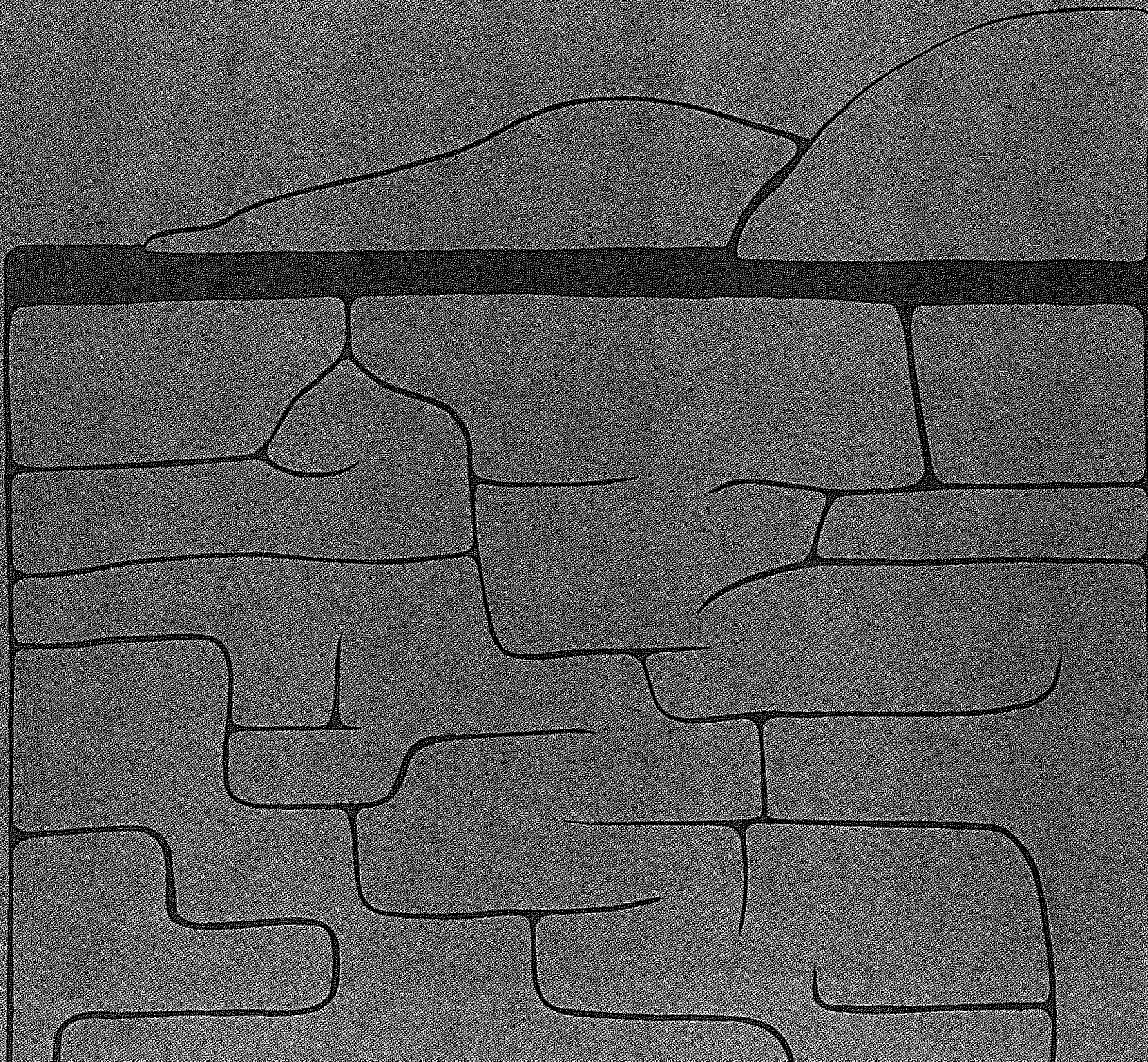
# FLOOD FREQUENCY ESTIMATION IN NORTHERN SPARSE DATA REGIONS



**INSTITUTE OF WATER RESOURCES**

University of Alaska

Fairbanks, Alaska 99701

Food frequency estimation in northern sparse data regions: Completion report

Robert F. Carlson
Patricia Fox

# FLOOD FREQUENCY ESTIMATION
# IN NORTHERN SPARSE DATA REGIONS

Completion Report
OWRR Project B-021 ALAS

Robert F. Carlson
Director
Institute of Water Resources
University of Alaska

and

Patricia Fox
Statistical Analyst
Institute of Water Resources
University of Alaska

