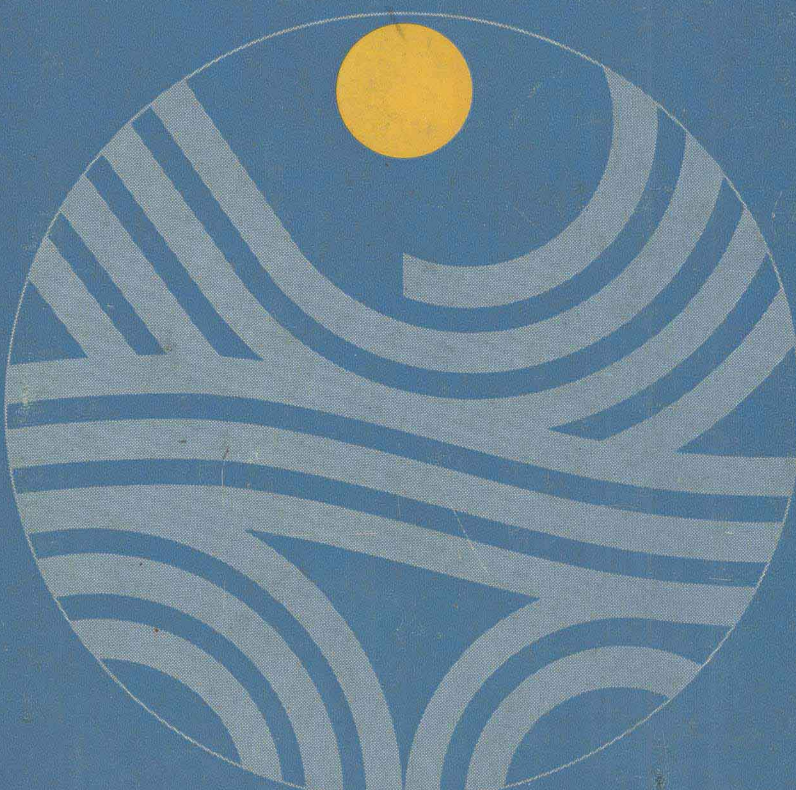
Studies and reports in hydrology 22

Floodflow computation

Methods compiled from world experience

A. A. Sokolov
S. E. Rantz
M. Roche



The Unesco Press

Studies and reports in hydrology 22

Recent titles in this series

18. Hydrological effects of urbanization. Report of the Sub-group on the Effects of Urbanization on the Hydrological Environment.
19. Hydrology of marsh-ridden areas. Proceedings of the Minsk Symposium, June 1972.
20. Hydrological maps. *Co-edition Unesco-WMO.*
21. World catalogue of very large floods / Répertoire mondial des très fortes crues / Catalogo mundial de grandes crecidas / Всемирный каталог больших паводков.
22. Floodflow computation. Methods compiled from world experience.

For details of the complete series please see the list printed at the end of this work.

Floodflow computation

Methods compiled from world experience

By A. A. Sokolov, S. E. Rantz and M. Roche

A contribution to the International Hydrological Decade

The Unesco Press Paris 1976

Published by The Unesco Press
7 Place de Fontenoy, 75700 Paris
Printed by NICI, Ghent

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the publishers concerning the legal status of any country or territory, or of its authorities, or concerning the frontiers of any country or territory.

ISBN 92-3-101350-5

Printed in Belgium

Preface

This work is the twenty-second volume to appear in the 'Studies and Reports in Hydrology' series, a series which was begun by Unesco, along with the publication of the 'Technical Papers in Hydrology' series, when the International Hydrological Decade (IHD) was launched.

The International Hydrological Decade, which ended in 1974, was launched in 1965 by the General Conference of Unesco at its thirteenth session. Its purpose was to advance knowledge of scientific hydrology by promoting international co-operation and by training specialists and technicians. At a time when the demand for water is constantly increasing as a result of the rise in population and of developments in industry and agriculture, all countries are endeavouring to make a more accurate assessment of their water resources and to use them more rationally. IHD has been a valuable means to this end.

By the end of the decade in 1974, national committees for the decade had been formed in 107 of Unesco's 135 Member States to carry out national activities and contribute to regional and international activities within the programme of the decade. The implementation of this programme was supervised by a co-ordinating council, composed of thirty Member States selected by the General Conference of Unesco, which studied proposals concerning the programme, recommended the adoption of projects of interest to all or a large number of countries, assisted in the development of national and regional projects and co-ordinated international co-operation. The promotion of collaboration in developing hydrological research techniques, exchanging hydrological data and organizing hydrological networks was a major feature of the programme of IHD, which encompassed all aspects of hydrological studies and research. Hydrological investigations were encouraged at national, regional and international levels, to strengthen and improve the use of natural resources in view of both local and global needs. The programme enabled countries well advanced in hydrological research to exchange information and developing countries to benefit from such exchanges in order to elaborate their own research projects and plan their own hydrological networks, taking advantage of the most recent developments in scientific hydrology.

