ASCE Manuals and Reports on Engineering Practice No. 28

# Hydrology Handbook

#### Second Edition



AMERICAN SOCIETY OF CIVIL ENGINEERS

# Hydrology Handbook Second Edition

Prepared by the Task Committee on Hydrology Handbook of Management Group D of the American Society of Civil Engineers

This is a completely re-written edition of the Manual published in 1949.

Published by



345 East 47th Street New York, NY 10017-2398

#### Abstract:

This new edition of the *Hydrology Handbook* (Manual No. 28) incorporates the many changes and advances that have occurred in the areas of planning, development, and management of water resources since the publication of the original manual in 1949. The first six chapters, Chapters 2 through 7, relate to the natural phenomena in the hydrologic cycle, while the next three chapters describe the predictions and effects of the phenomena previously described. The final chapter reviews the applications of hydrology starting with study formulation, then reviews data management, then discusses calibration and verification of hydrologic models, and concludes with accessing accuracy and reliability of results. With this new edition, academic and practicing hydrologists have a thorough and up-to-date guide to the field of hydrologic engineering.

Library of Congress Cataloging-in-Publication Data

Hydrology handbook / prepared by the Task Committee on Hydrology Handbook of Management Group D of the American Society of Civil Engineers. -- 2nd ed.
p. cm. -- (ASCE manuals and reports on engineering practice ; no. 28)
Includes bibliographical references and index.
ISBN 0-7844-0138-1
1. Hydrology. I. American Society of Civil Engineers. Task Committee on Hydrology Handbook. II. Series.
GB661.2.H93 1996 96-41049
551.48--dc20 CIP

The material presented in this publication has been prepared in accordance with generally recognized engineering principles and practices, and is for general information only. This information should not be used without first securing competent advice with respect to its suitability for any general or specific application.

The contents of this publication are not intended to be and should not be construed to be a standard of the American Society of Civil Engineers (ASCE) and are not intended for use as a reference in purchase specifications, contracts, regulations, statutes, or any other legal document.

No reference made in this publication to any specific method, product, process or service constitutes or implies an endorsement, recommendation, or warranty thereof by ASCE.

ASCE makes no representation or warranty of any kind, whether express or implied, concerning the accuracy, completeness, suitability, or utility of any information, apparatus, product, or process discussed in this publication, and assumes no liability therefore.

Anyone utilizing this information assumes all liability arising from such use, including but not limited to infringement of any patent or patents.

Photocopies. Authorization to photocopy material for internal or personal use under circumstances not falling within the fair use provisions of the Copyright Act is granted by ASCE to libraries and other users registered with the Copyright Clearance Center (CCC) Transactional Reporting Service, provided that the base fee of \$4.00 per article plus \$.50 per page is paid directly to CCC, 222 Rosewood Drive, Danvers, MA 01923. The identification for ASCE Books is 0-7844-0138-1/96/\$4.00 + \$.50 per page. Requests for special permission or bulk copying should be addressed to Permissions & Copyright Dept., ASCE.

Copyright © 1996 by the American Society of Civil Engineers, All Rights Reserved. Library of Congress Catalog Card No: 96-41049 ISBN 0-7844-0138-1 Manufactured in the United States of America.

#### MANUALS AND REPORTS ON ENGINEERING PRACTICE

(As developed by the ASCE Technical Procedures Committee, July 1930, and revised March 1935, February 1962, April 1982)

A manual or report in this series consists of an orderly presentation of facts on a particular subject, supplemented by an analysis of limitations and applications of these facts. It contains information useful to the average engineer in his everyday work, rather than the findings that may be useful only occasionally or rarely. It is not in any sense a "standard," however; nor is it so elementary or so conclusive as to provide a "rule of thumb" for nonengineers.

Furthermore, material in this series, in distinction from a paper (which expresses only one person's observations or opinions), is the work of a committee or group selected to assemble and express information on a specific topic. As often as practicable the committee is under the direction of one or more of the Technical Divisions and Councils, and the product evolved has been subjected to review by the Executive Committee of the Division or Council. As a step in the process of this review, proposed manuscripts are often brought before the members of the Technical Divisions and Councils for comment, which may serve as the basis for improvement. When published, each work shows the names of the committees by which it was compiled and indicates clearly the several processes through which it has passed in review, in order that its merit may be definitely understood.

In February 1962 (and revised in April, 1982) the Board of Direction voted to establish:

A series entitled 'Manuals and Reports on Engineering Practice,' to include the Manuals published and authorized to date, future Manuals of Professional Practice, and Reports on Engineering Practice. All such Manual or Report material of the Society would have been refereed in a manner approved by the Board Committee on Publications and would be bound, with applicable discussion, in books similar to past Manuals. Numbering would be consecutive and would be a continuation of present Manual numbers. In some cases of reports of joint committees, bypassing of Journal publications may be authorized.

