ADVANCING RIVER RESTORATION AND MANAGEMENT

SECOND EDITION

TOOLS IN FLUVIAL GEOMORPHOLOGY

EDITED BY

G. MATHIAS KONDOLF AND HERVÉ PIÉGAY

WILEY Blackwell

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Second Edition

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and

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Series Foreword

Advancing River Restoration and Management

The field of river restoration and management has evolved enormously in recent decades, driven largely by increased recognition of the ecological values, river functions and ecosystem services. Many conventional river management techniques, emphasizing strong structural controls, have proven difficult to maintain over time, resulting in sometimes spectacular failures, and often a degraded river environment. More sustainable results are likely from a holistic framework, which requires viewing the 'problem' at a larger catchment scale and involves the application of tools from diverse fields. Success often hinges on understanding the sometimes complex interactions among physical, ecological and social processes.

Thus, effective river restoration and management require nurturing the interdisciplinary conversation, testing and refining of our scientific theories, reducing uncertainties, designing future scenarios for evaluating the best options, and better understanding the divide between nature and culture that conditions human actions. It also implies that scientists should communicate better with managers and practitioners, so that new insights from research can guide management, and so that results from implemented projects can, in turn, inform research directions.

This series provides a forum for 'integrative sciences' to improve rivers. It highlights innovative approaches, from the underlying science, concepts, methodologies, new technologies and new practices, to help managers and scientists alike improve our understanding of river processes, and to inform our efforts to steward and restore our fluvial resources better for a more harmonious coexistence of humans with their fluvial environment.

G. Mathias Kondolf,
University of California, Berkeley

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Preface to the Second Edition

Since the publication of the first edition of *Tools in Fluvial Geomorphology* in 2003, the field has been in the course of a revolution sparked by the development of new tools such as improved remote sensing data, acoustic Doppler profilers and radiometric dating methods. The field has arguably entered a new era in knowledge production, the emergence of a second period of active quantification, likely to have similarly profound impacts as the quantitative revolution of the 1960s. While traditional cross-section surveys and bed material sampling still have their place, analysis of drone-based photogrammetry and GIS analysis of large data sets can yield insights that allow the researcher to see the 'forest' beyond the individual 'trees' knowable from field work at the reach scale.

Moreover, the role of fluvial geomorphology within society is changing, as geomorphologists are increasingly called upon to provide input into ecological assessments, sustainable management and restoration schemes. Sometimes, geomorphology is applied by non-geomorphologists, summarized to simple rules of thumbs, misused, and results misinterpreted. The discipline is fairly rich in terms of techniques available and conceptual background. Practitioners can benefit from a broader array of tools if they understand the full range of methods available and the context of their use in an integrative perspective.

By virtue of its position at the intersection of geography, geology, hydrology, river engineering and ecology, fluvial geomorphology is an inherently interdisciplinary field. The tools used reflect this diversity of backgrounds, with techniques borrowed from these different fields. This diversity is now compounded by the new tools available thanks to recent technological innovations, and by the new demands placed on the field. Thus, the need to update *Tools* to provide a reference work for scientists in allied fields, managers seeking guidance on what kind of geomorphic study is best suited to their needs and students seeking to make sense of the plethora of approaches coexisting within fluvial geomorphology. Geomorphic studies based on this large set of knowledge, and placed within an integrative and interdisciplinary perspective, are more likely to solve the often complex problems faced today.

Most of us are familiar and comfortable with a fairly narrow range of tools. Even if we are not 'one-trick ponies', if left to our own devices, we are still likely to fall back on a small set of more familiar methods of study. The problem is summed up in the popular expression, 'If your only tool is a hammer, every problem looks like a nail'. To enlarge our toolboxes, it can be helpful to have a reference that succinctly summarizes the techniques of specializations other than our own, to help understand the kinds of problems to which different methods are best adapted, and the advantages and disadvantages of each. That is the goal of this book. As we were frequently reminded by the late Reds Wolman, who contributed to the first edition and who provided much of the inspiration for both editions, '*Let the punishment fit the crime*'. That is, use a tool that is well adapted to the specific problem. This requires some understanding of the range of tools available to us, which this book attempts to convey.

