 32 hours and large baseflows. During these months the recession curve is controlled by water released from the aquifer (Singh and Stall, 1971). The large baseflow amount of 5.28 cfs on March 15, 1979, was due to the release of water from snow storage. Snow had melted and infiltrated into the shallow aquifer to later be released in the stream as baseflow. As illustrated by the results in Table 28, a rain on snow event (March 15, 1979) yields much more baseflow than a rain on bare ground event (January 23, 1981). Baseflow usually comprised 80 percent or more of the total runoff during March runoff events, as illustrated by the event on March 15, 1979. The results also show that baseflow during a runoff event has seasonal variations and is highly influenced by snow storage on the watershed, as seen by the March 15, 1979, runoff event.

# CHAPTER 6

## RUNOFF EVENT MODELLING

A knowledge of when ground-water recharge occurs is useful but where the water originates is also of importance. Not all runoff events yield water in the same manner. As suggested by Churchill (1981), the time of year and ground cover greatly influence runoff patterns. Three different runoff events on Crumarine Creek watershed were analyzed with the use of HEC-1, the Army Corps of Engineers' (1981) flood hydrograph model. These events were a rainfall event, a snowmelt event and a rain on snow event. Since the actual runoff hydrograph for each event was known, the objective was to regenerate the actual hydrograph by simulating the movement of precipitation. The HEC-1 results were then compared to separated hydrograph results. Hydrographs were separated by the computer program developed by Bethlahmy (1972). The precipitation excess from HEC-1 was compared to the direct runoff values obtained from the hydrograph separation. The two values should be close since excess precipitation is the amount of precipitation that contributes to direct runoff. If the two values matched then it was concluded that the correct parameters were used in HEC-1 to generate the runoff hydrograph.

HEC-1 requires the precipitation losses, snowmelt rate and rate of recession to be modelled to generate the desired output hydrograph. Precipitation losses include interception, depression storage and infiltration. Three different methods- the exponential loss rate, SCS Curve Number method and the Holtan loss rate- are available to calculate precipitation losses. Snowmelt is simulated by either the degree-day method or the energy-budget method. The SCS, Clark and Snyder unit hydrographs are available to model the runoff hydrograph. To model the rate of recession, the baseflow at which recession started and a recession constant were required. The baseflow at which recession starts was determined by using the hydrograph separation program by Bethlahmy (1972).

The data required for HEC-1 varies depending on the type of event. For a rainfall event occurring on bare ground only the rainfall data are required. All rainfall data were obtained from the Moscow 5NE gage, which is located near the western boundary of Crumarine Creek watershed at an elevation of 3040 feet and records precipitation on an hourly basis. For a snowmelt event, temperature and wind speed are required. Hourly temperatures were estimated from the University of Idaho weather station located at the base of Moscow Mountain at an elevation of 2660 feet. Only maximum and minimum temperatures are published from this station. In order to obtain hourly temperatures a sinusoidal distribution of temperatures was assumed with the minimum occurring at 5:00 in the morning and the maximum occurring at 2:00 in the afternoon. An average wind speed of five miles per hour was assumed.

## Summer Rainfall Events

The first type of event examined was a summer rainfall event on Crumarine Creek watershed. Hourly rainfall data were used and hourly discharge values were generated. For both events the Holtan loss rate was used (Army Corps of Engineers, 1981). The Holtan loss rate was used because it was the only loss rate option that accounted for soil moisture and surface storage recovery.

$$f=GIA\ (SA)^{BEXP} + FC \qquad (20)$$

f=infiltration capacity, in/hr
GI=growth index
A=infiltration capacity, in/hr
SA=equivalent depth of pore space in surface layer of soil, inches
BEXP=an empirical exponent usually around 1.4
FC=constant rate of percolation of water through the soil profile below the surface layer, in/hr

Table 29 lists the values used in the Holtan equation for each storm. The growth index (GI) describes the growth stage of the crop with a growth index of 1.0 corresponding to a mature crop. As seen, not much variation occurred in the growth index from July to August. By July the wheat is well established and so is the ground cover within the forest.

Table 29. Holtan loss rate values.

| Date of Event | GI | A in/hr | SA inches | BEXP | FC in/hr |
|---|---|---|---|---|---|
| July 13, 1975 | 0.90 | 0.33 | 0.20 | 1.33 | 0.11 |
| Aug 28, 1978 | 0.95 | 0.98 | 0.41 | 1.30 | 0.11 |

The infiltration capacity (A) and depth of pore space (SA) exhibited a large difference from the July storm to the August storm. This is mostly a

Table 30. Antecedent conditions.

| Date of Event | Precipitation, inches | | | |
| --- | --- | --- | --- | --- |
| | | 7/12* | 7/13 | |
| July 13, 1975 | | 0.5 | 0.3 | |
| | 8/12** | 8/15 | 8/20 | 8/22 |
| Aug 22, 1978 | 0.4 | 0.5 | 0.2 | 1.2 |

*No rain in July, 1975, prior to July 12
**No rain in August, 1978, prior to August 12

reflection of the antecedent conditions (Table 30). On July 12, 1975, 0.5 inch of rain was received, which decreased the amount of pore space available for storage for rainfall on July 13, 1975. Prior to August 22, 1978, not much rain had been received and much more pore space was available for storage of infiltrated water. The empirical exponent (BEXP) of 1.3 and constant infiltration rate (FC) of 0.11 inches per hour were assumed to remain constant for each event. The constant infiltration rate was obtained from values recommended by Musgrave (1955). He suggested that for a soil of hydrologic group B the constant infiltration rate ranged from 0.15 to 0.30 inches per hour and for a soil of hydrologic group C the constant infiltration rate ranged from 0.05 to 0.15 inches per hour. Soils from hydrologic groups B and C are on the watershed so an average constant infiltration rate of 0.11 inches per hour was used.

A Snyder unit hydrograph was used on both events to model the output hydrograph. The lag time ($T_1$) and Snyder's peaking coefficient ($C_p$) were required for the Snyder unit hydrograph. The lag time was calculated by the following equation (Viessman and others, 1977):

$$T_1 = C_t (LL_{ca})^{0.3} \qquad (21)$$

$T_1$=lag time=3.1 hours
$C_t$=coefficient representing variations of watershed slopes and storage=1.8
L=length of main stream channel=3.3 miles
$L_{ca}$=length along the main channel to a point nearest the watershed centroid=1.8 miles

L and $L_{ca}$ were measured directly from a map of the watershed. Viessman and others (1977) determined that the coefficient $C_t$ usually ranged from 1.8 to 2.2 and decreased as slope steepness increased. A value of 1.8 was assumed for Crumarine Creek watershed because many steep slopes are present on the upper half of the watershed. A lag time of 3.1 hours was calculated for the watershed using the above equation. The coefficient $C_p$ accounts for flood waves and storage conditions. It is also a function of lag time, duration of runoff producing rain, effective area contributing to peak flow and drainage area (Viessman and others, 1977). $C_p$ ranges from 0.4 to 0.8 and larger $C_p$ values are associated with smaller $C_t$ values. A value of 0.7 was used for $C_p$ to calculate runoff on Crumarine Creek watershed. The coefficient $C_p$ is used to calculate peak runoff values by the following equation:

$$Q_p = \frac{640\ C_p\ A}{T_1} \qquad (22)$$

$Q_p$=peak discharge, cfs
$C_p$=Snyder's peaking coefficient
A=watershed area, square miles
$T_1$=lag time, hours

Figures 19 and 20 show the actual and generated hydrographs for the rainfall events. These events are summarized in Tables 31 and 32. From Figures 19 and 20 it can be seen that there are some differences between the actual and generated hydrographs. The generated hydrograph on July 13, 1975, peaked two hours later than the actual hydrograph. The generated hydrograph on August 22, 1978, peaked two hours earlier than the actual hydrograph. Differences were also evident in the rising limb and the falling limb of the generated hydrograph when compared to the actual hydrograph. These differences indicate that the lag time is subject to variations depending on the type of storm. Also, HEC-1 assumed that the precipitation was uniformly distributed over the watershed, which is not always the case. Summer storms are often convective in nature and these storms can be very localized. This discrepancy between the actual and modelled precipitation distribution was an additional source of error.

From Tables 31 and 32 it was evident that only a very small amount of precipitation becomes excess precipitation. Since HEC-1 only prints precipitation loss and excess to two decimal places it appeared as if almost all precipitation was lost in the rainfall event on July 13, 1975. The event on August 22, 1978, was of higher rainfall magnitude and a precipitation excess of 0.01 inches was computed. The hydrograph separation results (Table 33) calculated a value of 0.0131 inches for direct runoff. Since HEC-1 only prints to the second decimal place it is difficult to determine how well the two numbers matched but they appear to

