ESSA WBTM WR 55

A UNITED STATES
DEPARTMENT OF
COMMERCE
PUBLICATION

ESSA Technical Memorandum WBTM WR 55

U.S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Weather Bureau

Application of the SSARR Model to a Basin Without Discharge Record

VAIL SCHERMERHORN AND DONALD W. KUEHL

Western Region

SALT LAKE CITY,
UTAH

August 1970

WESTERN REGION TECHNICAL MEMORANDA

The Technical Memorandum series provide an informal medium for the documentation and quick dissemination of results not appropriate, or not yet ready, for formal publication in the standard journals. The series are used to report on work in progress, to describe technical procedures and practices, or to report to a limited audience. These Technical Memoranda will report on investigation devoted primarily to Regional and local problems of interest mainly to Western Region personnel, and hence will not be widely distributed.

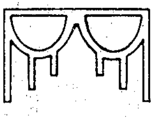
These Memoranda are available from the Western Region Headquarters at the following address: Weather Bureau Western Region Headquarters, Attention SSD, P. O. Box 11188, Federal Building, Salt Lake City, Utah 84111.

The Western Region subseries of ESSA Technical Memoranda, No. 5 (revised edition), No. 10 and all others beginning with No. 24, are available also from the Clearinghouse for Federal Scientific and Technical Information, U. S. Department of Commerce, Sills Building, Port Royal Road, Springfield, Va. 22151. Price: $3.00 paper copy; $0.65 microfiche. Order by accession number shown in parentheses at end of each entry.

Western Region Technical Memoranda:

No. 1* Some Notes on Probability Forecasting. Edward D. Diemer. September 1965.
No. 2 Climatological Precipitation Probabilities. Compiled by Lucianne Miller. Dec. 1965.
No. 3 Western Region Pre- and Post-FP-3 Program. Edward D. Diemer. March 1966.
No. 4 Use of Meteorological Satellite Data. March 1966.
No. 5** Station Descriptions of Local Effects on Synoptic Weather Patterns. Philip Williams, Jr. October 1969 (Revised). (PB-178 000)
No. 6* Improvement of Forecast Wording and Format. C. L. Glenn. May 1966.
No. 7 Final Report on Precipitation Probability Test Programs. Edward D. Diemer. May 1966.
No. 8* Interpreting the RAREP. Herbert P. Benner. May 1966. (Revised January 1967.)
No. 9 A Collection of Papers Related to the 1966 NMC Primitive-Equation Model. June 1966.
No. 10* Sonic Boom. Loren Crow (6th Weather Wing, USAF, Pamphlet). June 1966. (AD-479 366)
No. 11 Some Electrical Processes in the Atmosphere. J. Latham. June 1966.
No. 12* A Comparison of Fog Incidence at Missoula, Montana, with Surrounding Locations. Richard A. Dightman. August 1966.
No. 13* A Collection of Technical Attachments on the 1966 NMC Primitive-Equation Model. Leonard W. Snellman. August 1966.
No. 14 Application of Net Radiometer Measurements to Short-Range Fog and Stratus Forecasting at Los Angeles. Frederick Thomas. September 1966.
No. 15 The Use of the Mean as an Estimate of "Normal" Precipitation in an Arid Region. Paul C. Kangieser. November 1966.
No. 16 Some Notes on Acclimatization in Man. Edited by Leonard W. Snellman. November 1966.
No. 17 A Digitalized Summary of Radar Echoes Within 100 Miles of Sacramento, California.
No. 18 Limitations of Selected Meteorological Data. December 1966.
No. 19* A Grid Method for Estimating Precipitation Amounts by Using the WSR-57 Radar. R. Granger. December 1966.
No. 20* Transmitting Radar Echo Locations to Local Fire Control Agencies for Lightning Fire Detection. Robert R. Peterson. March 1967.
No. 21 An Objective Aid for Forecasting the End of East Winds in the Columbia Gorge. D. John Coparanis. April 1967.
No. 22 Derivation of Radar Horizons in Mountainous Terrain. Roger C. Pappas. April 1967.
No. 23 "K" Chart Application to Thunderstorm Forecasts Over the Western United States. Richard E. Hambidge. May 1967.
No. 24 Historical and Climatological Study of Grinnell Glacier, Montana. Richard A. Dightman. July 1967. (PB-178 071)
No. 25 Verification of Operational Probability of Precipitation Forecasts, April 1966-March 1967. W. W. Dickey. October 1967. (PB-176 240)
No. 26 A Study of Winds in the Lake Mead Recreation Area. R. P. Augulis. Jan. 1968. (PB-177 830)
No. 27 Objective Minimum Temperature Forecasting for Helena, Montana. D. E. Olsen. Feb. 1968. (PB-177 827)

*Out of Print
**Revised



A western Indian symbol for rain. It also symbolizes man's dependence on weather and environment in the West.

U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

Weather Bureau Technical Memorandum WR-55

APPLICATION OF THE SSARR MODEL TO A BASIN WITHOUT DISCHARGE RECORD

Vail Schermerhorn
Principal Assistant
RFC, Portland, Oregon

Donald W. Kuehl
Hydrologist
RFC, Portland, Oregon

WESTERN REGION
TECHNICAL MEMORANDUM NO. 55

SALT LAKE CITY, UTAH
AUGUST 1970

TABLE OF CONTENTS

LIST OF FIGURES

APPLICATION OF THE SSARR MODEL TO A BASIN WITHOUT DISCHARGE RECORD

I. INTRODUCTION

Hydrologic models are usually designed and tested on basins where high quality data are available with adequate areal and time coverage. In operational forecasting the model must be applied where the forecast is needed and not necessarily where all desired data are available. The flexibility, adaptability, and rationality of a model are often severely tested when applied to practical forecasting situations.

The SSARR (Streamflow Synthesis and Reservoir Regulation) model was designed to be a general, flexible model with special provisions for use in daily river forecasting operations. It has been tested on many basins with adequate data, thus demonstrating its ability to reliably synthesize watershed response to both rainfall and snow melt (1) (2).

In the present application the model is used to answer a need for flood forecast service on the Skookumchuck River at Centralia, Washington (172 square mile basin, Figure 1). Streamflow data consist of short period gage height records, but no discharge information except for smaller headwater areas. Precipitation must be estimated from two stations in an adjacent watershed.