We are indebted to our contributors, acknowledged experts in their specific fields, all of whom endeavoured to explain in plain English the workings and pros and cons of various methods in their fields. We thank them for their thoughtful contributions and hope that the book as a whole will encourage readers to expand horizons and integrate geomorphologists' knowledge and know-how in their practices.

Matt Kondolf
Hervé Piégay

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SECTION I

Background

CHAPTER 1

Tools in fluvial geomorphology: problem statement and recent practice

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Let the punishment fit the crime.

Popular saying invoked by the late M.G. Wolman during drafting of the first edition of *Tools in Fluvial Geomorphology* to capture the idea that the tools should be selected based on the problem to be solved.

1.1 Introduction

As noted by Wolman (1995), in his essay *Play: the handmaiden of work*, much geomorphological research is applied. The spatial and temporal scales of geomorphic analysis can provide insights for the management of risk from natural hazards, solving problems in river engineering (Giardino and Marston 1999) and river ecology (Brookes and Shields 1996), with recent developments in river restoration in terms of assessment, design and monitoring (Morandi *et al.* 2014). As do all scientists, fluvial geomorphologists employ tools in their research, but the range of tools is probably broader in this field than others because of its position at the intersection of geology, geography and river engineering, which draws upon fields such as hydrology, chemistry, physics, ecology and human and natural history. Increasingly, the tools of fluvial geomorphology have been adopted, used and sometimes modified by non-geomorphologists, such as scientists in allied fields seeking to incorporate geomorphic approaches in their work, managers who prescribe a specific tool be used in a given study, and consultants seeking to package geomorphology in an easy-to-swallow capsule for their clients.

Frequently, a lack of geomorphic perspective shows in the questions posed, which are often at spatial and temporal scales smaller than the underlying cause of the problem. For example, to address complaints about bank erosion problem, we have frequently seen costly structures built to alter flow patterns within the channel. Although the designers may have employed hydraulic formulae to design the structures, they may have neglected to look at geomorphic processes at the basin scale, even at reach scale, so that the driving factors are not well identified. Intervening on the symptoms rather than on the underlying disease itself is usually not the best option to solve problems. In such a case, controlling bank erosion through mechanical means will at best provide only temporary and local relief from a system-wide trend. Moreover, it is now well understood that bank erosion and deposition are essential processes to create the complex and diverse channel (Florsheim *et al.* 2008) and floodplain (Stanford *et al.* 2005) habitats needed by many valued species. Thus, what is seen locally as a problem by a riparian landowner may simply be part of the naturally dynamic river behaviour that supports river ecology, and if bank erosion has increased due to catchment-wide changes, even applying geomorphic tools at the site scale only will ultimately prove ineffective (or at least not sustainable) and ecologically detrimental, because the question was poorly posed at the outset without any robust diagnosis and geomorphic expertise based on the range of available tools.

The purpose of this book is to review the range of tools employed by geomorphologists and to link clearly the choice of tools to the question posed, thereby providing guidance to scientists in allied fields and to practitioners about the sorts of methods available to address questions in the field and the relative advantages and disadvantages of each. This book is the result of a collective effort, involving contributors with diverse ages, disciplinary expertise, professional experience and geographic origins to illustrate the range of tools in the field and their application to problems in other fields or management problems. This second edition has incorporated substantial updates, involving new authors with significant contributions to the field over the past decade.

Tools in Fluvial Geomorphology, Second Edition. Edited by G. Mathias Kondolf and Hervé Piégay.

1.2 Tools and fluvial geomorphology: the terms

Webster's Dictionary defines a tool as anything used for accomplishing a task or purpose (Random House 1996). By a tool, we refer comprehensively to concepts, theories, methods and techniques. The distinction among these terms is not always clear, depending on the level of thinking and abstraction. Moreover, definitions vary somewhat with dictionaries (e.g. Merriam 1959 versus Random House 1996) and definitions of one term may include the other terms. In our usage, a concept is defined as a mental representation of a reality and a theory is an explicit formulation of relationships among concepts. Both are tools because they provide the framework within which problems are approached and techniques and methods deployed. A method involves an approach, a set of steps taken to solve a problem and would often include more than one technique. As suggested by *Webster's Dictionary* (Random House 1996), it is an orderly procedure, or process, regular way or manner of doing something. Techniques are the most concrete and specific tools, referring to discrete actions that yield measurements, observations or analyses.