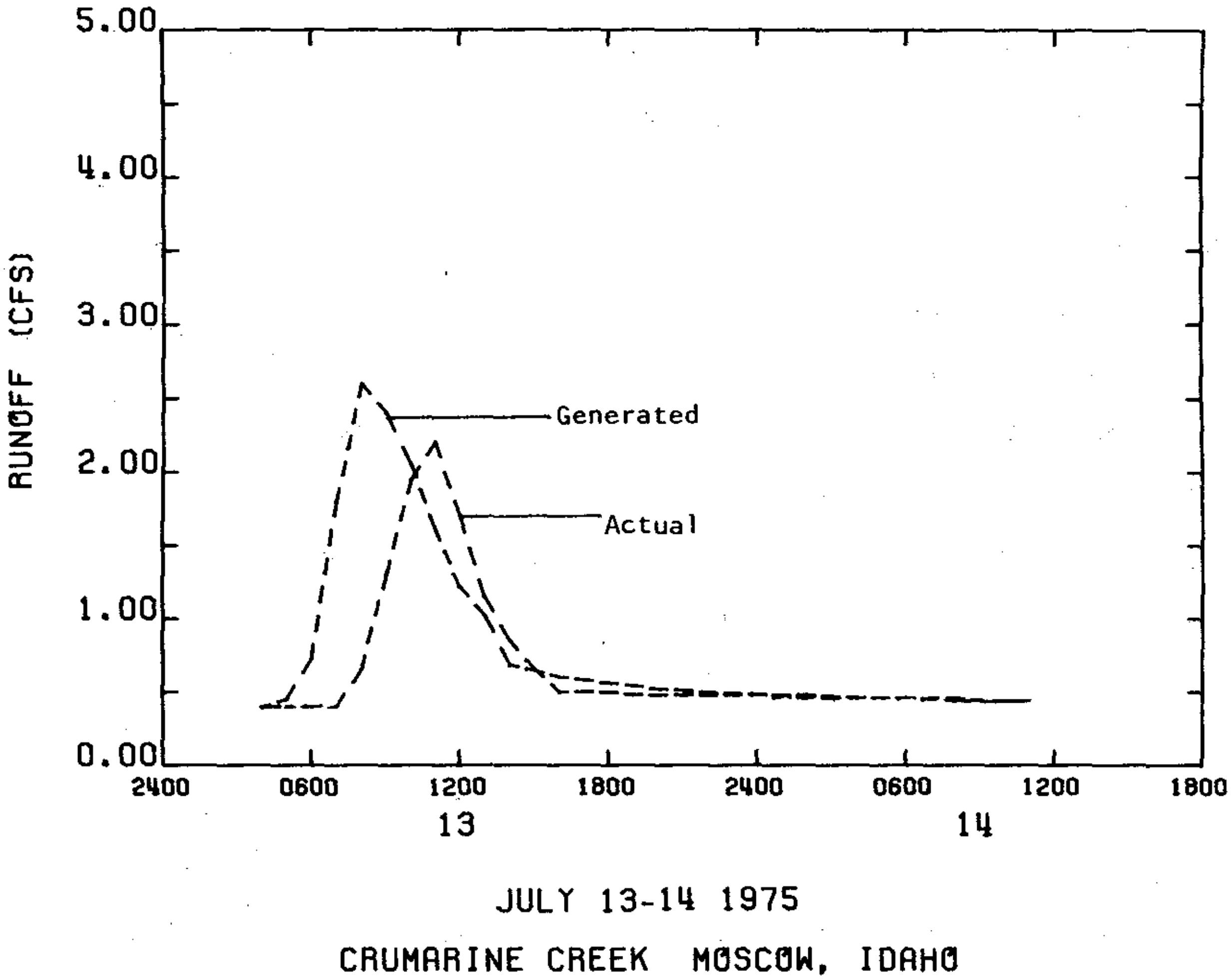


Figure 19. Actual and generated runoff hydrographs for July 13, 1975.

Table 31. HEC-1 results for July 13, 1975.

| Date | Time | Rain inches | Rain Loss inches | Rain Excess inches | Computed Runoff cfs | Actual Runoff cfs |
|---|---|---|---|---|---|---|
| 7/13 | 0400 | 0.00 | 0.00 | 0.00 | 0.40 | 0.40 |
| 7/13 | 0500 | 0.10 | 0.10 | 0.00 | 0.40 | 0.45 |
| 7/13 | 0600 | 0.00 | 0.00 | 0.00 | 0.40 | 0.72 |
| 7/13 | 0700 | 0.00 | 0.00 | 0.00 | 0.40 | 1.80 |
| 7/13 | 0800 | 0.20 | 0.20 | 0.00 | 0.65 | 2.60 |
| 7/13 | 0900 | 0.00 | 0.00 | 0.00 | 1.30 | 2.40 |
| 7/13 | 1000 | 0.00 | 0.00 | 0.00 | 1.95 | 2.05 |
| 7/13 | 1100 | 0.00 | 0.00 | 0.00 | 2.20 | 1.62 |
| 7/13 | 1200 | 0.00 | 0.00 | 0.00 | 1.70 | 1.22 |
| 7/13 | 1300 | 0.00 | 0.00 | 0.00 | 1.15 | 1.02 |
| 7/13 | 1400 | 0.00 | 0.00 | 0.00 | 0.85 | 0.68 |
| 7/13 | 1500 | 0.00 | 0.00 | 0.00 | 0.65 | 0.64 |
| 7/13 | 1600 | 0.00 | 0.00 | 0.00 | 0.50 | 0.60 |
| 7/13 | 1700 | 0.00 | 0.00 | 0.00 | 0.50 | 0.58 |
| 7/13 | 1800 | 0.00 | 0.00 | 0.00 | 0.50 | 0.56 |
| 7/13 | 1900 | 0.00 | 0.00 | 0.00 | 0.48 | 0.54 |
| 7/13 | 2000 | 0.00 | 0.00 | 0.00 | 0.48 | 0.52 |
| 7/13 | 2100 | 0.00 | 0.00 | 0.00 | 0.48 | 0.51 |
| 7/13 | 2200 | 0.00 | 0.00 | 0.00 | 0.48 | 0.50 |
| 7/13 | 2300 | 0.00 | 0.00 | 0.00 | 0.48 | 0.49 |
| 7/14 | 0000 | 0.00 | 0.00 | 0.00 | 0.48 | 0.48 |
| 7/14 | 0100 | 0.00 | 0.00 | 0.00 | 0.46 | 0.48 |
| 7/14 | 0200 | 0.00 | 0.00 | 0.00 | 0.46 | 0.48 |
| 7/14 | 0300 | 0.00 | 0.00 | 0.00 | 0.46 | 0.47 |
| 7/14 | 0400 | 0.00 | 0.00 | 0.00 | 0.46 | 0.46 |
| 7/14 | 0500 | 0.00 | 0.00 | 0.00 | 0.46 | 0.46 |
| 7/14 | 0600 | 0.00 | 0.00 | 0.00 | 0.46 | 0.46 |
| 7/14 | 0700 | 0.00 | 0.00 | 0.00 | 0.46 | 0.45 |
| 7/14 | 0800 | 0.00 | 0.00 | 0.00 | 0.46 | 0.44 |
| 7/14 | 0900 | 0.00 | 0.00 | 0.00 | 0.44 | 0.44 |
| 7/14 | 1000 | 0.00 | 0.00 | 0.00 | 0.44 | 0.44 |
| 7/14 | 1100 | 0.00 | 0.00 | 0.00 | 0.44 | 0.44 |
| Total | | 0.30 | 0.30 | 0.00 | | |

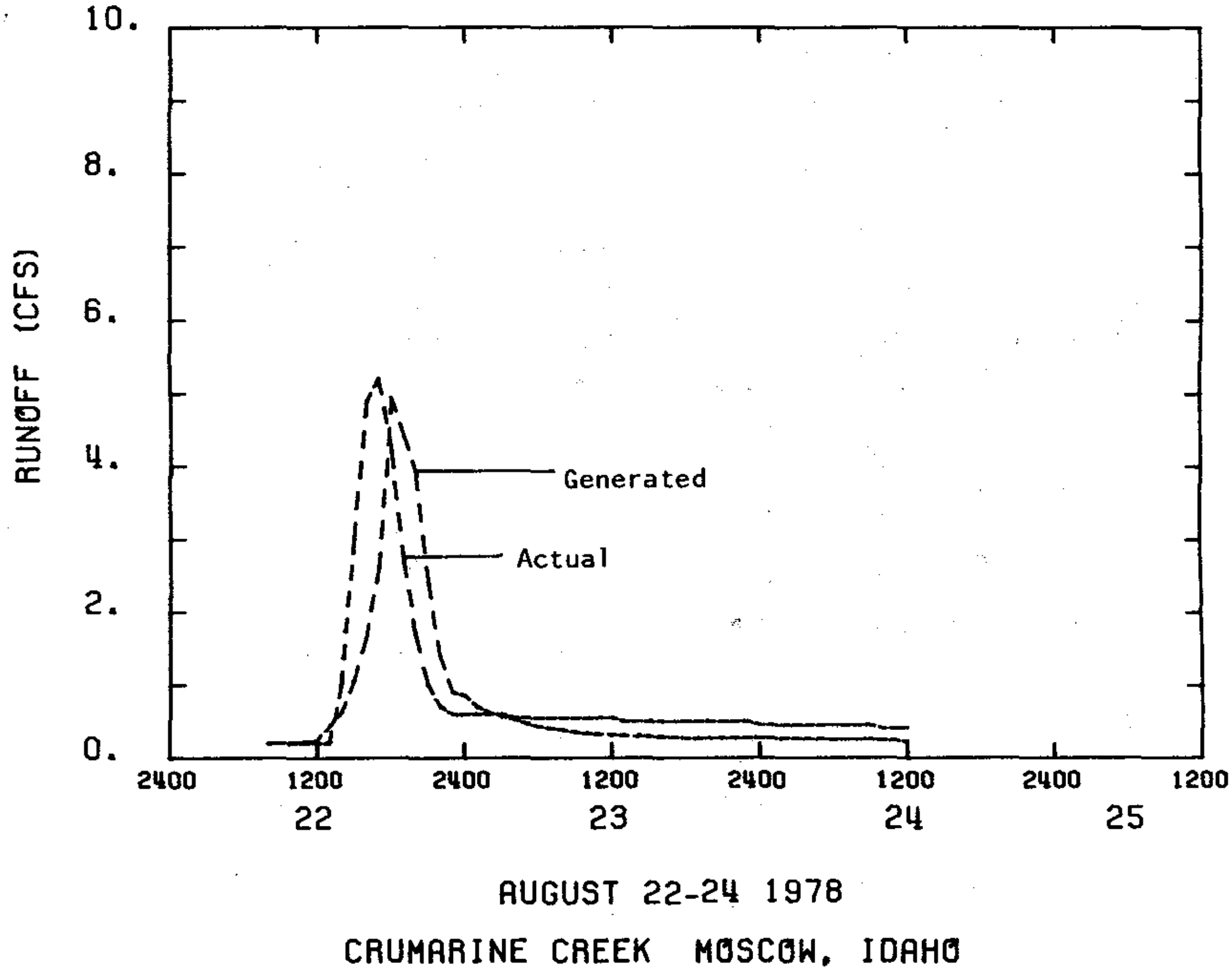


Figure 20. Actual and generated runoff hydrographs for August 22, 1978.

