

Hydrology

Water in its different forms has always been a source of wonder, curiosity and practical concern for humans everywhere. This textbook presents a coherent introduction to many of the concepts and relationships needed to describe the distribution and transport of water in the natural environment.

Continental water transport processes take place above, on and below the Earth's surface, and consequently the book is split into four main parts. Part I deals with water in the atmosphere. Part II introduces the transport of water on the surface. Water below the surface is the subject of Part III. Part IV is devoted to flow phenomena at the basin scale and statistical concepts useful in the analysis of hydrologic data. Finally, the book closes with a brief history of ideas concerning the hydrologic cycle. Hydrologic phenomena are dealt with at spatial and temporal scales at which they occur in nature. The physics and mathematics necessary to describe these phenomena are introduced and developed, and readers will require a working knowledge of calculus and basic fluid mechanics.

Hydrology – An Introduction is a textbook that covers the fundamental principles of hydrology, based on the course that Wilfried Brutsaert has taught at Cornell University for the past 30 years. The book will be invaluable as a textbook for entry-level courses in hydrology directed at advanced seniors and graduate students in physical science and engineering. In addition, the book will be more broadly of interest to professional scientists and engineers in hydrology, environmental science, meteorology, agronomy, geology, climatology, oceanology, glaciology and other Earth sciences.

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HYDROLOGY
AN INTRODUCTION

WILFRIED BRUTSAERT
Cornell University



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FOREWORD

Water in its different forms has always been a source of wonder, curiosity and practical concern for humans everywhere. The goal of this book is to present a coherent introduction to some of the concepts and relationships needed to describe the distribution and transport of water in the natural environment. Thus it is an attempt to provide a more thorough understanding, and to connect the major paradigms that bear upon the hydrologic cycle, that is the never-ending circulation of water over the continents of the Earth.

Continental water transport processes take place above, on and below the Earth's landsurfaces. Accordingly, in Part I, water is considered as it passes through the lower atmosphere; this part consists of a general description of atmospheric transport in Chapter 2, followed by the application of these concepts to precipitation and evaporation in Chapters 3 and 4, respectively. In Part II, water transport on the Earth's surface is dealt with; this part consists of a general description of the hydraulics of free surface flow in Chapter 5, which is then applied to overland runoff and streamflow routing in rivers in Chapters 6 and 7, respectively. Water below the surface is the subject of Part III; again, a general introduction to flow in porous materials in Chapter 8 is followed by applications to phenomena involving infiltration and capillary rise in Chapter 9, and groundwater drainage and baseflow in Chapter 10. Part IV is devoted to flow phenomena, mostly fluvial runoff, in response to precipitation at the catchment and river basin scales, which result from the combination of flows both above and below the Earth's surface, already treated at smaller scales separately in Parts II and III. Various interactions of these flow phenomena and the major paradigms regarding the subscale mechanisms are described in Chapter 11. This is followed by a treatment of the available parameterizations in Chapter 12. In Chapter 13 the fourth part of the book concludes with a brief description of some of the more common statistical concepts that are useful in the analysis of hydrologic data. Finally, as an afterword, Chapter 14 closes the book with a brief history of the ideas on the water cycle, which over the centuries evolved to our present understanding; Santayana's dictum may be a bit worn by now, but several recent reinventions of the hydrologic wheel could have been avoided, if the past had been better remembered.

These transport phenomena in the hydrologic cycle on land are treated at spatial and temporal scales, at which they are commonly encountered in everyday life and at which they are tractable with presently available data. Hydrology is a physical science, and the language of physics is mathematics. Accordingly, plausible assumptions are introduced and the mathematical formulations and parameterizations are derived, which describe the

more relevant mechanisms involved in the different phases of the continental hydrologic cycle. The resulting equations are then examined and, if possible, solved for certain prototype situations and boundary conditions. The motivation for this is, first, to gain a better understanding of their structure and underlying assumptions, and of the physics they are intended to represent; and second, to provide the basis and background for more complex modeling exercises, simulations and predictions in practical applications.

The subject material covered in this book grew out of the lecture notes for my courses in hydrology and related topics in the School of Civil and Environmental Engineering, at Cornell University. I have not tried to cover all possible angles and points of view of the subject matter. Rather, I have followed a line of thought, which over the years I have come to find effective in conveying a broad understanding of the more important phenomena, and in stimulating further inquiry in the subject. Similarly, no attempt has been made to compile a complete bibliography. But the references that are listed refer to other works, so that it should be possible to trace back the more important developments.

As its subtitle indicates, this book is intended as an introduction; as such, it should be suitable as a textbook for an entry-level course in hydrology directed at advanced seniors and beginning graduate students in engineering and physical science, who have a working knowledge of calculus and basic fluid mechanics. The book contains much more material than can reasonably be covered in a first course. Thus it will depend on the objectives of the course, and on the orientation and level of the students, which specific topics should be selected for coverage. Naturally, the instructor should be the ultimate judge in this. However, to facilitate this selection, the text is printed in two different type formats. The main subject matter, which in the experience of the author can be suggested for inclusion in a first course, is presented in regular type. An effort has been made to lay out this part of the text in such a way that the student should be able to grasp the material with little or no reliance on the more advanced sections. For certain topics, clarification by an experienced instructor in the lectures will undoubtedly be helpful. Subject matter of a more advanced or specialized nature, is printed as indented text in a slightly smaller type and with a grey rule on the left-hand side of the page. This material is intended either as optional or explanatory reading for the first course, or as subject matter to be covered in a second and more advanced course. Sections of this second type of material have also been used as major portions in more specialized courses, namely in Groundwater Hydrology (Chapters 8, 9 and 10) and in Boundary Layer Meteorology (Chapters 2, 3 and 4) at Cornell.

The book is intended mainly for students of hydrology; it should, however, also be more broadly of interest to professional scientists and engineers, who are active in environmental matters, meteorology, agronomy, geology, climatology, oceanology, glaciology and other Earth sciences, and who wish to study some of the underlying concepts of hydrology, relevant to their discipline. In addition, it is hoped that the book

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FOREWORD

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will be of use to workers in fluid dynamics, who want to become acquainted with applications to some intriguing and fascinating phenomena in nature.

Wilfried Brutsaert

Ter nagedachtenis van mijn ouders Godelieve S. G. Bostijn (-B.) en Daniel P. C. B.
妻トヨに捧げる
And to the life of Siska, Hendrik, Erika and Karl.

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NOTE ON THE TEXT

Readers should note that more advanced material in this book is printed in smaller type than the main subject matter, with a grey rule in the left-hand margin. A fuller explanation may be found in the Foreword.