II. EVOLUTION OF THE SSARR MODEL

The SSARR model and the associated computer program was designed to synthesize all the various hydrologic and hydraulic processes in a large complex river system. Hydrologically and hydraulically it is very general in that it synthesizes the following processes: separation of areas of rain and snow, soil moisture accounting, watershed rainfall runoff, snowmelt, snowpack accumulation, watershed routing, channel routing, overbank flow routing, lake routing, reservoir regulation and backwater computation. All of these processes can be specified as part of the synthesis of a complex river system consisting of various basins, channels, reservoirs, and lakes.

The associated computer program provides for a great deal of flexibility and ease in specifying prototype configuration, model coefficients, data input, output of results, plotting of input data and system results, computational period length, and units used. The program is designed to facilitate the revision of, or addition to the model.

The present SSARR model and its computer program is the second major modification of the basic model designed in 1957 by Rockwood (3). The first modification was programmed for the IBM 1920 and was used operationally by the Cooperative Columbia River Forecast Unit* from 1962 through 1967. The latest major redesign, as well as subsequent refinements, is a cooperative effort of the Corps of Engineers, North Pacific Division, and the River Forecast Center, ESSA, Weather Bureau. Since the first operational use of the present model in the winter of 1968, the model and program have undergone continuous refinement.

III. BASIC CONCEPTS IN THE WATERSHED MODEL

Because this application in the Skookumchuck Basin uses only the watershed portion of the SSARR model, the description will be limited to that portion. A schematic representation, as presented by Anderson (4), is shown in Figure 2. This is a low elevation basin in a maritime climate where snowfall and snow melt are not significant. Thus, the four snow-related functions of Figure 2 were not generally employed.

A basin may be considered a homogeneous unit and runoff calculated for the whole, or subareas may be computed individually and combined to produce the watershed outflow. Each of these subareas may have its own data input, weightings, coefficients and functions as implied in Figure 2.

Watershed precipitation may be input in the form of station amounts (each individually weighted) or in basin average quantities. Precipitation can be entered in any period length from 0.1 hour to 24 hours (or a mixture of periods) independent of the computational interval. Amounts of precipitation can be in inches or in percent of period normals, or rainy day ratios (5) if it is necessary to adjust for station and basin elevation effects. Metric units may also be used.

---

*This unit was formed in 1962 by formal agreement between the Weather Bureau, ESSA, and the Corps of Engineers, U. S. Army, to make the best use of streamflow forecasting capabilities of the Portland River Forecast Center of the Weather Bureau and the North Pacific Division office of the Corps of Engineers. The Unit prepares flood forecasts and streamflow and reservoir inflow forecasts for the entire Columbia Basin, and the adjacent coastal areas in Washington and Oregon. The forecasts are used to satisfy the public service responsibilities of the Weather Bureau as well as the Corps of Engineers' requirements for forecasts for project operation. Forecasts are supplied to agencies, both public and private in United States and Canada, which have river-related activities and responsibilities.

The combined weighted station amounts of precipitation are, in the case of no snowfall or snow melt, the total moisture input.

Soil Moisture Function. The essence of the rainfall-runoff computation is performed in the Soil Moisture-Runoff function labeled SMI in Figure 2. A typical Soil Moisture Index-Runoff percent relation is shown in Figure 3. The percent of the watershed rainfall for each computational period which will later appear as flow in the stream is termed Runoff Percent (ROP). This is total runoff including base flow. The complement of the ROP is added to the soil moisture and is removed only by evapo-transpiration. The SMI is computed as follows:

$$SMI_2 = SMI_1 + (MI-RO) - KE(ETI)$$

where ETI is an evapo-transpiration amount which, during periods of rainfall, is reduced by a function KE, MI is moisture input, RO is computed runoff. The quantity (MI-RO) can be termed recharge and be restated as (1-ROP)MI.

Computation of SMI and ROP is done once for each computational interval or period and the value of the ROP for the beginning of the period is applied to all the moisture input for the period. The computational period is made sufficiently short to account for the effects of intensity. The computational period may be varied during the run.

The minimum runoff percent is related to the amount of impervious area and water surface in the watershed--lakes, streams, swamps, or other areas which even after a long dry spell would produce 100 percent runoff. The maximum SMI, usually equivalent to 100 percent runoff from the entire watershed, is related to the soil's total moisture holding capacity.

Base Flow Infiltration Function. Base flow is the first of three arbitrary components of runoff to be separated and routed with its own time delay. It is a function of the Base Flow Infiltration Index (BII) and is determined each computational period from a relationship such as shown in Figure 4. The volume of runoff is (MI) (ROP) (BFP) where BFP is the base flow percent. This component is somewhat analogous to that portion of the discharge hydrograph which is excluded in the standard base flow separation techniques to leave "direct storm runoff" (6). The BII is a value which integrates the effect of immediately antecedent runoff. In simplified form, its computation is:

$$BII_2 = BII_1 + (RO-BII_1)\ (K_r)$$

where K_r is a recession constant. The index is high during a period of high runoff, but it can decay to near zero after three or four days of no runoff generation. This is in contrast to the SMI which is usually a slowly changing value and can be thought of as a seasonal index. As in the case of the SMI, the BII at the beginning of the computational period is used to compute the BFP for that period.

The Base Flow Infiltration relationship may be thought of as evaluating the amount of the runoff volume which is detained in depression storage and in transit in the soil but which will later contribute to groundwater storage and ultimately appear in the stream as base flow. The contribution to base flow is usually the greatest portion of the runoff following a period of low runoff generation.

Surface, Subsurface Separation. The remaining runoff after the base flow percentage is satisfied is available for separation into the other two arbitrary flow components: surface and subsurface flow. The surface, subsurface function shown in Figure 5 is a simple relationship which evaluates the period surface runoff as a function of the intensity of direct runoff. The remaining runoff is then assigned to the subsurface component.

Watershed Routing. Each of the components of watershed runoff is routed separately with a given time-delay to the stream at the watershed outflow. Thus the separation and separate routing accomplishes what some hydrologists have simulated by "variable-peaked" unit hydrographs.