Table 32. HEC-1 results for August 22, 1978.

| Date | Time | Rain inches | Rain Loss inches | Rain Excess inches | Computed Runoff cfs | Actual Runoff cfs |
|---|---|---|---|---|---|---|
| 8/22 | 0800 | 0.00 | 0.00 | 0.00 | 0.20 | 0.19 |
| 8/22 | 0900 | 0.10 | 0.10 | 0.00 | 0.20 | 0.20 |
| 8/22 | 1000 | 0.10 | 0.10 | 0.00 | 0.20 | 0.21 |
| 8/22 | 1100 | 0.00 | 0.00 | 0.00 | 0.20 | 0.22 |
| 8/22 | 1200 | 0.00 | 0.00 | 0.00 | 0.20 | 0.24 |
| 8/22 | 1300 | 0.40 | 0.40 | 0.00 | 0.20 | 0.44 |
| 8/22 | 1400 | 0.30 | 0.29 | 0.01 | 1.00 | 0.62 |
| 8/22 | 1500 | 0.00 | 0.00 | 0.00 | 3.00 | 1.05 |
| 8/22 | 1600 | 0.10 | 0.10 | 0.00 | 4.90 | 1.64 |
| 8/22 | 1700 | 0.00 | 0.00 | 0.00 | 5.20 | 2.60 |
| 8/22 | 1800 | 0.00 | 0.00 | 0.00 | 4.20 | 4.94 |
| 8/22 | 1900 | 0.00 | 0.00 | 0.00 | 2.70 | 4.40 |
| 8/22 | 2000 | 0.00 | 0.00 | 0.00 | 1.70 | 3.90 |
| 8/22 | 2100 | 0.10 | 0.10 | 0.00 | 1.00 | 2.40 |
| 8/22 | 2200 | 0.00 | 0.00 | 0.00 | 0.70 | 1.39 |
| 8/22 | 2300 | 0.00 | 0.00 | 0.00 | 0.60 | 0.90 |
| 8/23 | 0000 | 0.00 | 0.00 | 0.00 | 0.60 | 0.86 |
| 8/23 | 0100 | 0.00 | 0.00 | 0.00 | 0.60 | 0.70 |
| 8/23 | 0200 | 0.00 | 0.00 | 0.00 | 0.60 | 0.62 |
| 8/23 | 0300 | 0.00 | 0.00 | 0.00 | 0.60 | 0.57 |
| 8/23 | 0400 | 0.00 | 0.00 | 0.00 | 0.55 | 0.52 |
| 8/23 | 0500 | 0.00 | 0.00 | 0.00 | 0.55 | 0.52 |
| 8/23 | 0600 | 0.00 | 0.00 | 0.00 | 0.55 | 0.43 |
| 8/23 | 0700 | 0.00 | 0.00 | 0.00 | 0.55 | 0.40 |
| 8/23 | 0800 | 0.00 | 0.00 | 0.00 | 0.55 | 0.38 |
| 8/23 | 0900 | 0.00 | 0.00 | 0.00 | 0.55 | 0.35 |
| 8/23 | 1000 | 0.00 | 0.00 | 0.00 | 0.55 | 0.33 |
| 8/23 | 1100 | 0.00 | 0.00 | 0.00 | 0.55 | 0.32 |
| 8/23 | 1200 | 0.00 | 0.00 | 0.00 | 0.55 | 0.31 |
| 8/23 | 1300 | 0.00 | 0.00 | 0.00 | 0.50 | 0.30 |
| 8/23 | 1400 | 0.00 | 0.00 | 0.00 | 0.50 | 0.29 |
| 8/23 | 1500 | 0.00 | 0.00 | 0.00 | 0.50 | 0.29 |
| 8/23 | 1600 | 0.00 | 0.00 | 0.00 | 0.50 | 0.28 |
| 8/23 | 1700 | 0.00 | 0.00 | 0.00 | 0.50 | 0.28 |
| 8/23 | 1800 | 0.00 | 0.00 | 0.00 | 0.50 | 0.27 |
| 8/23 | 1900 | 0.00 | 0.00 | 0.00 | 0.50 | 0.27 |
| 8/23 | 2000 | 0.00 | 0.00 | 0.00 | 0.50 | 0.27 |
| 8/23 | 2100 | 0.00 | 0.00 | 0.00 | 0.50 | 0.27 |
| 8/23 | 2200 | 0.00 | 0.00 | 0.00 | 0.55 | 0.31 |
| 8/23 | 1300 | 0.00 | 0.00 | 0.00 | 0.50 | 0.30 |
| 8/23 | 1400 | 0.00 | 0.00 | 0.00 | 0.50 | 0.29 |
| 8/23 | 1500 | 0.00 | 0.00 | 0.00 | 0.50 | 0.29 |
| Total | | 1.10 | 1.09 | 0.01 | | |

Table 33. Results of separated summer runoff hydrographs. All values are in inches.

| Event | Precipitation | Total Runoff | Direct Runoff | Baseflow |
|---|---|---|---|---|
| July 13, 1975 | 0.30 | 0.0107 | 0.0060 | 0.0047 |
| Aug 22, 1978 | 1.10 | 0.0177 | 0.0131 | 0.0046 |

be close. Also seen from the hydrograph separation results was that direct runoff accounted for 74 percent of the total runoff (0.0131/0.0177). As seen from the HEC-1 results (Table 32) 1.09 inches were lost to infiltration, interception and depression storage. Of the 1.09 inches that were lost to infiltration only 0.0046 inches eventually appeared as baseflow. Similar results were obtained from the July 13, 1975 event. Precipitation excess was small, as seen from Table 28, but HEC-1 computed all of the 0.30 inches of precipitation as a loss. Of the 0.30 inches of precipitation lost to infiltration, only 0.0047 inches returned as baseflow to the stream. From these results it was concluded that the amount of infiltrated and intercepted precipitation that was returned to Crumarine Creek as baseflow was negligible during a summer rainfall event. Since soil moisture was lacking during this time of year it made sense that the infiltrated rainfall was stored in the soil pore space or lost to evapotranspiration instead of percolating through the soil to the underlying shallow aquifer and then returning to the stream as baseflow.

## Snowmelt Events

The next event to be modelled was a snowmelt event on Crumarine Creek watershed. Two different snowmelt events were modelled- one on March 10, 1976, and one on March 16, 1985. For both events the energy-budget method and exponential loss rate were used. The following energy-budget equation was used in running HEC-1 (Army Corps of Engineers, 1981):

$$\text{SNWMT}=\text{COEF}\ (0.09 + (0.029 + 0.00504\ \text{WIND}\ \ 0.007\text{RAIN})(\text{TMPR} - \text{FRZTP}) \tag{23}$$

SNWMT=snowmelt, inches/day
COEF=dimensionless snowmelt coefficient
WIND=wind speed 50 feet above the snow, miles/hour
RAIN=rainfall, inches/day
TMPR=temperature, °F
FRZTP=freezing temperature, °F

Temperature, rain and wind speed were entered at two hour intervals. A constant wind speed of five miles per hour was assumed and the freezing temperature was taken as 32 °F. The snowmelt coefficient was adjustable and varied for each snowmelt event.

The exponential loss rate was required by HEC-1 to model snowmelt losses. The Army Corps of Engineers (1981) suggested the following equations to represent exponential loss:

$$\text{AK}=\text{STRKR}\ (\text{RTIOL}^{-0.1\text{CUML}}) \tag{24}$$

$$\text{DLTK}=0.2\ \text{DLTKR}(1.0-(\text{CUML}/\text{DLTKR}))^2 \tag{25}$$

$$\text{ALOSS}=(\text{AK}+\text{DLTK})\text{PRCP}^{\text{ERAIN}} \tag{26}$$

AK=loss rate coefficient at the beginning of the time interval
STRKR=starting loss rate, inches/hour
RTIOL=ratio of STRKR to that corresponding to STRKR after 10 inches of accumulated loss
CUML=accumulated loss, inches
DLTK=incremental increase in the loss rate coefficient during the first DLTKR inches
ERAIN=exponent of precipitation for the rain loss function that reflects the influence of precipitation rate
ALOSS=potential loss rate, inches/hour

Values for STRKR, RTIOL, DLTKR and ERAIN were required for the exponential loss rate of precipitation. An exponential loss rate of snowmelt was also used. Only two values were required for the snowmelt exponential loss:

STRKS=initial snowmelt loss, inches/hour
RTIOK=ratio of STRKS to that corresponding to STRKS after 10 inches more of accumulated snowmelt loss

Table 34 lists the exponential loss values and the snowmelt coefficient used for the two snowmelt events. The reason for the ERAIN parameter being zero is for a snowmelt event, losses are not precipitation dependent. Losses are more temperature dependent in a snowmelt event. The starting values for snowmelt losses (STRKS) were low, which was expected since the ground is nearly saturated at this time of year.

In order to simulate snowmelt, HEC-1 required that the watershed be divided into zones of equal elevation increments. Crumarine Creek watershed was divided into four zones and snow water equivalent values were determined for each zone. The reason for using only four zones was that snow water equivalents could be determined fairly accurately for each zone.

Table 34. Exponential loss values and snowmelt coefficient.

| | Event | | |
|---|---|---|---|
| Parameter | March 10, 1976 | March 16, 1985 | |
| STRKR | 0.64 | 0.64 | in/hr |
| RTIOL | 5.0 | 5.0 | |
| DLTKR | 0.20 | 0.20 | inches |
| ERAIN | 0.0 | 0.0 | |
| STRKS | 0.08 | 0.11 | in/hr |
| DLTKS | 3.60 | 3.60 | inches |
| COEF | 0.164 | 0.165 | |

Determining snow water equivalents for more than four zones would have resulted in larger errors. Using less than four zones would not have represented the snow distribution on the watershed properly. Snow water equivalent values were obtained from SCS snow surveys conducted on Moscow Mountain. A lapse rate of 3 °F per 1000 feet was used. Table 35 lists the snow zones and initial snow water equivalent values used for each event.

A Snyder unit hydrograph was used to route the precipitation excess. The same peaking coefficient of 0.7 was used as in the summer rainfall events but a different lag time was used. The lag time was increased from the calculated value of 3.1 hours to a value of 3.5 hours. The reason for increasing the lag time was because there is a delay due to water passing through the snow pack (Viessman, 1977). Although Snyder unit hydrograph values were given, HEC-1 converted these initial values into Clark unit

Table 35. Snow zones for Crumarine Creek watershed.

| | | Snow Water Equivalent, inches | |
|---|---|---|---|
| Zone | Range of Elevation, feet | March 10, 1976 | March 16, 1985 |
| 1 | 2800-3300 | 3.0 | 4.0 |
| 2 | 3300-3800 | 7.0 | 8.0 |
| 3 | 3800-4300 | 11.0 | 12.0 |
| 4 | 4300-4800 | 15.0 | 18.0 |

hydrograph values. The final runoff hydrograph was routed using a Clark time-area unit hydrograph.

