

FLOOD FREQUENCY DESIGN IN SPARSE-DATA REGIONS

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Project Completion Report
OWRT Contract No. 14-31-0001-5217
Grant No. B-030-ALAS

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The work upon which this completion report is based was supported by funds provided by the U. S. Department of the Interior, Office of Water Research and Technology, as authorized under the Water Resources Research Act of 1964, Public Law 88-379, as amended.

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INTRODUCTION

This report summarizes work conducted with funds received from the Office of Water Research and Technology (OWRT), Project B-030-ALAS, Flood Frequency in Sparse-Data Regions. The study was conducted from July 1, 1974, to June 30, 1976, plus a one-year extension to June 30, 1977. The technical results are given in a number of publications which are referenced and abstracted here along with a presentation of the overall philosophy of the project and a coherent summary of the work.

Alaska may be characterized, as can most northern areas, by a very sparse data collection network of hydrologic variables. In combination with several physical characteristics of northern hydrology, the sparse data network leads to a very difficult design circumstance.

The most well known physical aspect of northern hydrology is permafrost. Other factors of importance are large elevation differences, regional inhomogeneity, high latitude, low temperatures, and the very dynamic nature of the spring breakup. These factors, in combination with the short data base in northern regions, cause hydrologic design to have a large degree of uncertainty. Many streamflow records cover a period of less than 25 years; most important basins are ungaged; and many design projects in northern regions require hydrologic predictions using historic flow and climatological records of much less than desirable length. Much data which has been gathered from field measurements are prone to large error because of physical conditions such as icing, cold temperature, permafrost, and wind. Snow, an important feature of northern hydrology, is difficult to measure and geographically highly variable. Incorporation of all of these uncertainties in design parameters calls for careful consideration of compounding uncertainty.

Initial work in addressing problems of northern hydrologic design was begun in 1969. The work is described in a number of reports: Carlson and Kane (1973), Kane and Carlson (1973), and Carlson (1974).

These reports point out the need to develop efficient means of extracting available information from the sparse data network.

Another project, conducted from 1972 to 1974, concentrated on flood frequency prediction in northern regions with a greater emphasis on runoff generated by snowmelt. The main results of that project are reported in three reports, Carlson, et al. (1974), Carlson and Fox (1974), and Carlson and Fox (1976). The conclusion drawn from the project is that more efficient use of available data could be gained by careful consideration of data-efficient modeling and concurrent consideration of the design needs of an engineering project.

The current project, begun in 1974, has carried out a program of study aimed at these goals. An example of northern hydrologic design is offered by the trans-Alaska pipeline which is faced with uncertain demand on river and stream crossings where little or no data exists. We were able to use information from that project to good advantage as the pipeline is faced with a number of stream crossings through several regional hydrologic regimes.

A pipeline represents only one of many projects in which crossing design must be determined with little or no data. Others are highways, housing projects, flood plains, mining operations, hydroelectric dams, and fish hatcheries.

OBJECTIVES

The overall objective of this project was to develop improved techniques for flood capacity design in areas of extremely sparse data, especially in cold regions. Specific objectives included development of methods to provide flood-frequency determinations in sparse-data regions and as well as a method to determine the appropriate risk selection by a Bayesian-analysis technique.

SUMMARY OF RESEARCH RESULTS

The objective of the research project was met by a series of activities each of which resulted in one or more publications. These activities can be conveniently divided into four areas for discussion purposes although the actual work was dispersed among several activities.

1. The most important step in designing an appropriate flood-frequency determination for northern sparse-data regions is in choosing the most appropriate model. A series of activities was directed toward examination of literature and choosing a model for characterizing the hydrological regime and its relationship to the design needs of the project.

We first conducted a literature review which examined pertinent applications of Bayesian and distribution-free techniques to water resource-related design. Normally a water resources engineer has several model techniques to choose from even before actual determination of the design. We developed a method, presented in a short paper by Fox and Carlson (1977), which outlines a simple but effective procedure for choosing an appropriate model. This approach has been refined somewhat in another paper by Fox and Carlson (1978).

The method includes consideration of specification of the relative understanding of uncertainty of output, minimum data requirements, data required to reduce the uncertainty, time needed to accumulate the data, and specification of the restrictive assumptions about the water resource being analyzed. It seems to give promise for providing a simple straightforward method of choosing a model.