The routing is accomplished by the multi-increment, reservoir-type storage method (3). Each component has its own number of increments (reservoirs) and time of storage. Typically, the subsurface component has a time-delay of two to three times that of the surface component.

IV. THE SKOOKUMCHUCK BASIN PROBLEM

The Skookumchuck River rises in the Cascade Mountain foothills east of Centralia, in southwestern Washington, and flows through the residential section of Centralia before joining the Chehalis River on the west edge of town. Flooding occurs fairly frequently and a river stage forecasting service is required.

The basin area is 172 square miles, and elevations range from 170 to over 3000 feet MSL. Floods are caused by heavy rainfall and since about 70 percent of the basin is below 1000 feet, snow melt is a minor consideration.

A staff gage was established by the Weather Bureau at the Harrison Avenue Bridge in 1950 (Figure 1). In 1965 the gage height record was moved upstream a few blocks to a better site at the Pearl Street Bridge after a one-season overlap in record. The U. S. Geological Survey operates a gaging station 24 miles upstream at a point representing one-third of the total drainage area. In December 1967 that agency also established a gaging station at Bucoda, where the drainage area is about two-thirds of the total. Thus, there is a reasonably long, composite record of river stages available, but essentially no usable discharge information at the forecast point.

The quality of rainfall data is rather typical of this size area. There is a standard climatological station in Centralia at the edge of the watershed, measuring 24-hour rainfall amounts, but no other precipitation stations within the basin. There are, however, two rather well-located recording rain gages at Chehalis and Cinebar, just outside the basin to the south.

Previous flood warnings had been prepared from a crude stage relation between the Skookumchuck and Chehalis River gages. Known differences in rainfall could not be handled objectively. Other direct correlation methods using crest stage data could have been pursued, but they fail to use the additional intelligence available in the complete storm stage hydrograph. Neither do they yield the desired forecast of the complete hydrograph. The problem was viewed as a challenge to the considerable flexibility of the SSARR model.

V. THE SOLUTION

In order to utilize the complete record in consistent fashion, it was necessary to synthesize the record at the present Pearl Street site from the earlier record at Harrison Street. There were eight significant storms in the total period for which reasonably complete rainfall and gage height data were available. The synthesis was accomplished with a gage height relation based on the period of concurrent record. Here one of the model's features made the conversion almost effortless. With the "adjacent basin" facility (7), any station's flow (or stage) can be made to vary as a function of a second station. The function can be defined by a two-variable table.

All original gage height observations were punched in a format (7) which permits time identification of irregular readings. The model permits entry of data directly in the form of discharge, or in the form of elevations when an elevation-discharge relation is supplied. Thus the second step in the "trial and error" process was to estimate a stage-discharge relation. This was done largely with the aid of limited discharge information from the smaller gaged portions of the basin.

Rainfall was supplied to the model in the form of three-hourly station amounts, that period being considered optimum for this climate and size of basin. Major storms are usually more than 24 hours in duration. Storm hydrograph durations varied from 6 to 9 days. Basin precipitation was defined as equal to the weighted average of the two station amounts. Weights were determined by the ratios of basin normal annual precipitation (NAP) to station NAP.

Other first trial coefficients of the model were assigned from a knowledge of the general hydrology of the basin and the region. Initial values of the indices were assigned on the basis of experience. Runoff coefficients in this area approach 100 percent in midwinter. Initial values between 90 and 100 percent were used in 7 of the 8 storms, with a lesser value in the one fall storm. BII values were near minimum at the beginning of each storm.

VI. RESULTS AND CONCLUSIONS

The performance of the model is indicated by the storm reconstitutions of Figure 6. This degree of agreement between the discharge computed from rainfall and that synthesized from the gage height record was achieved with only 4 trials. Each took 5 minutes of computer time. Surprisingly, the first trial stage discharge relation required no modification.

The satisfactory reproduction of eight storm hydrographs gives promise that the SSARR model coefficients are adequate for operational forecasting, and that the synthetic stage discharge relationship provides a reasonable estimate of the flow in the Skookumchuck River at Centralia. The computer model and the derived coefficients are also used to prepare tables for a backup procedure which can be used during a computer failure, or which can be provided another office. This manual backup procedure is entirely compatible with the computer calculations and can be used to modify a computer forecast, or to prepare an original forecast.

Results of reconstitutions and ease of application are testimony to the adaptability and rationality of a model which can translate such "bits and pieces" of input data into practical forecasts.

VII. ACKNOWLEDGMENT

Earlier versions of the model were conceived and developed by David M. Rockwood. Revisions incorporated in the present version are a result of collaboration between the authors and Mr. Rockwood.

Mr. Edward Davis, Corps of Engineers System Analyst, must be recognized for converting the basic hydrologic and hydraulic philosophy of the SSARR model into an effective computer program. His expertise in system programming plus his many suggestions have added materially to the flexibility of the SSARR model.

VIII. REFERENCES

1. Kuehl, D. W., and Schermerhorn, V. P., "Hydrologic Digital Model of Willamette Basin Tributaries for Operational Forecasting", Unpublished, presented at ASCE National Meeting on Water Resources Engineering, New York, October 19, 1967.

2. Schermerhorn, V. P., and Kuehl, D. W., "Operational Streamflow Forecasting with the SSARR Model", in *The Use of Analog and Digital Computers in Hydrology*, IASH-UNESCO, 1968. Volume I, pp. 317-328.

3. Rockwood, D. M., "Columbia Basin Streamflow Routing by Computer", *Journal of Waterways and Harbors Division, American Society of Civil Engineers*, December 1958, Volume 84, Part I, Paper No. 1874.