A key part in simulating the snowmelt hydrograph was the baseflow recession curve since baseflow accounts for approximately 80 percent of the total runoff in a snowmelt event. HEC-1 used the following baseflow recession curve:

$$Q=Q_o k^{-t} \tag{27}$$

Q=baseflow discharge, cfs
$Q_o$=flow at which recession begins, cfs
k=recession constant
t=time, hours

An initial value of the beginning recession flow ($Q_o$) was obtained by separating the hydrograph as previously described. It was necessary to increase these initial baseflow values in order to obtain a generated recession curve similar to the actual recession curve. Table 36 lists recession curve values used for each event. The recession constant (k) has a minimum value of 1.0, which results in a straight line. The recession constants of 1.01 indicates that the recession curve is rather flat and of long duration.

Table 36. Recession curve values.

| Baseflow Parameter | Event March 10, 1976 | Event March 16, 1985 |
|---|---|---|
| $Q_o$ | 3.80 | 3.50 |
| k | 1.01 | 1.01 |

Figures 21 and 22 illustrate the generated and the computed hydrographs. Tables 37 and 38 summmarize the results. The computed and the actual hydrographs peaked at the same time, as seen from the graphs. The rising limb of the computed hydrograph lagged behind the actual hydrograph in its rate of rise. Also, the falling limb of the computed hydrograph descended much quicker than the actual hydrograph. Differences in the computed and actual hydrograph falling limb were due to baseflow not being modelled correctly. The actual starting value of baseflow recession was higher than the values used in Table 36.

Again, the HEC-1 results were compared with the hydrograph separation results (Table 39). Only snowmelt was included in the table because any precipitation falling on the watershed was assumed to be absorbed by the

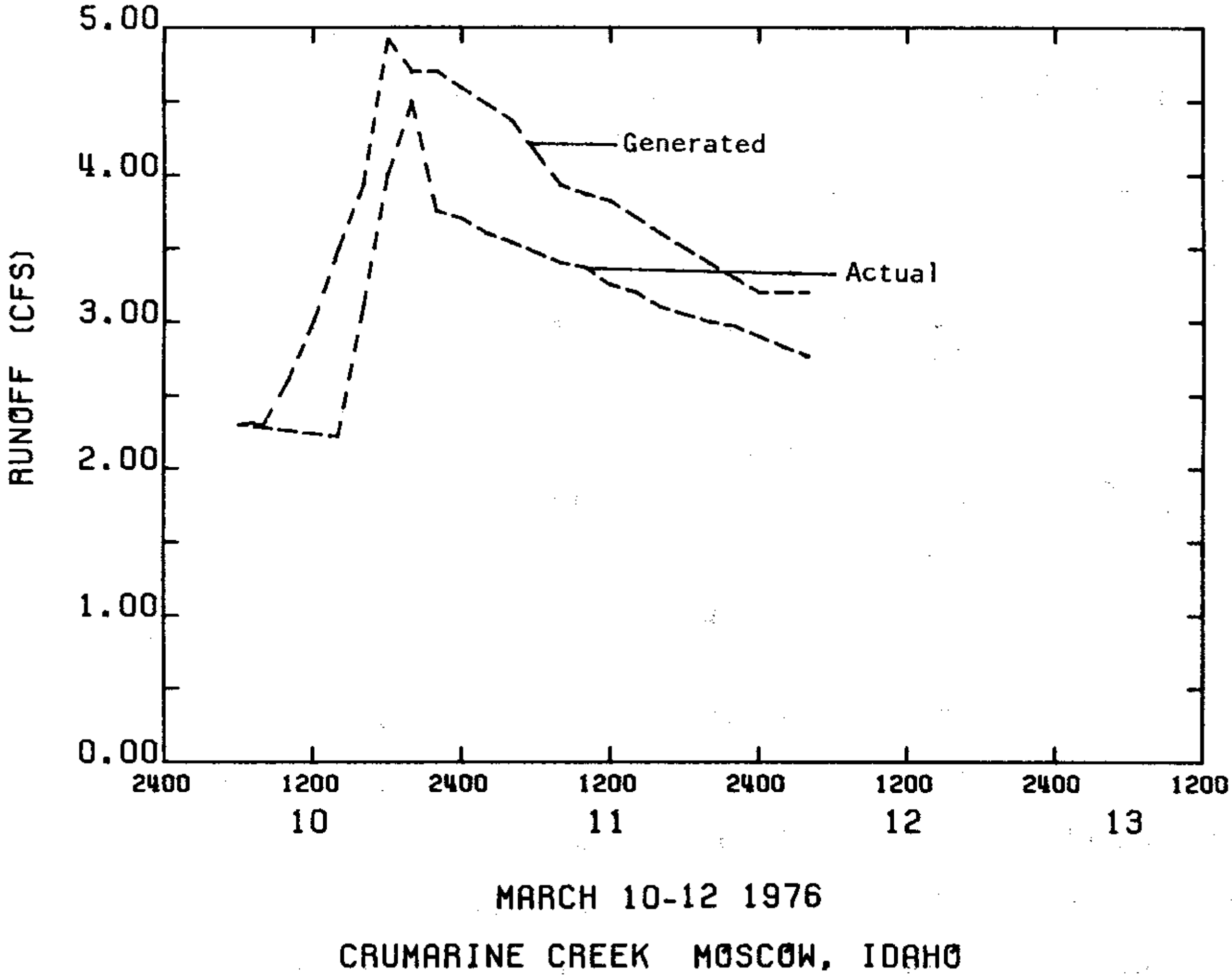


Figure 21. Actual and generated runoff hydrographs for March 10, 1976.

Table 37. HEC-1 results for March 10, 1976.

| Date | Time | Precipitation Inches | Temperature °F | Snowmelt Inches | Snow Loss Inches | Snow Excess Inches | Rain Loss Inches | Computed Runoff cfs | Actual Runoff cfs |
|---|---|---|---|---|---|---|---|---|---|
| 3/10 | 0600 | 0.00 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 2.30 | 2.30 |
| 3/10 | 0800 | 0.00 | 33 | 0.00 | 0.00 | 0.00 | 0.00 | 2.28 | 2.30 |
| 3/10 | 1000 | 0.00 | 37 | 0.03 | 0.03 | 0.00 | 0.00 | 2.26 | 2.60 |
| 3/10 | 1200 | 0.00 | 41 | 0.09 | 0.09 | 0.00 | 0.00 | 2.24 | 3.00 |
| 3/10 | 1400 | 0.00 | 44 | 0.13 | 0.13 | 0.00 | 0.00 | 2.22 | 3.50 |
| 3/10 | 1600 | 0.00 | 46 | 0.16 | 0.15 | 0.01 | 0.00 | 3.10 | 3.93 |
| 3/10 | 1800 | 0.00 | 42 | 0.10 | 0.10 | 0.00 | 0.00 | 4.00 | 4.92 |
| 3/10 | 2000 | 0.10 | 36 | 0.02 | 0.02 | 0.00 | 0.03 | 4.50 | 4.70 |
| 3/10 | 2200 | 0.00 | 33 | 0.00 | 0.00 | 0.00 | 0.00 | 3.75 | 4.70 |
| 3/11 | 0000 | 0.00 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 3.70 | 4.59 |
| 3/11 | 0200 | 0.00 | 27 | 0.00 | 0.00 | 0.00 | 0.00 | 3.60 | 4.48 |
| 3/11 | 0400 | 0.00 | 25 | 0.00 | 0.00 | 0.00 | 0.00 | 3.54 | 4.37 |
| 3/11 | 0600 | 0.00 | 28 | 0.00 | 0.00 | 0.00 | 0.00 | 3.47 | 4.15 |
| 3/11 | 0800 | 0.00 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 3.40 | 3.93 |
| 3/11 | 1000 | 0.00 | 34 | 0.00 | 0.00 | 0.00 | 0.00 | 3.37 | 3.87 |
| 3/11 | 1200 | 0.00 | 36 | 0.02 | 0.02 | 0.00 | 0.00 | 3.25 | 3.82 |
| 3/11 | 1400 | 0.00 | 36 | 0.02 | 0.02 | 0.00 | 0.00 | 3.20 | 3.71 |
| 3/11 | 1600 | 0.00 | 34 | 0.00 | 0.00 | 0.00 | 0.00 | 3.10 | 3.60 |
| 3/11 | 1800 | 0.00 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 3.05 | 3.50 |
| 3/11 | 2000 | 0.00 | 27 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 | 3.40 |
| 3/11 | 2200 | 0.00 | 24 | 0.00 | 0.00 | 0.00 | 0.00 | 2.97 | 3.30 |
| 3/12 | 0000 | 0.00 | 22 | 0.00 | 0.00 | 0.00 | 0.00 | 2.90 | 3.20 |
| 3/12 | 0200 | 0.00 | 20 | 0.00 | 0.00 | 0.00 | 0.00 | 2.83 | 3.20 |
| 3/12 | 0400 | 0.00 | 20 | 0.00 | 0.00 | 0.00 | 0.00 | 2.77 | 3.20 |
| Total | | 0.10 | | 0.57 | 0.56 | 0.01 | 0.03 | | |

snowpack. For the March 10, 1976 event, 0.56 inches of the 0.57 inches of total snowmelt were lost to infiltration. Of the 0.56 inches that infiltrated, 0.0692 inches appeared as baseflow, or 12 percent. HEC-1 recorded a snowmelt excess of 0.01 inches and the hydrograph separation resulted in a value of 0.0198 inches for direct runoff. Since HEC-1 only prints to two decimal places it was difficult to determine how close the two results matched. For the March 16, 1985 event, 0.76 inches of the 0.78 inches of snowmelt were lost to infiltration. Of the 0.76 inches that infiltrated, 0.0387 inches returned to Crumarine Creek as baseflow, or five percent. HEC-1 recorded a snowmelt excess of 0.02 inches and the