INSTITUTE OF WATER RESOURCES
University of Alaska
Fairbanks, Alaska

Report No. IWR-55

July, 1974

## ACKNOWLEDGEMENTS

*The work upon which this report is based was supported by funds (Project B-021 ALAS) provided by the United States Department of the Interior, Office of Water Resources Research, as authorized by Water Resources Research Act of 1964, Public Law 88-379, as amended.*

TABLE OF CONTENTS

# INTRODUCTION

The northern regions of the world are presently a focal point for international interest due to the tremendous resource development now underway. With "energy crisis" an everyday issue in the world press, the oil and gas pipelines of the north offer important hope for solutions. What we are now seeing is only the beginning of an explosion of resource development, a development which will be highly dependent on water resource information.

Flood regimes of northern regions are complicated by the extreme climate and by ice formation. Construction of the many structures related to resource extraction, pipelines, roads, dams, reservoirs, etc., makes it imperative that flood frequency information be available for design considerations. However, Alaska is characterized by a limited data base, which leads to questionable design flood estimates if standard estimation methods are used.

The necessary approach to flood frequency estimation in a region characterized by a sparse data network and predominantly ice or snowmelt-caused floods, should have few parameters which require estimation. There should be a strong physical basis for the method and it should be a technique which depends on input with a high degree of area homogeneity. These characteristics will strengthen the validity of flood design estimates in northern regions.

When developing a new technique, such as new flood frequency design determination, it is important to examine older techniques. By evaluating these older techniques, several advantages can be incorporated in the new method. Determination of problem areas can lead to their solution in the new method. Older techniques can also be used for comparison with the new method or as a basis for further use of all or part of the older technique.

This report describes a series of studies directed toward the examination and development of better methods for flood frequency design in northern sparse data regions. The salient features of the overall work are described in this paper. Details are reported in two technical reports and two journal papers which are abstracted in a later section and are listed below:

I. Methods of peak-flow determination in sparse data regions (1974). Carlson, Fox and Shrader.

II. A northern snowmelt model (1974). McDougall and Carlson.

III. Comparison of current methods for peak flow determination in sparse data regions (1974). Fox and Carlson.

IV. A northern-snowmelt flood frequency model (1974). Carlson, McDougall and Fox.

# OBJECTIVES

The primary objective of this project was to complete development of an arctic hydrologic model and to evaluate its usefulness in generating information useful for a design tool in estimation of peak flow discharges. The peak flow discharges studied were those generally analyzed and evaluated in the design of facilities for stream crossings. This overall objective was broken into four sub-objectives:

1. Evaluation of existing methods of design which are used to provide peak flow information.
2. The selection of suitable test sites for testing the validity of the model.
3. Further development of a northern hydrologic model.
4. Comparison of the model-generated information with information generated by usual methods.

## RESEARCH RESULTS

The objectives listed for this project were worked on concurrently throughout the research period. However, the order of development can be traced as a series of steps.

The first objective was satisfied by a preliminary investigation of the methods used in flood frequency determination. In Report I the historical development and current flood prediction methods are discussed. This phase of the project also encompassed an investigation of the physiography and availability of data in Alaska. The results of this preliminary investigation demonstrated the sparseness of the data in Alaska, identified homogeneous physiographic regions and led to the selection of three methods of flood frequency determination for further analysis. These three methods, Graphical, Log Pearson Type III, and Regional Multiple Regression, were selected on the basis of:

1. Applicability to a sparse data region
2. Ease of calculation
3. Superficial satisfaction of underlying assumptions
4. General acceptance and/or previous use in Alaska

During the initial phase of the project, work was also underway on the second objective. The Chena River was chosen as the site to be used for application of the model. The criteria used for selection of the test site were mostly related to the available hydrologic data. Since snowmelt and icemelt have been determined to be major factors in flooding in northern regions, one of the requirements for the test site was the availability of snowcourse records in the basin. Flow gage records and a first class weather station within the basin were necessary requirements. A suitable record length (> 10 years) was desirable. Having restricted our consideration to the basins along the pipeline corridor, the basin which satisfied these needs was the Chena River. The weather station and gage records at Fairbanks were used in the study, and snowcourse data was available.

