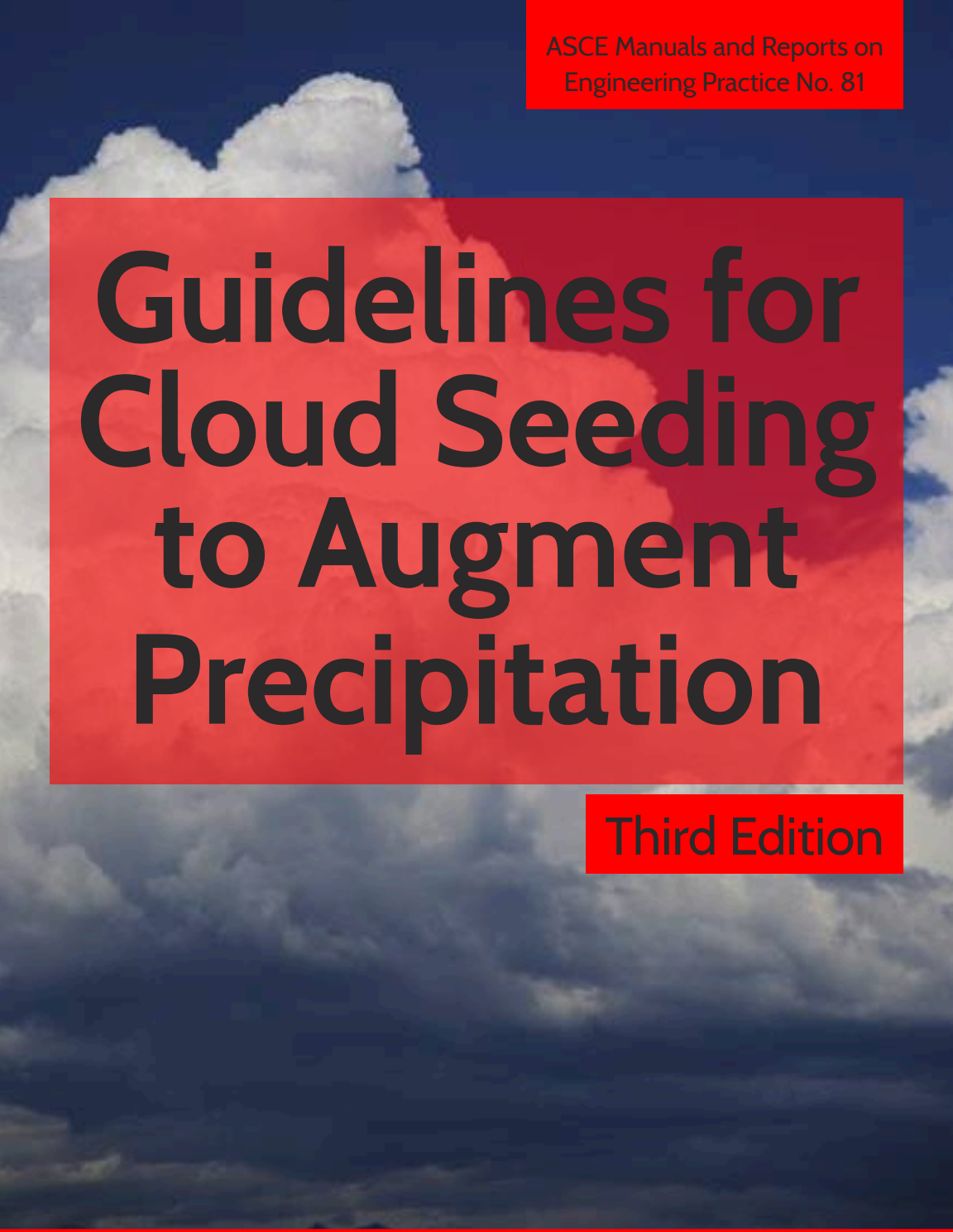

ASCE Manuals and Reports on Engineering Practice No. 81

Guidelines for Cloud Seeding to Augment Precipitation

Third Edition

ASCE

EDITED BY
Conrad G. Keyes Jr., George W. Bomar, Thomas P. DeFelice, Don A. Griffith,

EWRI ASCE ENVIRONMENTAL & WATER RESOURCES INSTITUTE

ASCE Manuals and Reports on Engineering Practice No. 81

Guidelines for Cloud Seeding to Augment Precipitation

Third Edition

Edited by
Conrad G. Keyes Jr.
George W. Bomar
Thomas P. DeFelice
Don A. Griffith
Darin W. Langerud