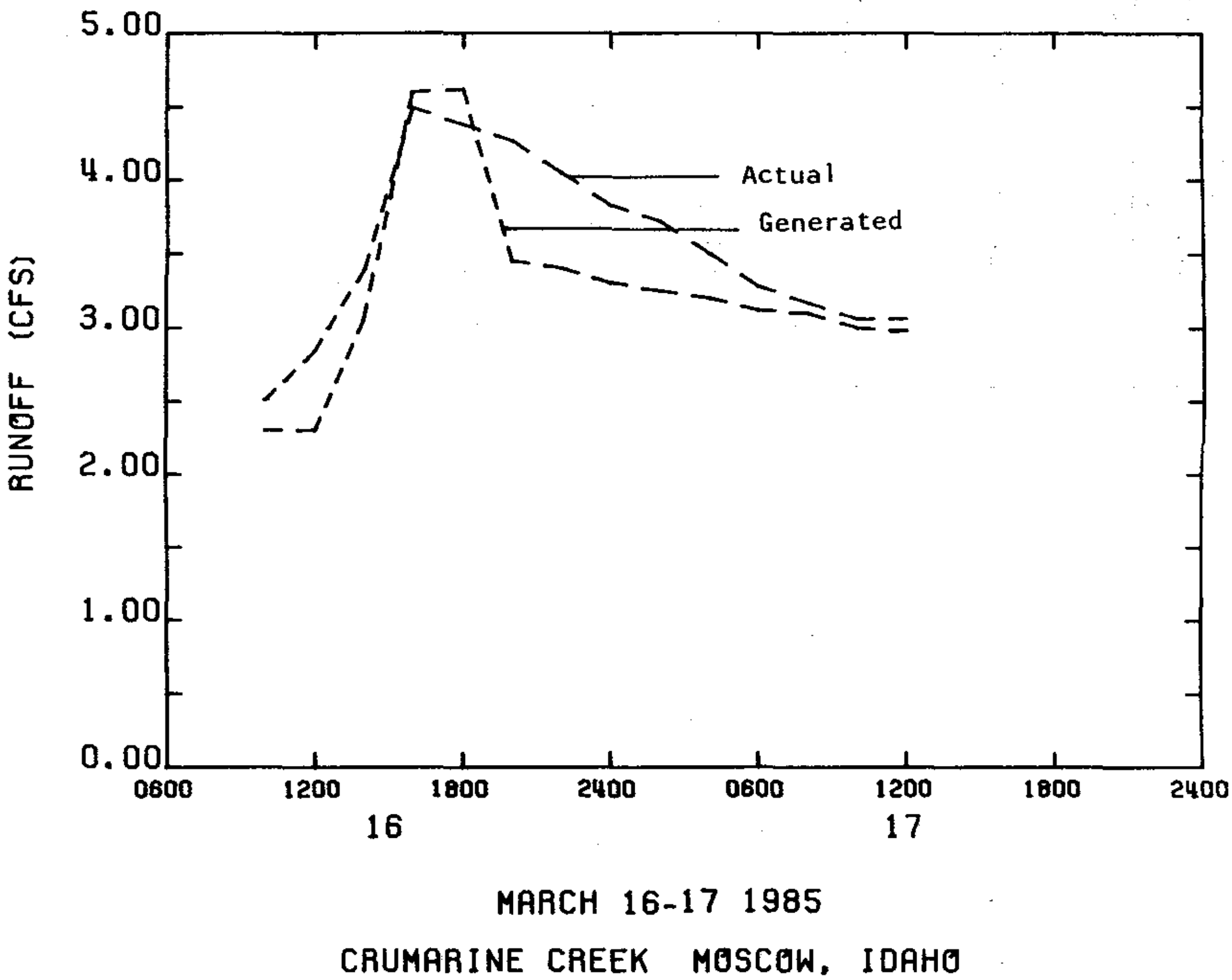


Figure 22. Actual and generated runoff hydrographs for March 16, 1985.

Table 38. HEC-1 results for March 16, 1985.

| Date | Time | Precipitation inches | Temperature °F | Snowmelt inches | Snow Loss inches | Snow Excess inches | Rain Loss inches | Computed Runoff cfs | Actual Runoff cfs |
|---|---|---|---|---|---|---|---|---|---|
| 3/16 | 1000 | 0.00 | 40 | 0.07 | 0.07 | 0.00 | 0.00 | 2.30 | 2.52 |
| 3/16 | 1200 | 0.00 | 44 | 0.13 | 0.13 | 0.00 | 0.00 | 2.30 | 2.84 |
| 3/16 | 1400 | 0.00 | 50 | 0.21 | 0.20 | 0.01 | 0.00 | 3.05 | 3.39 |
| 3/16 | 1600 | 0.02 | 47 | 0.17 | 0.17 | 0.00 | 0.02 | 4.60 | 4.49 |
| 3/16 | 1800 | 0.02 | 43 | 0.12 | 0.12 | 0.00 | 0.02 | 4.62 | 4.38 |
| 3/16 | 2000 | 0.00 | 39 | 0.06 | 0.06 | 0.00 | 0.00 | 3.45 | 4.27 |
| 3/16 | 2200 | 0.00 | 36 | 0.02 | 0.02 | 0.00 | 0.00 | 3.40 | 4.05 |
| 3/17 | 0000 | 0.00 | 34 | 0.00 | 0.00 | 0.00 | 0.00 | 3.30 | 3.83 |
| 3/17 | 0200 | 0.00 | 33 | 0.00 | 0.00 | 0.00 | 0.00 | 3.25 | 3.72 |
| 3/17 | 0400 | 0.00 | 31 | 0.00 | 0.00 | 0.00 | 0.00 | 3.20 | 3.50 |
| 3/17 | 0600 | 0.00 | 34 | 0.00 | 0.00 | 0.00 | 0.00 | 3.12 | 3.28 |
| 3/17 | 0800 | 0.00 | 40 | 0.00 | 0.00 | 0.00 | 0.00 | 3.10 | 3.17 |
| 3/17 | 1000 | 0.00 | 44 | 0.13 | 0.13 | 0.00 | 0.00 | 3.00 | 3.06 |
| 3/17 | 1200 | 0.00 | 44 | 0.13 | 0.13 | 0.00 | 0.00 | 2.98 | 3.06 |
| Total | | 0.04 | | 0.78 | 0.77 | 0.01 | 0.04 | | |

hydrograph separation resulted in direct runoff of 0.0126 inches. Again, since HEC-1 only prints to two decimal places it was difficult to determine how close the two results matched. As seen from the hydrograph separation results, baseflow accounted for over 75 percent of the total runoff in both snowmelt events. These results agreed with Kobayashi (1985). He determined that surface runoff only comprised 15 to 20 percent of the total runoff in a snowmelt event.

Table 39. Results of separated snowmelt hydrographs.

| Event | Snowmelt inches* | Snowmelt Excess inches* | Snowmelt Loss inches* | Total Runoff inches | Direct Runoff inches | Baseflow inches |
|---|---|---|---|---|---|---|
| March 10, 1976 | 0.57 | 0.01 | 0.56 | 0.0890 | 0.0198 | 0.0692 |
| March 16, 1985 | 0.78 | 0.02 | 0.76 | 0.0513 | 0.0126 | 0.0387 |

*Obtained from HEC-1 results

Table 40. Exponential loss values and snowmelt coefficient.

| Parameter | February 18-25, 1982 |
|---|---|
| STRKR | 0.72 in/hr |
| RTIOL | 5.7 |
| DLTKR | 0.11 inches |
| ERAIN | 0.0 |
| STRKS | 0.12 in/hr |
| DLTKS | 4.0 inches |
| COEF | 0.14 |

Rain on Snow Event

The last event examined was a rain on snow event. Only one event, February 25, 1982, was examined. An exponential loss rate of precipitation and snowmelt was used. The energy-budget method was used to simulate snowmelt on the watershed. Table 40 lists the values used for the exponential loss rate and the snowmelt coefficient. Again, a lapse rate of 3 °F per 1000 feet, a freezing temperature of 32 °F and a wind speed of five miles per hour were used. A Snyder unit hydrograph was used with a lag time of 3.5 hours and a peaking coefficient of 0.7 but the final hydrograph was routed as a Clark unit hydrograph by HEC-1.

The values used for the precipitation exponential loss rate (STRKR, RTIOL, DLTKR and ERAIN) caused the majority of rain to be lost. Little, if any, of the rain eventually infiltrated into the ground. Most of the rain was intercepted and held in the snow pack. The values of STRKS and DLTKS for the snowmelt loss caused the rate of snowmelt infiltration to be low. During this time of year the ground is close to saturation and infiltration rates into the ground are small.

Figure 23 illustrates the generated and the actual hydrograph. Table 38 summarizes the results. As seen, major differences exist between the two hydrographs. The most obvious difference occurs in the peaks of the hydrographs, which was probably a result of the temperatures used. All hourly temperatures were estimated from maximum and minimum temperatures. The minimum temperature was assumed to occur at 5:00 in the morning and the maximum at 2:00 in the afternoon. This situation does not always hold true and warming temperatures during the night are not uncommon. Since snowmelt is dependent on temperature, errors in the temperature data used would cause errors in the resulting hydrograph.

