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978-0-521-57125-8 - Scale Dependence and Scale Invariance in Hydrology
Edited by Garrison Sposito
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SCALE DEPENDENCE AND SCALE INVARIANCE IN HYDROLOGY

Whether processes in the natural world are dependent or independent of the scale at which they operate is one of the major issues in hydrologic science. In this volume, leading hydrologists present their views on the role of scale effects in hydrologic phenomena occurring in a range of field settings, from the land surface to deep fractured rock.

Self-contained and thought-provoking chapters cover both theoretical and applied hydrology. They provide critical insights into important topics such as general circulation models, floods, river networks, vadose-zone processes, groundwater transport, and fluid flow through fractured media. This book is intended as an accessible introduction for graduate students and researchers to some of the most significant questions and challenges that will face hydrologic science in the twenty-first century.

SCALE DEPENDENCE AND SCALE INVARIANCE IN HYDROLOGY

Edited by

GARRISON SPOSITO

University of California at Berkeley

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FOR JAMES J. MORGAN

And sensibly, though so much
later, the wandering Bloom
replied, "Ireland," said Bloom
"Iwas born here. Ireland."

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Preface

The reverse side also has a reverse side.
—sign on Telegraph Avenue (6.9.96)

In his Josiah Willard Gibbs Lecture[1] some years ago, the gifted theoretical physicist Elliott Montroll recounted a statistical analysis of the prices of merchandise offered in the Sears annual catalog during the first 85 years of the twentieth century. That catalog, which Montroll termed "a magnificent database of Americana," was prepared carefully to feature items that reflected current public taste at prices that were appropriate for competitive merchandising of the time. The price of an item that was sold by Sears over many years would, of course, be expected to change in the catalog as the cost of living changed, or as technology related to the manufacture of the item improved. Some catalog items (e.g., the buggy whips sold in the 1910 catalog) would disappear altogether and be replaced as new technologies made them obsolete.

Despite the many vicissitudes of American life and of company operation, Montroll found that the frequency distribution of the prices in any one of the Sears catalogs published since 1900 closely approximated a lognormal distribution. More remarkably, the single-catalog standard deviation of the logarithm of price remained essentially constant over the 85-year period, although the single-catalog mean of the logarithm of price generally increased annually, reflecting an increasing cost of living. Montroll was quick to point out that this observed constancy of the single-catalog standard deviation of log(price) was to be expected if price changes were primarily the results of inflation, for then the price of an item in a given catalog would differ only by a scale factor from its price in a previous catalog, and that factor would always drop out when the single-catalog standard deviation of log(price) was calculated. Thus the constancy of the latter statistic signaled the fact that the distribution of prices in the Sears catalogs was scale-invariant. Evidently, year after year, catalogs were created with the items in them priced so as to maintain constant the relative number of items

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available within any selected range of prices, provided only that this range was scaled annually for inflation.

No reader of the Montroll lecture can be left untouched by the evident simplicity and beauty of his analysis. Whatever may be the complexity of American socioeconomic behavior, or the vagaries in Sears merchandising activities, the catalog pricing structure that emerged exhibited an inherent symmetry that typified it profoundly: that of *scale invariance*. The search for scale invariance is, of course, not limited to economics. It has had a long and successful history in the engineering disciplines,[2] nucleated by a celebrated theorem of the soil physicist Edgar Buckingham.[3] It is also a flourishing industry within the earth sciences, particularly the geophysical branches. Stefan Machlup, in an entertaining reminiscence,[4] has described a number of temporal geophysical phenomena, ranging from the stages of rivers to the magnitudes of earthquakes, for which the frequency distribution is scale-invariant, or approximately so. He infers that these natural phenomena must be complex enough to possess "a large ensemble of mechanisms with no prejudice about scale." An important corollary he adds is that present human efforts to control them likely will eliminate part of this ensemble, thereby producing frequency distributions that do exhibit intrinsic scales.

Scale invariance in the spatial domain is now almost universally associated with fractal concepts that emerged 30 years ago when Benoit Mandelbrot[5] reinterpreted the exponent in the power-law relationship between coastline length and measuring increment that was discovered by the eccentric dilettante Lewis Fry Richardson,[6] who himself had been motivated by the notion that the extent of conflict between countries was positively correlated with the degree of irregularity in their common borders. Fractal geometry has since become the signature approach to both spatial-scale invariance and temporal-scale invariance, as epitomized by self-similarity in the patterns of hydrologic and other geophysical processes.[7]

This volume is a compendium of essays contributed by engineers and scientists who have spent much of their recent professional lives thinking about and investigating issues of scale dependence or scale invariance in terrestrial hydrologic phenomena. More precisely, as occurs in the more encompassing sister discipline of landscape ecology,[8] the fundamental question they have been asking is whether "a given phenomenon appears or applies across a broad range of scales, or whether it is limited to a narrow range of scales." Their research has thus been motivated by a desire for understanding and application, rooted in a common quest for simplicity in scientific explanation, and informed by successful insights communicated through three decades of intense study by physical scientists concerned with scale effects. What they have to say herein is not necessarily shared belief among their colleagues in hydrology, nor is it necessarily comprehensive in the sense of a normal review article. What they do have to impart to the reader is a considered distillate of their own professional experience, gained by grappling both experimentally and conceptually

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with scale issues as they arise in continental hydrologic processes. Whether the reader ultimately will find the result to be an engaging book of ideas or simply a volume that would be more aptly entitled (in the current spate of Austenmania) *Pride and Prejudice*, only time can resolve.

I am most grateful to my colleagues Roger Beckie, Vivek Kapoor, Peter Kitanidis, Keith Loague, Shlomo Neuman, Donald Nielsen, Jean-Yves Parlange, Andrea Rinaldo, Ignacio Rodríguez-Iturbe, Yoram Rubin, David Russo, Chin-Fu Tsang, and Eric Wood for their dedicated service as referees for the chapters of this book while in draft form. I am also much indebted to Catherine Flack for suggesting that I edit such a book, to Holly Johnson of the Cambridge University Press for superb management of all matters relating to the production of this book, and to my wife, Mary, for her continual encouragement and support, at all scales.

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