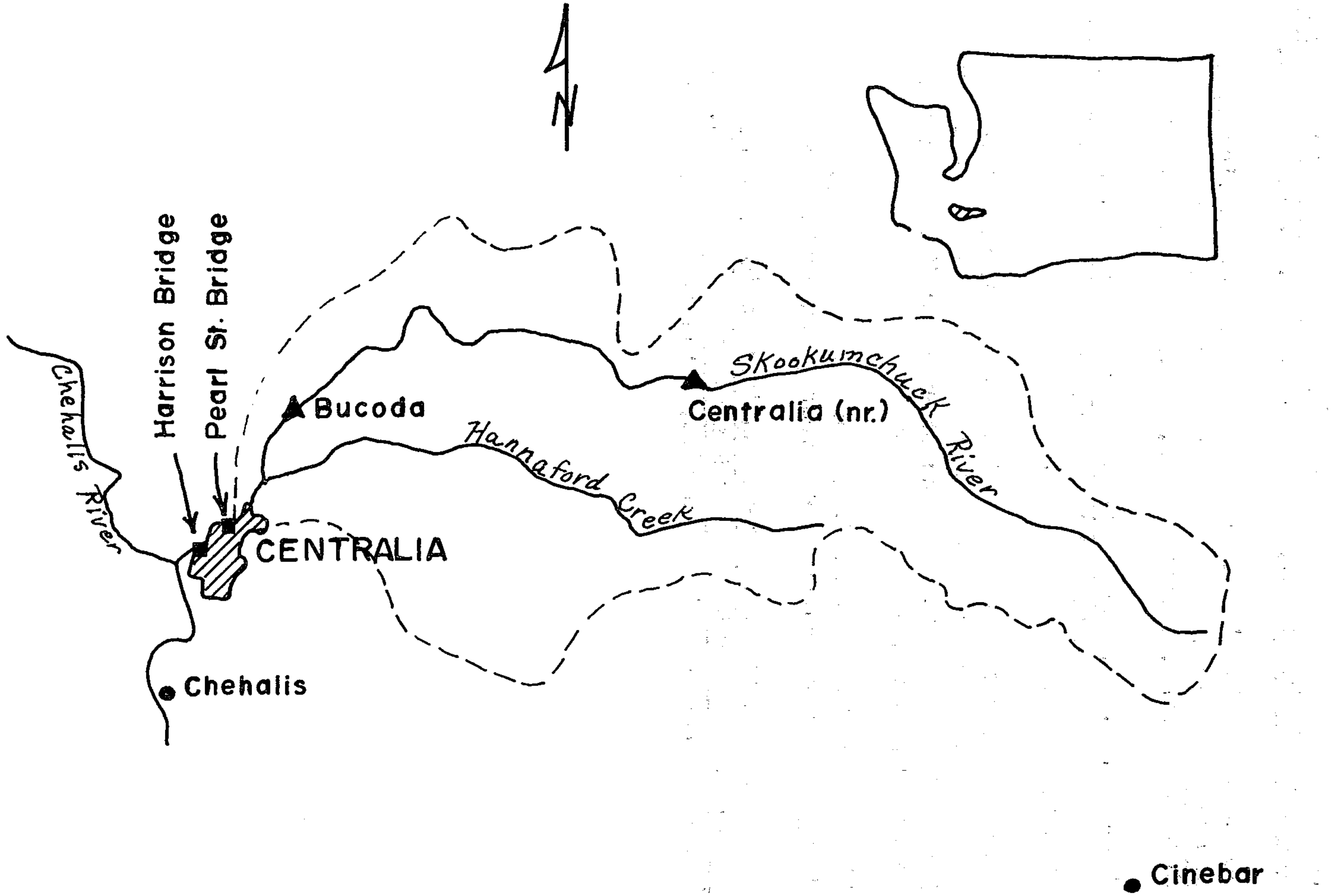
4. Anderson, J. A., *Runoff Evaluation and Streamflow Simulation by Computer*, U. S. Army Engineer Division, North Pacific, Portland, Oregon, December 1969 (Draft).

5. Weaver, R., and Denney, W., "Normalized Quantitative Precipitation Forecasting in California", Unpublished Weather Bureau Manuscript, presented at National Meeting of American Meteorological Society, Vancouver, B. C., June 24, 1964.

6. Linsley, R. K., Kohler, M. A., and Paulhus, J. L., *Applied Hydrology*, McGraw-Hill Book Company, New York, 1949, pp. 397-404.

7. Davis, E. M., *Draft of Operating Instructions, Computer Program for Streamflow Synthesis and Reservoir Regulation*, U. S. Army Engineer Division, North Pacific, Portland, Oregon, June 1967.