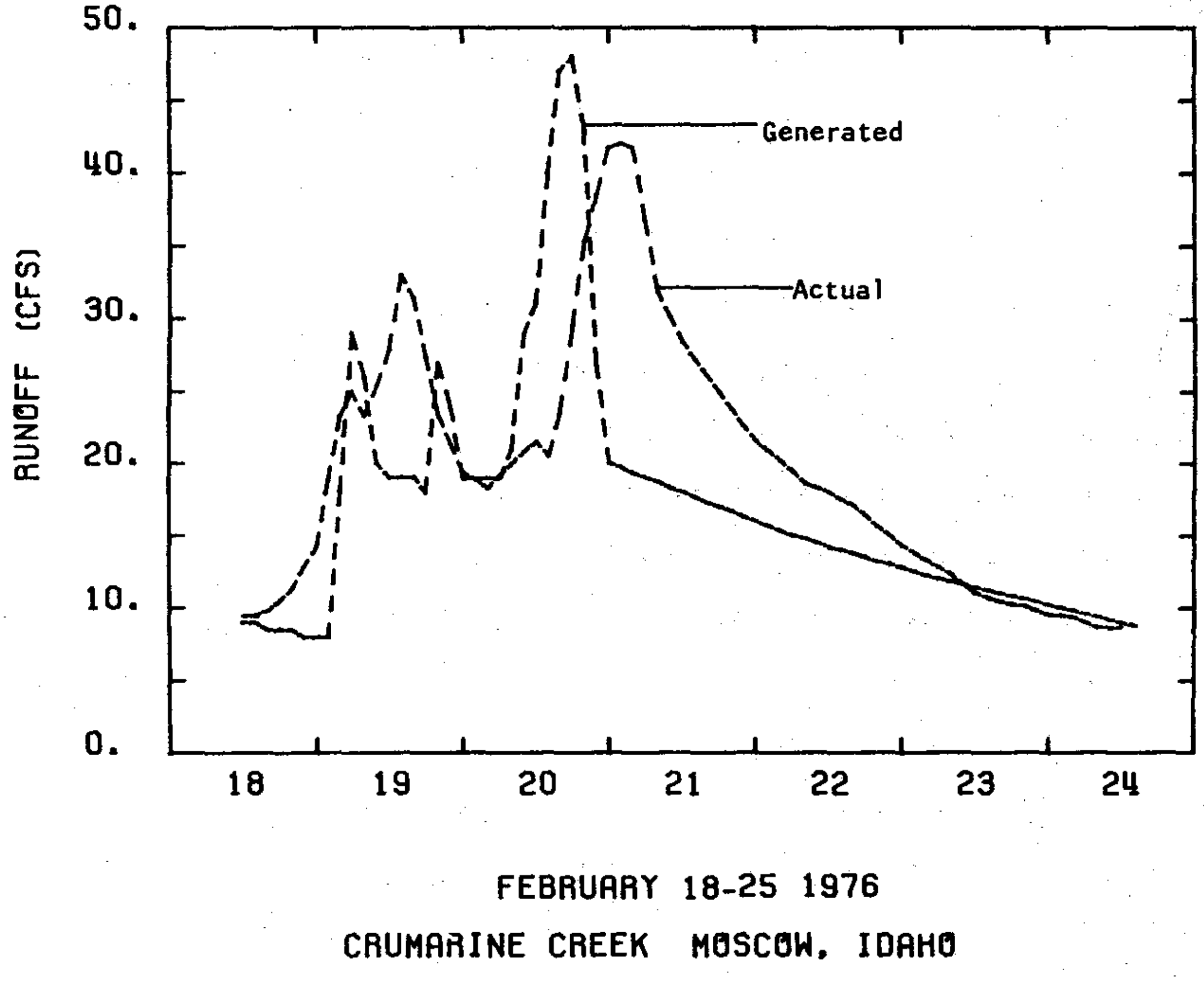


Figure 23. Actual and generated runoff hydrographs for February 18-25, 1982.

Table 41. HEC-1 results for February 18-25, 1982.

| Date | Time | Precipitation Inches | Temperature °F | Snowmelt Inches | Snow Loss Inches | Snow Excess Inches | Rain Loss Inches | Rain Excess Inches | Computed Runoff cfs | Actual Runoff cfs |
|---|---|---|---|---|---|---|---|---|---|---|
| 2/18 | 1200 | 0.00 | 39 | 0.05 | 0.05 | 0.00 | 0.00 | 0.00 | 9.00 | 9.45 |
| 2/18 | 1400 | 0.00 | 42 | 0.09 | 0.09 | 0.00 | 0.00 | 0.00 | 9.00 | 9.50 |
| 2/18 | 1600 | 0.00 | 42 | 0.09 | 0.09 | 0.00 | 0.00 | 0.00 | 8.50 | 9.76 |
| 2/18 | 1800 | 0.00 | 41 | 0.08 | 0.08 | 0.00 | 0.00 | 0.00 | 8.50 | 10.4 |
| 2/18 | 2000 | 0.10 | 40 | 0.06 | 0.06 | 0.00 | 0.10 | 0.00 | 8.50 | 11.3 |
| 2/18 | 2200 | 0.20 | 39 | 0.04 | 0.04 | 0.00 | 0.17 | 0.00 | 8.00 | 12.8 |
| 2/19 | 0000 | 0.10 | 38 | 0.04 | 0.04 | 0.00 | 0.08 | 0.00 | 8.00 | 14.2 |
| 2/19 | 0200 | 0.10 | 38 | 0.04 | 0.04 | 0.00 | 0.08 | 0.00 | 8.00 | 18.8 |
| 2/19 | 0400 | 0.20 | 38 | 0.04 | 0.04 | 0.00 | 0.17 | 0.00 | 18.0 | 23.3 |
| 2/19 | 0600 | 0.20 | 41 | 0.08 | 0.06 | 0.02 | 0.17 | 0.03 | 29.0 | 25.0 |
| 2/19 | 0800 | 0.10 | 44 | 0.11 | 0.11 | 0.00 | 0.10 | 0.00 | 26.0 | 23.3 |
| 2/19 | 1000 | 0.00 | 48 | 0.16 | 0.16 | 0.00 | 0.00 | 0.00 | 20.0 | 25.4 |
| 2/19 | 1200 | 0.00 | 50 | 0.19 | 0.18 | 0.00 | 0.00 | 0.00 | 19.0 | 27.8 |
| 2/19 | 1400 | 0.00 | 52 | 0.21 | 0.19 | 0.02 | 0.00 | 0.00 | 19.0 | 33.0 |
| 2/19 | 1600 | 0.00 | 49 | 0.17 | 0.17 | 0.00 | 0.00 | 0.00 | 19.0 | 31.5 |
| 2/19 | 1800 | 0.00 | 48 | 0.16 | 0.14 | 0.01 | 0.00 | 0.00 | 18.0 | 27.4 |
| 2/19 | 2000 | 0.10 | 47 | 0.15 | 0.11 | 0.04 | 0.08 | 0.02 | 27.0 | 23.3 |
| 2/19 | 2200 | 0.00 | 45 | 0.13 | 0.13 | 0.00 | 0.00 | 0.00 | 24.0 | 21.4 |
| 2/20 | 0000 | 0.00 | 43 | 0.10 | 0.10 | 0.00 | 0.00 | 0.00 | 20.0 | 19.4 |
| 2/20 | 0200 | 0.00 | 42 | 0.06 | 0.06 | 0.00 | 0.00 | 0.00 | 19.0 | 18.9 |
| 2/20 | 0400 | 0.00 | 41 | 0.05 | 0.05 | 0.00 | 0.00 | 0.00 | 19.0 | 18.3 |
| 2/20 | 0600 | 0.00 | 43 | 0.07 | 0.07 | 0.00 | 0.00 | 0.00 | 19.0 | 19.2 |
| 2/20 | 0800 | 0.10 | 45 | 0.08 | 0.06 | 0.02 | 0.08 | 0.02 | 21.0 | 20.0 |
| 2/20 | 1000 | 0.10 | 46 | 0.09 | 0.06 | 0.03 | 0.08 | 0.02 | 29.0 | 20.8 |
| 2/20 | 1200 | 0.00 | 48 | 0.11 | 0.10 | 0.00 | 0.00 | 0.00 | 31.0 | 21.5 |
| 2/20 | 1400 | 0.10 | 50 | 0.13 | 0.07 | 0.05 | 0.07 | 0.03 | 40.0 | 22.5 |
| 2/20 | 1600 | 0.00 | 52 | 0.14 | 0.11 | 0.03 | 0.00 | 0.00 | 47.0 | 23.5 |
| 2/20 | 1800 | 0.10 | 48 | 0.11 | 0.06 | 0.04 | 0.08 | 0.02 | 48.0 | 29.4 |
| 2/20 | 2000 | 0.10 | 44 | 0.07 | 0.05 | 0.02 | 0.09 | 0.01 | 43.0 | 35.3 |
| 2/20 | 2200 | 0.10 | 40 | 0.04 | 0.04 | 0.00 | 0.10 | 0.00 | 27.0 | 38.5 |
| 2/21 | 0000 | 0.30 | 35 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 20.0 | 41.7 |
| 2/21 | 0200 | 0.00 | 32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 19.7 | 42.0 |
| 2/21 | 0400 | 0.00 | 33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 19.3 | 41.7 |
| 2/21 | 0600 | 0.00 | 36 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 19.0 | 36.8 |
| 2/21 | 0800 | 0.00 | 39 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 18.7 | 31.9 |
| 2/21 | 1000 | 0.00 | 42 | 0.06 | 0.06 | 0.00 | 0.00 | 0.00 | 18.3 | 30.2 |
| 2/21 | 1200 | 0.00 | 45 | 0.08 | 0.08 | 0.00 | 0.00 | 0.00 | 18.0 | 28.4 |
| 2/21 | 1400 | 0.00 | 49 | 0.12 | 0.10 | 0.02 | 0.00 | 0.00 | 17.7 | 27.3 |
| 2/21 | 1600 | 0.00 | 47 | 0.10 | 0.09 | 0.01 | 0.00 | 0.00 | 17.3 | 26.2 |
| 2/21 | 1800 | 0.00 | 45 | 0.08 | 0.08 | 0.00 | 0.00 | 0.00 | 17.0 | 25.0 |
| 2/21 | 2000 | 0.10 | 41 | 0.05 | 0.04 | 0.01 | 0.09 | 0.01 | 16.7 | 23.8 |
| 2/21 | 2200 | 0.00 | 38 | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 16.3 | 22.7 |
| 2/22 | 0000 | 0.00 | 36 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 16.0 | 21.6 |
| 2/22 | 0200 | 0.00 | 32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.7 | 20.9 |
| 2/22 | 0400 | 0.00 | 28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.3 | 20.2 |
| 2/22 | 0600 | 0.00 | 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.0 | 19.4 |
| 2/22 | 0800 | 0.00 | 20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14.8 | 18.6 |
| 2/22 | 1000 | 0.00 | 16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14.5 | 18.3 |
| 2/22 | 1200 | 0.00 | 12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14.2 | 18.0 |
| 2/22 | 1400 | 0.00 | 13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14.0 | 17.5 |
| 2/22 | 1600 | 0.00 | 15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.8 | 17.1 |
| 2/22 | 1800 | 0.00 | 18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.5 | 16.4 |
| 2/22 | 2000 | 0.00 | 20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.2 | 15.6 |
| 2/22 | 2200 | 0.00 | 22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.0 | 15.0 |
| 2/23 | 0000 | 0.00 | 23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.8 | 14.3 |
| 2/23 | 0200 | 0.00 | 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.5 | 13.8 |
| 2/23 | 0400 | 0.00 | 25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.2 | 13.3 |
| 2/23 | 0600 | 0.00 | 26 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 12.0 | 12.8 |
| 2/23 | 0800 | 0.00 | 27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 11.8 | 12.3 |
| 2/23 | 1000 | 0.00 | 28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 11.6 | 11.6 |
| 2/23 | 1200 | 0.00 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 11.4 | 11.0 |
| 2/23 | 1400 | 0.00 | 32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 11.2 | 10.7 |
| 2/23 | 1600 | 0.00 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 11.0 | 10.4 |
| 2/23 | 1800 | 0.00 | 28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.8 | 10.2 |
| 2/23 | 2000 | 0.00 | 26 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.6 | 10.1 |
| 2/23 | 2200 | 0.00 | 24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.4 | 9.80 |
| 2/24 | 0000 | 0.00 | 23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.2 | 9.55 |
| 2/24 | 0200 | 0.00 | 22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.0 | 9.48 |
| 2/24 | 0400 | 0.00 | 22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.80 | 9.37 |
| 2/24 | 0600 | 0.00 | 23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.60 | 9.02 |
| 2/24 | 0800 | 0.00 | 25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.40 | 8.67 |
| 2/24 | 1000 | 0.00 | 28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.20 | 8.67 |
| 2/24 | 1200 | 0.00 | 32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.00 | 8.67 |
| 2/24 | 1400 | 0.00 | 35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.80 | 8.50 |
| 2/24 | 1600 | 0.00 | 34 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.60 | 8.43 |
| 2/24 | 1800 | 0.00 | 33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.40 | 8.09 |
| 2/24 | 2000 | 0.00 | 32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.20 | 7.88 |
| 2/24 | 2200 | 0.00 | 31 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.10 | 7.74 |
| 2/25 | 0000 | 0.00 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.00 | 7.61 |
| 2/25 | 0200 | 0.00 | 29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.90 | 7.47 |
| 2/25 | 0400 | 0.00 | 28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.80 | 7.35 |
| 2/25 | 0600 | 0.00 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.70 | 7.22 |
| 2/25 | 0800 | 0.00 | 33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.60 | 7.08 |
| 2/25 | 1000 | 0.00 | 35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.50 | 7.08 |
| 2/25 | 1200 | 0.00 | 37 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 7.40 | 7.08 |
| Total | | 2.00 | | 3.50 | 3.16 | 0.31 | 1.28 | 0.23 | | |