The choosing procedure follows logical steps, thus allowing the project to be addressed in each of its various phases. First, the design criteria assesses the applicability of the model's design. Then, after subsequent evaluation, each model is ranked according to its criteria satisfaction. The arithmetic is carried out without the use of a computer and has the advantage of simplicity and straightforwardness. Both papers present an example to illustrate how four models may be addressed for the problem of estimating summer streamflow for northern

mining development. A subtle but important feature of the choosing procedure is that it allows one to explain the model choice thoroughly to one's peers.

The procedure reviews the general strength and weaknesses of the existing models and should aid in the broad use of existing models for design in northern sparse-data regions. With short data length and high project cost, dependence on a familiar but inappropriate method could be disastrous.

2. Many streams in the north have peculiar channel characteristics as a result of their steepness, large alluvial bed load, and dominance of ice-choked channels for much of the winter. Several techniques were developed to describe the channel dynamics of northern braided rivers with particular emphasis on scour phenomena as it would affect engineering structures.

It is particularly important to understand the nature of channel dynamics of the north because of the predominance of very steep rivers, heavy bedload transport which gives a very active bed regime and the great importance of the frozen ice-choked channels and their relationship to springtime breakup. Because of the peculiar features of northern rivers the empirical relationships developed elsewhere do not necessarily give accurate results. The project sponsored research directed toward the development of a method to describe the hydraulics of braided streams which dominate many northern stream crossings. Details of the procedure are presented in a thesis by Drage (1977) which relates channel characteristics of width and depth to mean flow, channel slope, and other hydrologic variables. An empirical relationship was developed which calculates certain hydrologic features such as scour depth. It compares favorably with results obtained on other kinds of stream systems. A condensation of the thesis work is presented in papers by Drage and Carlson (1977) and Drage and Carlson (1978).

In addition to the thesis work described above, additional effort was directed toward the specification of the hydraulic characteristics of pipeline crossing design with particular emphasis on the streamflow-water level relationship.

3. An accurate evaluation of the efficiency of flood-frequency analysis should depend on evaluation of existing engineering structures. It seemed important, in view of the limited design experience in the north, to evaluate carefully existing design criteria. This is carried out through a field review of existing hydraulic engineering design including bridges, culverts, and pipeline crossings along the Alyeska route from Fairbanks to Prudhoe Bay.

In an Institute of Water Resources (Alaska) internal memorandum report, Kane and Hartman (1975) describe several difficulties of hydraulic engineering design, particularly in the area of mislocation, the relationship to surrounding terrain and the threat of icings during the important spring runoff. The study concludes that large crossings are probably overdesigned and several minor crossings are underdesigned or neglected entirely. Icing problems, particularly in northern braided rivers, are severe and erosions may take place where drainage is parallel to the road or impinge against bridge structures. The spring of 1974, during which the field trip was made, had a mild breakup, implying that possible damage in future years could be much greater.

4. After a hydrologic analysis model has been appropriately selected, the design hydrology characterized, the channel relationship addressed, and design demands defined, the application of the analysis and design must proceed in an efficient manner, particularly in the sparse-data environment of the north. We developed a Bayesian based method which provides maximum reliability given very little available data.

Once the appropriate hydrologic characterization is chosen, the channel dynamics understood, and experience of existing structures evaluated, a design strategy must be developed which efficiently uses all of the existing information regardless of how meager it may be.

After choosing four major river crossings, we further analyzed the uncertain cost of probably failure, problems of failure which may occur with the existing and alternative designs, and the selection of the best possible design. The method uses a combination of Bayesian and distribution-free statistical decision techniques which allow for efficient use of the sparse-data base. The method uses all pertinent available data, objective design decisions, and knowledge of underlying distribution of key parameters. This work was developed partially in a

master's project paper by Hartman, which concentrates on the cost information of the Alyeska pipeline stream-crossing design and is further developed extensively in the papers by Fox and Carlson (1974 and 1976). Results of the study illustrate how a design project in the north may be approached in a uniformly objective and intelligent manner even though a very sparse data base may exist.