Skookumchuck River Watershed



Traced from Hoquiam U.S. Series Map Scale 1:250,000 FIGURE 1

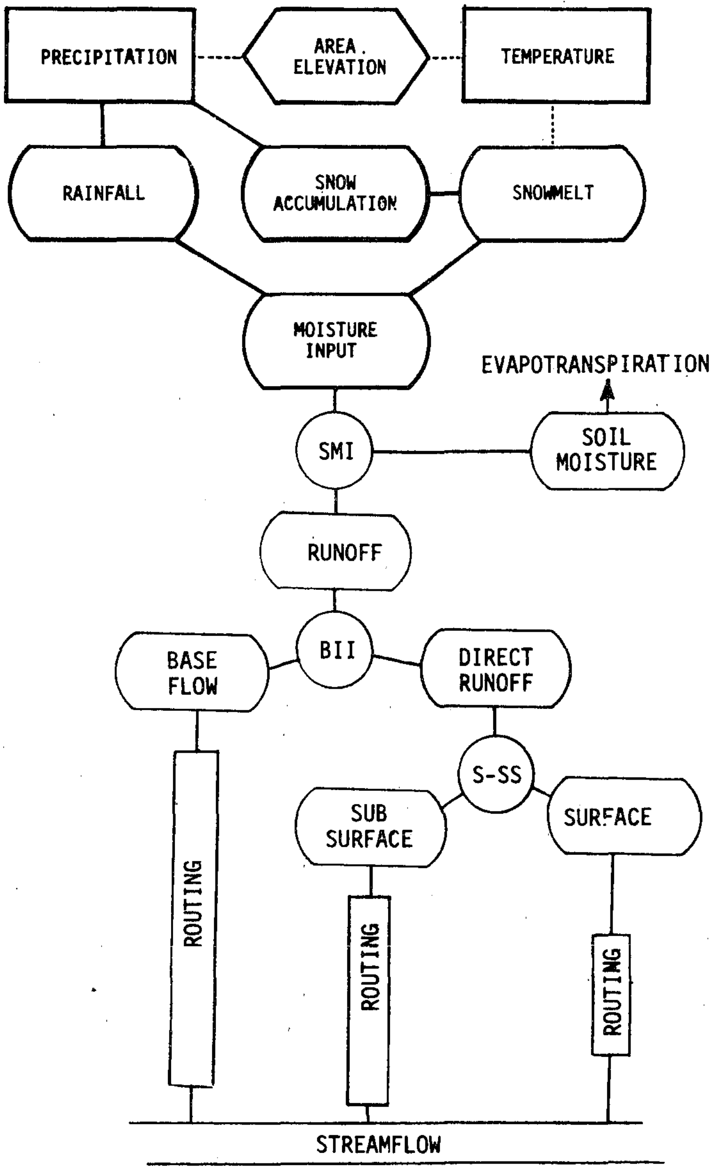
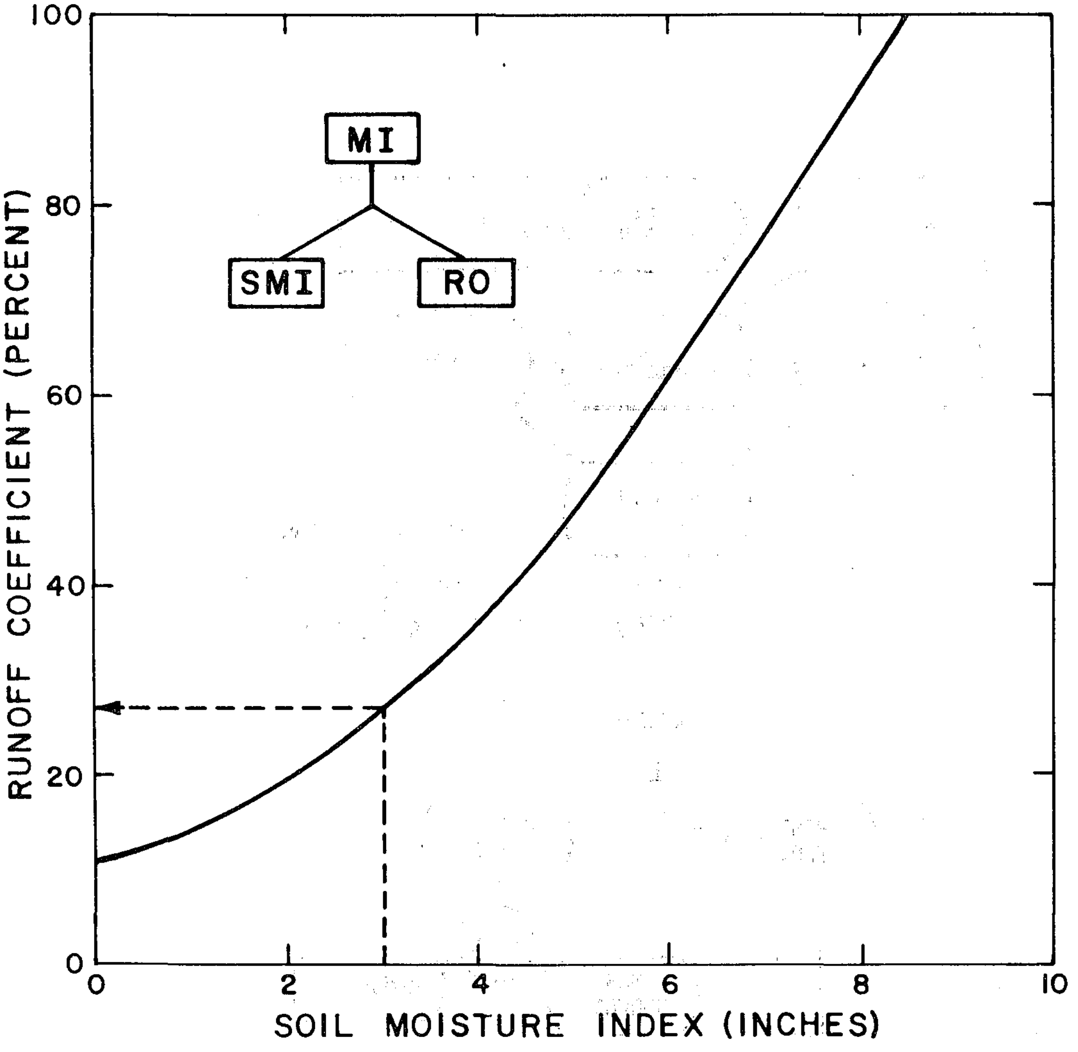


