Chapter 1
Introduction

1-1. Purpose

This manual provides technical background and guidance for computing basin snowmelt runoff as is necessary in the design and operation of U.S. Army Corps of Engineers (USACE) water control projects. This manual discusses the basic theoretical principles of snow hydrology and the practical applications of this theory in forecasting and design. It summarizes several important snowmelt runoff models and offers guidelines for model selection. This manual represents an update of EM 1110-2-1406, Runoff from Snowmelt, dated 5 January 1960, which is now obsolete. While many of the basic principles and techniques presented in that manual have been retained, numerous advancements in computer, communications, and data acquisition technologies are now reflected. This manual is applicable to USACE offices in which snow hydrology considerations affect runoff and streamflow derivations.

1-2. Background

In the mid-1940s, the Federal Government initiated a major research program as a cooperative effort between the U.S. Army Corps of Engineers and U.S. Weather Bureau, with the major impetus being to develop procedures to derive spillway design floods for the major dams that were being planned for western river basins subject to snow runoff. The *Cooperative Snow Investigation Program* established three snow laboratories that were operated until the mid-1950s. The Central Sierra Snow Laboratory was located in the Sierra Mountains of California near Donner Pass; the Upper Columbia Snow Laboratory was located in Glacier National Park in Montana; and the Willamette Basin Snow Laboratory was in the upper McKenzie River drainage in Western Oregon. (The Central Sierra Laboratory continues to be operated by the Department of Agriculture.) The results of the laboratory experiments and other scientific research of the program were documented in numerous Technical Reports, Research Notes, and Technical Bulletins. These were in turn compiled into a summary report, *Snow Hydrology* (U.S. Army Corps of Engineers 1956). This document remains a valuable resource for hydrologists and engineers working with snow hydrology applications. The final product of the *Cooperative Snow Investigations Program* was EM 1110-2-1406, the predecessor of this document. Since the 1960s, advances in applied snow hydrology have centered primarily around computer applications of the methodologies developed by USACE and subsequent researchers. These include the following:

a. Development of many conceptual snowmelt models.

b. Use of new technology to acquire data for measuring various aspects of snow.

c. Employment of computers in managing and analyzing hydrometeorological data.

d. Use of new communications technologies for rapid access to data, even in the near real-time.

With all these changes, snowmelt models are now internalized in operational forecasting more than ever before, and their future use will increase as more efficient capabilities for data acquisition, communications, and analysis are developed.

1-3. Snow Hydrology Modeling

In this manual, focus is placed primarily on computing runoff and streamflow in which snow has played a role in the process. This computation, typically accomplished with a computer model of some sort, includes the following considerations.

a. Collection and handling of competent spatial and temporal data for model input. This operation, critical especially in real-time forecasting, has been enhanced in recent years by the development of remote sensing and the availability of near-real-time water control data.

b. Formulation of the structure of the snowmelt model. How the model deals with the complex physics of accumulation, snowmelt, areal snow distribution, and snow-soil interactions must be defined so that new data collection and handling techniques can be rationally analyzed and incorporated

as input. This step involves selecting a computer program that is appropriate for the application, then using the options available correctly and intelligently.

c. Application of the model in either analysis or forecasting. Here the skill and experience of the user come into play as a model is calibrated, tested, then applied in the intended application. This cannot be done without a thorough background in snow hydrology, making use of basic principles that are described in this manual and in other references.

1-4. References

Related publications include:

a. ER 1110-2-248 Requirements for Water Data Transmission Using GOES/DCS

b. ER 1110-2-249 Management of Water Control Data Systems

c. EM 1110-2-1415 Hydrologic Frequency Analysis

d. EM 1110-2-1416 River Hydraulics

e. EM 1110-2-1417 Flood-Runoff Analysis

f. EM 1110-2-3600 Management of Water Control Systems

1-5. Bibliography and Definitions

A bibliography of other reports and important papers pertaining to snowmelt runoff that are cited in the text is provided in Appendix A of this manual. Additionally, a glossary of terms and definitions is included in this Engineer Manual as Appendix B. A comprehensive listing of literature pertaining to snow is contained in the *Bibliography on Cold Regions Science and Technology* that is periodically published by the U.S. Army Cold Regions Research and Engineering Laboratory and the Library of Congress. By regularly reviewing this Bibliography, the user can efficiently keep abreast of continuing developments in the field of snow hydrology to supplement the contents of this manual.

1-6. Scope and Content

This manual includes both theoretical and practical topics. The basic theoretical concepts of snow hydrology are presented in Chapter 2, "Snowmelt Runoff—A Review of the Fundamental Processes." This chapter draws upon *Snow Hydrology* and more recent research work to summarize the physical processes involved in snow accumulation, metamorphosis, and melt, and to present fundamental equations that describe these processes. After a discussion of data collection and analysis in Chapter 3, the physical processes are again discussed, this time with regard to practical applications in forecasting and design, in Chapters 4 through 9. Chapter 4, "Snow Accumulation and Distribution," discusses techniques—both simple and complex—that can be used to estimate snow quantity and areal extent at the beginning of a snowmelt runoff event. Chapter 5, "Snowmelt—Energy Budget Solutions," presents the semiempirical equations that have been developed from the basic theoretical principles for use primarily in the derivation of design floods in a snow environment. In Chapter 6, "Snowmelt— Temperature Index Solutions," the simpler alternative method of estimating snowmelt rates, used widely in real-time hydrologic forecasting, is discussed. Chapter 7, "Effect of Snow Condition on Runoff," covers the practical considerations associated with the metamorphosis of snow—how the condition of the snow can affect the determination of runoff. Chapter 8, "Snowmelt—Accounting for Changes in Snow and Snowcover," describes approaches to modeling the change of snow quantity and areal extent during snowmelt. Chapter 9, "Statistical Analyses," summarizes statistical techniques that are commonly used in snow hydrology.

a. The techniques and "tools" described in Chapters 4 through 9 are further described in terms of their use in practical engineering applications in Chapter 10, "Snowmelt Runoff Analysis for Engineering and Forecasting Applications." Examples include simple and complex derivations of design floods, reservoir operational analysis, and operational forecasting. In Chapter 11, "Guidelines for Snowmelt Model Selection," available operational models are described.

b. In addition to Appendixes A and B noted above, several other appendixes provide detailed technical material to augment the information presented in the main body of the manual. Appendix C, "Summary of Basic Physics Principles—Heat, Heat Transfer, and Thermal Properties of Water," summarizes some basic physics of water that are applicable in snow hydrology. Included are some basic tables of physical properties in both English and SI units. Appendix D, "Meteorological Relationships," presents a number of charts drawn from the *Cooperative Snow Investigation Studies* that are useful in describing the influence of meteorological phenomena on snowmelt. Appendix E presents SI unit versions of the generalized energy budget equations that are discussed in Chapter 5. Finally, Appendix F, "Summary Descriptions of Selected Operational Snowmelt Models," summarizes the characteristics of several widely used computer models that can be used to simulate snowmelt runoff.

1-7. Units

The equations in this manual will be presented in both SI and English units. If the reader refers to modern textbooks on physics and meteorology, the SI convention would be used exclusively. However, once the discussion involves the experimental relationships that were developed in the 1950s, a shift to current U.S. practice (English units) must be made. Further discussion of units can be found in Paragraph 5-2*b*.