Table 42. Results of rain on snow separated hydrograph.

| Event | Rain and Snowmelt inches* | Rain and Snowmelt Excess inches* | Rain and Snowmelt Loss inches* | Total Runoff inches | Direct Runoff inches | Baseflow inches |
|---|---|---|---|---|---|---|
| Feb 18-25, 1982 | 5.50 | 0.54 | 4.44 | 1.434 | 0.552 | 0.822 |

*Obtained from HEC-1 results

Although the hydrographs peaked at different times, the peak discharge values were similar enough to make conclusions about a rain on snow event. As seen from the results in Table 41, snowmelt and rain losses were high. These results were compared to the hydrograph separation values in Table 42. HEC-1 determined 0.31 inches of the 3.50 inches of snowmelt and 0.23 inches of the 2.00 inches of precipitation accumulated as precipitation excess. A total of 0.54 inches of precipitation and snowmelt excess was calculated by HEC-1, which matched close to the 0.552 inches of direct runoff obtained from the hydrograph separation. Of the 4.44 inches of snowmelt and rainfall lost, 0.822 inches eventually became baseflow, or 18 percent. Baseflow comprised 60 percent of the total runoff.

Summary of HEC-1 results

Table 43. Summary of HEC-1 results.

| Date | Event | Percent Losses as Baseflow |
|---|---|---|
| July 13, 1975 | Summer Rainfall | 1.6 |
| Aug 22, 1978 | Summer Rainfall | 0.4 |
| Mar 10, 1976 | Snowmelt | 12.0 |
| Mar 16, 1985 | Snowmelt | 5.0 |
| Feb 18, 1982 | Rain on | 18.0 |

The results from HEC-1 gave some indication of how precipitation and snowmelt are disposed of on the watershed. During a summer rainfall event most of the precipitation is lost to infiltration, interception and depression storage, with infiltration being the biggest loss. Also, the amount of rainfall infiltrated is held between soil pores and the amount returned to the stream as baseflow is negligible. Losses are higher for a snowmelt event than for a summer rainfall event but a higher percentage of the infiltrated snowmelt eventually becomes baseflow in a snowmelt event (Table 43). Although infiltration rates are higher in the summer than in the spring a smaller percentage of infiltrated precipitation is held in the soil in the spring. The soil is more saturated in the spring than in the summer. This allows water to percolate more easily to the underlying shallow aquifer in spite of the fact that infiltration occurs at a slower rate. Once the water reaches the shallow aquifer it is then released to the stream as baseflow. This process accounts for the higher values and percentage of baseflow during spring runoff events than in summer runoff events.

# CONCLUSION

By use of a water balance equation it has been shown that Crumarine Creek does experience deep percolation, with an annual average of 7.5 inches based on data from 1969 to 1973 water years. Of the total annual precipitation entering the watershed, 30 percent was lost to runoff, 35 percent was lost to evapotranspiration, 15 percent was lost to interception and sublimation and 20 percent was lost to deep percolation. May had the largest amount of deep percolation, which is mostly influenced by the large amount of snowmelt. The months of October through March experience little, if any, deep percolation. The deep percolation values for these months are negative, which indicates that water is temporarily stored below the root zone and is later released as baseflow into the stream or permanently leaves the watershed. Also, large negative deep percolation values (greater than -1.5 inches) can be attributed to error. The amount of deep percolation on Crumarine Creek that eventually reaches the Moscow aquifer is unknown.

Through hydrograph separation of selected events, it was observed that baseflow accounted for 80 percent or more of the total runoff for runoff events in March, April and May. Water released from snow storage was the factor influencing this high baseflow percentage. As the snow melts it percolates through the ground to the underlying shallow aquifer. After the infiltrated water enters the shallow aquifer it is then released to the stream as baseflow. This movement of snowmelt was examined with the use of HEC-1 and hydrograph separation. It was found that a higher percentage of snowmelt and precipitation losses comprised baseflow during snowmelt events than during a summer rainfall event. Precipitation that is lost during summer rainfall events contributes negligible amounts of water to baseflow. Most of the precipitation lost during the summer to infiltration is soon lost to evapotranspiration, as seen by the water balance results. The results from HEC-1 showed that infiltration rates are much slower during a snowmelt event than during a summer rainfall event but more of the infiltrating precipitation is transmitted to the underlying shallow aquifer during the a snowmelt event than in a summer event. A portion of the infiltrating water that finally reaches the shallow aquifer during a snowmelt event is discharged into Crumarine Creek as baseflow. The HEC-1 results helped illustrate the movement of precipitation on Crumarine Creek watershed and explain the reason for high amounts of baseflow during late winter and spring runoff events.

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# APPENDIX A

## Runoff Equations

Equations used to Generate Runoff

The following equations were developed by computing regressions on data from Missouri Flat Creek and Crumarine Creek. Data from 1959 to 1979 were used to develop the equations with Missouri Flat Creek as the independent variable and Crumarine Creek as the dependent variable. The following equations were used to generate daily flows for Crumarine Creek.

CC=Crumarine Creek

MF=Missouri Flat Creek

Oct

$$CC=0.1886+0.0471(MF)+0.0393(MF^2)-0.0101(MF^3)$$

$r^2=0.2162$

Nov

$$CC=0.2222+0.0528(MF)-2.09\times10^{-4}(MF^2)$$

$r^2=0.6474$

Dec

$$CC=0.1269+0.1454(MF)-3.086\times10^{-3}(MF^2)+2.353\times10^{-5}(MF^3)-1.835\times10-8(MF^4)$$

$r^2=0.4170$

Jan

$$CC=0.5248+0.0894(MF)-4.692\times10^{-4}(MF^2)+8.538\times10^{-7}(MF^3)-4.704\times10^{-10}(MF^4)$$

$r^2=0.3473$

Feb

$$CC=0.6437+0.0814(MF)-3.653\times10^{-4}(MF^2)+6.002\times10^{-7}(MF^3)$$

$r^2=0.5817$

<u>Mar</u>

$$CC=0.8151+0.2199(MF)-2.751X10^{-3}(MF^2)+1.339X10^{-5}(MF^3)-2.127X10^{-8}(MF^4)$$
$r^2=0.1981$

<u>Apr</u>

$$CC=0.9059+0.8816(MF)-0.0355(MF^2)+5.807X10^{-4}(MF^3)-3.081X10^{-6}(MF^4)$$
$r^2=0.4378$

<u>May</u>

$$CC=0.7876+1.765(MF)-0.0967(MF^2)+1.952X10^{-3}(MF^3)-1.237X10$$
$$-1.237X10^{-5}(MF^4)$$
$r^2=0.4252$

<u>June</u>

$$CC=0.0580+1.819(MF)-0.1769(MF^2)+6.271X10^{-3}(MF^3)-7.060X10^{-5}(MF^4)$$
$r^2=0.5386$

<u>Jul</u>

$r^2=0.0000$

<u>Aug</u>

$r^2=0.0000$

<u>Sep</u>

$$CC=0.1743+0.0138(MF)+0.1371(MF^2)-0.0889(MF^3)+0.0152(MF^4)$$
$r^2=0.1642$

# APPENDIX B

## Net Radiation and Evapotranspiration Calculations

Calculations for Net Radiation

Net radiation was calculated by a method proposed by Schwab and others (1981).

$$R_n=(1-a)R_s-R_b$$

$R_n$=net radiation, cal/cm$^2$-day
a=albedo or short wave reflectance
$R_s$=incoming solar radiation, cal/cm$^2$-day
$R_b$=net outgoing longwave radiation on a clear day, cal/cm$^2$-day

Solar radiation values were obtained from a publication by Satterlund and Means (1979) for the Pacific Northwest (Table 44).

Table 44. Solar radiation ($R_s$), cal/cm$^2$-day.

| Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|
| 121 | 205 | 304 | 462 | 558 | 653 |
| Jul | Aug | Sep | Oct | Nov | Dec |
| 699 | 562 | 410 | 245 | 146 | 96 |

The long wave radiation was calculated by a formula presented by Schwab and others (1981).

$$R_b = \sigma T_a^4 (0.56 - 0.08\sqrt{e_a})(0.10 + 0.9S)$$

$R_b$=net outgoing long wave radiation on a clear day

$\sigma$=Stefan-Boltaman constant (11.71X10$^{-8}$ cal/cm$^2$-day)

$T_a$=air temperature, degrees Kelvin

$e_a$=actual vapor pressure

S=ratio of actual to possible hours of sunshine (obtained from Schwab and others, 1981)

Net outgoing long wave radiation and ratio of actual to possible hours of sunshine are listed in Table 45.