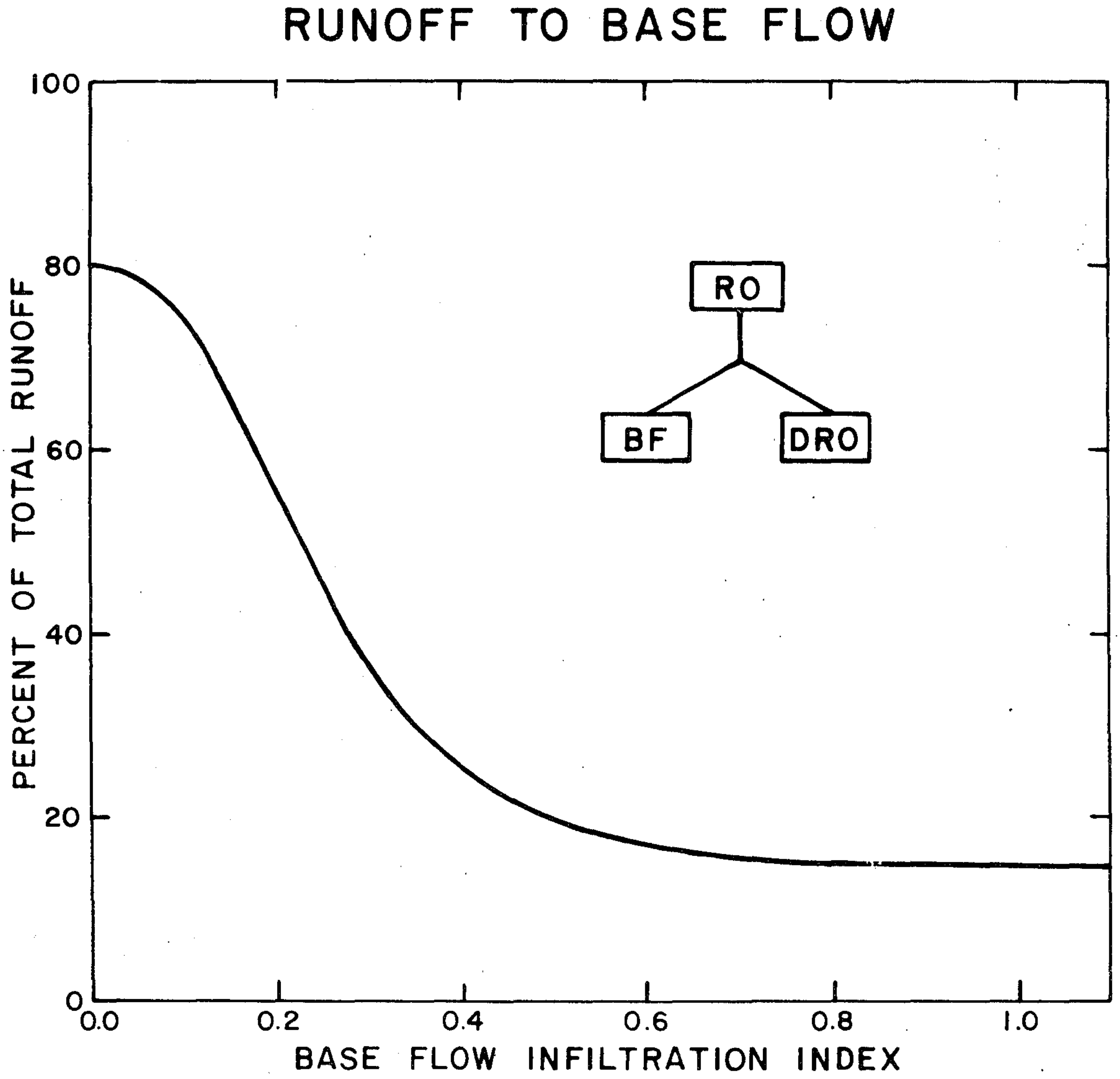
FIG. 2 SCHEMATIC REPRESENTATION OF SSARR WATERSHED MODEL

RUNOFF COEFFICIENT



$$SMI_2 = SMI_1 + (MI - RO) - KE(ETI)$$

FIGURE 3. TYPICAL SOIL MOISTURE INDEX - RUNOFF RELATION.



$$BII_2 = BII_1 + (RO - BII_1)\ (K_r)$$

FIGURE 4. RELATIONSHIP OF BASE FLOW INFILTRATION INDEX TO RUNOFF.

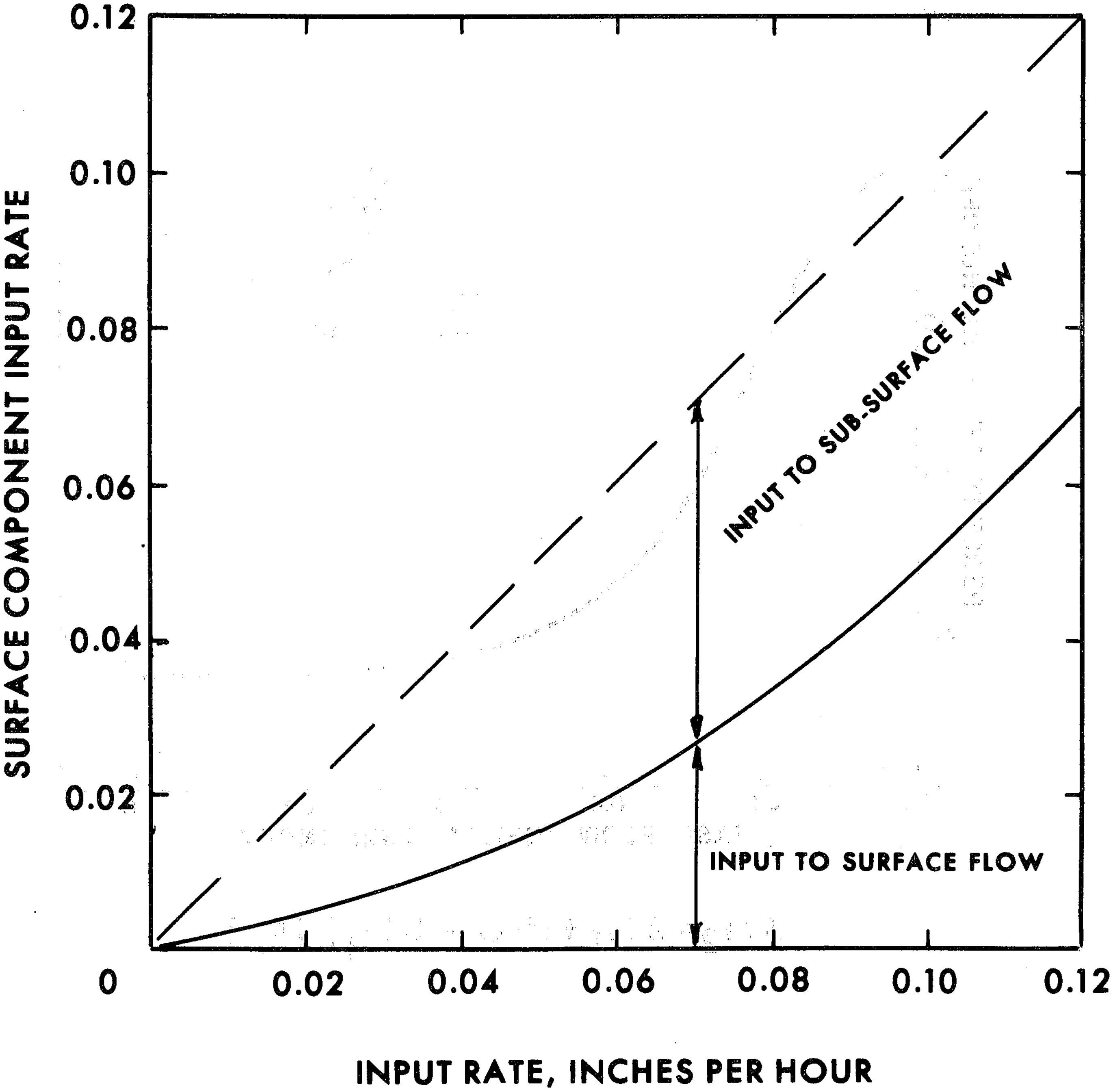


FIGURE 5. SEPARATION OF SURFACE AND SUBSURFACE FLOW.

