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FORECASTING RAINFALL AND SNOWMELT FLOODS ON UPPER MIDWEST WATERSHEDS

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PREFACE

The study reported on herein was sponsored by the Office of Water Research and Technology under OWRR Matching Grant 14-31-0001-3902, B077 Minn, with C. Edward Bowers as Chief Investigator.

The objective of the study was the application and evaluation of mathematical simulation models relative to snowmelt floods in large watersheds in the Upper Midwest. The SSARR and HEC-1 models were fitted to 15 watersheds of the 16,200-square-mile Minnesota River Basin. The Kentucky model was fitted to one 129-square-mile watershed, and the new NWSRFS was fitted to the 1100-square-mile Le Sueur watershed for summer runoff conditions. The snowmelt routines of the latter model were received too late for proper implementation.

The SSARR model simulated snowmelt floods very well for the selected years of 1965, 1967, and 1969. As this model had no optimizing routines, it was difficult to fit to the watersheds, but after use with several years' data, fitting proceeded at a fairly rapid pace. The model shows considerable promise for this area and should be operated with data for other years. It is of the continuous synthesis type.

The HEC-1 model is equipped with optimizing routines and was relatively easy to fit to the watersheds. However, it was prepared for one primary rainfall event and has no procedure for soil moisture depletion between rains. It also is a very useful tool for snowmelt flood forecasting, but requires an independent analysis of soil moisture and runoff conditions at the time of snowmelt.

The Kentucky Fortran version of the Stanford Watershed Model was tested on only one watershed with only moderate success. Further testing would be necessary for a final evaluation.

The new National Weather Service model, NWSRFS, is based in part on the Stanford Watershed Model with time increments selected for large watersheds. Time limitations permitted the fitting of this model to only the Le Sueur watershed for snow-free periods. Its performance was excellent for those conditions, and it deserves further study in this area. It is a continuous synthesis model requiring large amounts of data and involving data input and manipulation on tape. This makes it somewhat difficult to use unless the user is familiar with such methods.

One Ph.D. thesis was supported in part by the project; it resulted in the development of a parametric analysis of the volume of spring runoff.

The cooperation of numerous organizations which provided computer programs and other assistance is gratefully acknowledged. The SSARR model was provided by the Corps of Engineers and the National Weather Service, the HEC-1 model by the Hydrologic Engineering Center of the Corps of Engineers, the Kentucky model by Dr. Douglas James, and NWSRFS by the Hydrologic Research Laboratory of the National Weather Service. Extensive data and associated maps on the water content of snow in Minnesota were provided by Joseph H. Strub, Meteorologist in Charge of the NOAA National Weather Service office in Minneapolis and river hydrologist, and the District Engineer, St. Paul District, U.S. Army Corps of Engineers. Dr. Arthur Pabst of the Hydrologic Engineering Center, Corps of Engineers, made a major contribution to the first year of this study while employed at St. Anthony Falls Hydraulic Laboratory. Special thanks are due Dr. Alfred Berner of the Madelia Wildlife Research and Management Center and Mr. Cliff Tussberg of the U.S. Army Corps of Engineers at Winton, Minnesota, for measurement of soil temperatures.

LIST OF TABLES

FORECASTING RAINFALL AND SNOWMELT FLOODS ON UPPER MIDWEST WATERSHEDS

I. INTRODUCTION

The objective of the studies reported on herein was the investigation of methods and mathematical simulation models associated with flood forecasting with particular reference to snowmelt floods in the Upper Midwest. It involved (1) procurement of data on streamflow, precipitation, air temperature, dewpoint, solar radiation, wind, and water content of snow on tape for use as input to computer programs; (2) procurement and use of some existing mathematical models of possible use in flood forecast studies; (3) operation of the models for some of the most severe floods of record; (4) modification of some features of the models; and (5) evaluation of some of the problems associated with flood forecasting in the Upper Midwest.

A. Data Acquisition

As part of this and a preceding project, meteorological and hydrological data were obtained on tape from the NOAA National Climatic Center, Asheville, North Carolina, and the U.S. Geological Survey, Washington, D.C. The data included the following:

1. Daily discharge data for 122 USGS gaging stations in Minnesota and adjacent states for the complete period of record.
2. Daily surface observations (card deck 486) on magnetic tape for the state of Minnesota for the period October 1963 through December 1971.
3. Hourly precipitation data (card deck 488) on magnetic tape for the state of Minnesota for the period January 1960 through June 1971.
4. Daily solar radiation data (card deck 480) for St. Cloud, Minnesota, for the periods July 1954 through April 1962 and June 1962 through December 1970 on tape.
5. Surface three-hourly data on tape in TDF 14 format for Minneapolis, Rochester, St. Cloud, Fargo, Sioux Falls, Duluth, and LaCrosse for the period January 1959 through December 1971.

6. Summary of day (card deck 345) for Alexandria, Duluth, Hibbing, Minneapolis, Redwood Falls, Rochester, St. Cloud, and Wilmar (periods vary, but are generally from 1948 through 1971).

The preceding data were obtained on 1/2-inch-wide, 2400-ft-long, 7-track, 556 BPI magnetic tape to be compatible with the CDC 6600 computing system. The NOAA data other than TDF 14 are in card image format, even parity, blocked ten card images per record, in chronological sort and may or may not have a beginning tape mark. (Ten logical records make one physical record on tape.) The USGS gaging station data required three 2400 ft tapes and the NOAA data required twenty-five 2400 ft tapes.

Water-content-of-snow data were obtained from the NOAA National Weather Service, Minneapolis, Minnesota, and the St. Paul district of the U.S. Army Corps of Engineers for 14 years in the interval between 1948 and 1971. (Maps are not available for years with low snowfall.) One map for each year (about March 15) was coded with water content of snow on a ten-minute-by-15-minute grid system and stored on tape.

A number of the models of interest in this study are of the continuous synthesis type. A typical run may use the complete data for one year, and one model has a recommended calibration period of 50 months. Thus the input of precipitation, temperature, and streamflow, and, for some models, dewpoint, solar radiation, and wind, requires a large amount of data. This necessitates the use of data stored on tape.

The USGS daily flow data required some modification before they could be used in the studies, and thus the tapes had to be recopied. In some instances, data were punched on cards for input to the models. However, when many runs were anticipated, the data and the model were stored on a random-access disk pack [18]*.

B. Mathematical Models

A review of available simulation models and a preliminary application in an earlier study suggested the following models for investigation:

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*Numbers in brackets refer to list of references on pages 44-47.

1. The Stanford Watershed Model IV [9].
2. A Fortran version of the Stanford Watershed Model III, translated from Balgol to Fortran by James [11] at the University of Kentucky and hereafter referred to as the Kentucky model.
3. The SSARR model (Streamflow Synthesis and Reservoir Regulation) [4,26,32] developed in a joint effort by the National Weather Service and the Corps of Engineers at Portland, Oregon.
4. The HEC-1 program [30] developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers at Davis, California.
5. During the course of the study the National Weather Service released the NWSRFS (National Weather Service River Forecast System), and it was added to the list. The initial release [17] did not include the snowmelt subroutines, and so the model was operated only for the snow-free period (April through October in Minnesota). The snowmelt subroutines were subsequently released [2] and were added to the main system, but time did not permit a proper evaluation.

In addition to the above, it would have been of interest to operate the following:

1. National Weather Service API model [28].
2. Ohio Fortran version of the Stanford model [23,24,25].
3. Sacramento model [7] developed in a cooperative effort by the National Weather Service and the state of California at Sacramento.
4. Texas model [10].

However, time and funds did not permit the use of the latter models.

C. Flood Analysis in the Upper Midwest

A number of the models listed above were developed for areas of high relief, such as the Columbia Basin. These areas require the use of methods such as the elevation band approach, in which the snowmelt computations must account for a variation of temperatures and snowmelt in elevation bands, usually in 1000-ft increments. In contrast, the Upper Midwest is quite flat; for example, the 16,200-square-mile Minnesota River basin used in these studies has only a 1300-ft variation in elevation. However, it does have a variation of 225 miles in latitude and 210 miles in longitude, which results in significant variations in climate and weather.

Figure 1 shows the Minnesota River basin with reference to the state boundaries of Minnesota. Most of the basin is characterized by glacial drift up to 500 ft thick overlying the bedrock. The bedrock generally consists of Cretaceous and Paleozoic sedimentary rock overlying Precambian granite.

The headwaters of the river are in the area of the South Dakota-Minnesota border. The river flows southeast for about 200 miles to the city of Mankato and then northeast for 100 miles to the junction of the Minnesota and Mississippi rivers at the Twin Cities of Minneapolis and St. Paul. It has a well-defined drainage pattern involving about 14 primary tributaries with areas on the order of 1000 to 2500 square miles. Surface elevations range from 2000 ft in the upland areas to 690 ft at the junction with the Mississippi River. The main stem slope averages about 1.4 ft per mile.

The Minnesota River Basin was selected for use in this study for the following reasons:

1. The river has a history of severe floods with major damage to many towns and villages along the main stream. Severe spring flooding occurred in 1952, 1965, and 1969. The flood of 1965 was 40 to 50 per cent higher than the previous flood of record for many locations in the basin. Damage in 1965 and 1969 totaled $300 million.

2. The U.S. Geological Survey, in cooperation with the Minnesota Department of Natural Resources, maintains six gaging stations on the main stem of the river and 11 on primary tributaries. These were invaluable in fitting mathematical models to the watersheds making up the basin. Actually, the basin was divided into 15 sub-areas, 11 of which had gaging stations.

3. There are 45 weather stations in or near the basin maintained or reported by the National Weather Service. These are essential to the use of mathematical flood forecast models.

Figure 2 shows the distribution of gaging and weather stations in the Minnesota River basin. The numbers 1 through 15 in Fig. 2 refer to the watersheds making up the Minnesota River Basin, whose names and areas are as follows:

1.	Little Minnesota River watershed	(447 sq mi)
2.	Whetstone River watershed	(389 sq mi)
3.	Ungaged area tributary to Big Stone Lake	(324 sq mi)
4.	Yellow Bank River watershed	(398 sq mi)
5.	Pomme de Terre River watershed	(905 sq mi)
6.	Lac qui Parle River watershed	(983 sq mi)
7.	Chippewa River watershed	(1870 sq mi)
8.	Ungaged area between Big Stone Lake and Montevideo	(864 sq mi)
9.	Yellow Medicine River watershed	(653 sq mi)
10.	Redwood River watershed	(697 sq mi)
11.	Cottonwood River watershed	(1280 sq mi)
12.	Blue Earth River watershed	(2430 sq mi)
13.	Le Sueur River watershed	(1100 sq mi)
14.	Collection of small streams between Montevideo and Mankato	(2560 sq mi)
15.	Collection of small streams between Mankato and Jordan	(1300 sq mi)
	TOTAL:	16,200 sq mi

Drainage areas above the main stem gaging stations are

A.	Minnesota River at Ortonville, Minnesota	(1160 sq mi)
B.	Minnesota River near Lac qui Parle, Minnesota	(4050 sq mi)
C.	Minnesota River above Montevideo, Minnesota	(6180 sq mi)
D.	Minnesota River at New Ulm, Minnesota	(9536 sq mi)
E.	Minnesota River at Mankato, Minnesota	(14900 sq mi)
F.	Minnesota River at Jordan, Minnesota	(16200 sq mi)

The records on the gaging stations vary in length up to 71 years for the main stem station at Mankato.

D. Soil Temperatures and Frost Depth

The largest flood of record for many stations in the Minnesota River basin (1965) was attributed in part to deep frost and a coating of ice beneath the snow. Frost depth and density are not directly included in simulation models, but their effect is reflected in the values of other parameters, such as infiltration rates. To assist in an understanding of the possible correlation between frost depth and factors such as snow depth, vegetative cover, and flood runoff, two soil temperature installations were made in the Minnesota River basin. Earlier work by Baker [5] at the University of Minnesota was used as a guide to these installations. As these units were to be temporary and useful primarily as a guide for possible future studies, they were made of inexpensive thermistors installed in wooden rods which were inserted into holes drilled in the ground. Soil was tamped around each rod and the connecting wires were placed in a shallow trench leading to a readout post about 15 ft from the thermistor rod. Thermistors were located at 5, 10, 20, 40, 80, 120, 160, and 200 cm (80 in.) below the ground surface. One unit was placed in a low dike adjacent to a farm field near Watson, Minnesota; this was near the center of the upstream half of the basin. The other was installed in a game refuge adjacent to a farm field near St. James, Minnesota, near the center of the downstream half of the basin. Additional details are given in Ref. [18].

II. MATHEMATICAL MODELS

A. The SSARR Model

The National Weather Service, Portland District, and the North Pacific Division of the U.S. Army Corps of Engineers made available a CDC compatible version of their Streamflow Synthesis and Reservoir Regulation, or SSARR, model [4,26,32] for an earlier study. The SSARR model is a continuous synthesis simulation model with a soil moisture accounting system and a runoff analysis based on a triple set of conceptual reservoir units. In this study the model was fitted to each of 15 sub-areas or watersheds and then routed along the mainstream by means of the storage routing method. It uses precipitation and temperature as input. At temperatures above freezing, precipitation is treated as rain; with temperatures below freezing, it is treated as snow accumulation which subsequently melts.

Figure 3 is a flow chart of the model. After the total amount of water available for runoff is determined, the water is separated into two amounts, one that will appear as runoff and one that will be lost to the atmosphere due to evapotranspiration. The separation for each day's moisture supply is based on the Soil Moisture Index (SMI), which is an indicator of the current moisture condition of the soil. A high SMI value would indicate a wet soil and high runoff. The SMI-runoff relationship is stored as a table; different tables or curves can be stored for each watershed and different tables can be used for winter (snow basin) and summer (rain basin). Figure 4 illustrates typical curves developed by trial and error for parts of the Minnesota basin.

The SSARR model uses a synthetic reservoir to simulate the movement of water to the outlet. First the water is divided into three components:

1. Water which travels relatively rapidly to the outlet--termed the surface flow;
2. Water which travels at a slower rate--termed the subsurface flow; and
3. Water which has a relatively long time of flow to the outlet--termed baseflow.

The split between these various phases is governed by functions input as tables by the user. The portion of the total runoff which becomes baseflow depends on a baseflow infiltration index (BII). When this index is low, the baseflow is a large portion of the total runoff. An example of this function is given in Fig. 5. The remaining volume, direct runoff, is then divided into surface and subsurface components depending on the volume of direct runoff. Figure 6 shows the surface runoff as a function of the total surface-subsurface runoff.

After the volumes of water have been determined for the three components, they must be transformed into flow at the outlet. Three synthetic reservoir systems are set up, each corresponding to one of the three phases. To transform the volume of surface runoff into a stream hydrograph, the volume is passed through a conceptual reservoir system that has a relatively short time delay. This component is characterized by a relatively short time to peak and steep rising and falling limbs. The subsurface flow and baseflow are handled similarly using synthetic reservoir systems which yield relatively longer times to peak and flatter rising and falling limbs. The total response at the outlet, then, is the sum of the surface, subsurface, and baseflow hydrographs.

The computations described above are made for each computation interval for the total duration of the simulation. The computation interval can be set by the user depending on the sizes of the watersheds and other considerations. A similar analysis is made for each sub-watershed in a study area. Sub-watershed flows can then be routed downstream and combined to produce a composite runoff hydrograph for a large area.

Several options are available for controlling the routing of flow through reservoirs. The results at any point in the system can be compared with observed flows, if available, and plotted for a visual display.

Figure 7 illustrates the input tables pertaining to SMI, BII, S-SS, and ETI. Each table is identified by a four-digit number such as 8005. There are usually two numbers for each point; this is indicated by a 2 following the four-digit table number. Thus the first S-SS table has the following: CT01, 8005, 2; 0,0; .010, .00672; .033, .023; .100, .09; 999.1, 999.05. These points (separated by semi-colons) can be compared with the solid line of Fig. 6. Additional graphs of tables are included in Appendix A along with information on the curve numbers used for each watershed.

1. Showmelt Options

The functions available to the user for melting snow are the degree-day method and an energy budget method. The degree-day method is based on the following equation:

$$\text{Melt} = \text{COEF} \times (\text{TEMP} - \text{BASE})$$

TEMP is usually taken as the mean daily air temperature, but may be maximum daily or some other temperature. BASE is some base temperature above which melting occurs. The value used for BASE depends on that used for TEMP. COEF is a melt coefficient which is multiplied by the excess temperature above the base temperature to yield the amount of melt. The SSARR model allows the user the flexibility of a varying melt rate coefficient. The coefficient may vary with time or with conditions in the watershed. If COEF is to vary with time, the user can specify the specific value to be used starting at a given time. This value is then used until another value is specified at a later time. Thus a low value can be given in early spring, and then as melting proceeds and the snowpack ripens larger coefficients can be specified.

Alternately, the melt coefficient can be specified as a function of the percentage of the seasonal runoff which has occurred. In early spring, with only a low percentage of the annual runoff having occurred, a low coefficient would be used. As the runoff percentage increased, the melt coefficient would normally be increased as shown in Fig. 8. This manner of varying the melt coefficient is preferable to basing it on time alone for areas where the beginning of melt varies from year to year. However, it requires an estimate of annual runoff. A third option was added as part of this study, one which utilizes a moving accumulation of degree-days. This is described in a subsequent section.

The basic options available for determining what portion of the watershed is snow-covered are the elevation band method and the snow cover depletion method. With the elevation band method, the watershed can be divided into one or more elevation bands. Each band can be treated as a separate watershed for the purpose of snowmelt computation. The precipitation falling on a given band can be either rain or snow, depending on the air temperature at the center of the band. If it occurs as rain, it immediately becomes moisture available for runoff. If it occurs as show it is added to the snowpack. Also, depending on air temperatures (i.e., for the degree-day melt method), snowmelt may occur in a given elevation band. This melt water would also become moisture available for runoff. Computations would proceed for each band, and after all the snow had melted on a given band, only runoff from rain would occur.

With the snow cover depletion method, the computations may consider runoff from the snow-covered area only (one-basin approach) or runoff from both the snow-covered and the snow-free areas (split-basin approach). With either approach the snow-covered area can be specified by the user either as a function of time or in relation to the percentage of seasonal runoff. Precipitation falling as rain on the snow-covered area becomes moisture available for runoff. Precipitation in the form of snow is not considered in the analysis. If substantial amounts of snow fall during the computation period, they must be taken into account in determining the total amount of seasonal runoff. When the split-basin approach is used, the first basin represents the portion of the basin which is covered by snow, and computations are done for this portion only. The snow-free area computations are done on a second basin. The total basin outflow is, then, the sum of the flow from the snow-covered area and that from the snow-free area. This approach has a marked advantage in that one set of runoff characteristics can be specified for the snow-covered area, reflecting frozen ground conditions, and a different set specified for the snow-free area reflecting normal ground conditions.

2. Revisions and Options for Midwest

Of the melt-accounting options that are available, the split-basin snow-cover-depletion approach has an advantage for application to the Upper Midwest. The multiple-elevation-band approach is unnecessary, as elevation differences within the individual watersheds are usually much less than one thousand feet.

With the split-basin snow-cover-depletion option, the amount of area covered by snow is usually made a function of the percentage of seasonal runoff. For the Midwest it was considered desirable to base the per cent of snow-covered area on the water equivalent of the snowpack. A function was used wherein a value of water equivalent greater than one inch indicated that one hundred per cent of the basin was covered by snow. In the absence of specific data on snow-covered area and water equivalent, the function was made to decrease linearly to zero for water equivalents of less than one inch. This function is illustrated by Curve A in Fig. 9. In the interim period since the SSARR runs were completed, some data have been procured on the relationship between per cent snow cover and water content of snow on the ground. Preliminary results, shown as Curve B in Fig. 9, differ from those shown by Curve A by amounts up to 20 per cent. It would appear that curves of this type depend on the amount of relief or the steepness of the terrain.

Making the melt rate coefficient in the degree-day method a function of percentage of seasonal runoff did not appear to provide the most desirable relationship. A change was made so that the melt coefficient depended on the percentage of the snowpack that had melted; this function is illustrated in Fig. 10. This formulation was used in the study and gave usable results. Another method developed and used in the study based the melt coefficient on a moving accumulation of degree-days. This is based in part on observations by the National Weather Service river forecaster for this area to the effect that an accumulation of 60 to 70 degree-days over a period on the order of 10 days was necessary to start the spring flood; similar observations are given in Ref. [12]. The moving accumulation of degree-days appears to have merit, but time did not permit a final evaluation of this method.

A third change which was made in the SSARR model allowed the snow cover depletion option to properly accumulate precipitation in the form of snow in the snowpack.

A revision which appears desirable for computations during the summer runoff period concerns the evapotranspiration function. Presently, evapotranspiration occurs at the potential rate on non-precipitation days regardless of how much moisture exists in the soil. An improved function would reduce evapotranspiration as the SMI approached zero.

The version of the SSARR model used on the University of Minnesota's CDC 6600 computing system was obtained on magnetic tape from the Rocky Mountain Forest Experiment Station at Colorado State University through the Portland, Oregon, division of the U.S. Army Corps of Engineers. Some changes had been made at the Forest Experiment Station to adapt the program to their CDC 6400 computer.

When first compiled on the 6600, the CDC Fortran Extended (FTN) compiler produced incorrect binary code. All subsequent runs were made with the CDC FUN compiler. The form of the EØF check required alteration, as the original form was not valid with the FUN compiler. Due to the manner in which the 6600 executes code, certain operations can be done in parallel to save execution time. The use of EQUIVALENCE in the routine LAKRT caused the compiler to produce incorrect code. This was remedied by adding new variable names and forcing a sequential execution.

One error was found in an input (DECODE) statement changed by the Forest Experiment Station.

Due to the unavailability of random access disk storage at Colorado State, this storage feature of the SSARR model had to be replaced with a limited amount of core storage. At the University of Minnesota the random access disk storage feature was restored. The subsequent changes altered the numerical results of the SSARR model due to changes in the model functions. Three such changes were made. In each case they required changes in the routine BASINE only. The purpose of the changes is described in a previous section. Due to changes in the model functions, slight alterations in the meanings of input data variables were required.

3. Sample Runs

Figure 11 is a tabular printout of a run with the SSARR model for the 1100-square-mile Le Sueur River Watershed. A split-basin option was used; the upper table in the figure shows the moisture accounting for the "snow basin" and the lower table that for the "rain basin." An explanation of the column headings is given in Table 1. Column 3 indicates the amount of precipitation for the day. Column 9 gives the "per cent snow covered area," which decreased to zero on April 4, 1969. Column 12 gives the melt in inches per day; it is zero after April 4. Column 14 is the soil moisture index. Column 15 is the runoff percentage, which was fixed at 80 per cent for the snow basin in this run. Columns 19, 20, 21, and 22 are baseflow, subsurface flow, surface flow, and total flow (for snow basin), respectively. Similar data are computed for the rain basin (lower table), and the flows are added to give the total flow.