During this time, ten other basins along the pipeline corridor were subsequently selected for consideration of the three methods chosen earlier for further study. These rivers were selected in order to compare results for various record lengths, regions, and basin characteristics. Unfortunately, the Arctic Coastal Plain had no rivers with sufficient record length to merit the comparisons. The ten rivers chosen, in addition to the Chena River, were:

1. Chandalar River
2. Copper River
3. Koyukuk River
4. Salcha River
5. Gakona River
6. Klutina River
7. Porcupine River
8. Tazlina River
9. Tonsina River
10. Yukon River

The third objective was satisfied in two major steps. A snowmelt model, previously developed for arctic conditions, was generalized and rewritten to apply to northern environments (Report II). This model, a modification of work done by Amarocho and Espildora (1966), requires daily weather input from a first class weather station within the basin and initial conditions of the pack prior to the snowmelt period. Using heat flow calculations into and out of the snowpack derived from the input and drive parameters, the model outputs the daily snowmelt and snowpack conditions for the entire snowmelt period. The major assumptions of the model are:

1. Rainfall is insignificant during the snowmelt period.
2. A weather station is available within the basin (or at least nearby) which records the needed driving variables.
3. Continuous records are available for the snowmelt period.

The snowmelt model was applied to the Chena River basin using daily climatological data from Fairbanks. The daily model output was compared with snow survey data for ten years. The predicted and observed snowpack conditions and snow depth compared favorably within elevation bands for the basin.

The second portion of this model, the flood frequency model, was developed from earlier work reported by Eagleson (1971, 1972). It is a hybrid modeling approach which used both stochastic and deterministic rationale. The snowmelt duration and intensity for "snowmelt storms" are fit to exponential distributions. A snowmelt storm is defined as the snowmelt which occurs from start to end of the snowmelt period. The melt period may end due to a temperature drop or other physical input which causes retention or delay of the melting process. There are essentially three components: precipitation model, runoff model, and transformation model. The output from the snowmelt model for each elevation band is used by the precipitation model for development of the statistical parameters for intensity and duration. Three main assumptions are made in development of the relationships:

1. Peak stream flows can be predicted using kinetic wave equations.

2. Direct runoff-producing area parameters and storm parameters are independent of each other, and storm parameters are independent amongst themselves.

3. The direct runoff-producing area is a band centered about the stream. Therefore, areally averaged storm snowmelt excess duration is greater than or equal to the combined time of concentration for the basin and direct stream runoff areas.

Input required for the flood frequency model: snowmelt series, basin descriptors, and runoff-producing areas. The final prediction equation is of the form

