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Methods of hydrological computations for water projects

A contribution to the International Hydrological Programme

Report prepared by the Working Group — Project 3.1

Edited by
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Preface

Although the total amount of water on earth is generally assumed to have remained virtually constant, the rapid growth of population, together with the extension of irrigated agriculture and industrial development, is stressing the quantity and quality aspects of the natural system. Because of the increasing problems, man has begun to realize that he can no longer follow a "use and discard" philosophy -- either with water resources or any other natural resource. As a result, the need for a consistent policy of rational management of water resources has become evident.

Rational water management, however, should be founded upon a thorough understanding of water availability and movement. Thus, as a contribution to the solution of the world's water problems, Unesco, in 1965, began the first world-wide programme of studies of the hydrological cycle -- the International Hydrological Decade (IHD). The research programme was complemented by a major effort in the field of hydrological education and training. The activities undertaken during the Decade proved to be of great interest and value to Member States. By the end of that period, a majority of Unesco's Member States had formed IHD National Committees to carry out relevant national activities and to participate in regional and international cooperation within the IHD programme. The knowledge of the world's water resources had substantially improved. Hydrology became widely recognized as an independent professional option and facilities for the training of hydrologists had been developed.

Conscious of the need to expand upon the efforts initiated during the International Hydrological Decade and, following the recommendations of Member States, Unesco, in 1975, launched a new long-term intergovernmental programme, the International Hydrological Programme (IHP), to follow the Decade.

Although the IHP is basically a scientific and educational programme, Unesco has been aware from the beginning of a need to direct its activities toward the practical solutions of the world's very real water resources problems. Accordingly, and in line with the recommendations of the 1977 United Nations Water Conference, the objectives of the International Hydrological Programme have been gradually expanded in order to cover not only hydrological processes considered in interrelationship with the environment and human activities, but also the scientific aspects of multipurpose utilization and conservation of water resources to meet the needs of economic and social development. Thus, while maintaining IHP's scientific concept, the objectives have shifted perceptibly towards a multidisciplinary approach to the assessment, planning, and rational management of water resources.

As part of Unesco's contribution to the objectives of the IHP, two publication series are issued: "Studies and Reports in Hydrology" and "Technical Papers in Hydrology". In addition to these publications, and in order to expedite exchange of information in the areas in which it is most needed, works of a preliminary nature are issued in the form of Technical Documents.

The purpose of the continuing series "Studies and Reports in Hydrology" to which this volume belongs, is to present data collected and the main results of hydrological studies, as well as to provide information on hydrological research techniques. The proceedings of symposia are also sometimes included. It is hoped that these volumes will furnish material of both practical and theoretical interest to water resources scientists and also to those involved in water resources assessments and the planning for rational water resources management.

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1 Introduction

1.1 OBJECTIVES AND SCOPE OF THE GUIDEBOOK

The planning and design of water resources projects relies heavily upon hydrologic computations. The objective of this publication is to provide guidance on hydrological analyses and computations which are required for these purposes. The guidebook is prepared for engineers, hydrologists and other specialists, particularly those from developing countries, who seek advice on currently available methods. State-of-the-art hydrologic techniques are briefly described, and alternative techniques are presented along with the conditions under which each technique may or may not be useful. In addition, the guidebook cites widely available international and national publications containing information on currently used practical hydrologic techniques that can be used in developing the hydrologic estimates required for various types of water resource projects. References to a number of widely available computer programs which should be useful as practical tools in developing the hydrologic estimate are also presented.

This guidebook is not intended to present the detailed computations required in order to develop the hydrologic estimates, but rather to provide information on where details of alternative techniques can be found in widely available publications, and to indicate which alternative technique may provide a more realistic answer under certain prescribed conditions.

The hydrological computations discussed in this guidebook deal mainly with the use of surface water resources. Computations associated with the use of groundwater resources are not treated herein.

This guidebook has been prepared by the International Hydrological Program Working Group on Methods of Computation of Hydrological Parameters for Water Projects (IHP-Project 3.1) under the Chairmanship of Prof. A.A. Sokolov. The Working Group consisted of:

Mr. N.B. Ayibotele (Ghana)
Mr. B.S. Eichert (USA)
Mr. R. Heggstad (Norway)
Mr. H. Heras (Spain)
Mr. H. Kikkawa (Japan)
Mr. J. Kindler (Poland)
Mr. J.A. Vander Made (Netherlands)
Mr. G.A. Schultz (Federal Republic of Germany)
Mr. A.A. Sokolov (USSR)
Mr. R.M. Vallejos (Argentina)

The Working Group elected Mr. B.S. Eichert, Mr. J. Kindler, Mr. G.A. Schultz and Mr. A.A. Sokolov as editors of the guidebook. WMO contributed to the activities of the working group and participated actively in the editorial group through Mr. A.J. Askew of the WMO Secretariat and Mr. B. Wingard from Norway. The final editing and the preparation of the manuscript in camera-ready form were carried out under the supervision of Mr. B.S. Eichert.