Conscious of the need to continue the efforts developed during the International

Hydrological Decade, and following the recommendations of Member States, the General Conference of Unesco decided at its seventeenth session to launch after the end of the decade a long-term intergovernmental programme, the International Hydrological Programme, and defined its basic objectives. These objectives are: (a) to provide a scientific framework for the general development of hydrological activities; (b) to improve the study of the hydrological cycle and the scientific methodology for the assessment of water resources throughout the world thus contributing to their rational use; (c) to evaluate the influence of man's activities on the water cycle, considered in relation to environmental conditions as a whole; (d) to promote the exchange of information on hydrological research and on new developments in hydrology; (e) to promote education and training in hydrology; (f) to assist Member States in the organization and development of their national hydrological activities.

As was done for the decade, the activities of the International Hydrological Programme are co-ordinated at international level by an intergovernmental council composed of thirty Member States. They are periodically elected by the General Conference and their representatives chosen by national committees.

The International Hydrological Programme became operational on 1 January 1975 and is to be executed through successive phases of six years' duration.

The purpose of the continuing series 'Studies and Reports in Hydrology' is to present the data collected and the main results of hydrological studies undertaken within the framework of the decade and the new International Hydrological Programme, as well as to provide information on the hydrological research techniques used. The proceedings of symposia will also be included. It is hoped that these volumes will furnish material of both practical and theoretical interest to hydrologists and governments and meet the needs of technicians and scientists concerned with water problems in all countries.

Contents

Foreword

From time immemorial floods have been a recurring menace in every country of the world. Many courses of action may be taken to prevent or alleviate the misery and damage that floods bring, but all such actions require a knowledge of the magnitude and frequency of flood stages and discharges. The problem of floodflow computation is therefore one of the most pressing in hydrology and is studied by scientists of all nations. Consequently flood studies were a prominent part of the programme of international co-operation in hydrology known as the International Hydrological Decade (IHD), which operated under the auspices of Unesco during the years 1965–74. Flood studies will be continued within the framework of the International Hydrological Programme.

Among the stipulations of the IHD programme was the establishment of a working group charged with the collection of information on flood studies and the compilation of the methodologies used in the participating countries for computing floodflow, particularly in those situations where hydrometeorological data are sparse or non-existent. Several complementary activities were carried out under Unesco's sponsorship. In 1967, in co-operation with the World Meteorological Organization (WMO) and the International Association of Scientific Hydrology (IASH), the International Symposium on Floods and their Computation was held in Leningrad. At that meeting more than 100 reports from many nations were presented. In addition, a report, 'Flood Studies: An International Guide for Collection and Processing of Data', was prepared by the working group and published by Unesco in 1971; its purpose was to unify and systematize the collection and processing of floodflow data in the participating countries. Extensive information on floods has been collected and is being compiled in the preparation of a world catalogue of major floods.

The present publication, a casebook on methods of computing floodflow, has been prepared in accordance with the programme developed by the IHD working group on floods and low-flow computation. It follows in logical sequence 'WMO Technical Paper No. 98' (1968), *Estimation of Maximum Floods*, which deals with international experience in the meteorological aspects of floodflow computation. The present work is a compilation of methods, drawn from world experience, on the computation of the magnitude and frequency of stages and discharges associated with both rainfall and snowmelt floods, with particular reference to the use of such information in the hydrologic design of engineering projects.

The following aspects of floodflow computation are treated here: determination of optimum design probabilities for flood discharge (Chapter 1), probability distributions used in hydrologic design (Chapter 2), methods of floodflow computation and analysis using streamflow data (Chapter 3) and in situations where streamflow data are inadequate (Chapter 4), methods of developing design-discharge hydrographs (Chapter 5) and computing design river and lake stages (Chapter 6), methods for evaluating flood characteristics by field investigation (Chapter 7), and the application of analogue and digital computers for modelling floodflow (Chapter 8).

This work was compiled from material received from the national IHD committees of the following countries: Bangladesh, Brazil, Bulgaria, Canada, Costa Rica, France, German Democratic Republic, Hungary, India, Italy, Japan, Netherlands, Poland, Romania, Spain, U.S.S.R., United Kingdom and the United States.