Figure 12 shows a portion of the graphical output of the SSARR for the Blue Earth watershed of the Minnesota River basin for March and April 1965. This run utilized the accumulated degree-day method of snowmelt calculation with a curve of the type shown in Fig. 13. This was the largest flood of

Table 1 -- Explanations of Figure 11 Column Headings

Col. No.		
1	DAY	Day of month
2	HOUR	Time of day
3	PCPN	Average basin precipitation for this time interval (inches)
4	RA	Percentage of area on which precipitation may occur
5	RN-AR	Accumulated runoff from rainfall only (inches)
6	ML-AR	Accumulated snowmelt only (inches)
7	AR	Percentage of snowpack melted
8	ELEV	Elevation of snow line (feet)
9	SCA	Percentage of snow-covered area
10	D-DY	Degree-day (i.e., difference between temperature at elevation of snow-covered area and base temperature)(°F-day)
11	MA	Percentage of area on which snowmelt may occur
12	MELT	Melt from snowpack (inches)
13	MI	Average moisture over basin from both rainfall and snowmelt (inches)
14	SMI	Soil Moisture Index (inches)
15	ROP	Runoff percentage (a function of SMI)
16	RGP	Runoff generated in period (product of ROP and MI) (inches)
17	BII	Baseflow Infiltration Index (inches)
18	BFP	Baseflow percentage (a function of BII)
19	BASEF	Baseflow component of flow (cfs)
20	SUBSF	Subsurface component of flow (cfs)
21	SURF	Surface component of flow (cfs)
22	DISCH	Stream discharge (the sum of the three components) (cfs)
23	HOUR	
24	DAY	

record for the 2430-square-mile watershed. The simulated or computed discharge (dotted line in Fig. 15) is in excellent agreement with the observed flow. The agreement was achieved after a trial-and-error process of optimizing the parameter tables associated with this model. As the model does not have a self-optimizing routine, numerous runs with data for a number of years are necessary for the user to gain sufficient familiarity with the method to achieve good results.

As one would expect, the parameter tables for SMI, BII, and S-SS differ when optimized for different years. This is an index of the complexity of the snowmelt-runoff process rather than a fault of this specific model. It appears desirable to optimize with about ten years- data to evaluate the parameter tables.

Figure 14 shows a comparison of three runs of the SSARR for the Blue Earth River in 1965 using for snowmelt (1) energy budget, (2) degree-day with coefficient a function of per cent snowmelt, and (3) degree-day with coefficient a function of a moving accumulation of degree-days. Detailed equations for these melt options are given in a following section in which different models are compared. The energy budget and moving-accumulation-of-degree-day methods appear superior for this watershed. This may not be true for all watersheds. Also, with changes in the melt coefficient for the degree-day, per-cent-snowmelt method the magnitude of the peak flow can be improved by further modification of the melt coefficient curve (Fig. 10). However, this method showed the peak of the flood occurring about 4.5 days late; this would be difficult to adjust.

Figure 15 shows the computed (SSARR model) and observed flow of seven tributaries and three main stem locations of the Minnesota River for the spring snowmelt-rain flood of 1965. In this set of runs the energy budget method was used to determine snowmelt in watersheds 6 through 15, where the main flood occurred. In the opinion of the writers this shows excellent agreement with observed flows. As the energy budget method requires additional data (solar radiation, dewpoint temperature, wind velocity, forest cover, and albedo), it is more difficult to use, but the results appear worthwhile. An albedo of 0.7 was used with most of the SSARR runs.

Precipitation data are available at 45 stations and temperature data at 35 stations in the basin. Solar radiation data are available at two locations in Minnesota, St. Cloud and the University of Minnesota campus in St. Paul. Neither of these is in the Minnesota River basin; however, both sites are close enough to it to provide reasonably satisfactory data. Dewpoint temperature data are available at St. Cloud, Rochester, Minneapolis, and Sioux Falls, South Dakota, near, but not in the basin, and wind velocity data are available at the same stations. For large basins it is obvious that some data are not available at as many sites as would be desirable. However, all models used must be designed to utilize data normally provided by the National Weather Service and the USGS.

The SSARR model appeared to perform very well when fitted to each of the 15 watersheds of the Minnesota River basin for 1965. This provided a fairly good understanding of the parameter tables (SMI, BII, S-SS, and melt coefficient). Additional runs were performed for one or two watersheds such as the Le Sueur (1100 sq mi) and the Blue Earth (2430 sq mi) for 1969 and 1967. As 1965 and 1969 were very severe flood years and 1967 was a mild flood year, the parameter curves arrived at in the fitting process provide a fair indication of the range of these variables, but runs for a total of ten years are desirable. If funding can be provided, the authors would welcome the opportunity to conduct additional studies with this model.

B. HEC-1 Program

The HEC-1 computer program or model [30] was developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers. It is actually a package of programs based on a unit hydrograph runoff analysis and a self-optimizing routine that optimizes up to ten parameters. In practice, precipitation and runoff data would be input for past events for a specific watershed and the parameters and unit hydrograph would be determined for that watershed for each event. The user would then select appropriate parameters and unit hydrographs for use with the design storm in which he was interested.

The program is design-oriented. The time increment can be varied as desired with up to 150 time increments in the design or observed period. Included in the program are functions for determination of mean basin precipitation from a combination of recording and non-recording stations in and near the basin. Several options are available for specifying basin average precipitation and formation of design storms for standard project and probable maximum analysis. Snowmelt can be determined by either the degree-day method or the energy budget method. Loss rates can be determined using either an initial loss and a uniform loss rate or a four-parameter loss function. The loss functions have no recovery feature between rains and are thus designed primarily for one sustained runoff event.

Hydrographs produced by the above methods can be routed downstream and combined with other hydrographs to produce a composite basin runoff analysis. Several streamflow routing options are available in addition to reservoir routing methods.

One of the most attractive features of this program is the self-optimizing routine. This is a univariate method that fits the computed discharge curve to the observed discharge curve. Coefficients or parameters included in the process are TC, Clark R, COEF, STRKR, STRKS, RTIOK, ERAIN, FRZTP, DLTKR, and RTIOL [30]. Four of these coefficients pertain to the loss function for rain and four to that for snowmelt. The loss function in which the four rain and four snow coefficients are used is

$$\text{LOSS RATE} = (\text{AK} + \text{DLTK})(\text{PRCP})^{\text{ERAIN}}$$

where AK is a logarithmic term

DLTK is associated with a higher initial loss at the start of a storm

PRCP is the precipitation in any period (both rainfall and snowmelt), and

ERAIN is a power in the equation (a nominal value might be 0.7, but for severe storms values as low as 0.15 have been obtained).

Snowmelt

As was noted above, snowmelt can be determined by a degree-day or an energy budget method. In the degree-day method, using notation from Ref. [30],

$$\text{MELT} = \text{COEF}(\text{TEMPR} - \text{FRZTP})$$

The user can specify COEF and FRZTP. Both are fixed for all computations. If the optimization routine is used, the best-fit values are determined by the program. In the energy budget method, dewpoint temperature, wind velocity, air temperature, and solar radiation are used. The energy budget method was not used in this study.

Up to ten elevation bands can be specified to account for temperature variation with elevation. Reference [19] covers earlier studies with HEC-1 and documents some changes made in the program. Figure 16 shows the output from a snowmelt run using HEC-1 for the Blue Earth River in 1965. Figure 17 illustrates the performance of HEC-1 for the entire Minnesota River basin in 1965 with coefficients optimized for 1965. Figures 18 and 19 show its performance with coefficients averaged for 1965 and 1967 and then used to compute the flow in those two years. (The average coefficients were based on three flood events, one in 1965 and two in 1967.) For any given year HEC-1 can be fitted to the observed values with excellent results. As a forecast tool it is necessary to predict the flood using the best estimate of 6 to 10 coefficients. In many instances it may be necessary to use average coefficients. Figures 18 and 19 indicate that the model would have performed very well in 1969 and underpredicted in the record flood year of 1965 on the basis of average coefficients. This suggests that information in addition to the basic coefficients is necessary in very severe flood years. Frost depth and ice cover are two items that obviously have an effect. Another is the temperature sequence during the melt. Appendix B contains data on parameter values for HEC-1.

C. Stanford and Kentucky Models

The Stanford model developed by Crawford and Linsley [1,8,9] has been presented and discussed so well in the literature that little needs to be said here. However, a few comments may be in order.

Basically, the model uses moisture accounting as it attempts to follow all the moisture entering the watershed through the various storage systems until it leaves via streamflow, subsurface flow, or evapotranspiration. The original version of the Stanford watershed model was written in the Burroughs computer language (Balgol).

A number of people and organizations have translated it into Fortran, including the National Weather Service and James [11] at the University of Kentucky. James translated Stanford Model III as given by Anderson and Crawford [1], but added a number of improvements associated with Stanford Model IV. This model is referred to herein as the Kentucky model. Liou at the University of Kentucky developed a self-optimizing version of SWM called OPSET [16] for use with the Kentucky model. OPSET optimized 13 parameters, of a nominal total of about 21 in the KWM, and computed the outflow for the optimizing period. These parameters would be used as input to the Kentucky model. The 13 parameters are optimized in two groups--first the land phase parameters, which determine the runoff volume and the interflow volume, then the channel flow routing parameters, which determine the shape of the outflow hydrograph, including the time to peak flow. The Kentucky model includes a snowmelt routine, but OPSET does not. Thus OPSET has serious limitations in areas in which snow provides a significant contribution to floods.

The Kentucky model and OPSET were used with one watershed of 129 sq mi in Minnesota. OPSET was used to optimize 13 parameters for two years, 1962 and 1970. Results were fairly good for 1970, but of lesser value for 1962. It was concluded that (1) further experience on the part of the users was necessary to optimize the many parameters and (2) introduction of a snowmelt routine into OPSET is desirable for use in northern areas.

D. National Weather Service River Forecast System, NWSRFS

NWSRFS is a new model recently released by the National Weather Service [17]. It is based in part on the Stanford Watershed Model IV. It is a continuous synthesis conceptual watershed model consisting of the components shown in Table 2 and Fig. 20. The computer programs were prepared for use on the CDC 6600 system, but can readily be adapted to other systems. Storage requirements are shown in Table 3.

In the initial release of the NWSRFS [17] the snowmelt subroutines were omitted, as they were still under development. In a second release [2] the snowmelt routines were provided. As part of this project the model was tested with the 1100-square-mile Le Sueur River watershed, a tributary of the Minnesota River. Due to the absence of the snowmelt routines, tests

Table 2 -- Computer Programs in NWSRFS

Stage	Computer Program	Function
Data Processing	HRTAPE	1. Processes hourly precipitation data. 2. Prepares working tape for MBP (mean basin precipitation) from NCC card deck 488 or standard format cards.
	DAILYF	Processes U.S.G.S. mean daily flow tape (see Note 1).
	NWSRFS1	1. Calculates station weight and mean areal precipitation for one or more areas or basins. 2. Estimates the missing records and distributes cumulative precipitation records.
	NWSRFS2	Reads various hydrologic data and arranges the data in one-month records, then loads onto magnetic tape as station month records.
	NWSRFS6 (MAT)	Computes mean areal temperatures for snowmelt analysis.
	SUPERTP	Merges NWSRFS standard format tape.
Calibration	NWSRFS3	Calibrates (sensitivity analysis and pattern search optimization).
Verification	NWSRFS4	Verifies parameter values by comparing computed and observed flows.
Operation	NWSRFS5	Operates (for forecast purposes).

Note 1. Reads mean daily discharge data from U.S.G.S. 7-track magnetic tape and puts out selected portion in one of two modes:

(a) Office of Hydrology card format
(b) NWSRFS tape format

Table 3 -- Program Dimensions, Storage Requirements, and Typical Run Times for NWSRFS Programs
(Storage requirements and run times are based on a CDC 6600 computer system.)

Program	Dimensions	Storage Requirements Decimal Words (Octal Words)	Typical Run Times
Mean Basin Precipitation Program (MBP Program) (NWSRFS1)	10 basins 20 precipitation stations for each basin	50K (142K) 67K (if the consistency check subroutine is included) when using 20 precipitation stations and 10 years of record (203K)	
Verification Program (NWSRFS4)	5 snowpack and soil-moisture accounting areas 5 streamflow points 3 upstream inflow points 2 PE stations	39K (114K)	2 sec/year for each snowpack and soil-moisture accounting area plus 3 sec/year for each streamflow point
Optimization Program (NWSRFS3)	2 snowpack and soil-moisture accounting areas 1 streamflow point 4 upstream inflow points 2 PE stations 50 months of data	32K (76K) for program plus 75K (211K) for data storage	5.5 sec/50 months for each snowpack and soil-moisture accounting area plus 1 sec/50 months for the streamflow point
Operational River Forecasting Program (NWSRFS5)	10 snowpack and soil-moisture accounting areas 10 streamflow points 5 upstream inflow points 3 PE stations 14 days of data	29K (65K) Enlargement of river system requires approximately 350 words/snowpack and soil-moisture accounting area plus 600 words/streamflow point	1 sec/14 days for each streamflow point

Mean Areal Air Temperature Program (MAT Program) (NWSRFS6)	40 10 4800	maximum-minimum air temperature stations areas to compute mean areal temperature months of data storage	37K for program plus 744 words of random access data storage per station year (110K)	7 sec/year for an analysis involving 10 stations
MAT Consistency Check Program (Program MATCON)	40 5 25	maximum-minimum air temperature stations groups for double mass analysis years of record	33K for program plus 24 words of data storage per station year (data are generated by MAT Program) (100K)	1 sec/year for an analysis involving 10 stations
Program TEMPCK			40K for program plus 1488 words of data storage per year (data are generated by MAT Program) (116K)	0.5 sec/year

were performed for the snow-free period April through October for 1967, 1968, and 1969. The snowmelt routines were added to the system upon receipt, but time did not permit their complete implementation.

As noted in Table 2, the NWSRFS consists of six programs for handling and processing data (HRTAPE, DAILYF, NWSRFS1, NWSRFS2, NWSRFS6, and SUPERTP) plus three operational programs (NWSRFS3, NWSRFS4, and NWSRFS5), each involving numerous subroutines. Table 2 indicates the primary function of each program, and Fig. 20 shows the normal flow chart for the main elements. Figure 21 shows a modified flow chart used in the studies reported herein. The change in input procedure was desirable because most of the data had been stored on a random access disk pack.

In a continuous synthesis model of this type, data requirements are naturally large. As the NWS recommends that 50 months' data be used to optimize the parameters in the model, it is apparent that tape and disk storage elements are desirable for processing the data.

With the data in the desired format and storage element, optimization of the parameters can begin. The system uses a "pattern search" and "trial and error" calibration process. After initial estimates of six parameters, NWSRFS3 is used to optimize 11 parameters plus four more evapotranspiration parameters optimized by region. After an initial optimization of these parameters by NWSRFS3, NWSRFS4 is used to compare the observed and computed variables for the calibration period. After inspection of the graphical output some of the parameters may be adjusted as a result of sensitivity tests; NWSRFS3 would again be used to optimize 11 parameters. This procedure would be repeated until adequate verification was achieved. NWSRFS5 could then be used for forecast purposes.

1. Data Requirements

Calibration of the model is based on a record of mean daily discharge. Channel routing coefficients require instantaneous hydrographs of a few events. Observed streamflow data are used to update the model periodically. Observations from each flowpoint every three to six hours are desirable, but not essential. A continuous record of six-hour basin means of precipitation is required. This can be obtained from any combination of recording and daily gages in and around the basin. The model uses for its evapotranspiration demand the product of PE and a seasonal correction curve that is optimized by the model or standardized by region. The PE record can be a day-by-day computed PE or a curve representing the long-term average.

2. Data Processing

Hourly and daily precipitation data are retrieved from the National Climatic Center, Asheville, North Carolina. Hourly data are in Card Deck 488 and daily precipitation data in Card Deck 486. Data are obtained on tape. Average precipitation can be determined using a grid point system, the Thiessen method, or predetermined station weights. Potential evapotranspiration input to NWSRFS--i.e., the evaporation from a free water surface with no heat storage--is given by

$$EP = (E)(PE)$$

where PE is the free water potential evapotranspiration for the day

E is a factor that adjusts free water potential to watershed potential

(E) is assumed to vary seasonally and is defined by four evapotranspiration parameters.

3. Soil Moisture Accounting

Figure 22 is the flow chart for soil moisture accounting in NWSRFS. Table 4 lists the 21 parameters concerned with soil moisture and the typical range of most of the parameters. The reader is referred to Ref. [17] for equations concerning per cent of interflow detention (LIRC6), per cent of groundwater flow reaching the channel each six hours (LKK6), and a weighting factor concerning groundwater recession (KV). The NWSRFS uses a six-hour input for precipitation on all computations except (a) infiltration, upper zone retention, surface and interflow detention, and lower zone retention, which are computed hourly; (b) percolation of water from upper zone to lower zone, which is on a one-day basis.

The infiltration analysis is similar to that of the Stanford model. A cumulative-distribution-of-infiltration-capacity curve is used to simulate

Table 4 -- Soil Moisture Parameters in NWSRFS

Parameter	Units	Typical Range	Description
K1	(none)		Ratio of average precipitation to precipitation input
A	Per cent		Per cent of impervious area
EPXM	Inches	0.10 - 0.50	Maximum amount of interception storage
UZSN	Inches	0.05 - 1.25	Nominal upper zone storage
LZSN	Inches	4 - 10	Nominal lower zone storage
CB	Inches/hour	0.05 - 0.75	Infiltration index
POWER	(none)	0.5 - 3.0	Exponent in infiltration curve
CC	(none)	0.25 - 1.25	Interflow index, determines ratio of interflow to surface runoff
K24L	Per cent	0	Per cent of groundwater recharge assigned to deep percolation
K3	Inches	0.28	Evaporation loss index for the lower zone
GAGEPE	(none)		Ratio of areal evapotranspiration to input evapotranspiration
EHIGH	(none)	0.9 - 1.2	Parameters for computing watershed potential evapotranspiration from free water potential evapotranspiration
ELOW	(none)	0.1 - 0.6	
NEP	(Julian date)	90 - 200	
NDUR	Days	0 - 100	
K24EL	Per cent	0 - 0.20	Per cent of watershed stream surfaces and riparian vegetation
SRC1	Per cent	0.9	Per cent of surface detention reaching the channel each hour
LIRC6	Per cent	0.1	Per cent of interflow detention reaching the channel each 6 hours $LIRC6 = 1.0 - (IRC)^{.25}$
LKK6	Per cent	0.05	Per cent of groundwater storage that reaches the channel when KV is zero $LKK6 = 1.0 - (KK24)^{.25}$
KV	(none)	0.7 - 5.0	Weighting factor to allow for variable groundwater recession rates
KGS	(none)	0.85 - 0.97	Recession factor for antecedent groundwater inflow index

the effect of different infiltration capacities throughout the watershed on runoff and infiltration. As shown in Fig. 23, the cumulative frequency distribution of infiltration capacity is assumed to be linear from zero to a maximum value $(c \cdot b)$. Figure 23 also shows the result of a moisture supply of $\overline{X}$ inches.

The value of the infiltration capacity as a function of lower-zone soil moisture ratio is defined as

$$b = CB/(LZS/LZSN)^{POWER}$$

where CB = infiltration index (in./hr)
LZS = lower zone storage (in.)
LZSN = nominal lower zone storage (in.)
POWER = exponent

Figure 24 illustrates the form of this equation. Figure 25 shows an example of land surface response as the moisture supply is increased. Components of this response are net infiltration, interflow detention, and overland flow surface detention.

Evaporation from stream surfaces and evapotranspiration from groundwater are computed jointly in NWSRFS. The parameter K24EL is the percentage of the watershed subject to evaporation from stream surfaces and riparian vegetation. The maximum amount of stream and riparian evaporation is equal to K24EL multiplied by the watershed potential evaporation for that day.

Because of the longer time interval used in NWSRFS, the overland flow routing equations of SWM-IV involving slope, overland-land-length, and roughness are not used. The equation for the amount of fast-response runoff reaching the channel during each hour is

$$ROST = SRC1 \cdot RX$$

where SRC1 is the per cent of the water in surface detention (RX) to reach the channel.

The water that does not reach the channel is available to become infiltration, upper zone storage, or runoff during the next hour.

As was noted above, the watershed potential evapotranspiration is

$$EP = E \cdot PE$$

where E is a factor which varies seasonally and is defined by four parameters:

ELOW = minimum value of E on February 15
EHIGH = maximum value of E
NEP = Julian date when E is a maximum
NDUR = number of days E remains a maximum

A sine curve connects the highs and lows.

4. Channel Routing

Routing in the NWSRFS is handled by "lag and K" channel routing as described in Ref. [15]. The essence of this procedure is (1) introducing a time delay (lag) to account for the travel time of a wave through the reach and (2) simulating wave attenuation using channel storage effects. The attenuation is simulated by routing the reach inflow, suitably lagged, through a hypothetical reservoir governed by the equation

$$\frac{ds}{dt} = I(t) - Q(t) = K\,\frac{dQ}{dt}$$

in which the reservoir storage constant K gives rise to the second half of the method name "lag and K." The reservoir storage is given by S, and its inflow and outflow are given by I and Q respectively.

5. Local Runoff

In the conceptual framework of the soil moisture accounting process, the runoff produced in a six-hour period is the first volume delivered to the channel system in that period. The first step in the channel routing is applying a constant lag to this channel inflow. This is accomplished using a time-delay histogram. The channel system is divided into reaches which have equal travel time. As a six-hour time interval is used for routing computations, the channel reaches have travel times that are multiples of six hours. Figure 26 gives an example of channel time delay histogram elements.

The antecedent index of groundwater flow (GWS) is

$$GWS = KGS \cdot (GWS + GW\ inflow)$$

where GW inflow is the inflow to groundwater storage and KGS is the antecedent index recession factor. (In SWM IV, KGS = 0.97 on a daily basis.)

To account for areal variations in runoff, allowance is made for each element of the time-delay histogram to have inflow from separate soil moisture accounting computations.

Some channel systems exhibit a lag that varies with inflow. In NWSRFS this can be provided by a constant lag component plus a variable component. The reservoir storage constant K may consist of two parts, a constant plus a variable that is a function of outflow.

6. Verification and Operational Programs

The verification program (NWSRFS4) and the operational program (NWSRFS5) use the same basic computation procedures. They differ in the length of the period that is run (quite long in NWSRFS4, but short in NWSRFS5) and the method of input and output. Five subroutines are common to NWSRFS4 and NWSRFS5. Six others are used only in NWSRFS4 and four others only in NWSRFS5. The reader is referred to Ref. [17] for details of these routines.

7. River System Organization

NWSRFS4 and NWSRFS5 will simulate a complete river system of virtually unlimited size. A typical system is shown in Fig. 27. In this illustration, flow is being computed at seven points in the system; at two points (8 and 9) flow enters from another area. Except at the latter two points, computations proceed from low to high numbers.

Figures 28a, b, and c illustrate the output of NWSRFS4 for the 1100-square-mile Le Sueur River watershed for April through September 1968. Prior to this run, 11 variables were optimized by NWSRFS3 and others adjusted in the trial-and-error process. Initially, the observed and simulated flows in the verification run agreed reasonably well (Fig. 28a) until precipitation of 0.58 and 1.32 inches occurred on April 22 and 23, respectively (precipitation and both simulated and observed flows are shown in tabular form at the top of the graph). The simulated flow then greatly exceeded the observed flow, possibly due to errors in the initial moisture levels. As time progressed, agreement generally increased. In June and July (Fig. 28b), agreement is very good. A storm of 3.29 inches on July 23 resulted in an observed flow of 10,000 cfs and a computed flow of 8600 cfs. In August and September (Fig. 28c) a storm of 2.66 inches on August 7 followed by 0.45 inch on August 8 produced an observed peak flow of 7050 cfs and a computed value of 8309 cfs, which is very close agreement. Simulation during the remainder of August and September is excellent. The parameter values for this run are shown in column 12 of Table C-1 in Appendix C.