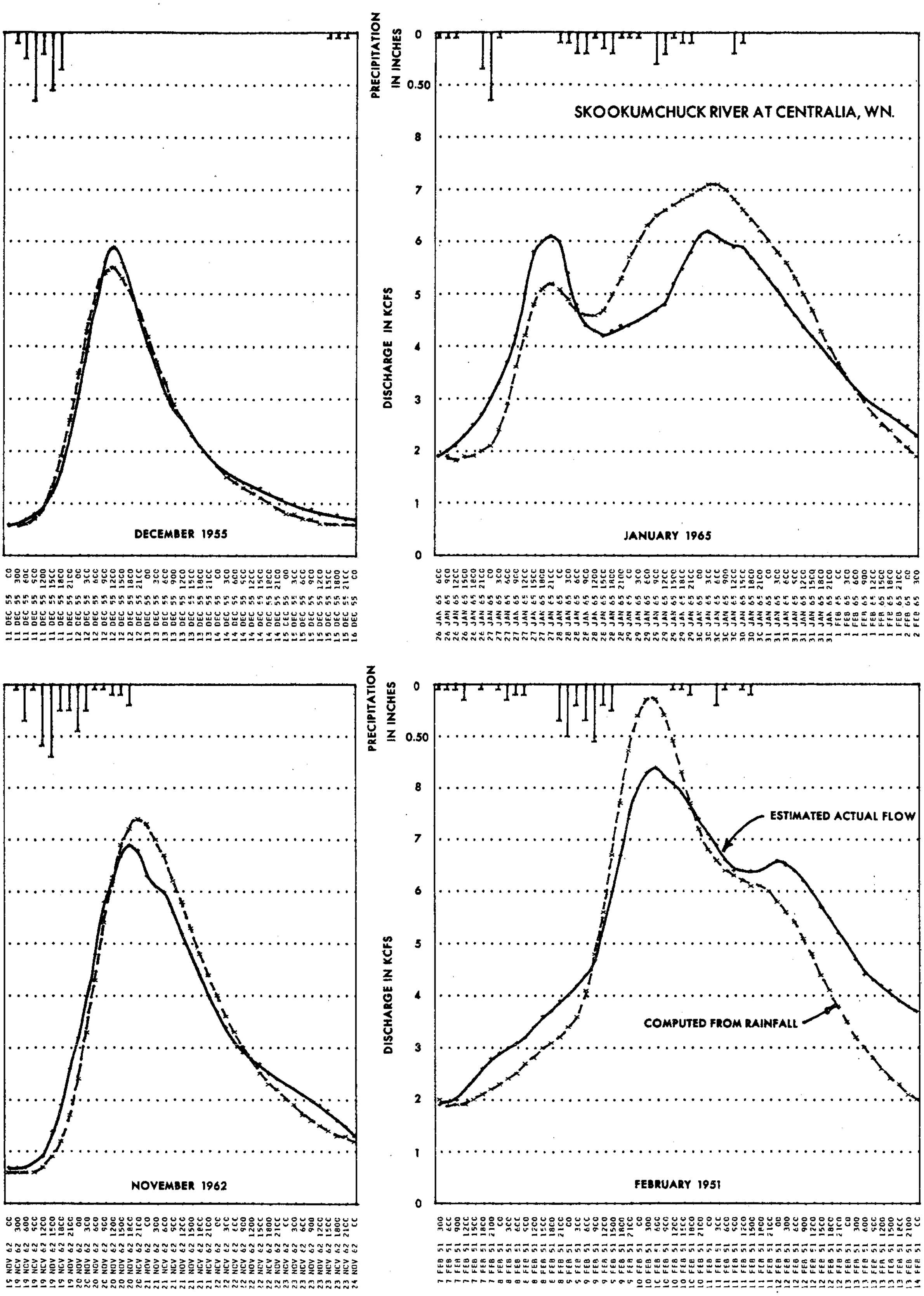


FIGURE 6A. STORM RECONSTITUTIONS FOR SKOOKUMCHUCK RIVER.