#### **# MANUALS AND REPORTS OF ENGINEERING PRACTICE**

- 10 Technical Procedures for City Surveys
- 13 Filtering Materials for Sewage Treatment Plants
- 14 Accommodation of Utility Plant Within the Rights-of-Way of Urban Streets and Highways
- 31 Design of Cylindrical Concrete Shell Roofs
- 33 Cost Control and Accounting for Civil Engineers
- 34 Definitions of Surveying and Associated Terms
- 35 A List of Translations of Foreign Literature on Hydraulics
- 36 Wastewater Treatment Plant Design
- 37 Design and Construction of Sanitary and Storm Sewers
- 40 Ground Water Management
- 41 Plastic Design in Steel-A Guide and Commentary
- 42 Design of Structures to Resist Nuclear Weapons Effects
- 45 Consulting Engineering-A Guide for the Engagement of Engineering Services
- 46 Report on Pipeline Location
- 47 Selected Abstracts on Structural Applications of Plastics
- 49 Urban Planning Guide
- 50 Planning and Design Guidelines for Small Craft Harbors
- 51 Survey of Current Structural Research
- 52 Guide for the Design of Steel Transmission Towers
- 53 Criteria for Maintenance of Multilane Highways
- 54 Sedimentation Engineering
- 55 Guide to Employment Conditions for Civil Engineers
- 57 Management, Operation and Maintenance of Irrigation and Drainage Systems
- 58 Structural Analysis and Design of Nuclear Plant Facilities
- 59 Computer Pricing Practices
- 60 Gravity Sanitary Sewer Design and Construction
- 62 Existing Sewer Evaluation and Rehabilitation
- 63 Structural Plastics Design Manual
- 64 Manual on Engineering Surveying
- 65 Construction Cost Control
- 66 Structural Plastics Selection Manual
- 67 Wind Tunnel Model Studies of Buildings and Structures
- 68 Aeration-A Wastewater Treatment Process
- 69 Sulfide in Wastewater Collection and Treatment Systems
- 70 Evapotranspiration and Irrigation Water Requirements
- 71 Agricultural Salinity Assessment and Management
- 72 Design of Steel Transmission Structures
- 73 Quality in the Constructed Project-a Guide for Owners, Designers, and Constructors
- 74 Guidelines for Electrical Transmission Line Structural Loading
- 75 Right-of-Way Surveying
- 76 Design of Municipal Wastewater Treatment Plants
- 77 Design and Construction of Urban Stormwater Management Systems
- 78 Structural Fire Protection
- 79 Steel Penstocks
- 80 Ship Channel Design
- 81 Guidelines for Cloud Seeding to Augment Precipitation
- 82 Odor Control in Wastewater Treatment Plants
- 83 Environmental Site Investigation
- 84 Mechanical Connections in Wood Structures
- 85 Quality of Ground Water
- 86 Operation and Maintenance of Ground Water Facilities
- 87 Urban Runoff Quality Manual
- 88 Management of Water Treatment Plant Residuals
- 89 Pipeline Crossings

### ACKNOWLEDGMENTS

#### MANAGEMENT GROUP D

This Handbook of Hydrology was prepared under the direction of Management Group D of the American Society of Civil Engineers Technical Activities Committee. The Handbook was initiated in 1988 and was completed in 1995. Membership of Management Group D during this period included the following persons.

1988 George E. Hecker, *Chair* Thomas Lee Jackson Conrad G. Keyes, Jr. Jerry R. Rogers Frank Stratton John R. Wegel

1991 Frank Stratton, *Chair* Catalino B. Cecilio Wayne B. Ingram Conrad G. Keyes, Jr. Michael L. Stevens Darell D. Zimbelman

1994 Darell D. Zimbelman, *Chair* Catalino B. Cecilio James E. Dailey Mriganka M. Ghosh Kenneth G. Renard Robert H. Wortman 1989 Jerry R. Rogers*, Chair* George E. Hecker Lloyd A. Held, Jr. Wayne B. Ingram Conrad G. Keyes, Jr. Frank Stratton

1992 Wayne B. Ingram, *Chair* Catalino B. Cecilio Kenneth G. Renard Michael L. Stevens Frank Stratton Darell D. Zimbelman

1995 Kenneth G. Renard, *Chair* Philip H. Burgi James E. Dailey Thomas Rackford Robert H. Wortman Darell D. Zimbelman 1990 Conrad G. Keyes, Jr., *Chair* Catalino B. Cecilio Wayne B. Ingram Jerry R. Rogers Michael L. Stevens Frank Stratton

1993

Catalino B. Cecilio, *Chair* Mriganka M. Ghosh Wayne B. Ingram Kenneth G. Renard Robert H. Wortman Darell D. Zimbelman

Management Group D appointed a Task Committee to prepare the Hydrology Handbook.