As was noted above, the snowmelt routines were not available for this run. If these had been incorporated, it is possible that the results would have been even better, particularly during the first month of the run.

In evaluating simulation models of this type it must be noted that comparative results depend on (1) the number and location of weather observation stations, particularly precipitation measurements; (2) the accuracy of flow measurements; and (3) experience in using the model. Precipitation data were available at six non-recording and two recording stations around the periphery of the Le Sueur watershed, but no measurements were available inside the watershed. These stations were located at Amboy, Albert Lea, Blue Earth, Bricelyn, North Mankato, Waseca, Wells, and Winnebago. With large storm systems the precipitation measurements are probably good, but with smaller, high-intensity storms the precipitation data may be inadequate. This factor, plus the authors' relative lack of experience with this model, must be considered in evaluating its performance.

Figures 29a, b, and c illustrate the verification run for April through August, 1967, with parameter values based only on 1967 data. There is very good agreement between observed and simulated data for a substantial flood of 8690 cfs in June and good-to-excellent agreement at low flows.

Figures 30a, b, and c illustrate computed (or simulated) and observed flows for the Le Sueur River in 1967 using the parameters optimized with 1968 data. The objective of this run was to see how the model would respond over a two-year period. Agreement was very good for the snow-free period of

April through September, although the peak flow in June did not match as well as in Fig. 29b when the parameters were optimized for data of the same year (1967) as the verification run. Additional runs would have been desirable for other years.

Figures 31a, b, and c show the NWSRFS4 model applied to the Le Sueur River for 1969, using parameters optimized with 1968 data, as a further check on performance over several years. With the exception of over-prediction in April, the agreement between observed and simulated flows is very good.

In general, the overall performance of the model as indicated by the verification runs for 1967, 1968, and 1969 are very encouraging. In retrospect, it would have been desirable to use a single set of parameters for runs in 1967, 1968, and 1969 or to make a complete run over the three-year period if snowmelt routines had been implemented. As runs could not be made for a full year because of the lack of snowmelt routines, comparisons were made between observed and simulated curves for 1967 using 1967 and 1968 parameters and for 1969 using 1968 parameters in order to provide some indication of general performance with parameters not necessarily of optimum magnitude.

Figure 32 illustrates a run with the forecast model NWSRFS5 for a two-week period in July 1968; the forecast is for July 28 to August 4 in six-hour increments. The objective of this run is merely to show the form of the NWSRFS5 output.

8. Snowmelt Runs

Following receipt of Ref. [2] the snowmelt routines were substituted for dummy routines in NWSRFS3, 4, and 5. No other changes were necessary. However, the preliminary runs were not successful, and additional runs are desirable. Use of the snow accumulation and ablation model requires only daily maximum and minimum temperatures in addition to the data required for normal use of NWSRFS3, 4, and 5. The NWSRFS package provided NWSRFS6 (MAT) to read data from a tape. At the University of Minnesota the program was modified to read the data from the disk. It is possible that this routine is causing difficulty with the snowmelt runs.

In order to process the data for runs with NWSRFS, several small programs were written for the CDC 6600 computer with a locally designed variant of the CDC operating system. These and a summary of some data are included in Appendix C.

9. Summary--NWSRFS

The NWSRFS, with snow subroutines omitted, was compiled and applied to a four-year set of test data for a watershed in the state of Mississippi. It was then applied to the 1100-square-mile Le Sueur watershed in south central Minnesota for 1967, 1968, and 1969. As the snow subroutines were not available at the time of these runs, the application was restricted to the snow-free period between April and September for each year. The system was initially calibrated, or fitted, for 1968. NWSRFS4 was used to verify the calibration by comparing observed and simulated flows as shown in Fig. 28. Using the same parameters, NWSRFS4 was then operated with precipitation data for 1967, followed by another run for 1967 with parameters optimized for 1967. Figures 29, 30, and 31 illustrate observed and simulated discharges for the snow-free period. The overall performance of the system for this period was considered to be excellent.

About one year after the NWSRFS was received, the snow accumulation and ablation subroutines were made available. An effort was made to calibrate and verify the snow parameters, but the result was not satisfactory. It was thought that available time and funds were not adequate to properly implement these routines. Part of the difficulty may have originated with the University of Minnesota data manipulation system.

III. COMPARISON OF MODELS

Table 5 is a comparison of some features of the models discussed herein. Also included is a summary of the snowmelt equations used in the models. It is not possible to rank the models on overall performance, because the performance of complex models of this type depends very heavily on the knowledge and ability of the user as well as the methods incorporated in the model. Many runs and many months of work are necessary to arrive at a general understanding of the model and become proficient in its use. However, some comments on specific features are in order.

Table 5 -- Comparison of Five Models

		SSARR	HEC-1	STANFORD IV	KENTUCKY	NWSRFS
1	Simulation	Continuous	Non-continuous	Continuous	Continuous (1 hr or 15 min incr.)	Continuous (6 hr increments)
2	Precipitation	Snow or rain	Snow or rain	Snow or rain	Snow or rain	Snow or rain
3	Precipitation analysis	Basin average or weights at each station	Basin average or weights at each station	Representative recording station	Representative recording station	Grid point method Thiessen method
4	Snowmelt equation	Degree day and energy budget	Degree day and energy budget	Energy budget	Degree hour	Combined method
5	Interception	Neglected	Neglected	Included	Included	Included
6	Evapotranspiration	Constant over a certain month	Neglected	Cumulative freq. dist. of ET opportunities	Cumulative freq. dist. of ET opportunities	Normal Daily ET $EP = E \cdot PE$
7	Depression storage	Neglected	Neglected	Neglected	Neglected	Neglected
8	Infiltration	Use relationship between SMI and runoff per cent	Cumulative loss rate Fn (4 variables)	Cumulative freq. dist. of infiltration capacity	Cumulative freq. dist. of infiltration capacity	Cumulative freq. dist. of infiltration capacity
9	Time distribution of runoff	Conceptual reservoir	Unit hydrograph method	Channel time delay histogram	Time-area histogram	Channel time delay histogram
10	Baseflow	Relationship between BII and total runoff	Use exponential recession	Fn of groundwater storage (LZS)	Fn of groundwater storage (LZS)	Fn of groundwater storage (LZS)
11	Channel routing	Storage routing	Muskingum, Tatum, straddle-stagger method	Storage routing $\frac{ds}{dt} = I - O = K \frac{do}{dt}$	Storage routing optimized K	Storage routing const. K + var. K

A. Snowmelt Equations

1. SSARR Model

a. Degree-Day Method

$$\text{MELT} = \text{Coefficient (Air Temp. - Base Temp.)}$$

The melt coefficient (or degree day factor) can be determined using

(1) percentage of seasonal runoff completed
(2) percentage of snowpack melted
(3) function of moving accumulation of degree days.

b. Energy Budget Method

$$\text{MELT} = k'(1 - F)(0.004\ Ii)(1 - a) + k(0.0084\ V)(0.22\ T_a' + 0.78\ T_d') + F(0.029\ T_a')$$

where k' = shortwave radiation melt factor, expressed as decimal
F = average forest canopy cover, expressed as decimal
Ii = solar radiation in langleys
a = average snow surface albedo, expressed as decimal
k = convection-condensation melt factor, expressed as decimal
V = wind velocity at 50 ft above snow, mph
T_a' = difference between the air temperature at 10 ft above surface of snow and the base temperature of snow surface (32°F)
T_d' = difference between the dewpoint temperature measured 10 ft above snow and the base temperature (32°F)

Snowmelt due to radiation is given by

$$k'(1 - F)(0.0040\ Ii)(1 - a)$$

Snowmelt due to convection-condensation is given by

$$k(0.0084\ V)(0.22\ T_a' + 0.18\ T_d')$$

Snowmelt due to longwave radiation is

$$F(0.029)\ T_a'$$

2. HEC-1 Model

a. Degree Day Method

$$MELT = COEF(TEMPR - FRZTP)$$

b. Energy Budget with Precipitation

$$MELT = COEF(0.09 + (0.029 + 0.00504\ WIND + 0.007\ PRCP)(TEMPR - FRZTP))$$

c. Energy Budget Without Precipitation

$$MELT = COEF(0.002\ SØL(1 - ALBDØ) + (0.0011\ WIND + 0.0145)(TEMPR - FRZTP)$$

$$+ 0.0039\ WIND(DEWPT - FRZTP)$$

where TEMPR = air temperature
FRZTP = freezing temperature
COEF = melt coefficient
PRCP = precipitation in inches/day
SØL = solar radiation in langleys/day
ALBDØ = albedo of snow
WIND = wind speed
DEWPT = dew point temperature

3. NWSRFS Model (Six-hour time interval)

a. Air temperature $> 32^\circ F$

(1) No rain or light rain (< 0.1 inch/6 hrs)

$$MELT = (T_a - MBASE) \cdot M_f$$

(2) Rain (≥ 0.1 inch/6 hrs)

Assume: No solar radiation, longwave = black body;
Radiation at air temperature;
Dewpoint = air temperature;
Temperature of rain = air temperature

$$\text{MELT} = 0.007\ (T_a - 32) + 7.5\ \gamma\ f(u)\ (T_a - 32) + 8.5\ f(u)\ (e_a - 0.18)$$
$$+ 0.007 \cdot \text{Rain} \cdot (T_a - 32)$$

b. Air temperature $\leq 32^{\circ}$F

$$\text{MELT} = (T_{a_2} - \text{ATI}_1)\ \text{NM}_f$$

$$\text{ATI}_2 = \text{ATI}_1 + \text{TIPM}\ (T_{a_2} - \text{ATI}_1)$$

where MELT = amount of melt, inches/6 hours
T_a = ambient air temperature, $^{\circ}$F
MBASE = base temperature, $^{\circ}$F
M_f = melt factor, inches/(6 hours $\cdot$ $^{\circ}$F)
γ = psychrometric constant, inches Hg/$^{\circ}$F
$f(u)$ = wind function, inches/(inches Hg $\cdot$ 6 hours)
e_a = vapor pressure of air, inches Hg
ATI = antecedent temperature index
NM_f = negative melt factor, inches/(6 hours $\cdot$ $^{\circ}$F)
TIPM = antecedent temperature index parameter

4. Kentucky Model

$$\text{MELT} = (T_a - T_i)\ F\ A(1 - R) + \frac{P(T_a - 32)}{144}\ \frac{W}{W_i}$$

where MELT = amount of melt, inches/hour
T_a = air temperature, $^{\circ}$F
T_i = base temperature, $^{\circ}$F
F = basic degree-hour factor (inches/$^{\circ}$F)
A = melt factor adjustment with seasonal variation
R = melt factor adjustment with albedo
W_i = index value of water equivalent of the snow with 100 per cent snow cover
W = current water equivalent of the snow

5. Stanford Watershed Model IV

$$\text{MELT} = H_m/203.2 + \text{C0NMELT}\ (T - 32) + \frac{(T - 32.0)PX}{144}$$

where MELT = amount of melt, inches/hour

H_m = net total radiation, langleys

C0NMELT = convection-condensation melt parameter

T = atmospheric temperature, °F

PX = rainfall, inches

B. SSARR Model

The SSARR model was fitted to the 15 watersheds of the 16,200-square-mile Minnesota River basin for three years. The model is of the continuous synthesis type, which is a very desirable feature. The process of learning its operational features and optimization of parameter tables was very difficult due to its complexity and the lack of a self-optimizing routine. The trial-and-error process is a slow and difficult method of fitting a model, especially if the user is not familiar with optimum parameter values.

In spite of these problems, the SSARR is a very useful and powerful tool for flood forecast purposes. The use of rain and snow basins is desirable in the Upper Midwest. Both the degree-day and the energy budget method were successfully used. However, it was necessary to modify the SSARR degree-day method to relate the melt coefficient either to per cent of snowpack melted or to a moving accumulation of degree-days. As the degree-day method requires less data, it is easier to use. Further tests with other years and other watersheds are necessary before the best melt routine can be selected.

C. HEC-1 Model

The HEC-1 model or program is based on the widely used and well-known unit-hydrograph runoff analysis. For this reason it is easy to use. Its most attractive feature is an excellent optimizing routine that will optimize up to ten variables with the hydrograph analysis or two variables associated with flood routing routines. To fully appreciate the merits of an optimizing routine, one must first attempt to fit a runoff model to a new watershed without such a routine. The digital computer is an excellent tool for use with an optimizing routine. However, some interaction between user and program is necessary to fix some variables or otherwise control the routine, especially for complex storms.

HEC-1 is limited to 150 time periods, although it could be extended if desired. However, HEC-1 does not have a loss-rate recovery feature for dry periods between rains, and this automatically limits it to one major precipitation event.

It was not difficult to fit HEC-1 to a given watershed for past snowmelt or rain floods. However, there is the serious problem of evaluating six to ten parameters and several adjustable variables for the "present condition" of a forecast operation. This in effect involves the evaluation of soil moisture, frost, ice cover, and related factors before inserting the parameter values for a forecast run. While this problem exists to some extent for all models, the continuous synthesis models solve part of the problem by continuous moisture accounting or soil moisture index methods.

D. Stanford and Kentucky Models

The Stanford model was not used directly in this study, because it was written in Balgol. A Fortran version prepared by Douglas James at the University of Kentucky and referred to herein as the Kentucky model was fitted to a 129-square-mile watershed. The area of this watershed was probably too large for proper use with this model, as there were no options to handle subwatersheds. Also, the rainfall data were considered somewhat questionable. As a result, agreement between observed and simulated flows was not as good as with some other models. Work with this model was discontinued when the NWSRFS became available, as it was also based on the Stanford model and was adapted to larger watersheds. Also, NWSRFS has an optimizing routine which is very helpful.

E. NWSRFS

Time and funds did not permit extensive tests with this model system, but it was fitted to the 1100-square-mile Le Sueur watershed for 1968 and 1967 and applied for 1969. The snowmelt routines were not available initially, and thus most of the runs were restricted to the period of April to October, with rainstorm floods. The National Weather Service recommended that the system, which consists of three primary models and auxiliary data processing routines, be calibrated with 50 months' data. A four-year set of data for a watershed in the state of Mississippi was used in implementing the system. NWSRFS was then applied to the Le Sueur watershed.

Overall performance with the Le Sueur watershed for three 7-month snow-free periods (1967, 1968, and 1969) was considered good to excellent. The calibration model, NWSRFS3, is available for optimization of parameters, and NWSRFS4 is available for verification of parameter values. The user must interact with the program to optimize other parameters. Thus multiple runs are necessary, alternating between NWSRFS3 and NWSRFS4, for optimization to be achieved. After optimization the forecast model NWSRFS5 is used.

Considerable study and numerous runs preceded initial use of the system, primarily so that procedures for handling the input data could be mastered. The data were taken initially from tapes obtained from the NOAA National Climatic Center in several standard card deck formats (CD 486, CD 488, and TDF 14). Two small programs were written at the University of Minnesota to assist in processing the data from a disk pack; these are included in Appendix C.

The overall assessment of the system as applied to the snow-free period of the year in the Le Sueur watershed is that it is an excellent and well documented system. The authors would welcome the opportunity to apply it to the remaining watersheds of the Minnesota River Basin.

Table 6 shows the core memory required with the CDC 6600 computer for three phases: compilation, loading, and execution of various mathematical models. The largest core memory requirement among these three phases must be satisfied for any model to be run successfully.

Table 6 -- Required Core Memory (Octal) for CDC 6600 System (Words)

Model	Compilation Phase	Load Phase	Execution Phase	Required Core Memory*
SSARR	55,000 (FUN compiler) 75,000 (MNF compiler)	47,000	77,700	77,700
HEC-1	50,000 (FUN compiler) 70,000 (MNF compiler)	101,000	66,600	101,600
HRTAPE	45,100 (FUN compiler)	35,400	26,100	45,100
NWSRFS1	64,100 (FUN compiler)	127,000	133,500	133,500
NWSRFS2	43,700 (FUN compiler)	41,500	32,100	43,700
NWSRFS3	FTN compiler	74,000	62,700	74,000
NWSRFS4	55,400 (FUN compiler)	113,500	102,200	113,500
NWSRFS5	43,100 (FUN compiler)	67,000	55,600	67,000

*Required core memory is the maximum value among the compilation, load, and execution phases.

IV. APPLICATION OF THE SSARR AND HEC-1 MODELS TO A RESEARCH PROBLEM

In 1965 the average water content of snow in the Le Sueur watershed was 2.7 inches; this resulted in a flood peak, due to snowmelt and rain, of 24,700 cfs. In 1969 the average water content of the snow was 5.7 inches, but the peak flow of 10,000 cfs was less than half that of 1965. The severity of the 1965 flood can be partially attributed to (1) high soil moisture, (2) deep soil frost, and (3) an ice covering beneath the snow. In an attempt to evaluate other factors, the water content of snow was varied after fitting of the SSARR and HEC-1 models to the Le Sueur watershed. The water content was increased and decreased by one-inch amounts and the runs repeated. Figure 33 illustrates the effect of varying amounts of initial snow water content on the computed flood <u>peak</u> of the Le Sueur River for 1965 and 1969. The curve for 1965 appears reasonable, with the flood peak approximately proportional to the initial water content. However, the curve for 1969 was quite different in shape and difficult to explain. Figure 34 shows the flood hydrograph of the Le Sueur River for 1969. Agreement between observed and computed or simulated flows is excellent.

A graph of average temperatures for the Le Sueur watershed for 1965 and 1969 (Fig. 35) is quite interesting. Normally, the average temperature for the day in the Le Sueur area passes through 32°F on about March 22. However, in 1965 the average temperature stayed below freezing until about April 1, when it suddenly warmed up to "normal," causing a sudden melt. In 1969, an intermittent warm period occurred from about March 19 to March 27, causing partial melt. This was followed by a very cool period of about one week and then a sudden increase to melting temperature. The cool period between the two warm periods permitted part of the flood to pass out of the watershed before the final melt occurred, as is shown in Fig. 34. To test this reasoning, the SSARR model was run with 1969 data and 1969 parameters with the temperature data for March and April of 1965 substituted for the 1969 data. With the initial water content of 5.7 inches this resulted in almost a doubling of the peak flow from 10,000 cfs to about 18,000 cfs, as is shown by the middle curve of Fig. 33. Referring again to Figs. 33, 34, and 35, it can be seen that a fitted mathematical model for investigating the effect of a complete temperature sequence over a month or more is a very useful and powerful tool. Likewise, the ability to vary the initial water content of snow (or the available moisture supply) is very useful.

The SSARR and HEC-1 models are obviously of great value for spring flood forecast purposes. Tests with the NWSRFS indicate that it is an excellent tool for snow-free flood prediction; further tests with the snow accumulation and ablation routines are necessary to properly evaluate them, but they are based on sound principles and should perform well.

The advantage of the continuous synthesis models, SSARR and NWSRFS, over single event models such as HEC-1 is that they provide for continuous soil moisture evaluation; thus, when new precipitation or melt water appears, the model is equipped to evaluate possible runoff. The user of HEC-1 must evaluate the situation and input four loss rate parameters for snowmelt and loss rate and possibly four for rain loss rate. This necessitates an estimate of moisture conditions or the use of some other soil moisture index independent of the model.

V. SOIL TEMPERATURE

Throughout this study there was interest in the effect of frost depth on snowmelt floods. Baker had published an earlier work [5] on the relationship between frost depth and both snow cover and vegetation. With this work as a guide, four temperature rods were installed, two in the Minnesota River basin and two in the Twin Cities area. In the Minnesota basin, one rod was installed near Watson, Minnesota, and one near St. James, Minnesota. Figures 36 and 37 show results obtained at the two Minnesota River basin stations for the winters of 1972-73 and 1973-74, respectively. These figures demonstrate the great variability in both snow cover and soil temperature that can occur in the same year in a limited area. The figures also emphasize the problem that may be encountered in assigning a value for freezing depth that is intended to represent an area even the size of a relatively small watershed.

Figures 36 and 37 show how greatly one winter can vary from another. For example, at Watson in 1972-73, which was a winter relatively free of snow, the soil froze to a depth of almost 190 cm compared to a depth of 120 cm in 1973-74, a winter of more usual snow cover.

It should be noted that the soil temperature profile obtained at Watson in 1973-74, Fig. 37, is very much like the mean winter soil temperature picture at St. Paul that is based on ten years of data. This similarity includes not only the depth of freezing, but also the dates of freezing and thawing.

Recommendations for soil temperature measurements in the future include continuation of the measurements to determine if, for example, the long-term data at St. Paul can be used instead of very local measurements. A second recommendation is that the present St. James site be investigated to see if it should be replaced by one that more nearly represents the area.

It would be of interest to investigate local variations in temperature profile by placing a series of about six gages over about a one-square-mile area. Sites would be selected to include variations in slope, cover (especially timber), and land use. An attempt would be made to determine whether deep snow might insulate the area sufficiently to permit thawing in advance of the main melt and thereby permit infiltration of significant portions of the spring melt.

VI. SPRING RUNOFF VOLUME

In addition to the peak rate of runoff, the total volume of runoff is of interest for use in determining peak rates of flow and, possibly, runoff parameter values. Baker [5] reports the results of earlier studies on this subject. Supported in part by the project reported herein, Pabst [20] completed further work on the volume of spring runoff using a regression analysis of key parameters. The reader is referred to the Pabst thesis for details of the study. The following regression equation was developed with a correlation coefficient of 0.93:

$$\begin{aligned} \mathrm{RO} = & - 6.53 + 0.00376\ \mathrm{MDD}_N + 0.0131\ \mathrm{FDD}_N \\ & + 0.32\ \mathrm{LIQUID}_{S+O+N} \\ & + 0.0053\ \mathrm{K} - 0.34\ \mathrm{FOREST} + 0.454\ (\mathrm{TAM}) \\ & + 6.52\ \mathrm{SHAPE} \end{aligned}$$

where RO = runoff in inches

MDD_N = melting degree-days for November

FDD_N = freezing degree-days for November

$LIQUID_{S+O+N}$ = sum of rain and melt for September, October, and November

FOREST = percentage of forest cover

TAM = total available moisture (water equivalent of snowpack before melt plus additional precipitation received from the date of the water equivalent value through April 30. In effect this is the total available moisture through the winter to April 30)

SHAPE = index of basin shape = area of basin divided by square of mainstream length

K = a runoff factor used by Minnesota Highway Department in determining peak rates of runoff ($Q_p = KA^b$), where

A = area

b = exponent

Each term in the equation represents either a source of moisture or a factor controlling runoff. Table 7 gives typical values.

Table 7 -- Typical Values for Parameters in Regression Equation for 1970

Parameter	Cottonwood Watershed	Le Sueur Watershed	Dimensions
R.O.	1.01	1.23	Inches of water
MDD_N	161	152	Degree days
FDD_N	101	117	Degree days
$LIQUID_{S+O+N}$	4.46	4.69	Inches
FØREST	0 - 1.0	0 - 1.0	--
K	350	250	--
SHAPE	0.188	0.291	--
TAM	5.19	5.38	Inches of water

Figures 38 through 42 summarize the total moisture available for spring runoff in the Minnesota River basin for 1965, 1966, 1967, 1969, and 1970 and the runoff in inches and per cent. The available moisture is the sum of the water content of snow, usually about March 15, and the precipitation from the date of the snow map to April 30. In 1965 the Blue Earth River basin (Fig. 38) had available moisture of 7.16 inches, runoff of 6.78 inches, retention of 0.38 inch, and per cent runoff of 95. For the Le Sueur River for the same period, 109 per cent runoff is indicated. This 9 per cent excess of runoff over moisture supply is probably due to inaccuracies in the water-content-of-snow maps and errors in determining average precipitation. Data for other years, shown in Figs. 39 through 42, illustrate the variability of per cent runoff.