1.2 STRUCTURE AND USE OF THE GUIDEBOOK

The guidebook is divided into four chapters and one appendix. Chapter 1 sets the background for the remainder of the guidebook by indicating the scope and intended readership, by relating hydrology to water resources management, and by describing the basic steps in water resources development (planning, design, construction and operations).

Chapter 2 on Overview of Hydrological Computations for Water Projects presents brief background information on hydrologic and meteorological data and its processing and briefly introduces the hydrologic techniques used in developing the hydrologic estimates necessary for various types of water resources projects. Table 2.1 relates the hydrological techniques briefly described in Chapter 2 (and critically analyzed and referenced in Chapter 4), with the grouping of types of projects used by Chapter 3 (where lists of all hydrologic estimates needed for each type of project are given).*

Chapter 3 on Hydrologic Estimates Required for Specific Types of Water Projects presents brief background information on various types of water resources projects and project purposes. In addition, Chapter 3 presents detailed lists of specific hydrologic estimates that are generally required for planning various types of projects. For each of the hydrologic estimates shown in Chapter 3, a cross-reference is given to the appropriate part of Chapter 4 where techniques for determining that estimate are critically reviewed and appropriate references are cited.

Chapter 4 on Hydrologic Techniques Available for Water Projects presents brief summaries and critiques of alternative techniques for determining the hydrologic estimates listed in Chapter 3 along with appropriate references to widely used international and national publications where the details of these techniques may be found. Chapter 4 also references some computer programs which are widely used in determining the hydrologic estimates required for various water resources projects.

The appendix to Chapter 4 briefly describes and provides references for selected generalized computer programs which should be useful for determining many of the hydrologic estimates.

The following procedure is recommended to make the most efficient use of the guidebook.

1) Review Chapters 1-3 and get generally acquainted with the introductory material and guidebook organization.
2) Check to see if you have access to the necessary major references to describe the hydrologic techniques you anticipate using (see Table 1.1). If not, order the relevant publications using Table 1.2 to locate the addresses.
3) Turn to Table 2.1 and locate the type of project for which hydrologic analyses are required (e.g., hydroelectric reservoir). Determine, from Table 2.1, which sections of Chapter 3 are needed for that type of project (e.g., Sec. 3.2.1 for all reservoirs and 3.2.3 for hydroelectric reservoirs). Using Table 2.1 determine which hydrologic techniques need to be used and where those techniques are discussed in Chapter 4. This determination provides an overview of the necessary work required (e.g., techniques will be needed which are discussed in Sec. 4.1-4.10).
4) Next, turn to the sections in Chapter 3 which are needed for your selected type of project (e.g., Sec. 3.2.1 and 3.2.3 based on Table 2.1 as determined above or from the table of contents for Chapter 3). Under the appropriate parts of Chapter 3, you will find a list of specific hydrologic estimates that need to be made to design the project (e.g., under 3.2.1, 15 estimates are listed and under 3.2.3, 7 estimates are listed). For each estimate required, determine the appropriate references (e.g., item 1 under 3.2.1 refers to regional studies contained in Sec. 4.1).
5) Now look at the Chapter 4 material that is referenced for each hydrologic estimate and determine the appropriate references that you will need to give you the details of the technique necessary to make the required estimate.
6) Determine the hydrologic estimate using the appropriate references from Chapter 4.

References in this guidebook are presented at the end of Chapters 1-3 and at the end of the Appendix to Chapter 4. However, Chapter 4 references are found at the end of each subchapter (i.e., 4.1, 4.2, etc.) because of the large number of references for each subchapter and since each subchapter concerns a major hydrologic computation which can be studied separately from those in the other subchapters.

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*The use of the terms "hydrologic estimate" and "hydrologic technique" may cause the reader some confusion if he tries to distinguish between them too much. In some cases, lists of hydrologic techniques (such as Table 2.1) may also represent lists of hydrologic estimates (i.e., a spillway design flood is a hydrologic estimate that is needed and there are several hydrologic techniques for calculating the spillway design flood).