$$Q_p = \left(\frac{26.9Ar}{\beta}\right) ln \left(T_e \phi \Theta\right)$$

where

$A_r$ = area producing direct runoff

$\beta$ = marginal distribution parameter of point snowmelt intensity

$\phi$ = fraction of snowmelt occurring as runoff

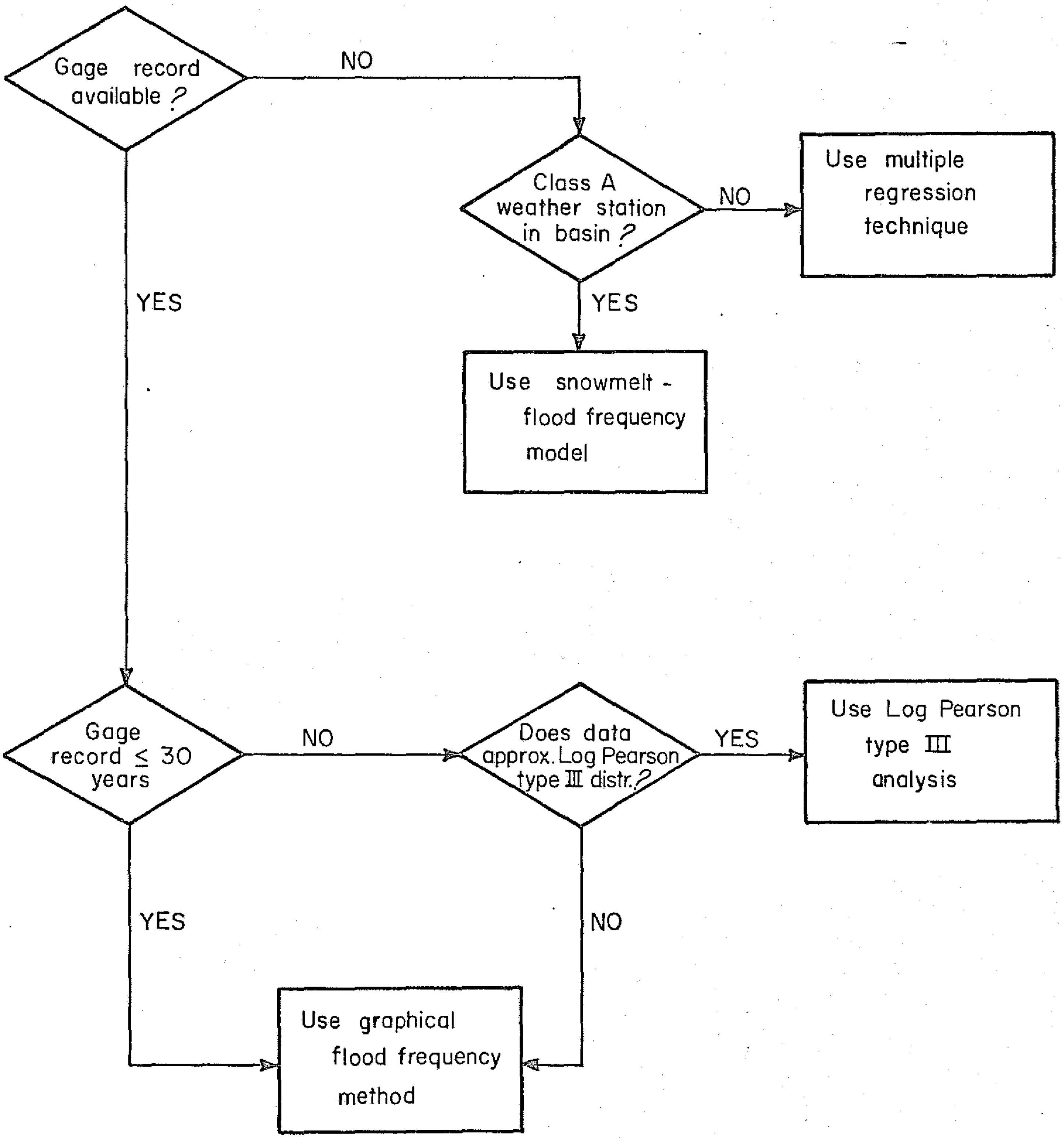
$\Theta$ = average annual number of independent snowmelt events.

The model produces estimates of flood magnitudes, $Q_p$, for given return periods, $T_e$.

Since the model has only been applied to one basin, its application requires further study. However, the sensitivity analysis of its parameters and distributions (Report IV) does allow for easier application to another basin. Some of the lesser developmental assumptions tend to limit model applications. For example, one such assumption is that the basin and the storm patterns are homogeneous, yet, the flood frequency model does permit estimation of peak floods when no stream gage records are available.

The fourth objective was accomplished by a statistically oriented comparison of the four methods of flood frequency determination. First the properties of the flood series were investigated, such as independence and time correlation. Due to the small sample sizes, nonparametric and distribution-free methods were chosen throughout the analysis. (A short description of the statistical properties of the flood series for each of the eleven basins is included in Report III). This allowed consideration of the developmental assumptions implicit in each of the four methods. Flood series were then split for evaluation of the efficiency, consistency, and power of the methods in relation to each basin. The illustration (p.10) demonstrates one of the decision trees developed during this section of the project. It is based on the availability of data for the analysis. This is a major deciding factor for sparse data regions. Further discussion of the degree of confidence and bias of the estimates can be found in Report III. Under certain basin and record conditions the simpler method may be the best estimator despite availability of data for more complex analysis.