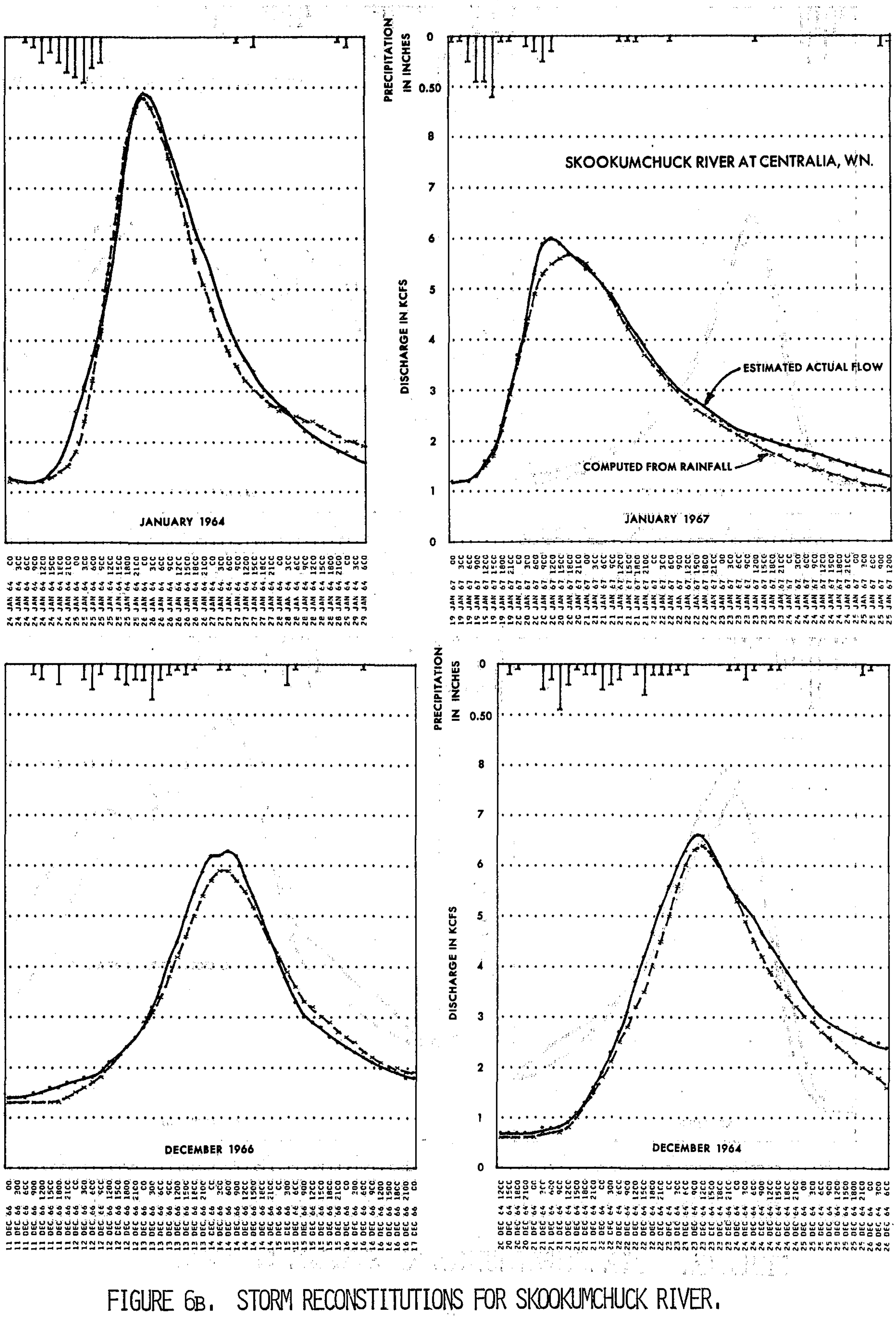


FIGURE 6B. STORM RECONSTITUTIONS FOR SKOOKUMCHUCK RIVER.

Western Region Technical Memoranda: (Continued)

No. 28** Weather Extremes. R. J. Schmidli. April 1968. (PB-178 928)
No. 29 Small-Scale Analysis and Prediction. Philip Williams, Jr. May 1968. (PB-178 425)
No. 30 Numerical Weather Prediction and Synoptic Meteorology. Capt. Thomas D. Murphy, U.S.A.F. May 1968. (AD-673 365)
No. 31* Precipitation Detection Probabilities by Salt Lake ARTC Radars. Robert K. Belesky. July 1968. (PB-179 084)
No. 32 Probability Forecasting in the Portland Fire Weather District. Harold S. Ayer. July 1968. (PB-179 289)
No. 33 Objective Forecasting. Philip Williams, Jr. August 1968. (AD-680 425)
No. 34 The WSR-57 Radar Program at Missoula, Montana. R. Granger. October 1968. (PB-180 292)
No. 35** Joint ESSA/FAA ARTC Radar Weather Surveillance Program. Herbert P. Benner and DeVon B. Smith. December 1968. (AD-681 857)
No. 36* Temperature Trends in Sacramento--Another Heat Island. Anthony D. Lentini. February 1969. (PB-183 055)
No. 37 Disposal of Logging Residues Without Damage to Air Quality. Owen P. Cramer. March 1969. (PB-183 057)
No. 38 Climate of Phoenix, Arizona. R. J. Schmidli, P. C. Kangieser, and R. S. Ingram. April 1969. (PB-184 295)
No. 39 Upper-Air Lows Over Northwestern United States. A. L. Jacobson. April 1969. (PB-184 296)
No. 40 The Man-Machine Mix in Applied Weather Forecasting in the 1970s. L. W. Snellman. August 1969. (PB-185 068)
No. 41 High Resolution Radiosonde Observations. W. W. Johnson. August 1969. (PB-185 673)
No. 42 Analysis of the Southern California Santa Ana of January 15-17, 1966. Barry B. Aronovitch. August 1969. (PB-185 670)
No. 43 Forecasting Maximum Temperatures at Helena, Montana. David E. Olsen. October 1969. (PB-185 762)
No. 44 Estimated Return Periods for Short-Duration Precipitation in Arizona. Paul C. Kangieser. October 1969. (PB-187 763)
No. 45/1 Precipitation Probabilities in the Western Region Associated with Winter 500-mb Map Types. Richard P. Augulis. December 1969. (PB-188 248)
No. 45/2 Precipitation Probabilities in the Western Region Associated with Spring 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189 434)
No. 45/3 Precipitation Probabilities in the Western Region Associated with Summer 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189 414)
No. 45/4 Precipitation Probabilities in the Western Region Associated with Fall 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189 435)
No. 46 Applications of the Net Radiometer to Short-Range Fog and Stratus Forecasting at Eugene, Oregon. L. Yee and E. Bates. December 1969. (PB-190 476)
No. 47 Statistical Analysis as a Flood Routing Tool. Robert J. C. Burnash. December 1969. (PB-188 744)
No. 48 Tsunami. Richard P. Augulis. February 1970. (PB-190 157)
No. 49 Predicting Precipitation Type. Robert J. C. Burnash and Floyd E. Hug. March 1970. (PB-190 962)
No. 50 Statistical Report of Aeroallergens (Pollens and Molds) Fort Huachuca, Arizona 1969. Wayne S. Johnson. April 1970. (PB-191 743)
No. 51 Western Region Sea State and Surf Forecaster's Manual. Gordon C. Shields and Gerald B. Burdwell. July 1970. (PB-193 102)
No. 52 Sacramento Weather Radar Climatology. R. G. Pappas and C. M. Veliquette. July 1970. (PB-193 347)
No. 53 Experimental Air Quality Forecasts in the Sacramento Valley. Norman S. Benes. August 1970.
No. 54 A Refinement of the Vorticity Field to Delineate Areas of Significant Precipitation. Barry B. Aronovitch. August 1970.

* Out of Print
**Revised