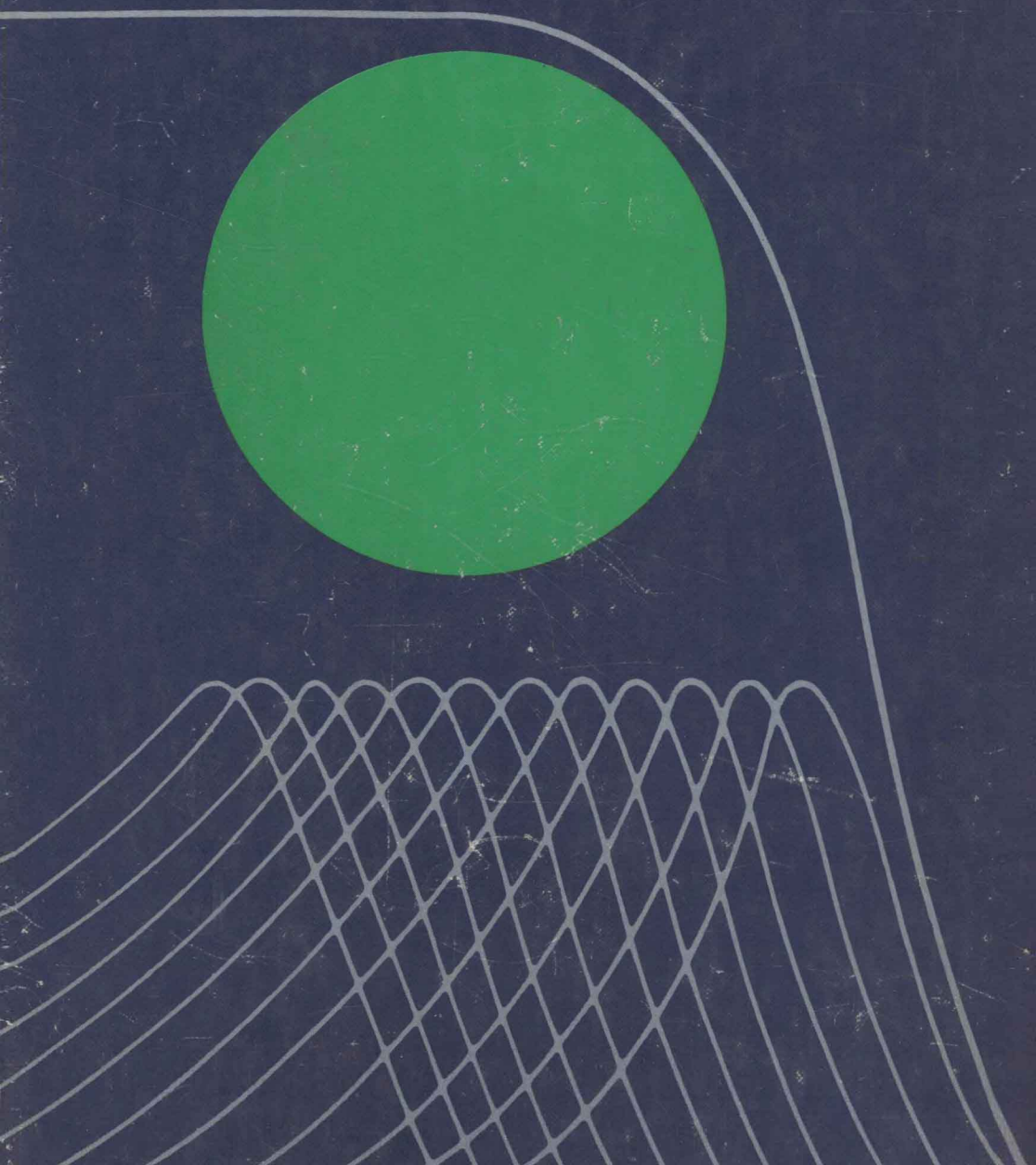


# INTRODUCTION TO HYDROLOGY

WARREN VIESSMAN, JR. · JOHN W. KNAPP  
GARY L. LEWIS · THE LATE TERENCE E. HARBAUGH

**SECOND EDITION**



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# **Introduction to Hydrology**

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To  
Jeanne,  
Peggy,  
Gayle,  
and  
Karen

# Preface

A desire to minimize the ecologic impact of the development and use of natural resources is now firmly established. It is, therefore, vitally important for engineers and scientists to thoroughly understand the nature of a particular environment before attempting to manipulate it or govern its uses. This book deals with one crucial resource—water.

There is sufficient material for either a one- or a two-semester, beginning course in hydrology. Although primarily intended for undergraduates, the content is sufficiently rigorous for a first graduate course as well. And because the book emphasizes hydrologic principles and their practical application to realistic problems, practitioners should find the material useful as a reference.

The second edition has been strengthened and expanded significantly in the areas of simulation and the application of hydrologic techniques to problems encountered on both large and small watersheds. Urban hydrology has been given much greater emphasis. And the organization of the book has been revised so that one moves from background material into rational models for hydrologic analysis and water resources planning. A chapter on water quality models has been added to introduce the important linkages between water quality and water quantity.

Frequent citations are made to computer applications and several programs included. Many solved examples illustrate the prin-

ciples developed. Statistical and numerical methods are widely employed.

Many sources have supplied subject matter for the book. The authors hope that suitable acknowledgment has been given to them and wish to thank their colleagues and students for helpful comments and review.