1.3 ASSOCIATION WITH OTHER PUBLICATIONS

In order to keep the volume of the present guidebook within reasonable limits, it was decided that this guidebook would not present detailed hydrologic techniques, but would rely on the many widely known international and national publications which provide this kind of information. The guidebook's main use then is to identify which hydrologic estimates are required for certain types of projects (Chapter 3) and to cite the specific publications where the detailed techniques are presented (Chapter 4 for hydrologic techniques and Chapter 3 for non-hydrologic techniques). The primary association of this guidebook with other publications is therefore based on material in Chapter 4. The key English-language references (English being the working language of the IHP Working Group) cited in Chapter 4 were used to construct Table 1.1 which reflects the most frequently cited references in the guidebook. In order to make the best use of this guidebook, it is therefore important (for the English reader) to at least have access to the references presented in Table 1.1. If the reader expects to concentrate on only a few subchapters, then he should try to obtain most of the references under those subchapters. Table 1.2 provides mailing addresses where these publications may be obtained. References to specific publishers in Table 1.2 are made on the right hand side of the reference list for each chapter or subchapter. In addition to the references used in the guidebook, numerous additional publications contain similar material, but were not included in the guidebook because these publications were:

1) Simply duplicative in nature to the ones shown,
2) Not known to the Working Group (particularly those that were not in English),
3) Not considered to be widely available to the international community.

Much of the material which is widely available to international audiences (references in Chapter 4 being the exceptions) is geared toward the more academic or scientific audiences than to the practicing engineer engaged in planning a water resources project.

Unesco, within the framework of IHP-II Project A.2.10 is now preparing a Casebook of examples on methods for computing hydrological parameters for water projects. This project continues the work of the Guidebook and will give examples of hydrological computations for the planning and design of various water projects. In order to be of practical and direct use to planners, designers and engineers, the Casebook will also include procedures and examples from actual water projects and highlight the specific hydrological computations for these projects.

During the IHD-IHP period, a wide exchange of ideas took place on the main problems of hydrology and on the scientific achievements in the field of hydrological computations. Numerous international scientific conferences, symposia, seminars, and sessions of working groups were held which were organized by Unesco, WMO, IAHS and by a great many of the IHP National Committees. Proceedings of many of the International conferences and symposia are contained in Table 1.3.

An international symposium on specific aspects of hydrological computations for water projects (on the very subject of the guide) was convened by Unesco in cooperation with WMO and IAHS and the USSR National Committee for the IHP in Leningrad (September, 1979). At this symposium, more than 70 scientific reports were presented from the IHP Member-States. The proceedings of this symposium are being published in the Unesco series "Studies and Reports in Hydrology" in the Soviet Union.

Results of hydrological research, and data obtained from hydrological measurements, have been summarized in a number of international publications. Noteworthy from the point of view of hydrological science and engineering practice are those on representative and experimental basins (Toebes, 1970), methods for water balance computations (Sokolov, 1974), data collection and processing for flood studies (Snyder, 1971), nuclear techniques in hydrology (International Atomic Energy Agency, 1968), hydrological maps (Unesco, 1977), water quality investigations (CMEA, 1977), and methods for flood flow computation (Sokolov, 1976).

A number of publications have been prepared by WMO on aspects of operational hydrology, such as "Meteorological and Hydrological Data Required in Planning the Development of Water Resources" (Andrejanov, 1975), "Guide to Hydrological Practices" (WMO, 1974), etc. The recent progress in hydrological knowledge is also reflected in a series of hydrological handbooks (Viessman, 1977; Dubreuil, 1974; Heras, 1972; and National Environmental Research Council, 1975).

Various organizations of the UN family have also made important contributions in the field of water quality monitoring, data processing and interpretation. These are reflected in the following publications: "Water Quality Surveys" (Unesco-WHO, 1978), "GEMS/Water Operational Guide" (UNEP, 1978), and others. Important contributions to hydrology have been made by the monograph, "World Water Balance and Water Resources of the Earth," and "Atlas of the World Water Balance" (Unesco, 1978b, Unesco, 1978a).

A "Manual on methods of computation of water balances of large lakes and reservoirs", Vol.1, Methodology; (Unesco, 1981), "Casebook on Low Flow Computation", and the technical paper "Investigation of water regime of river basins affected by irrigation," have been prepared for publication within the framework of the International Hydrological Programme.

A recent very relevant development in WMO's activities has been the initiation of the Hydrological Operational Multipurpose Subprogramme (HOMS). This provides a means for the transfer between Member countries of a whole range of technology relating to operational hydrology, including that required for the collection, transmission and processing of hydrological data for use in the design and operation of water projects. The technology is transferred as a series of components in the form of guidance manuals, instrument specifications and computer software. These components are available to all National Hydrological and Meteorological Services and, in a manner similar to that described in Chapter 3 of this Guidebook, they can be compiled into sequences which can be used to satisfy the various needs of different water projects.