Table 45. Black body radiation ($R_b$), cal/cm$^2$-day.

| Month | S | $R_b$ |
|---|---|---|
| Jan | 0.38 | 111 |
| Feb | 0.43 | 124 |
| Mar | 0.50 | 139 |
| Apr | 0.57 | 156 |
| May | 0.62 | 174 |
| Jun | 0.66 | 174 |
| Jul | 0.64 | 172 |
| Aug | 0.59 | 168 |
| Sep | 0.52 | 149 |
| Oct | 0.45 | 127 |
| Nov | 0.40 | 114 |
| Dec | 0.36 | 106 |

An albedo of 0.14 was suggested by Lee (1980) for a coniferous forest. The net radiation values in Table 46 were then determined from the first equation.

Table 46. Net radiation ($cal/cm^2$-day).

| Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|
| -7 | 52 | 122 | 241 | 306 | 388 |
| **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
| 430 | 315 | 204 | 84 | 12 | -23 |

Calculations for Evapotranspiration

Using the Shuttleworth and Calder (1979) form of the Priestley-Taylor equation the following ET values were calculated.

$$ET = \frac{(0.72 \pm 0.07)}{L} \frac{(R_n - G)}{(1 + \gamma/\Delta)}$$

ET=actual ET, cm/day
$\alpha = 0.72 \pm 0.07$
$\Delta$=slope of saturation vapor pressure curve, mb/K
$\gamma$=psychrometric constant, 0.66 mb/K
L=latent heat of vaporization, 590 cal/g
$R_n$=net radiation, cal/cm2-day
G=soil heat flux=(assumed=0)

| Month | α | ET, in |
|---|---|---|
| Oct | 0.69 | 0.5 |
| Nov | 0.73 | 0.1 |
| Dec | 0.76 | 0.0 |
| Jan | 0.79 | 0.0 |
| Feb | 0.79 | 0.3 |
| Mar | 0.79 | 0.9 |
| Apr | 0.78 | 1.8 |
| May | 0.76 | 2.8 |
| Jun | 0.73 | 3.4 |
| Jul | 0.70 | 4.2 |
| Aug | 0.67 | 3.0 |
| Sep | 0.65 | 1.6 |
| Annual | | 13.1 |

# APPENDIX C

## Climatological Data

Climatological Data

Mean monthly temperatures were determined for the watershed mean elevation of 3670 feet by lapsing temperatures from the Nutterville station at 3040 feet. A lapse rate of 3 °F/1000 feet was used (Linsley and others, 1982). Relative humidity was determined by lapsing temperatures from the Thompson site at 2800 feet to the mean elevation of 3670 feet. Relative humidity at Thompson for 1969 to 1973 were recorded by Davis (1971) and Druffel (1973). The mixing ratio at Thompson could be determined and was assumed to remain constant at a higher elevation of 3670 feet. Knowing the mixing ratio and temperature at the mean elevation, the relative humidity could be calculated.

| Month | Temperature °F | Relative Humidity Percent |
|---|---|---|
| Jan | 24.0 | 86.0 |
| Feb | 29.9 | 83.0 |
| Mar | 32.3 | 77.0 |
| Apr | 39.0 | 72.0 |
| May | 47.5 | 64.0 |
| Jun | 51.4 | 62.0 |
| Jul | 59.5 | 59.0 |
| Aug | 63.7 | 50.0 |
| Sep | 49.4 | 57.0 |
| Oct | 41.0 | 70.0 |
| Nov | 31.8 | 82.0 |
| Dec | 24.3 | 85.0 |

# APPENDIX D

## Hydrograph Separation Results

## Hydrograph Separation Results

The hydrograph separation results are as follows:

T.R.=total runoff in inches
%B.F.=percent baseflow of total runoff
%D.R.=percent direct runoff of total runoff
%I.F.=percent interflow of total runoff
%O.F.=percent overland flow of total runoff

### Water Year 1979-1980

| Date | T.R. | %B.F. | %D.R. | %I.F. | %O.F. |
|---|---|---|---|---|---|
| 01/13 | 0.0355 | 58 | 42 | 38 | 4 |
| 02/16 | 0.1061 | 50 | 50 | 44 | 6 |
| 02/28 | 0.0952 | 83 | 17 | 16 | 1 |
| 03/11 | 0.0756 | 80 | 20 | 19 | 1 |
| 03/15 | 0.0842 | 86 | 14 | 13 | 1 |
| 04/09 | 0.0670 | 82 | 18 | 16 | 2 |
| 04/28 | 0.0644 | 90 | 10 | 9 | 1 |
| 05/15 | 0.0488 | 76 | 23 | 19 | 4 |
| 05/25 | 0.3150 | 65 | 35 | 29 | 6 |
| 06/01 | 0.1378 | 87 | 13 | 12 | 1 |
| 06/22 | 0.0278 | 91 | 9 | 9 | 0 |
| 08/18 | 0.0121 | 83 | 17 | 17 | 0 |

### Water Year 1980-1981

| Date | T.R. | %B.F. | %D.R. | %I.F. | %O.F. |
|---|---|---|---|---|---|
| 10/13 | 0.0073 | 85 | 15 | 15 | 0 |
| 11/06 | 0.0187 | 56 | 44 | 43 | 1 |
| 11/21 | 0.0097 | 53 | 47 | 44 | 3 |
| 12/20 | 0.0413 | 39 | 61 | 51 | 10 |
| 01/23 | 0.0479 | 46 | 54 | 41 | 13 |
| 02/18 | 0.2523 | 91 | 9 | 8 | 1 |
| 03/16 | 0.0316 | 72 | 28 | 24 | 4 |
| 05/25 | 0.0817 | 84 | 16 | 16 | 0 |
| 06/05 | 0.0369 | 69 | 31 | 30 | 1 |
| 06/18 | 0.1102 | 81 | 19 | 19 | 0 |
| 07/06 | 0.0433 | 75 | 25 | 24 | 1 |

## Water Year 1981-1982

| Date | T.R. | %B.F. | %D.R. | %I.F. | %O.F. |
|---|---|---|---|---|---|
| 10/07 | 0.0062 | 58 | 42 | 39 | 3 |
| 11/12 | 0.0061 | 62 | 38 | 38 | 0 |
| 11/16 | 0.0119 | 55 | 45 | 43 | 2 |
| 12/02 | 0.0106 | 46 | 54 | 46 | 8 |
| 12/05 | 0.0159 | 44 | 56 | 53 | 3 |
| 01/16 | 0.0103 | 61 | 39 | 38 | 1 |
| 01/23 | 0.0160 | 96 | 4 | 4 | 0 |
| 02/18 | 0.4636 | 58 | 42 | 32 | 10 |
| 02/28 | 0.1568 | 83 | 17 | 16 | 1 |
| 04/06 | 0.0635 | 84 | 16 | 15 | 1 |
| 05/27 | 0.0267 | 90 | 10 | 8 | 2 |
| 07/01 | 0.0051 | 72 | 28 | 24 | 4 |
| 07/15 | 0.0064 | 78 | 22 | 22 | 0 |
| 08/03 | 0.0045 | 71 | 29 | 29 | 0 |
| 08/10 | 0.0065 | 74 | 26 | 25 | 1 |
| 09/11 | 0.0092 | 58 | 42 | 38 | 4 |
| 09/25 | 0.0064 | 52 | 48 | 45 | 3 |

## Water Year 1982-1983

| Date | T.R. | %B.F. | %D.R. | %I.F. | %O.F. |
|---|---|---|---|---|---|
| 10/06 | 0.0062 | 71 | 29 | 29 | 0 |
| 10/26 | 0.0049 | 61 | 39 | 37 | 2 |
| 11/05 | 0.0089 | 70 | 30 | 30 | 0 |
| 12/03 | 0.0303 | 57 | 43 | 41 | 2 |
| 12/21 | 0.0347 | 74 | 26 | 25 | 1 |
| 01/26 | 0.0468 | 67 | 33 | 32 | 1 |
| 02/11 | 0.1193 | 51 | 49 | 47 | 2 |
| 02/18 | 0.3617 | 77 | 23 | 20 | 3 |
| 03/29 | 0.1573 | 76 | 24 | 22 | 2 |
| 04/02 | 0.1086 | 94 | 6 | 5 | 1 |
| 05/05 | 0.1160 | 82 | 18 | 15 | 3 |
| 06/10 | 0.0266 | 70 | 30 | 25 | 5 |
| 06/17 | 0.0117 | 68 | 32 | 27 | 5 |
| 07/20 | 0.0087 | 52 | 48 | 38 | 10 |
| 08/25 | 0.0076 | 71 | 29 | 29 | 0 |
| 09/10 | 0.0103 | 70 | 30 | 30 | 0 |

Water Year 1983-1984

| Date | T.R. | %B.F. | %D.R. | %I.F. | %O.F. |
|---|---|---|---|---|---|
| 10/22 | 0.0095 | 68 | 32 | 29 | 3 |
| 11/06 | 0.0095 | 50 | 50 | 38 | 12 |
| 12/09 | 0.0262 | 48 | 52 | 49 | 3 |
| 01/24 | 0.1024 | 50 | 50 | 42 | 8 |
| 02/12 | 0.3222 | 62 | 38 | 35 | 3 |
| 03/01 | 0.0969 | 75 | 25 | 23 | 2 |
| 04/05 | 0.0902 | 97 | 3 | 3 | 0 |
| 05/01 | 0.0773 | 94 | 6 | 6 | 0 |
| 05/23 | 0.1031 | 90 | 10 | 10 | 0 |
| 06/05 | 0.0397 | 83 | 17 | 14 | 3 |
| 06/20 | 0.0688 | 84 | 16 | 15 | 1 |
| 07/29 | 0.0072 | 50 | 50 | 36 | 14 |
| 08/31 | 0.0039 | 59 | 41 | 33 | 8 |
| 09/22 | 0.0065 | 85 | 15 | 15 | 0 |

Water Year 1984-1985

| Date | T.R. | %B.F. | %D.R. | %I.F. | %O.F. |
|---|---|---|---|---|---|
| 10/11 | 0.0061 | 72 | 28 | 26 | 2 |
| 11/02 | 0.0155 | 57 | 43 | 41 | 2 |
| 11/23 | 0.0111 | 74 | 26 | 25 | 1 |
| 12/09 | 0.0119 | 68 | 32 | 32 | 0 |