Further studies concerning the implications of the degree of error for a given design flood estimate would give an even better understanding of which method to utilize for any given situation. It is also expected that with some refinements the model approach will provide very reliable estimates. As the results in Report III describe, it is essential that the applicability of the flood determination method be examined before it is used for a major design project. Blanket application of any one method, for example Log Pearson Type III, will most often lead to poor estimates due to the variability between basins.




*Decision Flow Diagram for Choosing Method for Determination of Flood Frequency in Sparse Data Regions*

## DISSEMINATION OF RESEARCH

Two technical reports and two journal reports were developed from this project:

Methods of Peak Flow Determination in Sparse Data Regions

This report presents material prepared in the early stages of the project and provides useful background information upon which the other reports were based. Three issues must be understood when embarking on a flood frequency design task: the fundamental basis of the design method, actual execution of the task, and the data environment. The first portion of this report presents a history and background of the many types of flood design methods presently available. The methods used by design agencies in Alaska are then reviewed. A presentation describing the Alaskan data and physical environment follows. The last section presents a summary and overview of the report and its relation to the entire project. Three currently used methods are suggested for further study.

[Carlson, Robert F., Patricia M. Fox, and Stephen D. Shrader, 1974, Institute of Water Resources Report-IWR-52, University of Alaska, Fairbanks, Alaska, 37 pp.]

Comparison of Current Methods for Peak Flow Determination in Sparse Data Regions

Four methods of flood frequency analysis are compared for use in Alaskan watersheds. The graphical frequency analysis, regional multiple regression technique, and the Log Pearson Type III analysis are compared for several basins in Alaska with varying record lengths, basin areas and physiographic regions. Consideration is given to the use of the snowmelt-flood frequency model modified for this project. The four methods are applied and compared for the Chena River basin. The methods are evaluated on the basis of sensitivity, bias, consistency, power and confidence estimations using split and entire data records. A description is also given of the statistical properties of the flood peak data which is used for a review of the applicability of the assumptions necessary for each method. Criteria for method selection are given on the basis of basin factors.

[Fox, Patricia M. and Robert F. Carlson, 1974, Institute of Water Resources, University of Alaska, Fairbanks, Alaska. In press.]

## A Northern Snowmelt Model

Snowmelt is a dominant factor in the hydrologic system in Alaska. This report presents a model of the snowmelt process with calibration and discussion of applications. Derivation of the model stems from a description of snowmelt physics in the first section. The model is described, followed by a summary of its application to the Chena River basin and other more northern basins.

The snowmelt model subdivides the snowpack into two layers. Daily climatological parameters govern the heat transfer between snowpack and atmosphere. Once the heat flux emitted or received by the snowpack has been computed, the melting processes of each layer are considered. Computed parameters of the snowpack are depth, density, water equivalent, water content, temperature and thermal quality. Comparison of model predictions with snow courses in the Chena River Basin indicate the model performs satisfactorily.

[McDougall, J. and Robert Carlson, 1974, Institute of Water Resources Report-IWR-54, University of Alaska, Fairbanks, Alaska.]

A Northern Snowmelt-Flood Frequency Model

Coupling the snowmelt model developed earlier with a flood frequency model allows for determination of flood peaks in regions where snowmelt is the dominant flood source. The model presented in this paper is a hybrid type in that is is both stochastic and deterministic. It was patterned after Eagleson (1971 and 1972) with the major modification from consideration of rainfall events to snowmelt events. The peak flow statisitics are related to the statistics of climate and to watershed parameters using kinematic wave equations for homogenous catchments and storms. A complete development of the model is presented so that differences from Eagleson's work may be considered. This is followed by a calibration and sensitivity analysis of the model parameters with respect to the Chena River basin.

[Carlson, Robert, J. McDougall, and P. Fox, Institute of Water Resources, University of Alaska, Fairbanks, Alaska. In press.]

## REFERENCES

Amorocho, J. and B. Espildora (1966). Mathematical simulation of the snowmelt processes. Department of Water Science and Engineering, University of California, Davis. 165 pp.

Eagleson, P.S. (1971). The stochastic kinematic wave. In: *Systems Approach to Hydrology*. Proceeding of the first bilateral U.S.-Japan Seminar in hydrology. Water Resources Publication, Fort Collins, Colorado, pp. 202-225.

Eagleson, P.S. (1972). Dynamics of flood frequency. *Water Resources Research* Vol. 8 (4), pp. 878-897.