1.4 HYDROLOGY AS A SOURCE OF INFORMATION FOR WATER RESOURCES MANAGEMENT

Hydrology is the basic science underlying water resources management since water cannot be managed without knowing the quantity, aerial distribution and timing of the movement of water. Hydrology has evolved significantly in recent years due in part to the improvements in data collection systems, i.e., from historical records of rare events (floods, droughts, ice regime anomalies, etc.) to systematic observations on ever-expanding network of stations. At present in the world, there are more than 60,000 stream-gaging stations, and over 100,000 meteorological stations where systematic observations are made on the elements of the hydrometeorological regime of rivers, lakes, reservoirs, oceans and ground water. In some countries, the procedures used in the design and operation of networks of hydrometeorological stations are prescribed by special instructions and guides (Gidrometeoizdat,1960, 1969, 1975, 1978, 1973; Gidrometeoizdat,1973; U.S. Geological Survey,1978).

The development of hydrological data networks has greatly increased the knowledge of world water resources. Gaps in the world and national maps on the hydrologic elements are becoming smaller. Hydrological interrelations with meteorology, hydrogeology and other sciences are becoming better understood, which enables improved regional and global studies of all the elements of the hydrological cycle.

One of the main aspects in practical application of hydrology is the computation of basic elements of the hydrological regime, including characteristics of streamflow, precipitation, evaporation, dynamics of the water masses, sediment transport and discharge, water quality, etc., which are essential for designing, constructing and operating water projects and hydraulic structures. Safety, cost and efficiency of projects and structures greatly depend on the reliability of hydrological estimates.

Reliable determination of hydrological estimates is complicated because of the need to account for possible time-series variations (for example, variations of flows and sediments) for different structures with variable project lives. General principles for the solution of these problems for planning water projects are presented in a number of publications (Kritsky,1952; Kritsky,1977; Maass,1962). Long-term hydrological and meteorological data series, published in hydrological and meteorological yearbooks, bulletins, etc., are of the utmost importance in making hydrological estimates. Many difficulties arise due to inadequate or missing data.

In addition to national and regional publications of flow data, many long-term observations from the world network of hydrological stations have been published since 1965 by Unesco in the series, "Discharges of Selected Rivers of the World," (Unesco,1965).

Until recently, the solution of individual water problems was done on a local basis. Many contemporary water projects, however, are not isolated or intended for a single purpose (as, e.g., hydroelectric power reservoirs or connecting navigation canals). Projects may involve interrelated systems covering entire basins and regions. These water projects can infringe upon the interests of many branches of a national economy and have environmental, economic and social impacts over vast areas. Such large-scale projects often introduce significant changes in the environment. They may affect landscape and biota, change the water and salt balance of inland seas, and create potential for a change in climate and water circulation in the atmosphere.

The understanding and prediction of man-induced changes in water regime and water balance is a complicated problem of hydrology. Whereas some preliminary solutions regarding the effects of specific changes such as urbanization and deforestation on hydrology have been attempted (Unesco,1974 and 1980; FAO,1969; Shiklomanov,1975), the effects of complex interrelated changes are extremely difficult to predict. The complexity of this problem is due in part to the fact that a large-scale interference in nature may not be discovered immediately. Decades may pass before any negative and irreversible change in nature is revealed. Estimation and prediction of possible changes in the environment is an essential aspect of contemporary water resources management.

Measures to protect the environment against pollution and depletion require scientific substantiation. For example, the effects of urbanization, forest cutting and afforestation, plowing and agrotechnical measures, irrigation and drainage, mining, acid precipitation, and other types of man's activity in channels and river basins that cause changes in water regime and balances must be recognized and evaluated. A contribution to the solution of these complex hydrological problems may possibly be obtained from the rapid development of remote sensing applications to hydrology and water resources management (Reeves, 1975; Kudritsky, 1977; Kupryanov, 1976; Wiesnet, 1979).

Development of water resources is affected and regulated by existing water laws. Such water laws affect priorities for water resources development. For example, laws may require that regional and basin-wide schemes for multipurpose development of water resources be prepared for current and future demands for all the sectors of the national economy on the basis of forecasts of economic and social development (Environment Canada, 1975). The prediction of water regime and balance changes is an integral part of such schemes and is the basis for a scientific substantiation of measures that will provide the most effective water resources use and protection.