Figures 43a, b, c, and d (from Ref. [20]) show available spring moisture supply for 1965, 1966, 1967, 1969, and 1970 together with observed runoff in inches and the runoff predicted by the above equation developed by Pabst. (In 1968 there was very little snow and no appreciable flooding.) A comparison of computed and observed runoff indicates very good agreement. Referring to the regression equation, the volume of spring runoff depends on

1. Number of freezing degree-days in November
2. Number of melting degree-days in November
3. Total available moisture due to accumulated snow and spring rain through April 30
4. Sum of rain and melt for September, October, and November
5. Watershed characteristics as indicated by
    a. per cent forest cover
    b. shape
    c. peak runoff characteristics as defined by the K values in $Q = K A^b$. (A high K indicates a high runoff rate.)

The above parameters are of interest because the regression analysis has reinforced the hypothesis that spring runoff and flooding depend on

1. The number of freezing degree-days in the fall (November); this is of special interest because there is usually little snow cover in November, and considerable cold weather at this time causes deep frost penetration.

2. The number of melting degree-days in November; these would counteract item 1.

3. The total amount of rain in September, October, and November; this gives an indication of the fall soil moisture and probable density of frozen ground.

Thus, spring floods should depend on

1. The amount of frost penetration in the fall before snow accumulation provides insulation;
2. The amount of soil moisture and type of frozen ground;
3. The accumulation of snow over the winter months;
4. Ice accumulation over or under the snow due to premature thaws;
5. Temperature sequences and values during late February, March, and early April; and
6. The amount of precipitation occurring during the melt and flood runoff period.

These concepts are not new and have been expressed in general terms by river hydrologists in this area. It is of special interest that the regression equation of Pabst provides a quantitative evaluation of these concepts.

The studies with simulation models described in the first portion of the report provide a different approach to the evaluation of runoff, particularly the rate of runoff. The evaluation of the volume of runoff may be useful in the selection of parameter values for the simulation models.

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LIST OF FIGURES

Fig.
No.

Fig. No.

Appendix A

REFERENCE DATA FOR SSARR MODEL

The SSARR model was fitted to all the watersheds in the Minnesota River basin for 1965 and 1968 and to the Blue Earth and Le Sueur rivers for 1969. Of the various functions in the SSARR model, the Soil Moisture Index curve (SMI), the Baseflow Infiltration Index curve (BII), and the Surface Flow-Subsurface Flow relationship (S-SS) are the most important. Table A-1 is a list of SMI curves for the snow basin and the rain basin at all the watersheds in the Minnesota River basin. Figure A-1 shows SMI curves for the snow basin, and Figs. A-2 through A-4 those for the rain basin, for 1965. Table A-2 is a list of BII curves for the snow and rain basins for all the watersheds in the Minnesota River basin. Figures A-5 and A-6 show BII curves for the snow basin and the rain basin, respectively, for 1965.

The SSARR model was also fitted to the Blue Earth and Le Sueur river watersheds for the snowmelt period of 1969. Figures A-7 and A-8 illustrate SMI curves of the SSARR model for the Blue Earth River and the Le Sueur River, respectively, for 1969. For surface-subsurface flow separation, Fig. 6 in the body of the report (Table 8005) was used for all Minnesota River basin runs (1965, 1968, and 1969). In 1968, the runoff from snowmelt was negligible compared with runoff from rainfall, and therefore snowmelt was not computed for that year; the model was fitted for the summer floods. Table A-3 is a list of SMI and BII curves of the SSARR model for 1968 runs. Figure A-9 shows SMI curves and Fig. A-10 shows BII curves. Figure A-11 illustrates typical input information for a SSARR run for 1965 exclusive of actual weather and runoff data.

Table A-1 -- List of SMI Curves for the SSARR Model for 1965

Basin No.	Watershed	Rain Basin	Snow Basin
1	Little Minnesota River	8201	9201
2	Whetstone River	8202	9202
4	Yellow Bank River	8204	9204
5	Pomme de Terre River	8205	9205
6	Lac qui Parle River	8206	9206
7	Chippewa River	8287	8287
9	Yellow Medicine River	8209	9209
10	Redwood River	8210	9210
11	Cottonwood River	8211	9211
12	Blue Earth River	8212	9212
13	Le Sueur River	8213	9213

Table A-2 -- List of BII Curves for the SSARR Model for 1965

Basin No.	Watershed	Rain Basin	Snow Basin
1	Little Minnesota River	8327	8329
2	Whetstone River	8326	8328
3	Drainage Basin Three	8326	8328
4	Yellow Bank River	8326	8328
5	Pomme de Terre River	8326	8328
6	Lac qui Parle River	8327	8329
7	Chippewa River	8326	8325
8	Drainage Basin Eight	8326	8328
9	Yellow Medicine River	8327	8329
10	Redwood River	8326	8328
11	Cottonwood River	8326	8324
12	Blue Earth River	8327	8329
13	Le Sueur River	8326	8328
14	Drainage Basin 14	8327	8329
15	Drainage Basin 15	8326	8328

Table A-3 -- List of SMI and BII Curves for the SSARR Model for 1968

Basin No.	Watershed	SMI	BII
1	Little Minnesota River	8202	8327
2	Whetstone River	8203	8326
3	Drainage Basin Three	8203	8326
4	Yellow Bank River	8203	8326
5	Pomme de Terre River	8203	8326
6	Lac qui Parle River	8203	8327
7	Chippewa River	8203	8326
8	Drainage Basin Eight	8203	8326
9	Yellow Medicine River	8202	8327
10	Redwood River	8202	8326
11	Cottonwood River	8201	8326
12	Blue Earth River	8201	8327
13	Le Sueur River	8208	8326
14	Drainage Basin 14	8201	8327
15	Drainage Basin 15	8201	8326

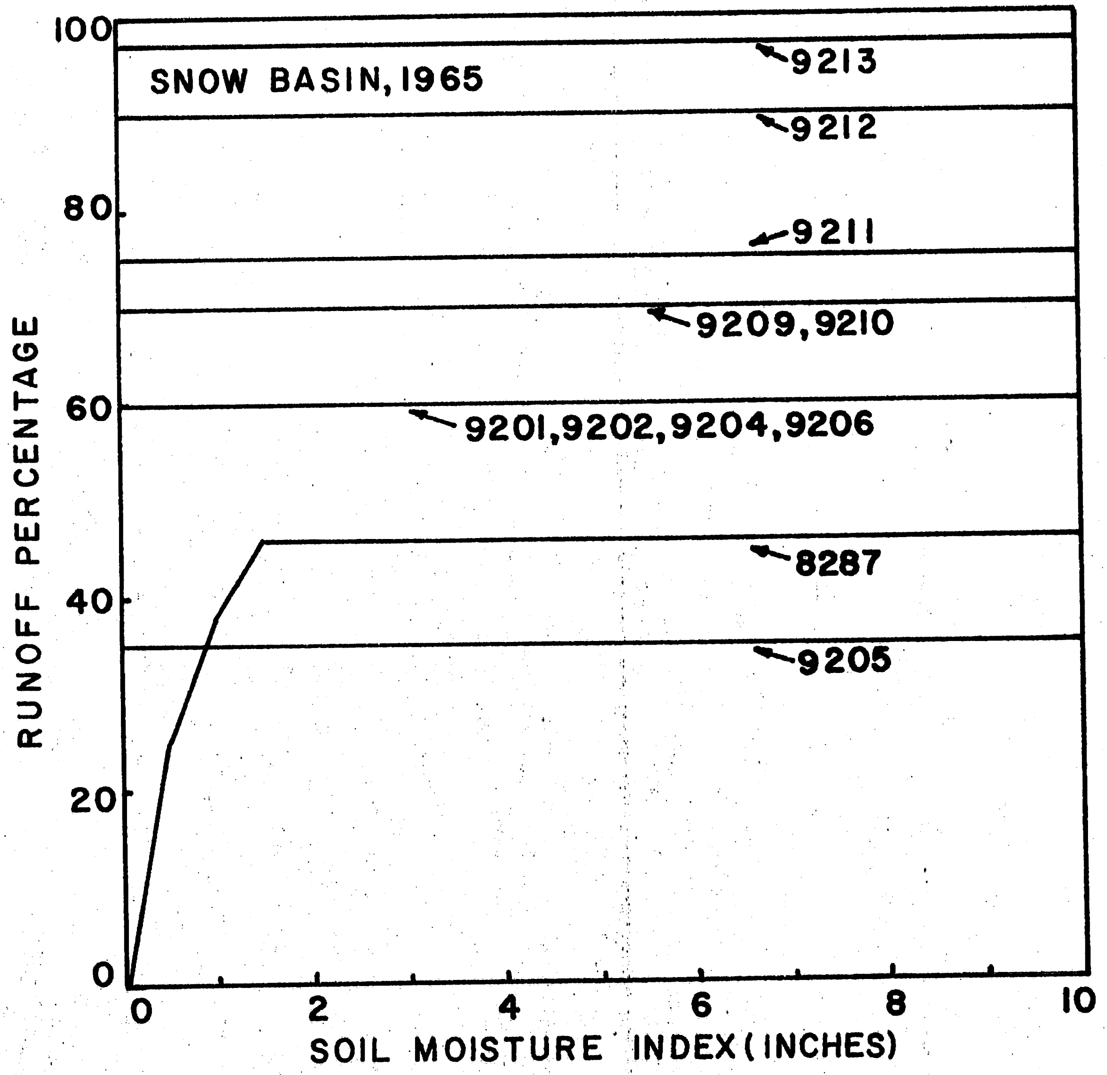

Fig. A-1 - Actual Relationships between Soil Moisture Index and Runoff Percentage for the SSARR Model (Refer to Table A-1)

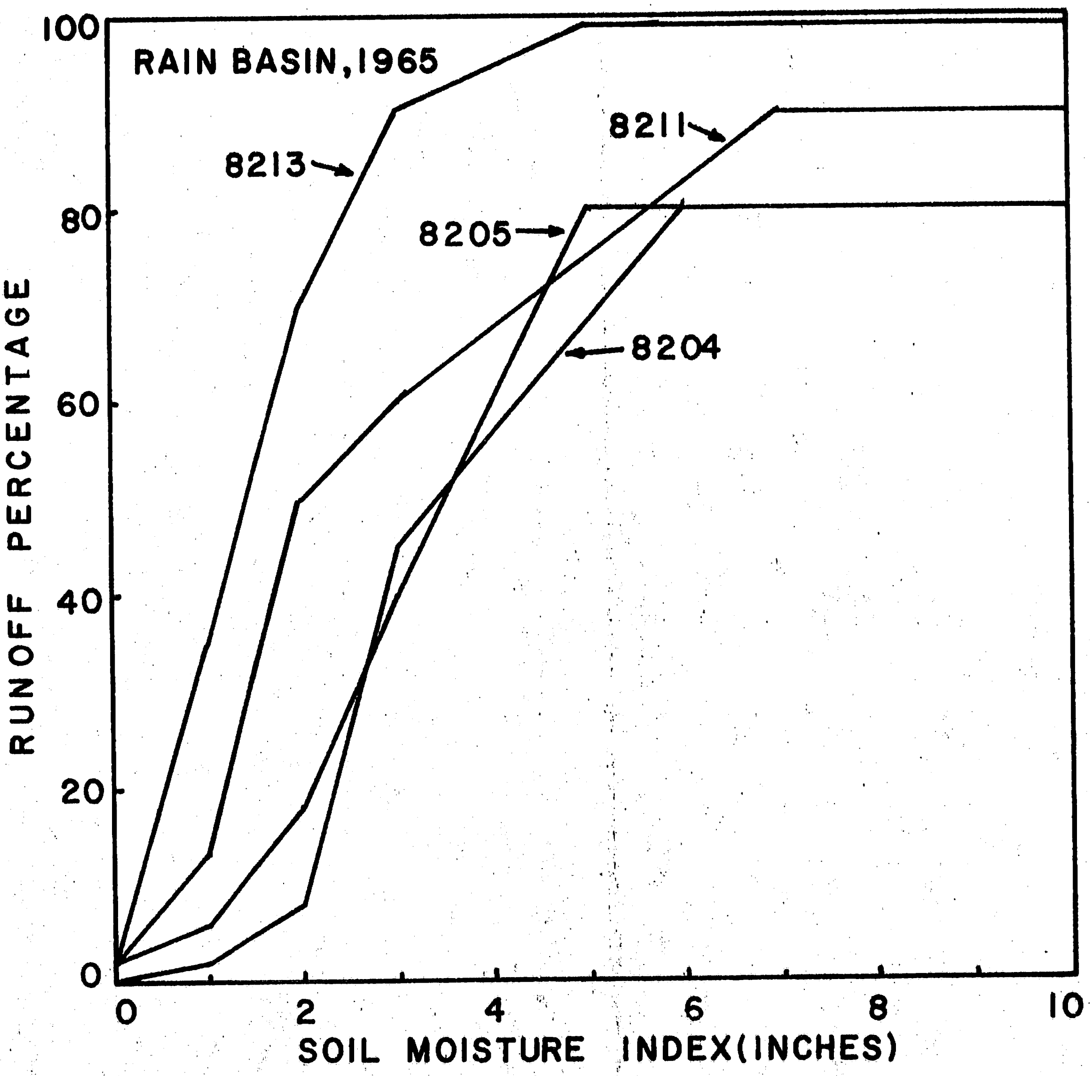

Fig. A-2 - Actual Relationships between Soil Moisture Index and Runoff Percentage for the SSARR Model (Refer to Table A-1)

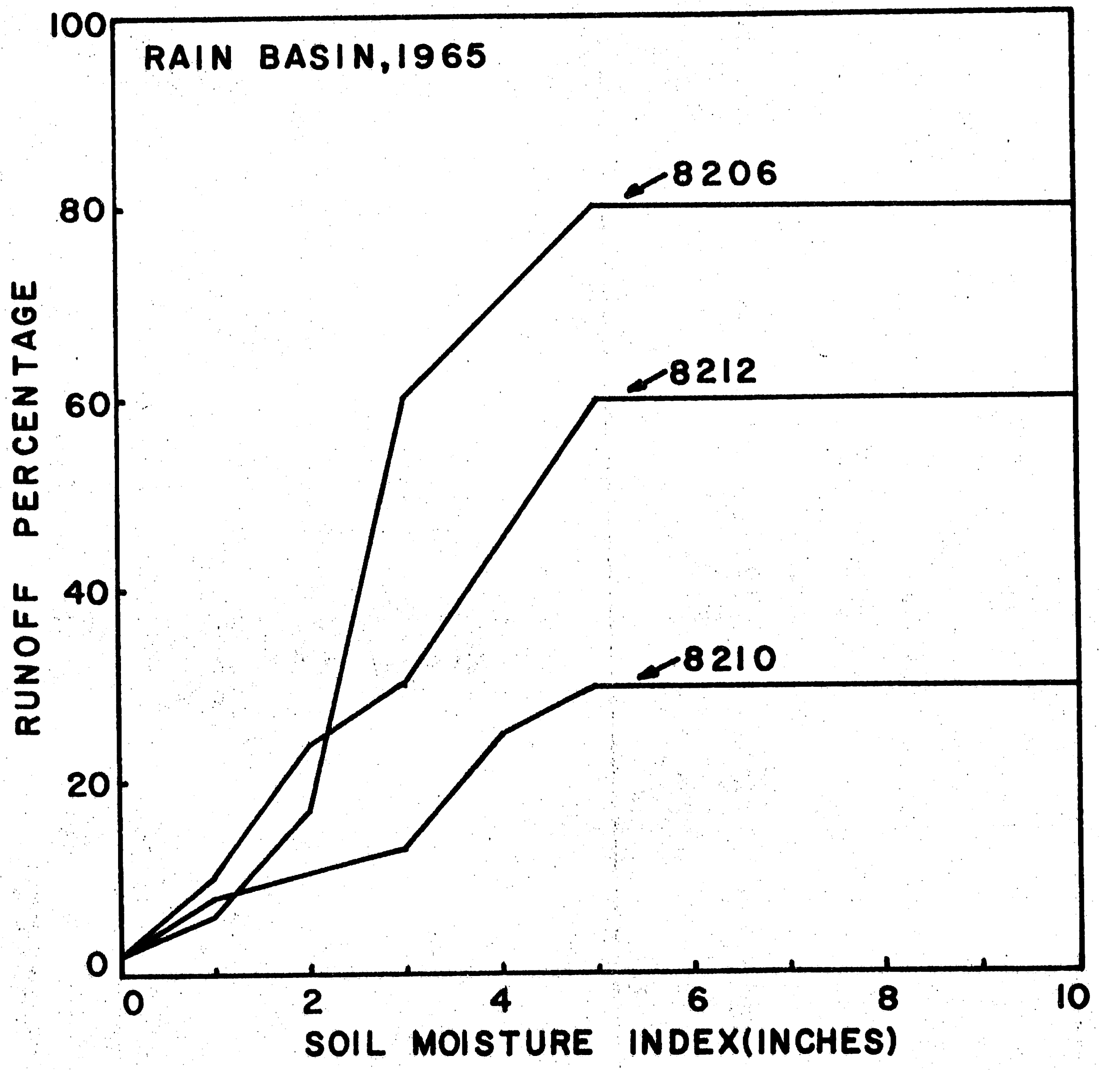

Fig. A-3 - Actual Relationships between Soil Moisture Index and Runoff Percentage for the SSARR Model (Refer to Table A-1)

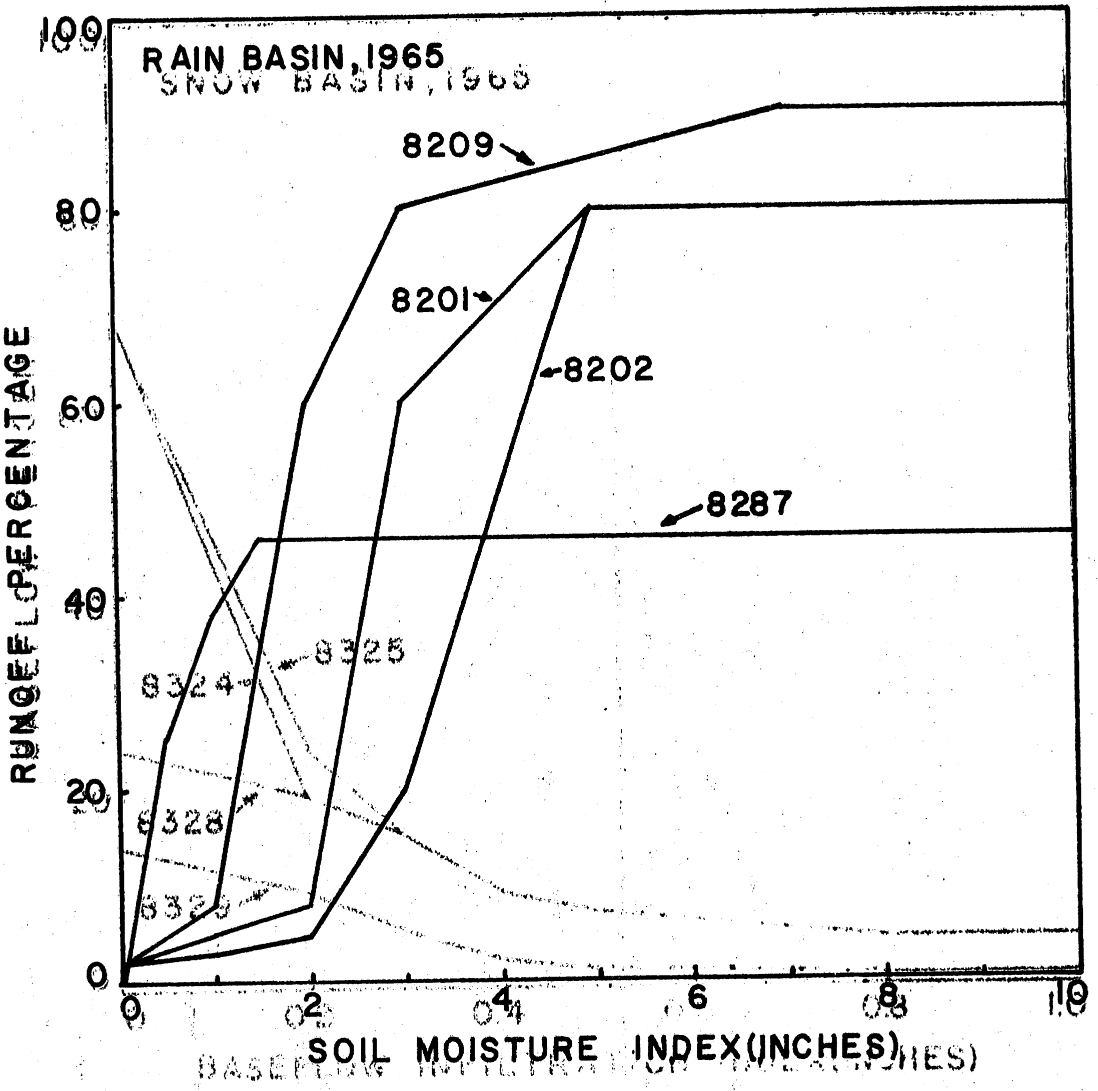

Fig. A-4 - Actual Relationships between Soil Moisture Index and Runoff Percentage for the SSARR Model (Refer to Table A-1)