DISSEMINATION OF RESEARCH RESULTS

Two papers were presented at a Canadian Hydraulic Conference with emphasis on northern hydraulics. Three manuscripts are in preparation for submission for national and international technical journals. A master's thesis, a master's project, and an internal report were completed as a result of the project.

TRAINING

The work supported two master's degrees candidates in part--one prepared a thesis and the other prepared a project paper.

ABSTRACTS OF PUBLICATIONS

Hydraulic Engineering Investigation of Braided Rivers Flowing from the Eastern Brooks Range, Alaska

Brent T. Drage

Thesis presented to the faculty of the University of Alaska in partial fulfillment of the requirements for the degree of Master of Science, May, 1977, Fairbanks, Alaska

The phenomena that lead to braided river patterns are far from established, but the more apparent causes are discussed. Braided patterns prevail throughout the eastern Arctic. The geological history that has formed and bounds the river valley and the occurrence and movement of the river's most dynamic element, water, are described in this study. The available field data collected for the trans-Alaska pipeline system and the Arctic gas pipeline, as well as by government agencies, has been reviewed, reduced, and analyzed by linear regression methods and is presented in the form of hydraulic geometry relationships.

The river-crossing design criteria developed for and used by the trans-Alaska pipeline is reviewed and the philosophy behind the criteria is discussed. The hydraulic geometry relationships developed for northern braided rivers are compared with these design criteria and suggestions for refinement are offered. A listing of the hydraulic parameters reduced from the field data is provided.

Hydraulic Geometry Relationships for Northern Braided Rivers

Brent Drage and Robert F. Carlson
Proceedings, Third National Hydrotechnical Conference, the Canadian Society for Civil Engineering, Quebec, May 30 and 31, 1977, pp 235-251.

Past studies of northern alluvial river behavior have often neglected braided rivers. Because braided rivers have several channels that may unpredictably change character and position with time and have stage and river banks that are poorly defined and relatively unstable, they do not lend themselves to the conventional methods of determining hydraulic geometry relationships or regime-theory equations. With the development of northern resources, previously unavailable field data on braided rivers have been collected by major oil and gas pipeline companies and interested government agencies.

The braided rivers flowing from the eastern Brooks Range in Alaska and Yukon Territory are reviewed and standard hydraulic geometry relationships and regime relationships are presented for the major subchannels within the braided system. These relationships can be used to help interpret the behavior of braided rivers and as design aids for engineered structures such as pipelines, bridges, or water conveyance facilities.

Hydrologic Estimation in Northern Sparse-Data Regions

Patricia M. Fox and Robert F. Carlson
Proceedings, Third National Hydrotechnical Conference, the Canadian Society for Civil Engineering, Quebec, May 30 and 31, 1977, pp 72-91.

In northern sparse-data regions, the model choice question is crucial to the specification of hydrologic design parameters. Following a discussion of available model types and factors for model comparison, a method is suggested for systematic review and choice between the models. The choice is based on criteria suggested by the project. This method is mathematically simple and can easily be applied by design engineers as well as administrative personnel.

Hydrologic Observations along the Haul Road - North of the Yukon River

Charles Hartman and Douglas L. Kane
Internal memorandum report, Institute of Water Resources, University
of Alaska, Fairbanks, Alaska 99701, 1975.

In 1975, the authors surveyed the hydrology of the region between the Yukon River and Prudhoe Bay along the pipeline haul road and analyzed problems related to the hydraulic control structures.

In general, the road seemed very well designed and constructed. Few design flaws or errors were found in proportion to a project of such large scale.

Maintenance problems at large river crossings were limited to erosion of embankment and abutment fills. By far the most repeated problem was water which ponded above the road as a result of nonexistent or improperly placed culverts. In addition there were a number of problems associated with culvert installation. These problems included improper culvert alignment (both vertical and horizontal) and insufficiently compacted fill beneath culverts.

As expected, aufeis was observed to be a problem along the road. Many cases of plugged culverts and diverted flow in streams were noted.

The little data available indicates that the breakup during the spring of 1975 was mild; other more severe breakups will no doubt impact the haul road to a greater extent.

Choosing a Northern Hydrologic Model

Patricia M. Fox and Robert F. Carlson
Prepared for submittal to the Canadian Journal of Civil Engineering,
1978.