1.5 PRINCIPAL STAGES OF WATER RESOURCES DEVELOPMENT (PLANNING, DESIGN, CONSTRUCTION AND OPERATION)

The development of a water resources project is a complex task that requires a minimum of three to five years from conception to construction and normally takes several times longer for large projects (James, 1971). The development is normally divided into the stages of planning, design, construction and operation. The planning stage is the principal stage discussed in this guidebook since hydrologic computations are so fundamental in the planning process. While hydrological computations are used in the design and construction stages, they have less impact on these stages and are not discussed in depth here. Although hydrologic computations are of paramount importance in the operation of many types of water resources projects, they are discussed in this guidebook only to the extent that they affect the planning process.

The separation of the four stages of project development is fairly straightforward except for the separation between the planning and design stages. The design stage can be thought of as the translation of the plan (from the planning stage) into the specific drawings and reports required for construction. The operations phase, while separate from the planning phase, is still greatly dependent upon the criteria, assumptions, and plans developed under the planning phase. It is certainly too late, after the project has been constructed, to start thinking about how the project will be operated. In most cases, the operation of the project will have major effects on the type, size, costs, and benefits of the project.

The specific steps with which a project proceeds from conception to construction vary from country to country and among agencies within the same country. However, James and Lee, (1971) provides some steps which are generally applicable to most projects and can be summarized as follows:

1) identify need for project,
2) authorize study,
3) hold public hearings,
4) perform feasibility study to determine if project is justified,
5) get local public assurances for financial and moral support for project,
6) get review of project by concerned parties,
7) get authorization for construction,
8) get funds appropriated for design and construction,
9) collect additional data and perform more detailed studies,
10) prepare final plans specifications and cost estimates,
11) select contractors and construct the project, and
12) turn project over to operations and maintenance.

Table 1.1

English Language References Referred to Frequently In Guidebook

References	Publishers From Table 1.2
International Publications	
Klemes, V., 1973, "Applications of Hydrology to Water Resources Management," WMO No. 356, Geneva.	A-10 (1)
Sokolov, A.A., S.E. Rantz, and M. Roche, 1976, "Flood Flow Computation Methods Compiled from World Experience," The Unesco Press, Paris.	A-7
Unesco, 1976, "World Catalogue of Very Large Floods," Studies and Reports in Hydrology, Vol. 21, The Unesco Press, Paris.	A-7
United Nations, 1967, "Assessment of the Magnitude and Frequency of Flood Flows," Water Resources Series No. 30, Economic Commission for Asia and the Far East, New York.	A-8
WMO, 1969, "Estimation of Maximum Floods," Technical Note No. 98, WMO No. 233, T.P. 126, Geneva.	A-10
WMO, 1973, "Manual for Estimation of Probable Maximum Precipitation," Operational Hydrology Report No. 1, WMO No. 332, Geneva.	A-10
WMO, 1974, "Guide to Hydrological Practices," 3rd edition, WMO No. 168, Geneva.	A-10 (2)
WMO, 1975, "Intercomparison of Conceptual Models Used in Operational Hydrological Forecasting," Operational Hydrology Report No. 7, WMO No. 429, Geneva.	A-10
Other Publications	
Bureau of Reclamation, 1977, "Design of Small Dams" 2nd edition, U.S. Department of the Interior	B-57
Chow, V.T., 1964, "Handbook of Applied Hydrology," McGraw-Hill Book Company, New York.	B-27
Davis, Calvin V., and Kenneth E. Sorensen, 1969, "Handbook of Applied Hydraulics, 3rd edition, McGraw-Hill Book Company, New York.	B-27
Henderson, F.M., 1966, "Open Channel Flow," The Macmillan Company, New York.	B-25
James, L.D., and R.R. Lee, 1971, "Economics of Water Resources Planning," McGraw-Hill Book Company, New York.	B-27
Linsley, Ray K., and Joseph B. Franzini, 1979, "Water Resources Engineering," 2nd edition, McGraw-Hill Book Company, New York.	B-27
Linsley, Ray K., Kohler, Max A., and Paulhus Joseph L.H. , 1975, "Hydrology for Engineers,"2nd Edition, McGraw-Hill Book Company, New York.	B-27
Rouse, Hunter, editor, 1950, "Engineering Hydraulics," John Wiley & Sons, Inc.	B-23
The Hydrologic Engineering Center, U.S. Army Corps of Engineers, 1971-1977, "Hydrologic Engineering Methods for Water Resources Development," A United States Contribution to the International Hydrological Decade, Vols. 1-12, California.	B-32 or B-52

(1) Out of print in 1980, (may be reprinted) library copy may be available.
(2) A fourth edition is to be published in two volumes in 1981.