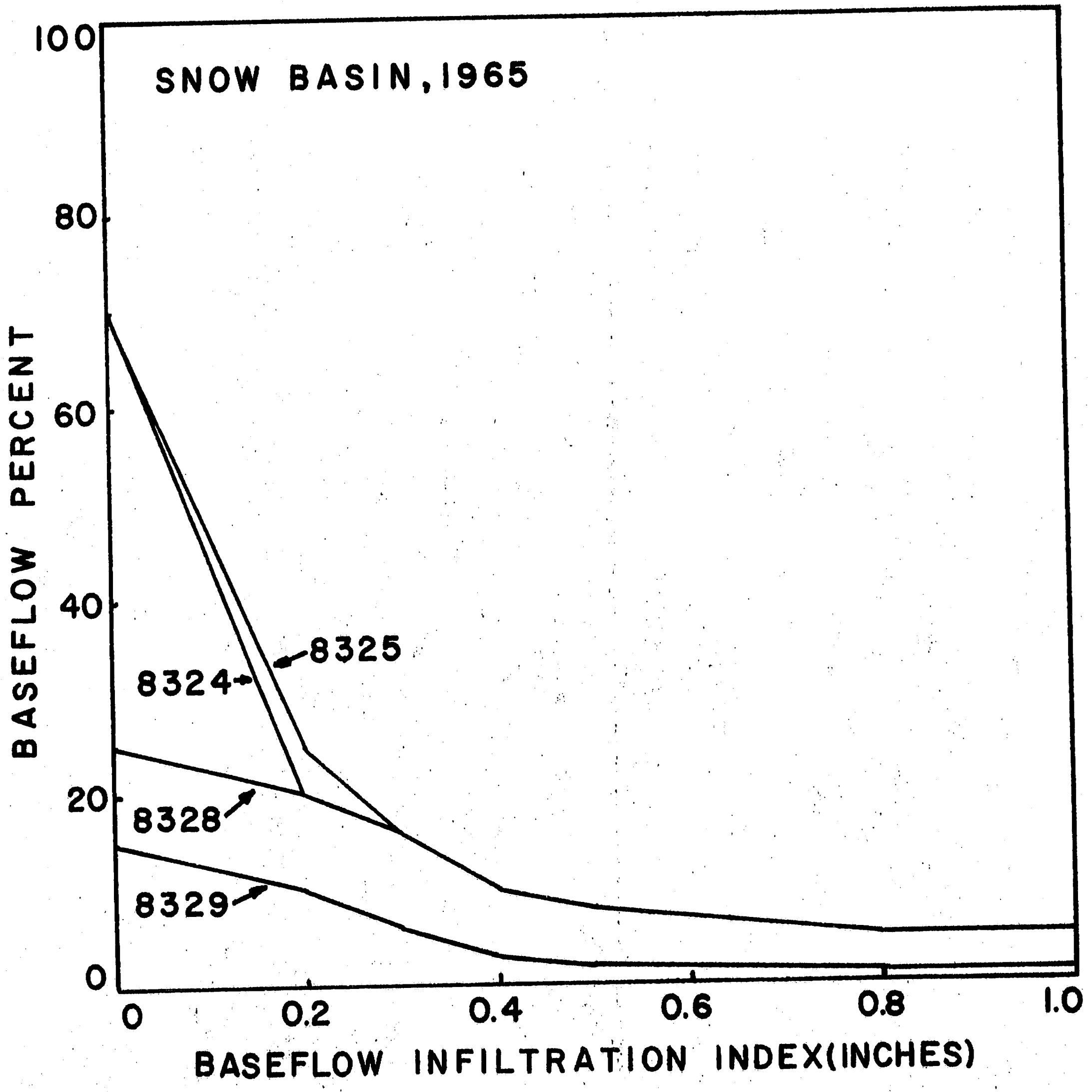

Fig. A-5 - Actual Relationships giving the Percentage of the Total Runoff which will become Baseflow as a function of Baseflow Infiltration Index for the Minnesota River Basin (Snow Basin, 1965)

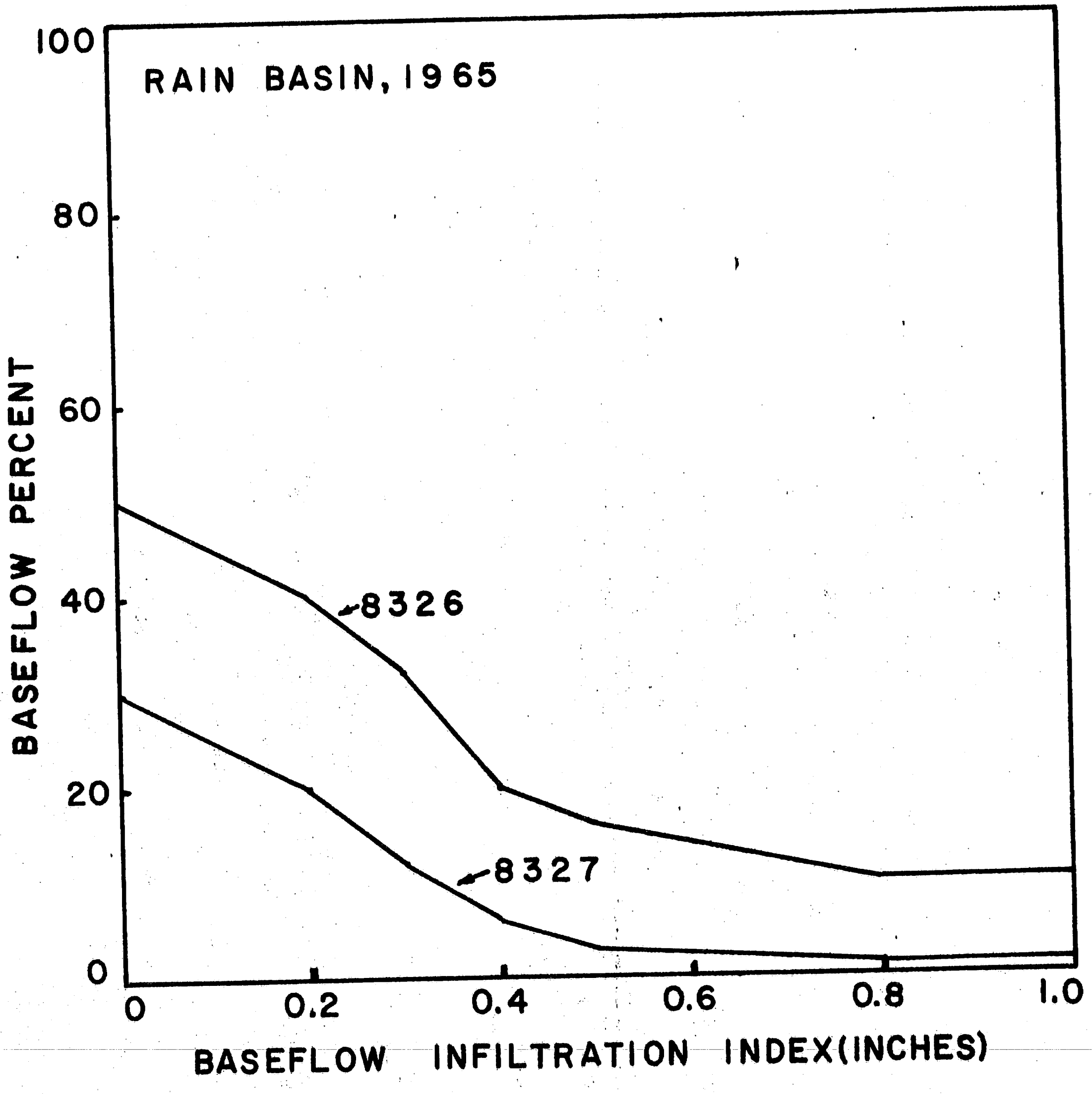

Fig. A-6 - Actual Relationships giving the Percentage of the Total Runoff which will become Baseflow as a function of Baseflow Infiltration Index for the Minnesota River Basin (Rain Basin, 1965)

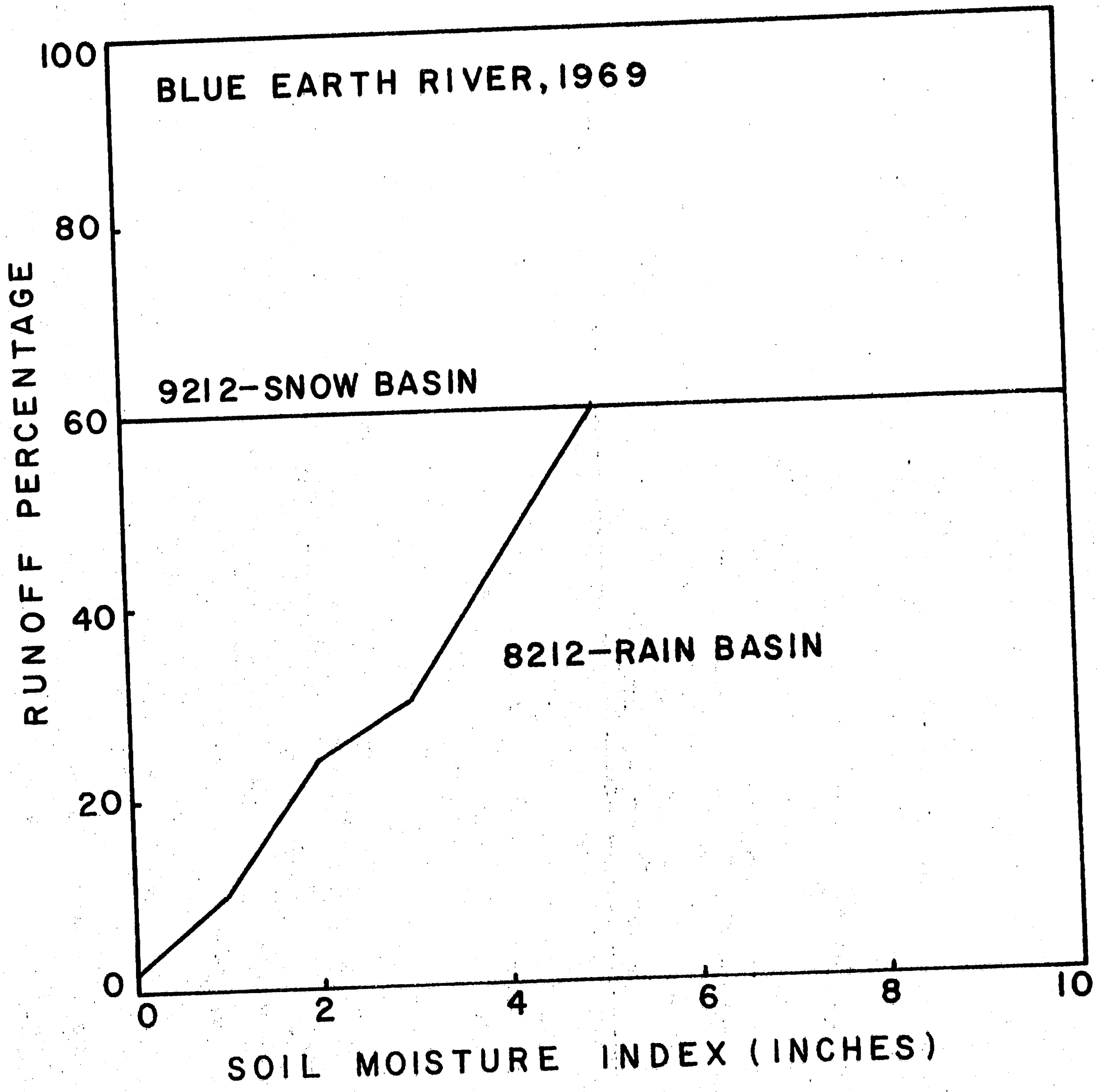

Fig. A-7 – Actual Relationship between Soil Moisture Index and Runoff Percentage for 1969 for the Blue Earth River Basin

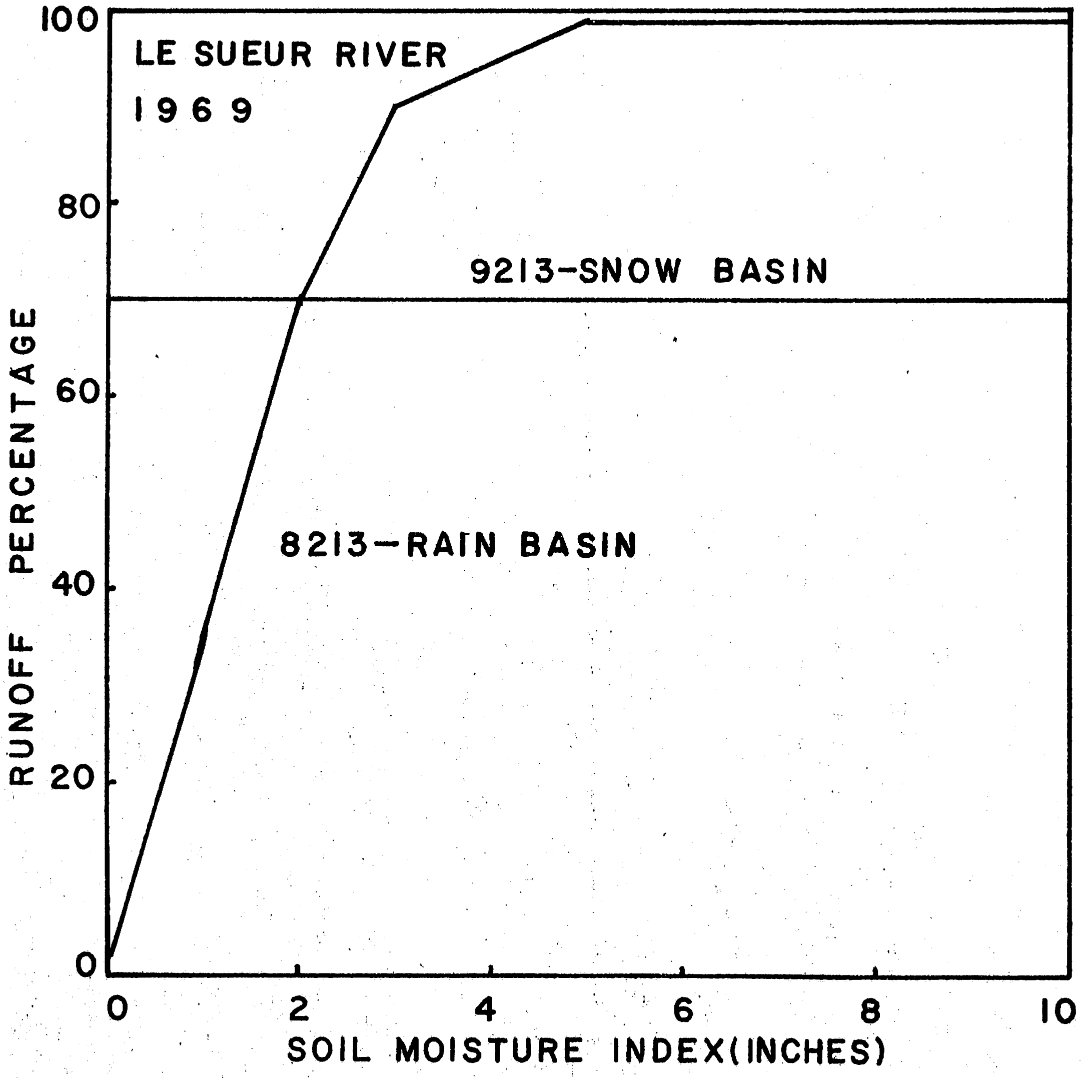

Fig. A-8 - Actual Relationship between Soil Moisture Index and Runoff Percentage for 1969 for the Le Sueur River Basin

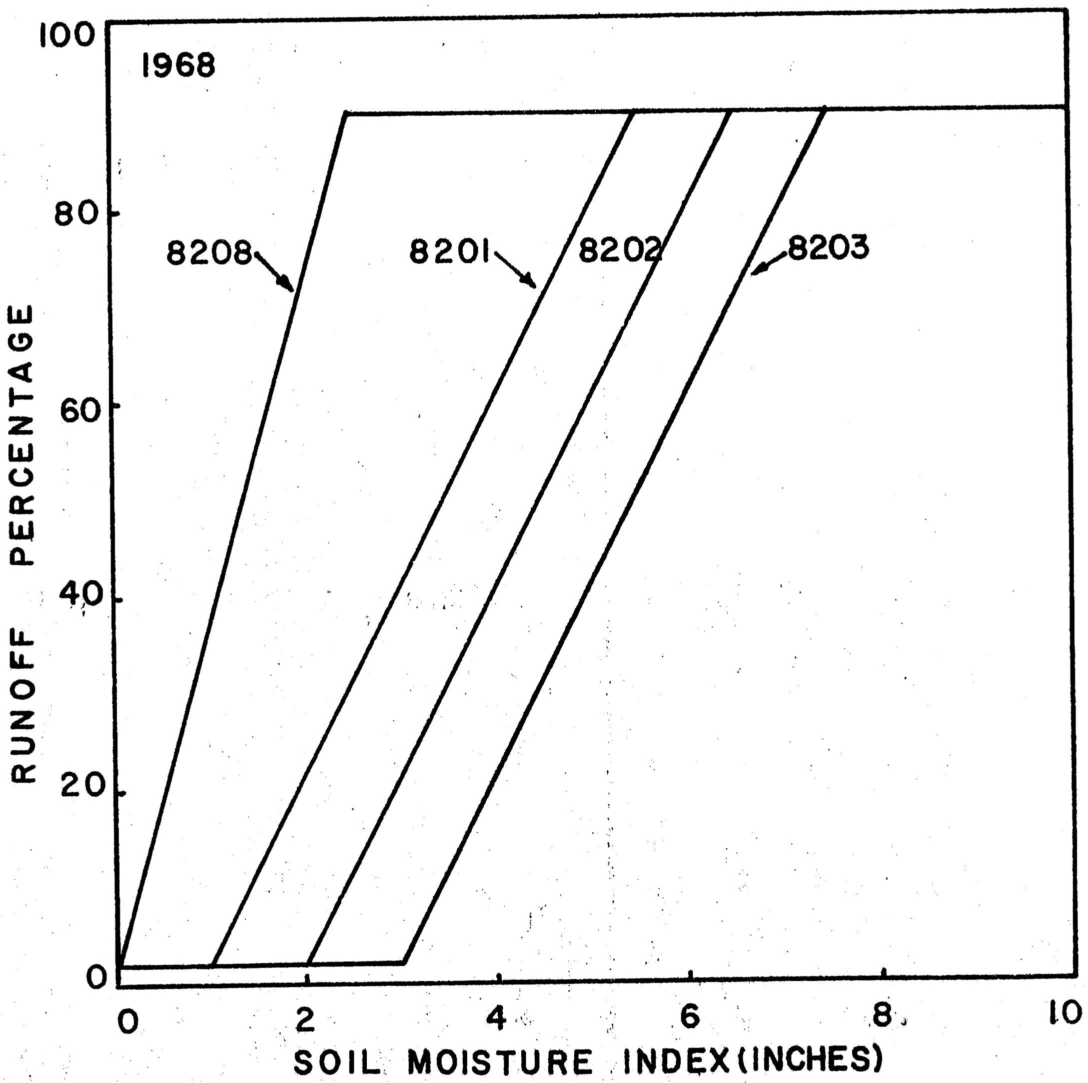

Fig. A-9 – Relationship between Soil Moisture Index and Runoff Percentage for 1968

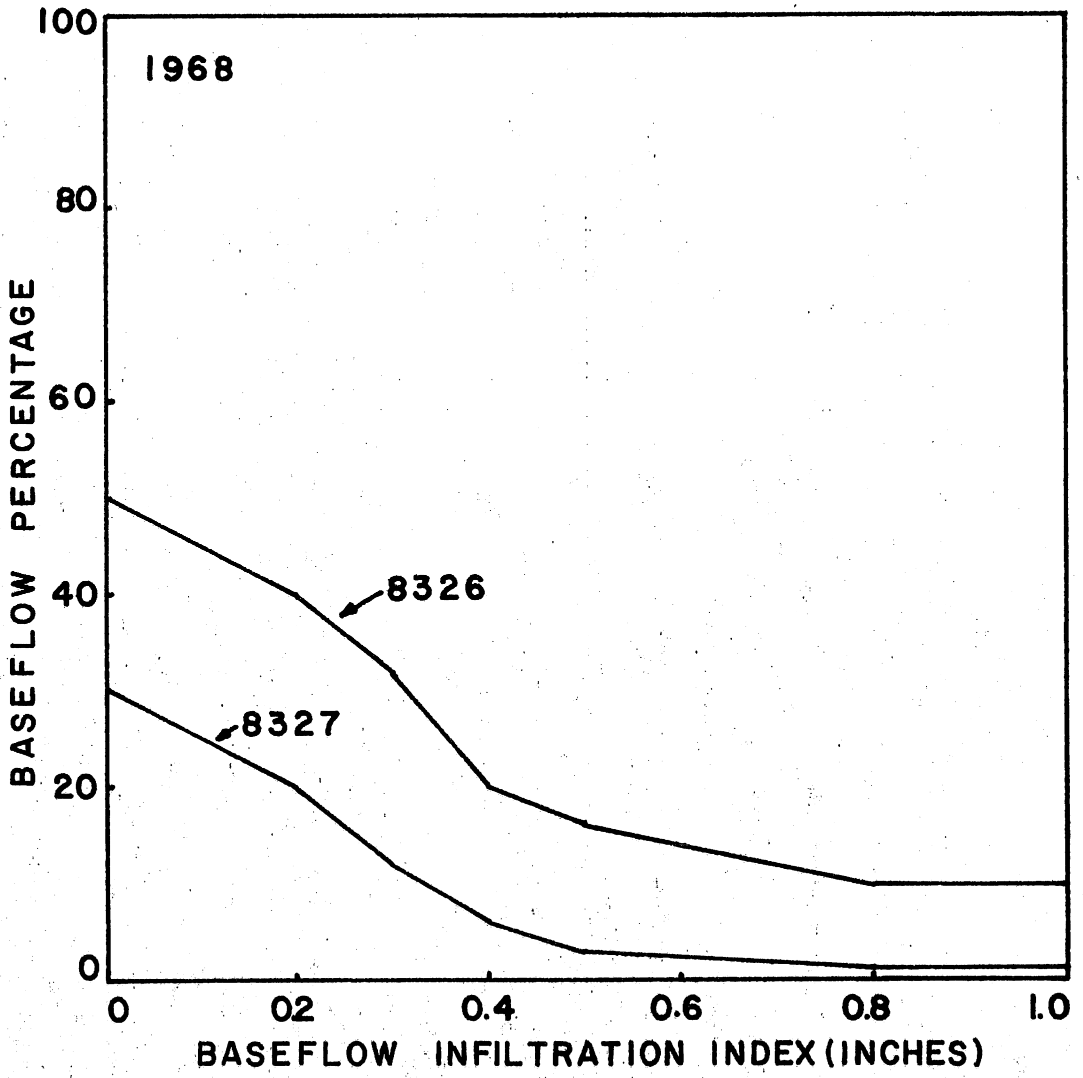

Fig. A-10 – Relationships Giving the Percentage of the Total Runoff which will become Baseflow as a function of Baseflow Infiltration for 1968