Sponsored by the
Atmospheric Water Management Standards Committee of
the Standards Development Council of the
Environmental and Water Resources Institute of the
American Society of Civil Engineers

ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS

EWRI ENVIRONMENTAL & WATER RESOURCES INSTITUTE

Published by the American Society of Civil Engineers

Library of Congress Cataloging-in-Publication Data

Names: Keyes, Conrad G., editor. | Environmental and Water Resources Institute (U.S.). Atmospheric Water Management Standards Committee.
Title: Guidelines for cloud seeding to augment precipitation / edited by Conrad G. Keyes, Jr. [and four others] ; sponsored by the Atmospheric Water Management Standards Committee of the Standards Development Council of the Environmental and Water Resources Institute of the American Society of Civil Engineers.
Description: Third edition. | Reston, Virginia : Published by the American Society of Civil Engineers, [2016] | Series: ASCE manuals and reports on engineering practice ; no. 81 | Includes bibliographical references and index.
Identifiers: LCCN 2015023957 | ISBN 9780784414118 (print: alk. paper) | ISBN 9780784479339 (pdf)
Subjects: LCSH: Rain-making—United States—Handbooks, manuals, etc. | Precipitation (Meteorology)—Modification—United States—Handbooks, manuals, etc.
Classification: LCC QC928.7. G85 2016 | DDC 551.68/76—dc23
LC record available at http://lccn.loc.gov/2015023957

Published by American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia, 20191-4382
www.asce.org/bookstore | ascelibrary.org

Errata: Errata, if any, can be found at http://dx.doi.org/10.1061/9780784414118.

ISBN 978-0-7844-1411-8 (print)
ISBN 978-0-7844-7933-9 (PDF)
Manufactured in the United States of America.

20 19 18 17 16 1 2 3 4 5

Front cover: Br

MANUALS AND REPORTS ON ENGINEERING PRACTICE

(As developed by the ASCE Technical Procedures Committee, July 1930, and revised March 1935, February 1962, and 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 or her everyday work, rather than 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, so that its merit may be definitely understood.

In February 1962 (and revised in April 1982), the Board of Direction voted to establish a series titled "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 joint committee reports, bypassing of Journal publications may be authorized.

A list of available Manuals of Practice can be found at http://www.asce.org/bookstore.

This page intentionally left blank

CONTENTS

PREFACE

Traditional water resources management pertains to making reasonable use of available water and desalinization and to minimizing loss because of floods. Atmospheric water management provides a cost-effective means for augmenting available water and reducing damage during meteorological events.

In many areas of the United States and the world, a need existes for new water supplies. These updated guidelines are intended to provide water resources managers and others with information and references that they will need for decision making regarding the use of cloud seeding to augment available water supplies.

This manual incorporates pertinent background on the science and practice of weather modification by cloud seeding to augment precipitation. Legal, social, environmental, and economic factors motivating and limiting operational cloud seeding are reviewed. The technologies, instrumentation, and procedures needed to implement a cloud seeding program are described. This is all intended to give water resources managers the broad spectrum and practical details of what is involved in utilizing cloud seeding (atmospheric water management) technology.

The American Society of Civil Engineers (ASCE) Weather Modification Committee (1960–1985) and the Climate and Weather Change Committee (1985–1996) were fortunate enough to bring together experts in the weather modification field and have them devote a great amount of uncompensated volunteer time to write the first versions of this valuable document. The 1982 Weather Modification Committee, the 1993 Climate and Weather Change Committee, and the 1982 and 1994 Executive Committees of the Irrigation and Drainage Division are to be commended for their thorough and helpful review of the first document that was published in the ASCE Journal of Irrigation and Drainage Engineering in March 1983, pp. 111–182 (parts written by Paul C. Summers: Foreword; Robert D. Elliott: Summary; Olin H. Foehner, Jr.: SEE Issues; Ray Jay Davis: Legal Aspects; Lewis O. Grant:

Scientific Basis; Don A. Griffith: Modes and Instrumentation; and Conrad G. Keyes Jr.: How to Implement).