#### TASK COMMITTEE MEMBERS

Thomas P. Wootton, *Chair* Catalino B. Cecilio Lloyd C. Fowler Samuel L. Hui

#### With overall editing by

Richard J. Heggen

#### **CHAPTER SUBCOMMITTEE MEMBERS**

Each of the technical chapters in the Handbook was prepared by a subcommittee under the direction of the Task Committee. The membership of each Chapter Subcommittee included the following individuals.

#### Chapter 1, Introduction

Lloyd C. Fowler

#### Chapter 2, Precipitation

#### Control Group:

Clayton L. Hanson, Chair	Marshal J. McFarland
Karl A. Gebhardt	James A. Smith
Gregory L. Johnson	

#### **Chapter 3, Infiltration**

Control Group: Walter J. Rawls <i>, Chair</i> David Goldman	Joseph A. Van Mullen Timothy J. Ward	
Reviewers:		
Lajpat R. Ahuja	Paul A. DeBarry	

2)F)	<b></b>
A. Osman Akan	Richard J. Heggen
Donald L. Brakensiek	George V. Sabol

#### Chapter 4, Evaporation and Transpiration

Control Group:	
Richard G. Allen, Co-Chair	Leo J. Fritschen
William O. Pruitt, Co-Chair	Marvin E. Jensen
Joost A. Businger	Frank H. Quinn

#### Chapter 5, Ground Water

Control Group:	
Lloyd C. Fowler, Chair	Clyde S. Conover
Nazeer Ahmed	Marvin V. Damm
Keith E. Anderson	Donald J. Finlayson

James D. Goff

A. Ivan Johnson

W. Martin Roche

Thomas P. Ballestero Ronald K. Blatchley Carl H. Carpenter

#### **Reviewers**:

John F. ClericiStuart T. PyleCalvin G. ClydeLou RiethmannPeter KitandisJ. Paul RileyPorter C. KnowlesRichard J. SchichtClark C-K LiuClaire WeltyGeorge E. MaddoxState State Stat

#### Chapter 6, Runoff, Streamflow, Reservoir Yield, and Water Quality

Control Group: Anand Prakash, *Chair* Richard J. Heggen Victor M. Ponce

Reviewer: Rafael G. Quimpo

#### Chapter 7, Snow and Snowmelt

Control Group:	
Douglas D. Speers, Chair	David M. Rockwood
George D. Ashton	

Reviewer: David C. Garen

#### **Chapter 8, Floods**

Control Group:	
Bi-Huei Wang, Chair	Khalid Jawed
Michael L. Anderson	John T. Riedel
Gary R. Dyhouse	Jery R. Stedinger
Vernon K. Hagen	
Reviewers:	

Arlen D. Feldman Janet C. Herrin

Donald M. Thomas

#### Chapter 9, Urban Hydrology

Control Group: David F. Kibler, *Chair* A. Osman Akan Gert Aron

Reviewers: G. V. Loganathan Christopher B. Burke Mark W. Glidden Richard H. McCuen

Andrew J. Reese

#### Chapter 10, Water Waves

Edward F. Thompson
J. Richard Weggel

#### Chapter 11, Hydrologic Study Formulation and Assessment

Control Group:	
John C. Peters, Chair	David Ford
Shawna Anderson	Katherine Hon
Patrick Atchison	Richard H. McCuen
John J. Buckley	

The following individuals participated in a final review of all or portions of this Handbook.

Raymundo Aguirre Catalino B. Cecilio Theodore G. Cleveland Lloyd C. Fowler Richard J. Heggen Samuel L. Hui Wayne B. Ingram Conrad G. Keyes, Jr. Rong-Heng Kuo Kenneth G. Renard J. Paul Riley James M. Robinson, Jr. Jerry R. Rogers Valerie Steinmaus Jeffry Stone Warren Viessman, Jr. Keh Han Wang Thomas P. Wootton

## CONTENTS

Acknowledg	ment	3	v
Conversion t	to SI U	Jnits x	xix
Chapter 1:	Intro	duction to the New Handbook of Hydrology	. 1
	I.	Historical Summary	. 1
	II.	Purpose of the New Handbook	. 1
	III.	Scope of the New Handbook	. 1
	IV.	The Hydrologic Cycle	
Chapter 2:	Prec	pitation	. 5
	I.	Introduction	. 5
	II.	<ul><li>Formation and Types of Precipitation</li><li>A. Mechanisms</li><li>B. Types of Precipitation</li><li>C. Principal Causes of Precipitation</li></ul>	.5 .6
	III.	<ul> <li>Variations in Precipitation</li></ul>	. 9 . 9 11 11 15
	IV.	The Measurement of Precipitation         A. Uses of Precipitation Measurements         B. Measurement of Precipitation with Gages         1. Standard Precipitation Gages in the United States         2. Tipping Bucket Recording Precipitation Gages         3. Orifice Diameter for Rain Gages         4. Measurement of Precipitation on Sloping Terrain         5. Measurement of Rainfall Intensity         C. Measurement Error with Precipitation Gages	22 22 22 23 23 24 25