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```
CB 1      1          1 2       LITTLE MINNESOTA RIVER SNOW
CB 2      1      4474 6004  6002 3000  75008400881399998l019201
CB 3      1       8329  1008005                          8907            32 32
CB 4      1       4 6011003 5011009 601100
C3        1      990      1010  998999999999999
CB 1     51          1 2       LITTLE MINNESOTA RIVER RAIN
CB 2     51      4474 4004  4002 3000  75008400             81018201
CB 3     51       8327  1008005
CB 4     51       3 50110029999100
CC 1     21          1 2       LITTLE MINNESOTA RIVER TOTAL
CB 1      2          1 2       WHETSTONE RIVER SNOW
CB 2      2      3899 1509  1502 2500  75008400881399998l019202
CB 3      2       8328  1008005                          8907            32 32
CB 4      2       4 6021003 5021009 602100
C3        2      990      1010  998999999999999
CB 1     52          1 2       WHETSTONE RIVER RAIN
CB 2     52      3893 1503  1502 2500  75008400             81018202
CB 3     52       8326  1008005
CB 4     52       3 50210029999100
CC 1     22          1 2       WHETSTONE RIVER TOTAL
CB 1      3          1 2       DRAINAGE BASIN THREE SNOW
CB 2      3      3249 1509  1502 2500  75008400881399998l019203
CB 3      3       8328  1008005                          8907            32 32
CB 4      3       4 6031003 5031009 603100
C3        3      990      1010  998999999999999
CB 1     53          1 2       DRAINAGE BASIN THREE RAIN
CB 2     53      3243 1503  1502 2500  75008400             81018203
CB 3     53       8326  1008005
CB 4     53       3 50310029999100
CC 1     23          1 2       DRAINAGE BASIN THREE TOTAL
CC 1     71          1 2       COMBINED LITTLE MINN., WHETSTONE AND BASIN 3
CR01     11          1 2       LITTLE MINN., WHETSTONE, 3 ROUTED TO BIG STONE
CR02     11                4 2    27
CL01     31          1 2       BIG STONE LAKE
CL02     31                               9720   9473
C101     31   4   9473     00     00      20000   960      00      00      42000
C102     31   4   9627     00     00      73000   9637     32      35      85000
C103     31   4   966      88     40     113500   967     124      45     126500
C104     31   4   968     170     50     139500   969     225      60     153000
C105     31   4   970     280     70     166500   971     349      80     181000
C106     31   4   972     434     90     19550099999  9999999999999999999999
CP01     12          1 2       MINN. RIVER ROUTED TO CC 72
CR02     12                4 2    27
CB 1      4          1 2       YELLOW BANK RIVER SNOW
CB 2      4      3986 1506  1502 1000  75008400881399998l019204
CB 3      4       8328  1008005                          8907            32 32
CB 4      4       4 6061003 5041009 606100
C3        4      990      1010  998999999999999
CB 1     54          1 2       YELLOW BANK RIVER RAIN
CB 2     54      3986 1006  1002  400  75008400             81018204
CB 3     54       8326  1008005
CB 4     54       3 50410029999100
CC 1     24          1 2       YELLOW BANK RIVER TOTAL
CB 1      5          1 2       POMME DE TERRE RIVER SNOW
CB 2      5      9052 9002  900210000  75008400881399998l019205
CB 3      5       8328  1008005                          8907            32 32
CB 4      5       4 6051003 5051009 605100
C3        5      990      1010  998999999999999
CB 1     55          1 2       POMME DE TERRE RIVER RAIN
CB 2     55      9052 4502  4502 2000  75008400             81018205
CB 3     55       8326  1008005
CB 4     55       3 50510029999100
CC 1     25          1 2       POMME DE TERRE RIVER TOTAL
CB 1      6          1 2       LAC QUI PARLE RIVER SNOW
CB 2      6      9838 1508  1504  800  75008400881399998l019206
CB 3      6       8329  1008005                          8907            32 32
```

Fig. A-11a - Input Information for the SSARR Model for 1965, All Watersheds in the Minnesota River Basin

563059

```
CB 4      6          4 6061003 5061009 606100
C3        6       990       1010  998999999999999
CB 1     56            1 2        LAC QUI PARLE RIVER RAIN
CB 2     56        9838 1008  1004  800  75008400          81018206
CB 3     56         8327  1008005
CB 4     56         3 5061002999100
CC 1     26            1 2        LAC QUI PARLE RIVER TOTAL
CB 1      7            1 2        CHIPPEWA RIVER SNOW
CB 2      7       18708 2208  2404 3200  7500840088139999981018287
                                                                       34 34
CB 3      7         8325  10080051    1
CB 4      7         4 6071003 5071005492210054925100549261007492610084922100
CB 5      7         8492510084926100б 907100
C3        7       990       1010  998999999999999
CB 1     57            1 2        CHIPPEWA RIVER RAIN
CB 2     57       18708 2208  2404 3200  75008400          81018287
CB 3     57         8326  1008005
CB 4     57         3 5071002999100
CC 1     27            1 2        CHIPPEWA RIVER TOTAL
CC 1      72           1 2        COMBINED ROUTE 12 AND BASINS 4, 5, 6, 7
CR01      13           1 2        72 ROUTED TO LAC QUI PARLE RESERVOIR
                             4 2     27
CR02      13           1 2        LAC QUI PARLE RESERVOIR
CL01      33                                950     923
CL02      33   4   923       00      00     20000  934       00     00     113500
CI01      33   4   935      360      35    133000  936      450     45     154500
CI02      33   4   937      560      60    177500  938      720     70     201000
CI03      33   4   939      890      85    227000  940     1100     95     255000
CI04      33   4   941     1320     120    285000  942     2100    140     316000
CI05      33   4   943     3450     165    34700099999  9999999999999999999999
CI06      33           1 2        MINN. RIVER ROUTED TO MONTEVIDEO(CC 74)
CR01      15                 4 2     27
CR02      15           1 2        DRAINAGE BASIN EIGHT SNOW
CB 1      8         8642 9002  900210000  7500840088139999981019208
                                                       8907            32 32
CB 2      8         8328  1008005
CB 3      8         4 6081003 5081009 608100
CB 4      8       990       1010  998999999999999
C3        8            1 2        DRAINAGE BASIN EIGHT RAIN
CB 1     58         8642 4502  4502 2000  75008400          81018208
CB 2     58         8326  1008005
CB 3     58         3 5081002999100
CB 4     58            1 2        DRAINAGE BASIN EIGHT TOTAL
CC 1     28            1 2        COMBINED BASIN 8, ROUTE 15
CC 1      73           1 2        MINN. RIVER ROUTED TO GRANITE FALLS
CR01      16                 4 2     27
CR02      16           1 2        YELLOW MEDICINE RIVER SNOW
CB 1      9         6539 1209  1202  700  7500840088139999981019209
                                                       8907            32 32
CB 2      9         8329  1008005
CB 3      9         4 6091003 5091009 609100
CB 4      9       990       1010  998999999999999
C3        9            1 2        YELLOW MEDICINE RIVER RAIN
CB 1     59         6539 1209  1202  700  75008400          81018209
CB 2     59         8327  1008005
CB 3     59         3 5091002999100
CB 4     59            1 2        YELLOW MEDICINE RIVER TOTAL
CC 1     29            1 2        COMBINED YELLOW MEDICINE, ROUTE 16
CC 1      74           1 2        MINN. RIVER ROUTED TO REDWOOD FALLS
CR01      17                 4 2     27
CR02      17           1 2        REDWOOD RIVER SNOW
CB 1     10        10042 4002  4002 1600  7500840088139999981019210
                                                       8907            32 32
CB 2     10         8328  1008005
CB 3     10         4 6101003 5101009 610100
CB 4     10       990       1010  998999999999999
C3       10            1 2        REDWOOD RIVER RAIN
CB 1     60        10042 5002  5002 1600  75008400          81018210
CB 2     60         8326  1008005
CB 3     60
```

Fig. A-11b - Input Information for the SSARR Model for 1965, All Watersheds in the Minnesota River Basin [continued]

563060

```
CC 1    30         1 2          REDWOOD RIVER TOTAL
CC 1     75        1 2          COMBINED REDWOOD. ROUTE 17
CR01     18        1 2          MINN. RIVER ROUTED TO NEW ULM
CR02     18              4 2     27
CB 1    11         1 2          COTTONWOOD RIVER SNOW
CB 2    11      12808 1008  1004 2000  75008400881399998101921l
CB 3    11        8328  10080051    1      5                         32 32
CB 4    11        4 6111003 5111005492210054925100549261007492610084922100
CB 5    11        6492510084926l006 907100
C3      11      990       1010  998999999999999
CB 1    61         1 2          COTTONWOOD RIVER RAIN
CB 2    61      12808 1008  1004 2000  75008400           81018211
CB 3    61        8326  1008005
CB04    61        3 51110029999100
CC 1    31         1 2          COTTONWOOD RIVER TOTAL
CC 1     76        1 2          COMBINED COTTONWOOD, ROUTE 18
CR01     19        1 2          MINN. RIVER ROUTED TO JUN OF MINN,BLUE ERATH
CR02     19              7 2     27
CB 1    12         1 2          BLUE EARTH RIVER SNOW
CB 2    12      24307 1008  1504 2500  7500840088139999810l9212
CB 3    12        8329  100800510001000000                           32 32
CB 4    12        4 6121003 512100           54925100749261008492510O6 907100
C3      12      990       1010  998999999999999
CB 1    62         1 2          BLUE EARTH RIVER RAIN
CB 2    62      24307 1008  1504 4000  75008400           81018212
CB 3    62        8327  1008005
CB 4    62        3 51210029999100
CC 1    32         1 2          BLUE EARTH RIVER TOTAL
CB 1    13         1 2          LE SUEUR RIVER SNOW
CB 2    13      11005 1005  1002 1000  750084008813999981019216
CB 3    13        8328  100800510001000000                           32 32
CB 4    13        4 6131003 51310054925100         7492610084925l006 907100
C3      13      990       1010  998999999999999
CB 1    63         1 2          LE SUEUR RIVER RAIN
CB 2    63      11005 2005  2002 1000  75008400           81018213
CB 3    63        8326  1008005
CB 4    63        3 51310029999100
CC 1    33         1 2          LE SUEUR RIVER TOTAL
CC 1     77        1 2          COMBINED BLUE EARTH, LE SUEUR, ROUTE 19
CR01     51        1 2          MINN. RIVER ROUTED TO MANKATO
CR02     51              7 2     27
CB 1    14         1 2          DRAINAGE BASIN FOURTEEN SNOW
CB 2    14      21212 6002  600225000  750084008813999981019214
CB 3    14        8329  100800510001000000                           32 32
CB 4    14        4 6141003 514100           549251007492610084925l006 907100
C3      14      990       1010  998999999999999
CB 1    64         1 2          DRAINAGE BASIN FOURTEEN RAIN
CB 2    64      21212 6002  6002 4500  75008400           81018214
CB 3    64        8327  1008005
CB 4    64        3 51410029999100
CC 1    34         1 2          DRAINAGE BASIN FOURTEEN TOTAL
CC 1     78        1 2          COMBINED BASIN 14, ROUTE 51
CR01     52        1 2          MINN. RIVER ROUTED TO JORDAN
CR02     52              8 2     27
CB 1    15         1 2          DRAINAGE BASIN FIFTEEN SNOW
CB 2    15      13008 1208  1202 2000  750084008813999981019215
CB 3    15        8328  100800510001000000                           32 32
CB 4    15        4 6151003 515100           549251007492610084925l006 907100
C3      15      990       1010  998999999999999
CB 1    65         1 2          DRAINAGE BASIN FIFTEEN RAIN
CB 2    65      13008 1208  1202 2000  75008400           81018215
CB 3    65        8326  1008005
CB 4    65        3 51510029999100
CC 1    35         1 2          DRAINAGE BASIN FIFTEEN TOTAL
CC 1     61        1 2          COMBINED BASIN 15, ROUTE 52
CC 1 5290000       1 2          OBSERVED FLOW OF LITTLF MINNFSOTA
```

Fig. A-11c - Input Information for the SSARR Model for 1965, All Watersheds in the Minnesota River Basin [continued]

Appendix B

REFERENCE DATA FOR HEC-1 MODEL

Table B-1 shows actual values of optimized parameters in the HEC-1 model for three different flood events, two in 1967 and one in 1965. The model was fitted to 11 of the 15 watersheds in the Minnesota River basin. The events of April 1965 and March 1967 were snowmelt-plus-rain floods, requiring ten parameters. The event of June 1967 was a rain flood, requiring only six parameters.

Table B-1 -- Actual Values of the Parameters in the HEC-1 Model for Three Flood Events

	Little Minnesota	Whetstone River	Yellow Bank River	Pomme de Terre River	Lac qui Parle River	Chippewa River	Yellow Medicine River	Redwood River	Cottonwood River	Blue Earth River	Le Sueur River
Basin No.	1	2	4	5	6	7	9	10	11	12	13
Area	447	389	398	905	983	1870	653	1004	1280	2430	1100
					April 1965						
T_c	203.00	66.00	24.00	102.00	128.00	27.00	57.00	39.00	44.00	27.00	25.00
R	90.00	68.00	30.00	198.50	99.00	178.00	104.00	108.00	66.00	97.00	29.00
COEF	0.06	0.12	0.10	0.03	0.06	0.10	0.08	0.16	0.10	0.14	0.08
STRKR	0.45	0.32	0.38	0.31	0.34	0.29	0.45	0.45	0.27	0.17	0.27
STRKS	0.25	0.21	0.15	0.23	0.15	0.22	0.09	0.20	0.13	0.04	0.01
RTI0K	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
ERAIN	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
FRZTP	34.00	30.00	32.00	32.00	30.00	34.00	33.00	34.00	32.00	31.50	30.00
DLTKR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RTIOL	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

March 1967

T_c	106.70	58.76	24.72	27.08	94.47	33.33	71.79	74.49	33.60	59.16	62.78
R	62.51	225.28	103.37	217.88	82.60	177.61	150.99	183.59	84.22	158.83	189.30
COEF	0.05	0.07	0.04	0.07	0.05	0.05	0.04	0.07	0.07	0.07	0.15
STRKR	0.32	0.31	0.25	0.25	0.27	0.21	0.29	0.42	0.26	0.32	0.24
STRKS	0.23	0.17	0.11	0.19	0.25	0.21	0.21	0.24	0.21	0.13	0.10
RTIOK	1.00	0.90	1.00	1.00	1.00	1.00	0.80	1.00	0.90	1.00	0.90
ERAIN	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
FRZTP	35.60	35.59	33.37	32.29	38.00	31.92	37.85	33.53	34.12	33.64	33.33
DLTKR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RTI0L	1.00	0.90	1.00	1.00	1.00	1.00	0.80	1.00	0.90	1.00	0.90

June 1967

T_c	184.38	54.08	79.17	64.91	62.61	107.66	153.57	62.88	170.49	176.13	150.00
R	52.67	53.11	25.98	136.24	172.86	203.93	74.24	94.85	80.68	148.48	60.00
STRKR	0.12	0.30	0.39	0.63	0.56	0.35	0.35	0.36	0.34	0.23	0.19
ERAIN	0.49	0.62	0.70	0.90	0.80	0.70	0.70	0.70	0.70	0.70	0.70
DLTKR	0.34	0.88	1.36	1.30	1.38	0.98	0.81	1.90	1.20	1.80	3.26
RTI0L	1.08	2.34	2.16	1.10	1.96	2.03	2.24	1.20	1.09	1.00	2.55

Appendix C

REFERENCE DATA FOR NWSRFS

Table C-1 lists the 26 parameters or variables in the National Weather Service River Forecast System and shows the typical range of the parameters and the step-by-step variation of the parameters as NWSRFS3 and NWSRFS4 are alternated in the development of optimized values of some parameters for the Le Sueur River watershed (1968) (column 12). Table C-2 lists the parameters by function:

1. Soil moisture volume parameters (9)
2. Evapotranspiration parameters (5)
3. Soil moisture timing parameters (5)
4. Soil moisture initial condition parameters (7)

Also shown are the optimum values for the Le Sueur River in 1967 and 1968.

Figures C-1 and C-2 show input information for NWSRFS4 and NWSRFS5, respectively. Data such as precipitation and temperature were read in from disk storage and cards, but would normally come from tape. Figure C-3 is a program written at the University of Minnesota to handle data from random access disk storage and cards. Figure C-4 is a program for punching evaporation data for use with NWSRFS.

Table C-1 -- NWSRFS Parameters, Le Sueur River Watershed, April 1968 through November 1968

Parameter No.	Parameter	Units	Typical Range	NWSRFS4 Initial guess	NWSRFS3 Optimization		NWSRFS3 Sensitivity Analysis		NWSRFS3 Optimization		NWSRFS4
					Input	Output	Input	Output	Input	Output	
1	UZSN	Inches	.05-1.25	0.6	0.6	0.428	0.428	0.320	0.320	0.1716	0.1716
2	LZSN	Inches	4-10	7.0	7.0	6.31	6.31	4.00	4.00	3.607	3.607
3	CB	Inches/hour	.05-.75	0.4	0.4	0.46	0.46	0.26	0.26	0.440	0.440
4	POWER	(none)	.5-3.0	1.75	1.75	2.111	2.111	3.00	3.00	1.607	1.607
5	CC	(none)	.25-1.25	0.75	0.75	0.905	0.905	0.905	0.905	0.905	0.905
6	KV	(none)	.7-5	3.0	3.0	2.705	2.705	4.00	4.00	2.998	2.998
7	KGS	(none)	.85-.97	0.91	0.91	0.892	0.892	0.892	0.892	0.844	0.844
*8	K24EL	Per cent	0-0.20	0	0	0	0	0	0	0	0
***9	A	Per cent	---	0.03	0.03	0.039	0.039	0.059	0.059	0.0218	0.0218
10	K24L	Per cent	0-0.20	0.1	0.1	0.0537	0.0537	0.070	0.070	0.114	0.114
11	EPXM	Inches	.1-.5	0.3	0.3	0.214	0.214	0.114	0.114	0.0572	0.0572
*12	K1(1)	(none)	=1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
*13	K1(2)	(none)	---	---	---	---	---	---	---	---	---
*14	PEADJ(1)	(none)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.447	1.447
*15	PEADJ(2)	(none)	---	---	---	---	---	---	---	---	---
*16	K3	Inches	.28	0.28	0.28	0.28	0.28	0.18	0.18	0.1575	0.1575
*17	SRC1	Per cent	.9	0.9	0.9	0.9	0.9	1.30	1.30	0.3094	0.3094
*18	LIRC6	Per cent	.1	0.1	0.1	0.1	0.1	0.15	0.15	0.1136	0.1136
***19	LKK6	Per cent	Formula	0.05	0.05	0.05	0.05	0.0325	0.0325	0.0308	0.0308
***20	CSSR	(none)	Formula	0.5	0.5	0.5	0.5	0.50	0.50	0.50	0.50
21	HWARP	(none)	Start = 1.0	1.0	1.0	1.077	1.077	1.0	1.0	1.0	1.0
22	VWARP	(none)		1.0	1.0	0.8059	0.8059	1.0	1.0	1.0	1.0
**47	EHIGH	(none)	.9-1.2	1.0	1.0	0.8059	0.8059	0.806	0.806	0.8872	0.8872
**48	EL0W	(none)	.1-0.6	0.35	0.35	0.2821	0.2821	0.282	0.282	0.450	0.450
**49	NEP	Julian date	90-200	150	150	160	160	160	160	160	160
**50	NDUR	Days	0-100	60	60	56	56	56	56	56	56

NOTES:

1. *** - Parameters that may be derived from observed streamflow data
   ** - Parameters that are likely to be standardized by region
   * - Parameters that are treated like coefficients
   The other parameters are normally optimized.
2. Initial soil moisture conditions for 1968 were used as follows: UZSI = 0, LZSI = 3.8, SGWI = .01, GWSI = 0, RESI = 0, SRGXI = 0, SCEPI = 0
3. NWSRFS4 was run with the final optimized parameter values. This output is shown in Fig. 28 and the input data are listed on Table C-2.

C-1a

4751498

```
CHU,T25,CM120000,21036097
P,A,SAFHL7(,UCC103,UN=21036097,PW=MELT.
R(LS68028)
R(NWS4B)
CCF(INPUT,DATA,1,ORP)
CS(DATA,OUTPUT)
R(DATA)
NWS4B(DATA,,,LS68028)
```

INPUT DATA NWSRFS4

```
                                                                                            CARD NO.
 NAT. WEATHER SERVICE RIVER FORCAST SYSTEM--LE SUEUR R. NR RAPIDAN 4/68-11/68                   1
 LE SUEUR RIVER BASIN--NR RAPIDAN                                                               2
     1    1    1    0                                                                           3
     1    1    1    0    0                                                                      4
     4   68   11   68                                                                           5
     1                                                                                          6
WASECA EXP. STATION                                      160.  54                               7
     1                                                                                          8
     1                                                                                          9
     1                                                                                         10
     0                                                                                         11
     1                                                                                         12
     0                                                                                         13
     0    0    0    0    1         1    1    0    1    0    0    0    3    1                   14
     0    1    1                                                                               15
     6   68    7   68    8   68                                                                15-A
 LE SUEUR RIVER      1.0  .0218, 572.17163.607 .4401.607 .905.1141            VOL PAR          16
 LE SUEUR RIVER      .15751.443 .887 .450  0.0                                SOIL FTR         17
 LE SUEUR RIVER       .309.1136.03082.498.8445                                SM TIME          18
 LE SUEUR RIVER       0.0  3.8 .013  0.0  0.0  0.0  0.0                       SOIL INI         19
 LE SUEUR R. NR RAPIDAN           1100.0    8    0    0    6   20    0    0    0               20
 LE SUEUR R. NR RAPIDAN                     1   10000.         300.                            21
TIME DELAY                    .005 .048 .060 .061 .062 .062 .063 .063 .062 .061 }
TIME DELAY                    .060 .061 .062 .062 .059 .052 .044 .033 .019 .001 }              22
GAGE AREA                        1    1    1    1    1    1    1    1    1    1 }
GAGE AREA                        1    1    1    1    1    1    1    1    1    1 }              23
0
                                                                                               24
```

```
    *** NOTE ***
*NWS4B IS THE BINARY FILE OF FORTRAN NWSRFS 4.
 *LS68028 IS THE BINARY FILE IN WHICH PRECIP., EVAPOTRANSPIRATION AND
  DISCHARGE DATA FOR THE MONTH 4/68 THROUGH 11/68 FOR THE LE SUEUR RIVER
  WATERSHED ARE STORED
*CARD 16 MOISTURE VOL. PARA.   KI, A, EPXM, UZSN, LZSN, CB, POWER, CC, K24L
*CARD 17 ETP. PARA.   K3, GAGEPE, EHIGH, ELOW, K24EL
*CARD 18 SOIL MOISTURE TIMING PARA, SRCI, LIRC6, LKK6, KV, KGS
*CARD 19 INITIAL SOIL MOISTURE COND. UZSI,LZSI,SGWI, GWSI, RESI, SRGXI, SCEPI
```

Fig. C-1a - Input Data for NWSRFS4, Le Sueur River Watershed, for 1968 (Output is shown in Fig. 28)

C-1b

```
CHU,T25,CM120000.21036097
ATTACH,SYSLIB.OLDSYS.
P,A,SAFHL70,UCC103,UN=2103607,PW=MELT.
R(LS5BB67)
R(NWS4B)
CCF(INPUT.DATA,I.ORR)
CS(DATA.OUTPUT)
R(DATA)
NWS4B(DATA,,,LS5B867)
```

INPUT DATA NWSRFS4

```
                                                                                                   CARD NO.
  NAT. WEATHER SERVICE RIVER FORCAST SYSTEM-LE SUEUR R. NR RAPIDAN 5/67-8/67                          1
 LE SUEUR RIVER BASIN--NR RAPIDAN                                                                     2
     1    1    1    0                                                                                 3
     1    1    1    0    0                                                                            4
     5   67    8   67                                                                                 5
     1                                                                                                6
 WASECA EXP. STATION                         160   56                                                 7
     1                                                                                                8
     1                                                                                                9
     1                                                                                               10
     0                                                                                               11
     1                                                                                               12
     0                                                                                               13
     0    0    0    0    1         1    1    0    1    0    0    0    3    1                         14
     0    1    1                                                                                     15
     5   67    6   67    7   67    8   67                                                            15-A
 LE SUEUR RIVER      1.0  .0218.0572.17163.667 .4401.667 .905.1141           VOL PAR                 16
 LE SUEUR RIVER      .15751.448 .887 .450  0.0                               ETR PARA                17
 LE SUEUR RIVER       .309.1136.03082.998.8445                               SM TIME                 18
 LE SUEUR RIVER        .08  5.5 .075  .02  0.0  0.0  .22                     SOILINIT                19
 LE SUEUR R. NR  RAPIDAN            110..0    8    0    0    6   20    0    0    0                 20
 LE SUEUR R. NR RAPIDAN                       1   10000.       300.                                  21
 TIME DELAY                      .005 . 48 .060 .061 .062 .052 .063 .063 .062 .061                  22
 TIME DELAY                      .060 .061 .062 .062 .059 .052 .044 .033 .019 .001
 GAGE AREA                         1    1    1    1    1    1    1    1    1    1                   23
 GAGE AREA                         1    1    1    1    1    1    1    1    1    1
 0                                                                                                   24


      *** NOTE ***
  *NWS4B IS THE BINARY FILE OF FORTRA  NWSRFS 4.
   *LS5B867 IS THE BINARY FILE IN WHICH PRECIP.. EVAPOTRANSPIRATION.
      AND DISCHARGE DATA FOR THE MONTH  5/67 THROUGH 8/67 FOR THE LE SUEUR RIVER
      WATERSHED ARE STORED
  *CARD 16 MOISTURE VOL. PARA.   K1. A. EPXM. UZSN. LZSN. CB. POWER. CC. K24L
  *CARD 17 ETR. PARA.   K3. GAGEPE. EMIGH. FLOW. K24EL
  *CARD 18 SOIL MOISTURE TIMING PARA. SRC1. LIRC6. LKK6. KV. KGS
  *CARD 19 INITIAL SOIL MOISTURE COND. UZSI.LZSI.SGWI. GWSI. RESI. SRGXI. SCEPI
```

Fig. C-1b - Input Data for NWSRFS4, Le Sueur River Watershed, for 1967 with 1968 Optimized Parameters

C-1c

```
CHU,T25,CM120000,21036,97
P,A,SAFHL7 ,UCC1 3,U =2113  77,  =  LI.
ATTACH,SYSLIB,OLDSYS.
R(LS5B867)
R(NWS4B)
CCF(INPUT,DATA,1,OER)
CS(DATA,OUTPUT)
R(DATA)
NWS4B(DATA,,,LS5B867)
```

475495

INPUT DATA NWSRFS4

```
                                                                                        CARD NO.