The original task committee appreciated the extensive technical editing of each section of the manual by the personnel of OPHIR Corporation. The Consortium of Atmospheric Resources Development provided funds for the review of the first version of this manual, and the North American Interstate Weather Modification Council provided funds for travel to a meeting of the 1992–1993 Task Committee involved in the revision of the 1983 guidelines published by ASCE.

The 1995 manual was authored by the following individuals (by section): (1) Robert D. Elliott, Conrad G. Keyes Jr., and Roger F. Reinking; (2) Roger F. Reinking, Neil H. Berg, Barbara C. Farhar, and Olin H. Foehner, Jr.; (3) Ray Jay Davis; (4) Lewis O. Grant, Harold D. Orville, Marcia Politovich, Roger F. Reinking, David Rogers, and Joseph Warburton; (5) Don A. Griffith, Marcia Politovich, James H. Renick, David W. Reynolds, and David Rogers; and (6) Conrad G. Keyes Jr., Joseph A. Warburton, and James H. Renick. Most of these individuals were involved with the Climate and Weather Change Committee of the Irrigation and Drainage Division of Management Group D of ASCE.

The 2006 manual was authored by the following individuals (by section): (1) Thomas P. DeFelice and Conrad G. Keyes Jr.; (2) Conrad G Keyes, Jr.; (3) George W. Bomar; (4) Robert Czys, Thomas DeFelice, and Don A. Griffith; (5) Don A. Griffith; and (6) Bruce A. Boe and Conrad G. Keyes Jr. Most of these individuals have been long-standing members and/or officers of the Weather Modification Association. The final reviewers from the Blue Ribbon Review Panel for the EWRI Standards Development Council included Darin W. Langerud, Paul L. Smith, Mark E. Solak, and William L. Woodley.

This current edition or revision of the manual was produced by those listed within each chapter and approved for publication by a majority of the Atmospheric Water Management (AWM) Standards Committee (SC). The editors from the EWRI Revision of Manual 81 Subcommittee are Chief Editor Conrad G. Keyes Jr. and Coeditors George W. Bomar, Thomas P. DeFelice, Don A. Griffith, and Darin W. Langerud. Other authors on chapters include Robert Czys and Bruce A. Boe (both were lead authors in 2006). The other subcommittee reviewers from the AWM SC and/or the Weather Modification Association include Joseph H. Golden, Maurice D. Roos, and Paul Smith. The final reviewers of all chapters from the Blue Ribbon Review Panel for the EWRI Standards Development Council (SDC) include Duncan Axisa of NCAR, Mark Schneider of NDARB, and Mark E. Solak of NAWC. Some members of the AWM SC had additional final input on the draft chapters before all work was provided to the Chair (Ben Willardson) of the EWRI SDC for approval for publication by ASCE.

Conrad G. Keyes Jr., ScD, P.E., P.S., D.WRE, WMA CM, Dist.M.ASCE, F.NSPE

Emeritus Professor and Department Head, New Mexico State University

DEDICATION

This manual is dedicated to many of the original coauthors of the 1983 and/or 1995 versions of the guidelines. These individuals made significant contributions to the "cloud seeding to augment precipitation" community during the many years of their professional lives and served ASCE as dedicated volunteers during many years of the development and publication of this subject.

RAY JAY DAVIS passed away August 10, 2000, at his home in Provo, UT. Ray received a B.A. from Idaho State University in 1948, a J.D. from Harvard Law School in 1953, and an L.L.M. from Columbia Law School in 1956.

An academician throughout his 45-year legal career, Ray Jay was a Professor of Law at Brigham Young University from 1979 until his retirement in April 2000. He also taught law at the University of Arizona (17 years), Temple University, and the University of Arkansas.

His research career was primarily devoted to studying and writing about the legal rules that govern, or should govern, the appropriation and use of water, particularly water contained in the earth's atmosphere. He served as chair for a monumental project undertaken by ASCE to produce a model state water code to be transmitted to all 50 state legislatures with a recommendation for adoption and to be published abroad as a law reform source in foreign countries. He was also the author of the legal section of first edition of ASCE Manual 81 and the initial version of the guidelines in 1983.

Ray served as the chair, a member, a principal investigator, or an advisor to countless committees to governmental agencies of different states and to agencies of the federal government. He represented the United States at the United Nations Conference on International Legal Principles for Weather Modification. He made presentations at conferences in foreign countries and served as an advisor on the legal ramifications of cloud seeding to nine western and midwestern states. Some of his writings have been translated