As an illustration, a researcher can base his approach on the fluvial system theory and, within this general framework, one of the field's seminal concepts, the notion of bankfull discharge as being the dominant/geomorphic discharge. To test the relation between bankfull discharge and dominant discharge, he can proceed step by step, identifying a general methodological protocol, first to determine what is the bankfull discharge, then its frequency. He may survey channel slope and cross-sectional geometry and measure water flow and velocity, or, if field measurements of flow were not possible, he might estimate flow characteristics from the surveyed geometry and hydraulic equations. In the general case, measuring flow in the field can be undertaken using several methods, such as applying a portable weir, salt dilution or current meter method, but the former are normally better suited for lower flows than the bankfull discharge being studied. The current meter method could be based on various techniques, such as those to measure flow depth and velocity (e.g. using Pryce AA or other current meters, wading with top-setting wading rods or suspending the meter from a cableway or bridge), mechanically improving the cross-section for measurement, accounting for flow angles and sources of turbulence when placing the current meter in the water and estimating the precision of the measurement. Also, given that channel capacity should be related to the long-term flow frequency (Wharton *et al.* 1989), the researcher would normally analyse long-term gauging data (if available for the river being studied), or synthesize from nearby gauges in the region.

Whereas some tools are specific to fluvial geomorphology, others are borrowed from sister disciplines and some (such as mathematical modelling, statistical analysis and inductive or hypothetico-deductive reasoning) are used by virtually all sciences (Bauer 1996; Osterkamp and Hupp 1996). Compared with many other disciplines, fluvial geomorphology has had a strong basis in field observation and measurement. Even with increased reliance on remote sensing and laboratory analysis, the field component is likely to remain critically important to fluvial geomorphology. In this book, our aim is not to describe generic tools, but to focus on tools currently used by fluvial geomorphologists.

We define fluvial geomorphology in its broadest sense, considering channel forms and processes and interactions among channel, floodplain, network and catchment. A catchment-scale perspective, at least at a network level, is needed to understand channel form and adjustments over time. Of particular relevance are links among various components of the fluvial system, controlling the transfer of water and sediment, states of equilibrium or disequilibrium, reflecting changes in climate, tectonic activity and human effects, over time-scales from Pleistocene (or earlier) to the present. Accordingly, to understand rivers can involve multiple questions and require the application of multiple methods and data sources. As a consequence, we consider fluvial geomorphology at different spatial and temporal scales, within a nested systems perspective (Schumm 1977). Analysis of fluvial geomorphology can involve the application of various approaches from reductionism to a holistic perspective, two extremes of a continuum of underlying scientific approach along which the scientist can choose tools according to the question posed.

1.3 What is a tool in fluvial geomorphology?

Roots and tools

Fluvial geomorphology being at the frontier of several disciplines, the choice of tools is fairly large and benefits from the multiple influences of the training of the investigators. The geologically trained fluvial geomorphologist may be more likely to apply tools such as new techniques of dating such as OSL (optical stimulated luminescence) or isotopes (U/Th isotopic ratios, ^{14}C, ^{137}Cs and ^{210}Pb) and techniques that provide subsurface information (e.g. ground-penetrating radar). By contrast, the investigator trained in river hydraulics and physics is more likely to apply tools such as numerical modelling, flume experiment and mechanics. Some geographers focus on spatial complexity, interactions of fluvial forms and processes according to the characters of the basin or bioclimatic regions within which they are observed, the influence of human activities, vegetation cover, or geological settings, employing tools such as remote sensing, GIS or statistics and field metrology.

Within fluvial geomorphology, different branches are also observed, with researchers tending to focus either on a historical perspective (palaeoenvironmental studies) or on processes (dynamic or functional geomorphology). Interactions with biology are reflected in the term *biogeomorphology* (Viles 1988; Gregory 1992) or *ecogeomorphology* (Frothingham *et al.* 2002;