In northern regions, hydrologic data is generally in short supply. As a result, design engineers must rely on available models to augment information. Currently the model selection procedure is usually subjective and based on prior usage or official decrees. The selection procedure presented in this paper provides a relatively simple method to review all possible applicable models in relation to specified project criteria. The selection of the best possible model and a defensible justification of the model selected should result. An example is given to show how the procedure can be applied.

A Regime Basis for Hydraulic Design of Northern Braided Rivers

B.S.

Brent Drage and Robert F. Carlson
Prepared for submission to the Canadian Journal of Civil Engineering,
1978.

Northern river engineering occurs in an environment very adverse to a successful design execution. Northern braided streams present a particularly poorly understood phenomenon which is complex in more temperate areas and, in addition, has the complicating factor of abrupt spring runoff, frozen bed material, and large blockage of ice and snow. A regime-oriented study of geomorphic and hydraulic parameters was conducted with data obtained at 69 field sites on rivers in northeast Alaska and northern Yukon. Empirical regression relationships are illustrated for discharge versus width, depth, and velocity, and depth versus width, maximum depth, and specific discharge. Comparison to data of other investigators indicates that northern braided rivers have greater widths, higher velocity, and shallower depths. Use of the derived relationships is shown for selected crossing design criteria of the trans-Alaska pipeline. Results indicate the derived relationship presents a better fit to the field data for the discharge versus width relationship and gives a much higher discharge for a measured channel width. A good correspondence is indicated for the depth versus specific discharge relationship. Comparison of the mean depth versus maximum depth indicates the minimum-maximum depth-to-mean ratio should be 2.5 for northern braided rivers rather than the range of 1.4 to 2.5 used in the crossing design. A maximum value cannot be established on the basis of the available data.

A Cost Analysis for Selected Pipeline River Crossings Using Bayesian Decision Theory

Charles Hartman
Master's project report, Engineering Management Department, School
of Engineering, University of Alaska, Fairbanks, Alaska 99701.

Engineering decisions and designs must necessarily be made with incomplete knowledge of external variables. It is impossible and uneconomical to study an engineering problem to the point that everything is known about it. Because of this, engineering designs are made conservatively to take unknowns into consideration. Traditionally, this has been done through the use of safety factors determined empirically by experience. With a few exceptions, this has worked satisfactorily; engineered structures are usually completed and conform to specifications. However, the more uncertain the external variables, the less efficient the design.

In Alaska as well as in many other sparsely populated regions, the problem is compounded by the comparative lack of available data. For example, in many areas of Alaska, there are few records of streamflow or precipitation and the uncertainties involved in designing hydraulically related structures in these areas are great.

A possible method of improving design decisions in the face of uncertainty may be obtained by using Bayesian statistical decision theory. This approach, named for the British mathematician, Thomas Bayes, recognizes that the subjective elements of an engineering analysis are inseparable from, and often are as important as, the more objective aspects. By expressing uncertainty as to natural probabilities, the Bayesian method allows one to analyze alternative design decisions to make possible a determination of the optimum choice.

This study determines the usefulness of Bayesian decision theory in the design of selected Alyeska pipeline river crossings. Several Alyeska pipeline crossings are analyzed statistically using Bayesian theory to determine optimum design. Each site is analyzed with respect to alternative design considerations, probabilities, and cost of possible failures; and conclusions are drawn as to the best possible design.

A Basis for Hydraulic Design, Use of Bayesian Decision Theory, and Application to Pipeline Crossings.

Patricia M. Fox and Robert F. Carlson
Prepared for submittal to the Journal of Hydraulics Division,
American Society of Civil Engineering, 1978.

The crossing of streams by large-diameter pipelines is a particularly different design problem in northern regions. Here the hydrologic estimate is established with a great deal of uncertainty and ice and snow blockage of the channel make discharge-failure likelihood poorly understood. Several pipeline crossings are examined using Bayesian decision techniques with a distribution-free statistical form of expressing the flow variable. The combined approach provides a useful means to minimize the necessary assumption and allow maximum use of all available information. This method is particularly useful in the sparse-data regime of the northern regions of the world.

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