 NAT. WEATHER SERVICE RIVER FORCAST SYSTEM-LE SUEUR R. NR RAPIDAN 5/67-8/67               1
LE SUEUR RIVER BASIN--NR RAPIDAN                                                          2
    1    1    1    0                                                                      3
    1    1    1    0    0                                                                 4
    5   67    6   67                                                                      5
    1                                                                                     6
WASECA EXP. STATION                        151   65                                       7
    1                                                                                     8
    1                                                                                     9
    1                                                                                    10
    0                                                                                    11
    1                                                                                    12
    0                                                                                    13
    0    0    0    0    1         1    1    0    1    0    0    0    3    1               14
    0    1    1                                                                          15
    5   67    6   67    7   67    8   67                                                 15-A
LE SUEUR RIVER       1.0  .021 . 595.1 113.252.31391.2951.396.1185        VOL PAR        16
LE SUEUR RIVER       .1575  1.01.050.5327  0.0                            ETR PARA       17
LE SUEUR RIVER       .3094.1135.3002.870.3372                             SM TIME        18
LE SUEUR RIVER         .08  5.5 .075  .02  0.0  0.0  .22                  SOILINIT       19
LE SUEUR R. NR  RAPIDAN          1100.0    8    0    0    6   20    0    0    0          20
LE SUEUR R. NR RAPIDAN                     1   10000.        300.                        21
TIME DELAY                 .005 .040 .060 .061 .062 .062 .063 .063 .062 .061
TIME DELAY                 .060 .061 .062 .062 .059 .052 .044 .033 .019 .001            22
GAGE AREA                     1    1    1    1    1    1    1    1    1    1
GAGE AREA                     1    1    1    1    1    1    1    1    1    1            23
0                                                                                        24


     *** NOTE ***
 *NWS4B IS THE BINARY FILE OF FORTRAN NWSRFS 4.
  *LS5B867 IS THE BINARY FILE IN WHICH PRECIP., EVAPOTRANSPIRATION,
   AND DISCHARGE DATA FOR THE MONTH  5/67 THROUGH 8/67 FOR THE LE SUEUR RIVER
   WATERSHED ARE STORED
 *CARD 16 MOISTURE VOL. PARA.   K1, ., EPXM, UZSN, LZSN, CB, POWER, CC, K24L
 *CARD 17 ETP. PARA.   K3, GAGEPE, EHIGH, ELOW, K24EL
 *CARD 18 SOIL MOISTURE TIMING PARA. SMCI, LIRC6, LKK6, KV, KGS
 *CARD 19 INITIAL SOIL MOISTURE COND. UZSI,LZSI,SGWI, GWSI, RESI, SRGXI, SCFPI
```

Fig. C-1c - Input Data for NWSRFS4, Le Sueur River Watershed, for 1967 with 1967 Optimized Parameters (Output is shown in Figs. 29a, b,c)

C-1d

4754189

```
CHU,T25,CM120000.21036097
ATTACH,SYSLIB,OLDSYS.
P,A,SAFHL70,UCC103,UN=21036097,PW=MELT.
R(LS5B869)
R(NWS4B)
CCF(INPUT,DATA,1,ORR)
CS(DATA,OUTPUT)
R(DATA)
NWS4B(DATA,,,LS5B869)
```

INPUT DATA NWSRFS4

```
                                                                                            CARD NO.
▲
 NAT. WEATHER SERVICE RIVER FORCAST SYSTEM-LE SUEUR R. NR RAPIDAN 5/69-8/69                    1
LE SUEUR RIVER BASIN--NR RAPIDAN                                                               2
    1    1    1    0                                                                           3
    1    1    1    0    0                                                                      4
    5   69    8   69                                                                           5
    1                                                                                          6
WASECA EXP. STATION                         160   56                                           7
    1                                                                                          8
    1                                                                                          9
    1                                                                                         10
    0                                                                                         11
    1                                                                                         12
    0                                                                                         13
    0    0    0    0    1    0    1    1    0    1    0    0    0    3    1                    14
    0    1    1                                                                               15
    5   69    6   69    7   69    8   69                                                      15-A
LE SUEUR RIVER        1.0  .0218. .572.17163.607 .4491.607 .905.1141         VOL PAR          16
LE SUEUR RIVER        .15751.448 .887 .450  0.0                              ETR PARA         17
LE SUEUR RIVER         .307.1135.3032.990.8445                               SM TIME          18
LE SUEUR RIVER          .03  5.5 .075  .02  0.0  0.0  .22                    SOILINIT         19
LE SUEUR R. NR  RAPIDAN           1100.0    8    0    0    6   20    0    0    0             20
LE SUEUR R. NR RAPIDAN                      1   10000.       300.                             21
TIME DELAY                        .005 .040 .060 .061 .062 .062 .063 .063 .062 .061 }
TIME DELAY                        .060 .061 .062 .062 .059 .052 .044 .033 .019 .001 }         22
GAGE AREA                            1    1    1    1    1    1    1    1    1    1 }
GAGE AREA                            1    1    1    1    1    1    1    1    1    1 }         23
0                                                                                             24
▼

     *** NOTE ***
 *NWS4B IS THE BINARY FILE OF FORTRAN NWSRFS 4.
 *LS5B869 IS THE BINARY FILE IN WHICH PRECP.,EVAPOTRANSPIRATION AND
  DISCHARGE DATA FOR THE MONTH 5/69 THROUGH 8/69 FOR THE LE SUEUR RIVER
  * WATERSHED ARE STORED
 *CARD 16 MOISTURE VOL. PARA.   K1, A, EPXM, UZSN, LZSN, CH, POWER, CC, K24L
 *CARD 17 ETR. PARA.   K3, GAGEPE, EHIGH, ELOW, K24EL
 *CARD 18 SOIL MOISTURE TIMING PARA. SRC1, LIRC6, LKK6, KV, KGS
 *CARD 19 INITIAL SOIL MOISTURE COND. UZSI.LZSI.SGWI. GWSI, RESI, SRGXI, SCEPI
```

Fig. C-1d - Input Data for NWSRFS4, Le Sueur River Watershed, for 1969 with 1968 Optimized Parameters (Output is shown in Figs. 31a, b,c)

C-2

INPUT DATA NWSRFS5

475492

```
CHU,T15,CM1[illegible]
P,A,SAFHL7,[illegible]
CCR(INPUT,DATA1,1,ERR)
CS(DATA1,OUTPUT)
R(TAPE1,TAPE2,NWS5B,DATA1)
NWS5B(DATA1)
                                                                                          CARD NO.
    1     1     0     1     0                                                                 1
   68     7    22     1    28     4     0     0     0     0     0                             2
 NWSRFS-LE SUEUR RIVER  7/22 - 7/28                                                           7
LE SUEUR RIVER                                                                                8
    1     1     1     0                                                                       9
 WASECA EXP. STATION                              160   55                                   10
    1                                                                                        11
    1                                                                                        12
    1                                                                                        13
    0                                                                                        14
    1     7     0     1                                                                      15
    0                                                                                        16
LE SUEUR RIVER      1.0  .0210. 572.1710 3.607 .4401.607 .905.1141        VOL PAR            17
LE SUEUR RIVER      .15751.444 .387 .450  0.0                                                18
LE SUEUR RIVER       .309.113.. 3082.99..8445                                                19
LE SUEUR RIVER      0.0003.41. .300 .132 0.00 0.00 .060                                      20
 RAPIDAN,MINN.                  1100.      8.     0     0     6    20     0     0     0      21
TIME DELAY                      .005 .043 .060 .061 .062 .062 .063 .063 .062 .061
TIME DELAY                      .060 .061 .062 .062 .059 .052 .044 .033 .019 .001           22
GAGE AREA                          1     1     1     1     1     1     1     1     1     1
GAGE AREA                          1     1     1     1     1     1     1     1     1     1     23
    7    22     0     0     0   .00
    7    23  2.84   .28   .17
    7    24     0     0     0   .4                                                           24
    7    25     0     0     0   .02       6 hr  PRECIP.
    7    26     0   .16     0   .22
    7    27     0     0   .74
    7    28     0     0     0
    7    22  .27
    7    23  .35
    7    24  .11
    7    25  .12             DAILY PE.                                                       25
    7    26  .31
    7    27  .23
    7    28  .34
    7    22        870        870        870        870
    7    23       1820       1820       1820       1820
    7    24       3430       3430       3430       3430                                    26
    7    25       5910       5910       5910       5910     6 hr  DISCHARGE
    7    26      10000      10000      10000      10000
    7    27       9300       9300       9300       9300
    7    28       7320       7320       7320       7320
▼

      *** NOTE ***
  *NWS5B IS THE BINARY FILE OF FORTRAN NWSRFS 5.
  *CARD 17 MOISTURE VOL. PARA.   K1, [illegible], EPXM, UZSN, LZSN, CB, POWER, CC, K24L
  *CARD 18 ETR. PARA.   K3, GAGEPE, E IGH, FLOW, K24EL
  *CARD 19 SOIL MOISTURE TIMING PARA. SRCI, LIRC6, LKK6, KV, KGS
  *CARD 20 INITIAL SOIL MOISTURE COND. UZSI,LZSI,SGWI, GWSI, RESI, SRGXI, SCEPI
```

Fig. C-2 - Input Data for NWSRFS5, Le Sueur River Watershed, for 1968 (Output is shown in Fig. 32)

C-3

400994

PRECPH & DFLOW - NWSRFS

PROGRAM LISTING & SAMPLE DATA

```
*** THIS RUN READ DAULY PRECIPITATION DATA OFF THE DISK AND PUNCHED IT ON O/H
*** CARDS (USING PRECPH AND OHDECK). IT THEN READ DAILY DISCHARGE DATA OFF THE
*** DISK USING DFLOW AND PUNCHED IT ON O/H CARDS USING OHDECK.
*** THE PRECIPITATION DATA WILL BE USED NEXT IN NWSRFS1. THE DISCHARGE DATA
*** WILL BE USED NEXT IN NWSRFS2.
LUN,T15,CM65000,21036097
CCP(INPUT,TEMP,1,ORR)                                  * COMPILE SUBROUTINE OHDECK
FUN(S,I=TEMP)                                          * AND STORE BINARY ON FILE
CRF(LGO,OHDK,1,ORR,IRR)                                * OHDK
P,A,SAFHL54,LAT101,UN=21036097,PW=SNOW.
FUN(S)                                                 * COMPILE PRECPH
LOAD(BIN)                                              * LOAD EX2IN AND RANDSK
LOAD(OHDK)
LGO.                                                   * EXECUTE
RAW.
EXIT.
R(PUNCH)
CS(PUNCH,OUTPUT)                                       * COPY CARD IMAGE PUNCHED
R(PUNCH)                                               * TO OUTPUT TO BE PUNCHED
P,F,SAFHL54.
FORGET(PUNCH)
RAW.
EXIT.
P,A,SAFHL53,LAT101,UN=21036002,PW=SNOW.
R(LGO)
R(PUNCH)
FUN(S)                                                 * COMPILE DFLOW
R(OHDK)
R(BIN)
LOAD(OHDK)
LOAD(BIN)
LGO.
RAW.
EXIT.
R(PUNCH)
CS(PUNCH.OUTPUT)
R(PUNCH)
C  EX2IN  IS A BINARY FILE STORED ON DISK.
C THIS ROUTINE WILL SEARCH THRU A STATION LIST ON THE DISK TO DETERMINE
C THE STATIONS RELATIVE NUMBER ON THE DISK )  IF STATION NOT IN LIST RETURN -1
C  RANDSK IS A BINARY FILE STORED ON DISK.
C      THIS ROUTINE WILL READ OR WRITE A RECORD FROM A RANDOM DISK FILE
C      THE RECORD MAY BE UP TO MAX WORDS IN LENGTH
C      FOUR (IR) LEVELS OF SUBSCRIPTING MAY BE USED TO IDENTIFY RECORDS
C      UP TO 125(IA) RECORDS MAY BE WRITTEN AT ANY LEVEL
C      IT IS ASSUMED BY THIS ROUTINE THAT THE FIRST WORD IN THE ARRAY
C      TO BE WRITTEN OR READ CONTAINS SOME ARRAY IDENTIFICATION CODES
C      THE SECOND ELEMENT SHOULD CONTAIN THE ACTUAL NUMBER OF USEFUL
C      WORDS IN THE ARRAY
C      IRW- READ OR WRITE INDICATOR(0=READ)(1=WRITE)
C      IBUFF-ARRAY TO BE TRANSFERRED TO OR FROM DISK
C      LEVEL-NUMBER OF SUBSCRIPTS USED TU IDENTIFY ARRAY (GE.1.AND.LE.4)
C      LEV(1)-1ST SUBSCRIPT (IE.YEAT) (GE.1.AND.LE.73)
C      LEV(2)-2ND SUBSCRIPT (IE.MONTH) (GE.1.AND.LE.73)
C      LEV(3)-3RD SUBSCRIPT (IE.STATION) (GE.1.AND.LE.73)
C      LEV(4)-4TH SUBSCRIPT (IE.PARAMETER) (GE.1.AND.LE.73)
C      IF ONLY 2 LEVELS OF SUBSCRIPTS USED LEVELS 3 AND 4 ARE IGNORED
C      IMX-MAXIMUM NUMBER OF WORDS TRANSFERRED ON A READ  USUALLY DIMENSION VALUE

▲7-8-9
      SUBROUTINE OHDECK(MAX,IDENT,TIME,CODE,HR,DA,MO,YR,FHR,FDA,FMO,
     1FYR,DEC,FDATA,FLAG,FIELD)
C UP TO DATE AT 11-20-73
C THIS SUBROUTINE PUNCHES THE CONTENTS OF THE ARRAY FDATA IN THE OFFICE
C  OF HYDROLOGY STD. FORMAT -- FOR NATIONAL WEATHER SERVICE PROGRAMS
```

Fig. C-3a - Program Listing for PRECPH and DFLOW for Reading Precipitation Data and Observed Runoff from Disk Pack

400995

```
C IT DETERMINES A NEW FIELD FOR EACH CARD IF FIELD=0, OTHERWISE IT USES
C  THE  VALUE TRANSFERED
C MAX=MAXIMUM NO. CARDS TO BE PUNCHED
C IDENT=STATION NO. READ BY A4 FORMAT
C TIME=TIME INCREMENT
C CODE= D/H CODE FOR TYPE OF DATA
C HR,DA,MO,YR=TIME OF FIRST DATA OBSERVATION
C FHR,FDA,FMO,FYR=TIME OF LAST OBSERVATION
C FDATA=ARRAY OF DATA TO BE PUNCHED--REAL ARRAY
C FLAG=WHAT IS TO BE PUNCHED ON THE LAST CARD (A4 FORMAT)
      INTEGER DAMO,COUNT,TIME,CODE,FHR,FDA,FMO,FYR,DATA,FIELD,
     1DEC,HR,DA,YR
      DIMENSION DATA(250),DAMO(12),FDATA(250)
      DIMENSION FMT(3)
C FMT CONTAINS THE VARIABLE FORMAT
      FMT(1)=10H(I4,2I1,A9
      FMT(2)=8H,I3,5I2,
C DETERMINING THE NUMBER OF DAYS PER MONTH, INCLUDING LEAP YEARS--
      DYR=FLOAT(FYR)
      AYR=DYR/4.
      IAYR=AYR+.01
      LEAP=0
      IAYR=4*IAYR
      IF(FYR.EQ.IAYR)LEAP=1
      DAMO(1)=31
      DAMO(2)=28+LEAP
      DAMO(3)= 31
      DAMO(4)=30
      DAMO(5)=31
      DAMO(6)=30
      DAMO(7)=31
      DAMO(8)=31
      DAMO(9)=30
      DAMO(10)=31
      DAMO(11)=30
      DAMO(12)=31
      MMO=0
C DETERMINING THE NUMBER OF HOURS FROM 1900 TO THE TIME OF LAST
C   OBSERVATION--USED TO TELL WHEN TO STOP
      IF(FMO.EQ.1)GO TO 810
      NFMO=FMO-1
      DO 700 I11=1,NFMO
  700 MMO=MMO+DAMO(I11)
  810 CONTINUE
      MTIME=FHR+24*FDA+24*MMO+FYR*365*24
      AYR=FYR-1
      AYR=AYR/4.
      IYR=AYR+.01
      MTIME=MTIME+IYR*24
      DYR=FLOAT(YR)
      AYR=DYR/4.
      IAYR=AYR+.01
      LEAP=0
      IAYR=4*IAYR
      IF(YR.EQ.IAYR)LEAP=1
      DAMO(2)=28+LEAP
C INITIAL VALUES
      COUNT=0
C NDATA=1+NUMBER OF OBSERVATIONS PUNCHED
      NDATA=1
      IFORM=2
      IF(FIELD.EQ.0)GO TO 100
C NCARD=NUMBER OF OBSERVATIONS ON CURRENT CARD
      NCARD=52/FIELD
      IFORM=FIELD
      ENCODE(5,200,FOR)NCARD,FIELD
```

Fig. C-3b - Program Listing for PRECPH and DFLOW for Reading Precipitation Data and Observed Runoff from Disk Pack [continued]

400996

```
  200 FORMAT(I2,*I*,I1,*)*)
      FMT(3)=FOO
C COUNT=NUMBER OF CARDS PUNCHED
  100 COUNT=COUNT+1
      PRINT 2323,COUNT,IFORM,FIELD,NCARD,DA,MO,ITIME,MTIME
 2323 FORMAT(1X,6I4,2I5)
C DETERMINING FIELD LENGTH--52 SPACES ON CARD
      IF(IFORM.EQ.0)GO TO 1123
      NCARD=52/FIELD
      LMO=MO
      LDA=DA
      LHR=HR+TIME*(NCARD-1)
 2230 IF(LHR.LE.24)GO TO 2240
      LDA=LDA+1
      LHR=LHR-24
      GO TO 2230
 2240 IF(LDA.LE.DAMO(LMO))GO TO 2778
      LDA=LDA-DAMO(LMO)
      NCARD=NCARD-LDA
      IF(NCARD.EQ.0)STOP11
 2778 CONTINUE
      NNDATA=NDATA
      DO 1122 K26=1,NCARD
      DATA(NNDATA)=FDATA(NNDATA)*10.**DEC+.5
 1122 NNDATA=NNDATA+1
      GO TO 1112
 1123 CONTINUE
      NCARD=1
      DATA(NDATA)=FDATA(NDATA)*10.**DEC+.5
      MMAX=DATA(NDATA)
      ARMMAX=FLOAT(MMAX)
      ILOG=0
      IF(ARMMAX.LT.1.)GO TO 995
      FILOG=ALOG10(ARMMAX)
      ILOG=FILOG
  995 CONTINUE
      IFIELD=ILOG+1
      DECC1=1+DEC
      IF(IFIELD.GE.DECC1)GO TO 1111
      IFIELD=1+DEC
      MMAX=10**(1+DEC)
 1111 CONTINUE
      INCARD=NCARD
      INDATA=NDATA
      LMO=MO
      LDA=DA
      LHR=HR+TIME
  157 IF(LHR.LE.24)GO TO 156
      LDA=LDA+1
      LHR=LHR-24
      GO TO 157
  156 IF(LDA.LE.DAMO(LMO))GO TO 300
      FIELD=IFIELD
      PRINT 2323,ILOG,IFIELD
      GO TO 320
  300 INDATA=INDATA+1
      DATA(INDATA)=FDATA(INDATA)*10.**DEC+.5
      INCARD=INCARD+1
      IF(MMAX.LT.DATA(INDATA))GO TO 310
  330 ITOTF=IFIELD*INCARD
      IF(ITOTF.GT.52)GO TO 320
      MMO=0
      IF(MO.EQ.1)GO TO 420
      NUMMO=MO-1
      DO 71   I12=1,NUMMO
   71 MMO=MMO+DAMO(I12)
```

Fig. C-3c - Program Listing for PRECPH and DFLOW for Reading Precipitation Data and Observed Runoff from Disk Pack [continued]

```
  820 CONTINUE
      ITIME=HR+24*DA+24*MMO+YR*365*24
      ITIME=ITIME+TIME*INCARD
      AYR=YR-1
      AYR=AYR/4.
      IYR=AYR+.01
      ITIME=ITIME+IYR*24
      NCARD=INCARD
      IF(ITIME.GT.MTIME) GO TO 320
      FIELD=IFIELD
      LDA=DA
      LHR=HR+TIME*INCARD
 1230 IF(LHR.LE.24)GO TO 1240
      LDA=LDA+1
      LHR=LHR-24
      GO TO 1230
 1240 IF(LDA.LE.DAMO(MO))GO TO 7778
      NCARD=INCARD
      GO TO 320
 7778 CONTINUE
      NCARD=INCARD
      FIELD=IFIELD
      GO TO 300
  310 MMAX=DATA(NDATA)
      ABMMAX=FLOAT(MMAX)
      ILOG=0
      IF(ABMMAX.LT.1.)GO TO 996
      FILOG=ALOG10(ABMMAX)
      ILOG=FILOG
  996 CONTINUE
      IFIFLD=ILOG+1
      GO TO 330
  320 CONTINUE
      PRINT 9752,ITOTF,LDA,DAMO(MO),IFIELD,INCARD,ITIME,MTIME
 9752 FORMAT(20X,5I4,2I15)
      IF(FIELD.LE.9)GO TO 350
      FIELD=9
      NCARD=5
  350 CONTINUE
      ENCODE(10,200,FOR)NCARD,FIELD
      FMT(3)=FOR
 1112 CONTINUE
      K1=NDATA+NCARD-1
      PUNCH FMT,COUNT,FIELD,DEC,IDENT,TIME,CODE,HR,DA,MO,YR,
     1(DATA(K33),K33=NDATA,K1)
C DETERMINING THE STARTING TIME OF THE NEAT CARD
      HR=HR+TIME*NCARD
  230 IF(HR.LE.24)GO TO 240
      DA=DA+1
      HR=HR-24
      GO TO 230
  270 CONTINUE
  240 IF(DA.LE.DAMO(MO))GO TO 250
      DA=DA-DAMO(MO)
      MO=MO+1
  250 IF(MO.LE.12)GO TO 240
      MO=MO-12
      YR=YR+1
      DYR=FLOAT(YR)
      APY=DYR/4.
      IAYR=AYR+.01
      LEAP=0
      IAYR=4*IAYR
      IF(YR.EQ.IAYR)LEAP=1
      DAMO(2)=28+LEAP
      GO TO 270
```

Fig. C-3d - Program Listing for PRECPH and DFLOW for Reading Precipitation Data and Observed Runoff from Disk Pack [continued]

400998