The work itself was prepared by a group of scientists at the State Hydrological Institute (U.S.S.R.) under the leadership of Professor A. A. Sokolov and Professor A. I. Chebotarev. The contributions of individual authors are as follows: Chapters 1 and 2, Dr B. M. Dobroumov; Chapter 3, Dr A. V. Rozhdestvenskij; Chapter 4, Professor A. I. Chebotarev and Dr B. I. Serpik (Sections 4.1 to 4.5); Dr A. I. Okhinchenko (Sections 4.6 to 4.9); Professor M. S. Grushevskij (Section 4.10); Chapter 5, Professor M. S. Grushevskij; Chapter 6, Dr O. L. Markova; Chapter 7, Dr O. B. Voskresenskij; and Chapter 8, Professor M. S. Grushevskij.

Acknowledgement is made of the contributions to individual chapters by S. E. Rantz (United States), M. Roche (France) and J. Cruette (France) at meetings of the editorial panel in Leningrad (October 1974) and Paris (April 1975). Special thanks are due to L. V. Lavrova (U.S.S.R.), whose devoted efforts as interpreter and translator in the preparation of the text and in meetings of the editorial panel, represent a major contribution to this report.

As indicated earlier, this work is intended for use in studies involving the hydrologic and economic design of flood-control facilities and other structures within the reach of floodwaters and as a basis for developing flood forecasting techniques.

1 Determination of optimum design probabilities of flood discharge

1.1 Objectives of studies of design probability

In the design of a hydraulic structure consideration must be given to the flood risk involved. The probability always exists that a flood of such magnitude will occur, that the design capacity of the structure will be exceeded, with resulting damage to the land and to the structure itself. The first step, therefore, in the design of a hydraulic structure is a flood-frequency study to determine the probability of exceedance of floods of various magnitudes. The next step is the determination of the optimum flood probability to be used in the design of the structure.

Social, or sociopolitical, considerations as well as economic considerations, enter into the determination of optimum design probabilities. Where a major flood can cause catastrophic property damage and human death, the design flood to be used is the probable maximum flood. (Probable maximum floods are discussed in Chapter 4, Section 10.) For areas with a lesser potential for flood damage, the design flood to be used is one whose probability of exceedance is such that the project meets the following criteria:

1. The structure will be economically feasible; that is, the construction and maintenance costs of the structure will not exceed the direct and indirect costs of possible property damage and inconvenience to the public during the life of the structure. In other words, a $1 million structure should not be built to protect a $100,000 property investment.
2. Average annual costs chargeable to the structure will be minimized. The average annual costs include the following: (a) annual cost of construction of a soundly engineered structure, prorated over the years of economic life of the structure; (b) annual operation and maintenance cost of the structure; (c) average annual monetary flood damage under project conditions (structure installed or in operation), including the cost of rehabilitating the structure if damaged by flood.

Sociopolitical considerations sometimes override economic considerations. For example, a project that is barely economically feasible may be authorized for construction in an area that is economically depressed, with the idea that the project will stimulate the economy of the area.

1.2 Determination of optimum design probability by analytical methods

This section of the report discusses the details of design practice in the U.S.S.R., United States and France, in determining the optimum peak flood discharge to be used in the design of hydraulic structures or projects. The optimum design discharge is the peak flow rate corresponding to an annual exceedance probability[1] whose use in the project design will minimize the average annual cost of the project.

1.2.1 *U.S.S.R. practice*

In the U.S.S.R. method the average annual cost *(U)* of the project includes the three following elements, as explained above.

First, U_1, the annual cost of construction of the project, prorated over the economic life (T years) of the project.

$$U_1 = \frac{K_0 + \alpha Q_P}{T}, \qquad (1.1)$$

where:

K_0 = portion of project construction cost that is independent of the design discharge;

α = a coefficient that represents the increase in construction cost for each increment of discharge;

Q_P = peak discharge corresponding to an annual exceedance probability, P.

Second, U_2, the annual cost of operation and maintenance of the project. (U_2 is considered to be proportional to the total construction cost, $K_0 + \alpha Q_P$.)

$$U_2 = r(K_0 + \alpha Q_P), \qquad (1.2)$$

where:

r = the constant of proportionality between annual cost of project operation and total cost of project construction.

Third, U_3, the average annual damage cost under project conditions, including damage to the structure.

$$U_3 = P[Y_0 + \eta(K_0 + \alpha Q_P)], \qquad (1.3)$$

where:

P = the exceedance probability of peak discharge Q_P;

Y_0 = the annual damage cost, exclusive of damage to the project structure, attributable to a peak discharge of the design probability;

η = the constant of proportionality between the cost of rehabilitating the project structure (if damaged) and the total cost of project construction.

1. The terms 'exceedance probability' and 'probability of annual exceedance' are used interchangeably in this report; they refer to the probability of a given discharge being exceeded as an annual maximum event.