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# Introduction

## 1-1 Hydrology Defined

Hydrology is an earth science. It encompasses the occurrence, distribution, movement, and properties of the waters of the earth and their environmental relationships. Closely allied fields include geology, climatology, meteorology, and oceanography. The emphasis of this book is on engineering hydrology.

## 1-2 A Brief History

Ancient philosophers focused their attention on the nature of processes involved in the production of surface flows and other phenomena related to the origin and occurrence of water in various stages of the perpetual cycle of water being conveyed from the sea to the atmosphere to the land and back again to the sea. Unfortunately, early speculation was often faulty.<sup>1,4-6\*</sup> For example, Homer believed in the existence of large subterranean reservoirs that supplied rivers, seas, springs, and deep wells. It is interesting to note, however, that Homer understood the dependence of flow in the Greek aqueducts on both conveyance cross section and velocity. This knowledge was lost to the Romans and the proper relationship between area, velocity,

\*Superior numbers indicate references at the end of the chapter.

and rate of flow remained unknown until Leonardo da Vinci discovered it during the Italian Renaissance.

During the first century B.C. Marcus Vitruvius, in Volume 8 of his treatise *De Architectura Libri Decem* (the engineer's chief handbook during the Middle Ages) set forth a theory generally considered to be the predecessor of modern notions of the hydrologic cycle. He hypothesized that rain and snow falling in mountainous areas infiltrated the earth's surface and later appeared in the lowlands as streams and springs.

In spite of the inaccurate theories proposed in ancient times, it is only fair to state that practical application of various hydrologic principles was often carried out with considerable success. For example, about 4000 B.C. a dam was constructed across the Nile to permit reclamation of previously barren lands for agricultural production. Several thousand years later a canal to convey fresh water from Cairo to Suez was built. Mesopotamian towns were protected against floods by high earthen walls. The Greek and Roman aqueducts and early Chinese irrigation and flood control works are also significant projects.

Near the end of the fifteenth century the trend toward a more scientific approach to hydrology based on the observation of hydrologic phenomena became evident. Leonardo da Vinci and Bernard Palissy independently reached an accurate understanding of the water cycle. They apparently based their theories more on observation than on purely philosophical reasoning. Nevertheless, until the seventeenth century it seems evident that little if any effort was directed toward obtaining quantitative measurements of hydrologic variables.

The advent of what might be called the "modern" science of hydrology is usually considered to begin with the studies of such pioneers as Perrault, Mariotte, and Halley in the seventeenth century.<sup>1,4</sup> Perrault obtained measurements of rainfall in the Seine River drainage basin over a period of three years. Using these and measurements of runoff, and knowing the drainage area size, he showed that rainfall was adequate in quantity to account for river flows. He also made measurements of evaporation and capillarity. Mariotte gauged the velocity of flow of the River Seine. Recorded velocities were translated into terms of discharge by introducing measurements of the river cross section. The English astronomer Halley measured the rate of evaporation of the Mediterranean Sea and concluded that the amount of water evaporated was sufficient to account for the outflow of rivers tributary to the sea. Measurements such as these, although crude, permitted reliable conclusions to be drawn regarding the hydrologic phenomena being studied.

The eighteenth century brought forth numerous advances in hydraulic theory and instrumentation. The Bernoulli piezometer, the



Pitot tube, Bernoulli's theorem, and the Chézy formula are some examples.<sup>8</sup>

During the nineteenth century experimental hydrology flourished. Significant advances were made in groundwater hydrology and in the measurement of surface water. Such significant contributions as Hagen-Poiseuille's capillary flow equation, Darcy's law of flow in porous media, and the Dupuit-Thiem well formula were evolved.<sup>9-11</sup> The beginning of systematic stream gauging can also be traced to this period. Although the basis for modern hydrology was well established in the nineteenth century, much of the effort was empirical in nature. The fundamentals of physical hydrology had not yet been well established or widely recognized. In the early years of the twentieth century the inadequacies of many earlier empirical formulations became well known. As a result, interested governmental agencies began to develop their own programs of hydrologic research. From about 1930 to 1950, rational analyses began to replace empiricism.<sup>3</sup> Sherman's unit hydrograph, Horton's infiltration theory, and Theis's nonequilibrium approach to well hydraulics are outstanding examples of the great progress made.<sup>12-14</sup>

Since 1950 a theoretical approach to hydrologic problems has largely replaced less sophisticated methods of the past. Advances in scientific knowledge permit a better understanding of the physical basis of hydrologic relationships, and the advent and continued development of high speed digital computers have made possible, in both a practical and an economic sense, extensive mathematical manipulations that would have been overwhelming in the past. The effective utilization of "men, models, methods, and machines" appears to be at hand.<sup>7</sup>

For a more comprehensive historical treatment, the reader is referred to the works of Meinzer, Jones, Biswas, et al.<sup>1,2,4,5,15</sup>

### 1-3 The Hydrologic Cycle

The hydrologic cycle is a continuous process by which water is transported from the oceans to the atmosphere to the land and back to the sea. Many subcycles exist. The evaporation of inland water and its subsequent precipitation over land before returning to the ocean is one example. The driving force for the global water transport system is provided by the sun, which furnishes the energy required for evaporation. Note that the water quality also changes during passage through the cycle; for example, sea water is converted to fresh water through evaporation.

The complete water cycle is global in nature. World water problems require studies on regional, national, international, continental, and global scales.<sup>17</sup> Practical significance of the fact that the total sup-