```
 260 CONTINUE
     NDATA=NDATA+NCARD
     IF(COUNT.GE.MAX)GO TO 9999
     MMO=0
     IF(MO.EQ.1)GO TO 830
     NUMMO=MO-1
     DO 730 I13=1,NUMMO
 730 MMO=MMO+DAMO(I13)
 830 CONTINUE
C ITIME=NUMBER OF HOURS FROM 1900 TO CURRENT TIME--USED
C   TO SEE IF PROGRAM HAS PUNCHED ALL THE DATA YET.
     ITIME=HR+24*DA+24*MMO+YR*365*24
     AYR=YR-1
     AYR=AYR/4.
     IYR=AYR+.01
     ITIME=ITIME+IYR*24
     IF(ITIME.GT.MTIME)GO TO 9999
     IEND=(MTIME-ITIME)/TIME
     IF(IEND.LT.NCARD)NCARD=IEND+1
     GO TO 100
9999 CONTINUE
     PUNCH 920,FLAG
 920 FORMAT(A4)
     RETURN
     END
▲ 7-8-9
     PROGRAM PRECPH(INPUT,OUTPUT,PUNCH,USWB,TAPE1=USWB)
C THIS PROGRAM READS DAILY PRECIPITATION OFF THE DISK PACK AND PUNCHES
C   IT IN OFFICE OF HYDROLOGY STANDARD FORMAT FOR USE IN NAT. WEATHER
C   SERVICE COMPUTER PROGRAMS
C TO PUNCH DATA IN STD FORMAT THIS PROGRAM MUST BE RUN WITH SUBROUTINE
C   OHDECK
C
C                          DATA DESCRIPTION--
C
C
C CARD NO.      FORMAT        DESCRIPTION
C ********      ******        ***********
C     1          4I5.        HOUR,DAY,MONTH,YEAR OF LAST OBSERVATION
C                                      TO BE PUNCHED
C
C     2         A4            CONTENTS OF LAST CARD (USUALLY 9999)
C     3          4I10          MAXIMUM NUMBER OF CARDS TO BE PUNCHED,
C                                      DATA TIME INTERVAL, DATA CODE
C                                      NUMBER OF PLACES PAST THE DEC PT
C
C     4           I2           NUMBER OF STATIONS TO BE PROCESSED
C ****************************************************************************
C REPEAT CARDS 5 AND 6 ALTERNATELY ONCE FOR EACH STATION
C ****************************************************************************
C     5           4I10         HOUR, DAY, MONTH, YEAR OF FIRST OBSERVATION
C     6           I6,A9       STATION NUMBER, STATION NUMBER WITH A (-)
C                                      AFTER THE STATE NUMBER--START IN
C                                      COLUMN 7
C
      INTEGER DEC,TIME,CODE,HR,DA,MO,YR,FHR,FDA,FMO,FYR
      INTEGER FIELD
      INTEGER DAMO
      DIMENSION DAMO(12)
      DIMENSION IDATA(114),DATA(114),ARRAY(250)
C THE EQUIVALENCE STATEMENT TAKES CARE OF THE POSSIBILITY THAT REAL
C    NUMBERS WILL BE RETURNED FROM RANDSK INSTEAD OF INTEGERS
      EQUIVALENCE(IDATA(1),DATA(1))
C NUMBER OF DAYS PER MONTH
      DAMO(1)=31
      DAMO(3)=31
      DAMO(4)=30
      DAMO(5)=31
      DAMO(6)=30
```

Fig. C-3e - Program Listing for PRECPH and DFLOW for Reading Precipitation Data and Observed Runoff from Disk Pack [continued]

400999

```
      DAMO(7)=31
      DAMO(8)=31
      DAMO(9)=30
      DAMO(10)=31
      DAMO(11)=30
      DAMO(12)=31
      READ 50,FHR,FDA,FMO,FYR
   50 FORMAT(4I10)
      READ 60,FLAG
   60 FORMAT(A4)
      READ 50,MAX,TIME,CODE,DEC
      READ 10,NSTAT
   10 FORMAT(I2)
      DO 20 I=1,NSTAT
      READ 50,HR,DA,MO,YR
C NORMAL YEAR DECK
C THE FOLLOWING STATEMENTS TAKE CARE OF LEAP YEAR
      IYR=YR
      YRRR=IYR
      YRRR=YRRR/4.
      JYR=YRRR+.01
      JYR=JYR*4
      LEAP=0
      IF(JYR.EQ.IYR)LEAP=1
      DAMO(2)=28+LEAP
      ISUB=0
      READ 30,ISTA,IDENT
   30 FORMAT(I6,A9)
      NW=38*3
      DO 40 L=4,11
C K=INTERNAL STATION NUMBER, ISTA=EXTERNAL STATION NUMBER
      K=EX2IN(ISTA)
      CALL RANDSK(.,DATA,3,L,68,K,0,NW)
      N=114+DAMO(L)-31
      DO 40 M=84,N
      ISUB=ISUB+1
C LOADING ARRAY. DATA(1)-(76) CONTAINS TEMPERATURE DATA,DATA(77)-(83)
C    ARE ZEROS
      IF(DATA(M).GT.9.99)DATA(M)=9.99
   40 ARRAY(ISUB)=DATA(M)
      FIELD=3
      PRINT 102,(ARRAY(NN2),NN2=1,ISUB)
  102 FORMAT(/////,100(1X,10F10.2/))
   20 CALL CHDECK(MAX,IDENT,TIME,CODE,HR,DA,MO,YR,FHR,FDA,FMO,FYR,DEC,
     1ARRAY,FLAG,FIELD)
      STOP
      END
▲7-8-9
          24 FHR         30 FDA        11 FMO        68 FYR
9999
         300 MAX         24 TIME (hr)   1 CODE (PRECIP)  2
 6
          24              1             4             68
21085221-0852  BLUE EARTH
          24              1             4             68
21096121-0961  BRYCELYN
          24              1             4             68
21600721-6007  NORTH MANKATO
          24              1             4             68
21869221-8692  WASECA
          24              1             4             68
21880821-8808  WELLS 1NW
          24              1             4             68
21904621-9046  WINNEBAGO
▲7-8-9
```

DAILY PRECIP. DATA OFF
THE DISK AND PUNCHED
IT ON O/H CARDS
April 4 — Nov., 1968
6 NON-RECORDING STATIONS

Fig. C-3f - Program Listing for PRECPH and DFLOW for Reading Precipitation Data and Observed Runoff from Disk Pack [continued]

401000

```
      PROGRAM DFLOW(INPUT,OUTPUT,PUNCH,USGS,TAPE1=USGS)
C THIS PROGRAM READS USGS DAILY FLOW DATA OFF THE DISC PACK AND PUNCHES
C   IT IN OFFICE OF HYDROLOGY STANDARD FORMAT.   IT PROCESSES DATA FROM
C   4-68 TO 11-68 (APRIL TO NOVEMBER).
C TO PUNCH ANOTHER YEAR CHANGE IY, AND POSSIBLY DAMO(2)
C   AND THE OHDECK CALL CARD
C TO PROCESS A DIFFERENT COMBINATION OF MONTHS CHANGE THE DO STATEMENT
C   AND THE OHDECK CALL CARD PARAMETERS
C TO CHANGE THE STATION CHANGE THE VALUE OF ISTA
C TO PUNCH DATA IN STD FORMAT THIS PROGRAM MUST BE RUN WITH SUBROUTINE
C   OHDECK
      INTEGER DAMO
      DIMENSION DATA(38),IDATA(38),FDATA(250)
      DIMENSION DAMO(12)
      EQUIVALENCE(IDATA(1),DATA(1))
C INTERNAL STATION NUMBER--
      ISTA=5320500
      ICOUNT=1
C DAYS PER MONTH
      DAMO(1)=31
      DAMO(2)=29
      DAMO(3)=31
      DAMO(4)=30
      DAMO(5)=31
      DAMO(6)=30
      DAMO(7)=31
      DAMO(8)=31
      DAMO(9)=30
      DAMO(10)=31
      DAMO(11)=30
      DAMO(12)=31
C  IM=MONTH
      DO 10 IM=4,11
      K=EX2IN(ISTA)
      NW=38
      IY=68
      CALL RANDSK(0,DATA,3,IM,K,IY,0,NW)
      PRINT 5,IM,NW
    5 FORMAT(1X,I10,*WORDS=*,I15)
      IF(NW.LE.0)STOP4
      IMAXX=ICOUNT+30
      J11=ICOUNT-1
      DO 4 J4=8,38
      J11=J11+1
    4 FDATA(J11)=DATA(J4)
   10 ICOUNT=ICOUNT+DAMO(IM)
      MAX=200
      READ 15,IDENT
   15 FORMAT(A9)
      READ 20,FLAG
   20 FORMAT(A4)
      PRINT 101,(FDATA(JJK),JJK=1,244)
  101 FORMAT(////(1X,10F10. ,/))
      IFIELD=0
      CALL OHDECK(MAX,IDENT,24, ,24,1,4,68,24,30,11,68,0,FDATA,FLAG,
     1IFIELD)
      STOP
      END
  ▲ 7-8-9

05-3205.0      IDENT
9999           FLAG
   ▼ 6-7-8-9
```

Fig. C-3g - Program Listing for PRECPH and DFLOW for Reading Precipitation Data and Observed Runoff from Disk Pack [continued]

401348

EVAP - NWSRFS

PROGRAM LISTING & SAMPLE DATA

```
LUN,T5,CM50000,21036097
FUN(S)
LGO.
RAW.
EXIT.
R(PUNCH)
CS(PUNCH,OUTPUT)
R(PUNCH)
* 7-8-9
      PROGRAM EVAP(INPUT,OUTPUT,PUNCH)
C THIS PROGRAM READS LAKE EVAPORATION DATA AND PUNCHES IT IN
C  STANDARD FORMAT FOR NWSRFS USE
C IT COULD ALSO BE USED FOR OTHER TYPES OF DATA WITH SOME MODIFICATIONS.
C TO PUNCH DATA IN STD FORMAT THIS PROGRAM MUST BE RUN WITH SUBROUTINE
C   OHDECK
C ALL MISSING DATA FOR THIS PROGRAM MUST BE ESTIMATED--SEE THE
C   COMMENT CARDS AT BEGINNING OF NWSRFS2
      INTEGER TIME,CODE,HR,DA,YR,FHR,FDA,FMO,FYR,DEC
      DIMENSION DATA(250)
      READ 10,NUMB
   10 FORMAT(I5)
      READ 20,(DATA(I),I=1,NUMB)
   20 FORMAT(25F3.2)
      READ 30,MAX,TIME,CODE
      READ 30,HR,DA,MO,YR
      READ 30,FHR,FDA,FMO,FYR
   30 FORMAT(4I10)
      READ 40,FLAG,IDENT
   40 FORMAT(A4,A9)
      DEC=2
      IFIELD=3
      CALL OHDECK(MAX,IDENT,TIME,CODE,HR,DA,MO,YR,FHR,FDA,FMO,
     1FYR,DEC,DATA,FLAG,IFIELD)
      STOP
      END
      SUBROUTINE OHDECK(MAX,IDENT,TIME,CODE,HR,DA,MO,YR,FHR,FDA,FMO,
     1FYR,DEC,FDATA,FLAG,FIELD)
C UP TO DATE AT 11-20-73
C THIS SUBROUTINE PUNCHES THE CONTENTS OF THE ARRAY FDATA IN THE OFFICE
C  OF HYDROLOGY STD. FORMAT -- FOR NATIONAL WEATHER SERVICE PROGRAMS
C IT DETERMINES A NEW FIELD FOR EACH CARD IF FIELD=0, OTHERWISE IT USES
C  THE  VALUE TRANSFERED
C MAX=MAXIMUM NO. CARDS TO BE PUNCHED
C IDENT=STATION NO. READ BY A9 FORMAT
C TIME=TIME INCREMENT
C CODE= O/H CODE FOR TYPE OF DATA
C HR,DA,MO,YR=TIME OF FIRST DATA OBSERVATION
C FHR,FDA,FMO,FYR=TIME OF LAST OBSERVATION
C FDATA=ARRAY OF DATA TO BE PUNCHED--REAL ARRAY
C FLAG=WHAT IS TO BE PUNCHED ON THE LAST CARD (A4 FORMAT)
      INTEGER DAMO,COUNT,TIME,CODE,FHR,FDA,FMO,FYR,DATA,FIELD,
     1DEC,HR,DA,YR
      DIMENSION DATA(250),DAMO(12),FDATA(250)
      DIMENSION FMT(3)
C FMT CONTAINS THE VARIABLE FORMAT
      FMT(1)=10H(I4,2I1,A9
      FMT(2)=8H,I3,5I2,
C DETERMINING THE NUMBER OF DAYS PER MONTH, INCLUDING LEAP YEARS--
      DYR=FLOAT(FYR)
      AYR=DYR/4.
      IAYR=AYR+.01
      LEAP=0
      IAYR=4*IAYR
      IF(FYR.EQ.IAYR)LEAP=1
      DAMO(1)=31
```

Fig. C-4a - Program Listing for EVAP for Punching Lake Evaporation Data

```
      DAMO(2)=28+LEAP
      DAMO(3)= 31
      DAMO(4)=30
      DAMO(5)=31
      DAMO(6)=30
      DAMO(7)=31
      DAMO(8)=31
      DAMO(9)=30
      DAMO(10)=31
      DAMO(11)=30
      DAMO(12)=31
      MMO=0
C DETERMINING THE NUMBER OF HOURS FROM 1900 TO THE TIME OF LAST
C   OBSERVATION--USED TO TELL WHEN TO STOP
      IF(FMO.EQ.1)GO TO 810
      NFMO=FMO-1
      DO 700 I11=1,NFMO
  700 MMO=MMO+DAMO(I11)
  810 CONTINUE
      MTIME=FHR+24*FDA+24*MMO+FYR*365*24
      AYR=FYR-1
      AYR=AYR/4.
      IYR=AYR+.01
      MTIME=MTIME+IYR*24
      DYR=FLOAT(YR)
      AYR=DYR/4.
      IAYR=AYR+.01
      LEAP=0
      IAYR=4*IAYR
      IF(YR.EQ.IAYR)LEAP=1
      DAMO(2)=28+LEAP
C INITIAL VALUES
      COUNT=0
C NDATA=1+NUMBER OF OBSERVATIONS PUNCHED
      NDATA=1
      IFORM=0
      IF(FIELD.EQ.0)GO TO 100
C NCARD=NUMBER OF OBSERVATIONS ON CURRENT CARD
      NCARD=52/FIELD
      IFORM=FIELD
      ENCODE(5,200,FOR)NCARD,FIELD
  200 FORMAT(I2,*I*,I1,*)*)
      FMT(3)=FOR
C COUNT=NUMBER OF CARDS PUNCHED
  100 COUNT=COUNT+1
      PRINT 2323,COUNT,IFORM,FIELD,NCARD,DA,MO,ITIME,MTIME
 2323 FORMAT(1X,6I4,2I15)
C DETERMINING FIELD LENGTH--52 SPACES ON CARD
      IF(IFORM.EQ.0)GO TO 1123
      NCARD=52/FIELD
      LMO=MO
      LDA=DA
      LHR=HR+TIME*(NCARD-1)
 2230 IF(LHR.LE.24)GO TO 2240
      LDA=LDA+1
      LHR=LHR-24
      GO TO 2230
 2240 IF(LDA.LE.DAMO(LMO))GO TO 2778
      LDA=LDA-DAMO(LMO)
      NCARD=NCARD-LDA
      IF(NCARD.EQ.0)STOP11
 2778 CONTINUE
      NNDATA=NDATA
      DO 1122 K26=1,NCARD
      DATA(NNDATA)=FDATA(NNDATA)*10.**DEC+.5
 1122 NNDATA=NNDATA+1
```

Fig. C-4b - Program Listing for EVAP for Punching Lake Evaporation Data [continued]

```
      GO TO 1112
 1123 CONTINUE
      NCARD=1
      DATA(NDATA)=FDATA(NDATA)*10.**DEC+.5
      MMAX=DATA(NDATA)
      ABMMAX=FLOAT(MMAX)
      ILOG=0
      IF(ABMMAX.LT.1.)GO TO 995
      FILOG=ALOG10(ABMMAX)
      ILOG=FILOG
  995 CONTINUE
      IFIELD=ILOG+1
      DECC1=1+DEC
      IF(IFIELD.GE.DECC1)GO TO 1111
      IFIELD=1+DEC
      MMAX=10**(1+DEC)
 1111 CONTINUE
      INCARD=NCARD
      INDATA=NDATA
      LMO=MO
      LDA=DA
      LHR=HR+TIME
  157 IF(LHR.LE.24)GO TO 156
      LDA=LDA+1
      LHR=LHR-24
      GO TO 157
  156 IF(LDA.LE.DAMO(LMO))GO TO 300
      FIELD=IFIELD
      PRINT 2323,ILOG,IFIELD
      GO TO 320
  300 INDATA=INDATA+1
      DATA(INDATA)=FDATA(INDATA)*10.**DEC+.5
      INCARD=INCARD+1
      IF(MMAX.LT.DATA(INDATA))GO TO 310
  330 ITOTF=IFIELD*INCARD
      IF(ITOTF.GT.52)GO TO 320
      MMO=0
      IF(MO.EQ.1)GO TO 820
      NNNMO=MO-1
      DO 710 I12=1,NNNMO
  710 MMO=MMO+DAMO(I12)
  820 CONTINUE
      ITIME=HR+24*DA+24*MMO+YR*365*24
      ITIME=ITIME+TIME*INCARD
      AYR=YR-1
      AYR=AYR/4.
      IYR=AYR+.01
      ITIME=ITIME+IYR*24
      NCARD=INCARD
      IF(ITIME.GT.MTIME) GO TO 320
      FIELD=IFIELD
      LDA=DA
      LHR=HR+TIME*INCARD
 1230 IF(LHR.LE.24)GO TO 1240
      LDA=LDA+1
      LHR=LHR-24
      GO TO 1230
 1240 IF(LDA.LE.DAMO(MO))GO TO 7778
      NCARD=INCARD
      GO TO 320
 7778 CONTINUE
      NCARD=INCARD
      FIELD=IFIELD
      GO TO 300
  310 MMAX=DATA(INDATA)
      ABMMAX=FLOAT(MMAX)
```

Fig. C-4c - Program Listing for EVAP for Punching Lake Evaporation Data [continued]

```
      ILOG=0
      IF(ABMMAX.LT.1.)GO TO 996
      FILOG=ALOG10(ARMMAX)
      ILOG=FILOG
  996 CONTINUE
      IFIELD=ILOG+1
      GO TO 330
  320 CONTINUE
      PRINT 9752,ITOTF,LDA,DAMO(MO),IFIELD,INCARD,ITIME,MTIME
 9752 FORMAT(20X,5I4,2I15)
      IF(FIELD.LE.9)GO TO 350
      FIELD=9
      NCARD=5
  350 CONTINUE
      ENCODE(10,200,FOR)NCARD,FIELD
      FMT(3)=FOR
 1112 CONTINUE
      K1=NDATA+NCARD-1
      PUNCH FMT,COUNT,FIELD,DEC,IDENT,TIME,CODE,HR,DA,MO,YR,
     1(DATA(K33),K33=NDATA,K1)
C DETERMINING THE STARTING TIME OF THE NEXT CARD
      HR=HR+TIME*NCARD
  230 IF(HR.LE.24)GO TO 240
      DA=DA+1
      HR=HR-24
      GO TO 230
  270 CONTINUE
  240 IF(DA.LE.DAMO(MO))GO TO 260
      DA=DA-DAMO(MO)
      MO=MO+1
  250 IF(MO.LE.12)GO TO 240
      MO=MO-12
      YR=YR+1
      DYR=FLOAT(YR)
      ARY=DYR/4.
      IAYR=AYR+.01
      LEAP=0
      IAYR=4*IAYR
      IF(YR.EQ.IAYR)LEAP=1
      DAMO(2)=28+LEAP
      GO TO 270
  260 CONTINUE
      NDATA=NDATA+NCARD
      IF(COUNT.GE.MAX)GO TO 9999
      MMO=0
      IF(MO.EQ.1)GO TO 830
      NNNMO=MO-1
      DO 730 I13=1,NNNMO
  730 MMO=MMO+DAMO(I13)
  830 CONTINUE
C ITIME=NUMBER OF HOURS FROM 1900 TO CURRENT TIME--USED
C   TO SEE IF PROGRAM HAS PUNCHED ALL THE DATA YET.
      ITIME=HR+24*DA+24*MMO+YR*365*24
      AYR=YR-1
      AYR=AYR/4.
      IYR=AYR+.01
      ITIME=ITIME+IYR*24
      IF(ITIME.GT.MTIME)GO TO 9999
      IEND=(MTIME-ITIME)/TIME
      IF(IEND.LT.NCARD)NCARD=IEND+1
      GO TO 100
 9999 CONTINUE
      PUNCH 920,FLAG
  920 FORMAT(A4)
      RETURN
      END
```

Fig. C-4d - Program Listing for EVAP for Punching Lake Evaporation Data [continued]

401352

```
▲7-8-9
  123 NUMB
.33.10.10.05.21.14.20.13.31.10.10.06.16.18.15.27.20.40.40.45.32.29.33.35.36
.44.47.14.12.25.38.50.33.54.20.20.16.28.16.13.12.10.20.22.28.20.15.09.31.29
.22.27.28.33.15.07.24.15.20.24.36.32.20.27.23.11.28.38.33.25.13.20.37.29.24
.30.32.11.20.26.25.23.41.27.35.30.25.25.22.28.30.29.26.25.26.30.27.25.25.13
.18.18.22.19.27.24.25.26.23.20.10.17.23.16.09.00.31.22.17.16.25.21.18
        100 MAX      24 TIME     72 CODE                 ↑
FLAG     24 HR        1 DA        5 MO     67 YR      ▲ LAKE EVAPORATION DATA
 ↓       24 FHR      31 FDA       8 FMO    67 FYR
999921-8692
▼6-7-8-9    ↖ IDENT
```

Fig. C-4e - Program Listing for EVAP for Punching Lake Evaporation Data [continued]