Preface

It is possible that you have this book in your hands because of its intriguing name (Chaos) or simply by accident, but I hope that you will continue to read it for its contents and then also recommend it to others.

In common parlance, the word 'chaos,' derived from the Ancient Greek word Χάος, typically means a state lacking order or predictability; in other words, chaos is synonymous to 'randomness.' In modern dynamic systems science literature, however, the term 'chaos' is used to refer to situations where complex and 'random-looking' behaviors arise from simple deterministic systems with sensitive dependence on initial conditions; therefore, chaos and randomness are quite different. This latter definition has important implications for system modeling and prediction: randomness is irreproducible and unpredictable, while chaos is reproducible and predictable in the short term (due to determinism) but irreproducible and unpredictable only in the long term (due to sensitivity to initial conditions).

The three fundamental properties inherent in the above definition of chaos, namely (a) nonlinear interdependence; (b) hidden order and determinism; and (c) sensitivity to initial conditions, are highly relevant in almost all real systems. In hydrology, for instance: (a) nonlinear interactions are dominant among the components and mechanisms in the hydrologic cycle; (b) determinism and order are prevalent in daily temperature and annual river flow; and (c) contaminant transport in surface and sub-surface waters is highly sensitive to the time (e.g., rainy or dry season) at which the contaminants were released. The first property represents the 'general' nature of hydrologic phenomena, whereas the second and third represent their 'deterministic' and 'stochastic' natures, respectively. Further, despite their complexity and random-looking behavior, hydrologic phenomena may be governed only by a few degrees of freedom, another basic idea of chaos theory; for instance, runoff in a well-developed urban catchment depends essentially on rainfall.

This book is intended to address a fundamental question researchers in hydrology commonly grapple with: is the complex, irregular, and random-looking behavior of hydrologic phenomena simply the outcome of random (or stochastic)

system dynamics, or is there some kind of order and determinism hidden behind? In other words, since simple deterministic systems can produce complex and random-looking outputs, as has been shown through numerous synthetic examples, is it reasonable then to ask if hydrologic systems can also belong to this category? A reliable answer to this question is important for proper identification of the type and complexity of hydrologic models to be developed, evaluation of data and computer requirements, determination of maximum predictability horizon for hydrologic processes, and assessment, planning, and management of water resources.

I approach the above question in a very systematic manner, by first discussing the general and specific characteristics of hydrologic systems, next reviewing the tools available at our disposal to study such systems, and then presenting the applications of such tools to various hydrologic systems, processes, and problems. In the end, I argue that chaos theory offers a balanced and middle-ground approach between the deterministic and stochastic extreme paradigms that are prevalent in hydrology (and in almost every other field) and, thus, serves as a bridge connecting the two paradigms.

The book is divided into four major parts, focusing on specific topics that I deem necessary to meet the intended goal. Part A (Hydrologic Systems and Modeling) covers the introduction to hydrology (Chap. 1), characteristics of hydrologic systems (Chap. 2), stochastic time series methods (Chap. 3), and modern nonlinear time series methods (Chap. 4). Part B (Nonlinear Dynamics and Chaos) details the fundamentals of chaos theory (Chap. 5), chaos identification and prediction (Chap. 6), and issues associated with chaos methods (Chap. 7), especially in their applications to real data. Part C (Applications of Chaos Theory in Hydrology) details the applications of chaos theory in hydrology, first with an overview of hydrologic applications (Chap. 8), followed by applications to rainfall (Chap. 9), river flow (Chap. 10), and other hydrologic data (Chap. 11), and then with studies on hydrologic data-related issues (Chap. 12). Part D (A Look Ahead) summarizes the current status (Chap. 13), offers future directions (Chap. 14), and includes a broader discussion of philosophical and pragmatic views of chaos theory in hydrology (Chap. 15).

I must emphasize that this book is about hydrology (and *not* about chaos theory), with focus on the applications of nonlinear dynamic and chaos concepts in hydrologic systems. Consequently, a significant portion of the presentation is devoted to hydrologic system characteristics, time series modeling in hydrology, relevance of nonlinear dynamic and chaos concepts in hydrology, and their applications and advances in hydrology, especially from an engineering perspective. The presentation about the fundamentals of chaos theory, methods for identification and prediction, and relevant issues in their applications is by no means exhaustive, and is deliberately kept to a minimum level that is needed to meet the above goal. However, the amount of literature cited on the theoretical aspects of chaos theory and methodological developments is extensive, which should guide the interested reader to further details. For the benefit of the reader, and especially

for someone new to the field, I also attempt to be descriptive in reviewing the theoretical concepts, detailing the applications, and interpreting the outcomes. All this, I believe, makes this book suitable for both experienced researchers and new ones in hydrology and water resources engineering, and beyond.

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