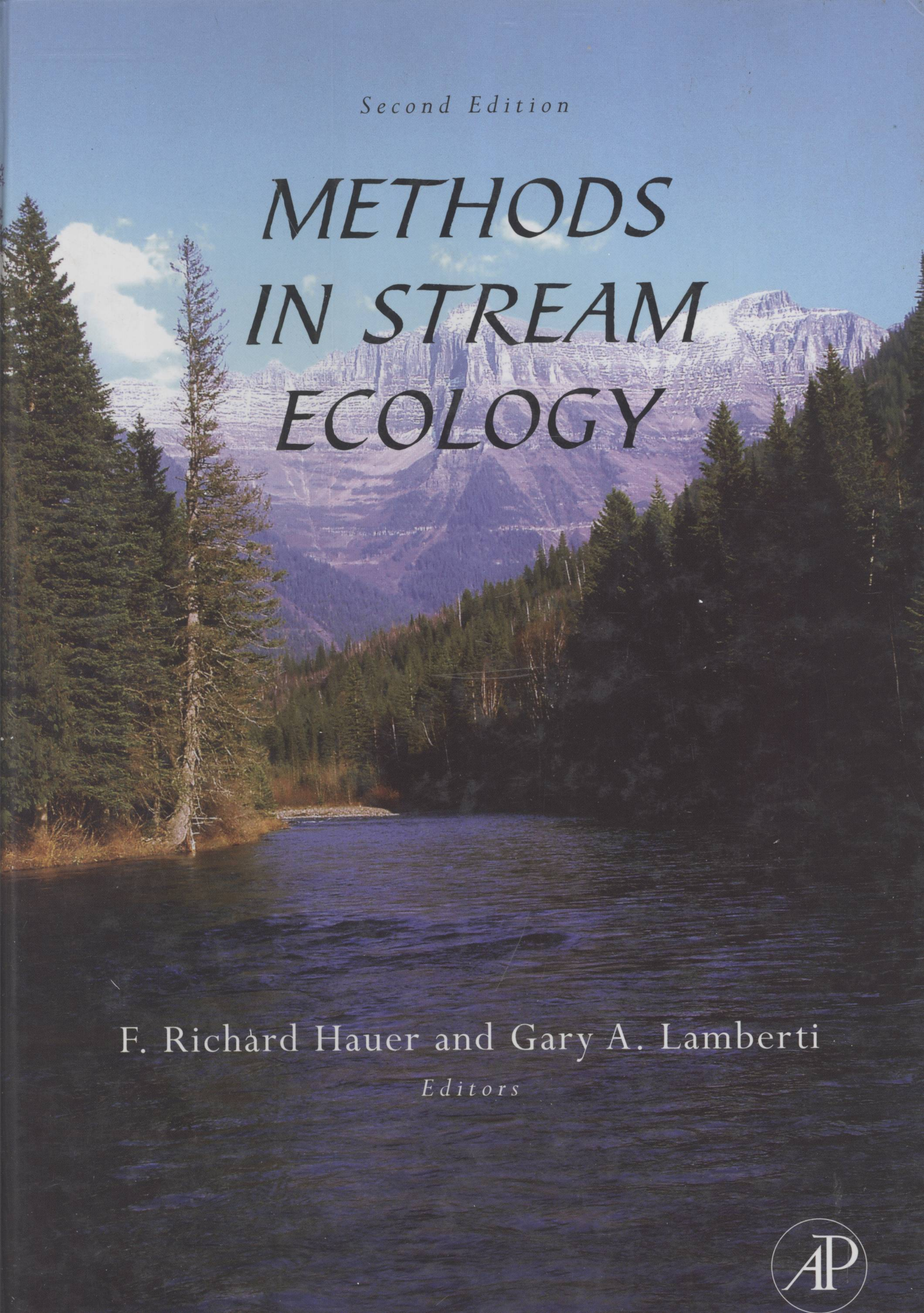

Second Edition

METHODS IN STREAM ECOLOGY

F. Richard Hauer and Gary A. Lamberti

Editors

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Second Edition

F. Richard Hauer and Gary A. Lamberti

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Methods in Stream Ecology

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Contributors

Numbers in the parentheses indicate the pages on which the authors' contributions begin

DONALD J. BAIRD (835) National Water Research Institute and Canadian Rivers Institute, Department of Biology, University of New Brunswick, Fredericton, NB, Canada E3B 6E1

DAVID J. BATES (79) FSCI Biological Consultants, Halfmoon Bay, BC, Canada V0N 1Y1

COLDEN V. BAXTER (119, 761) Department of Biological Sciences, Idaho State University, Pocatello, ID 83209

E. F. BENFIELD (711) Department of Biology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0406

ARTHUR C. BENKE (691) Department of Biological Sciences, University of Alabama, Tuscaloosa, AL 35487-0206

MELODY J. BERNOT (213) Department of Biological Sciences, Murray State University, Murray, KY 42071

PETER A. BISSON (23) Pacific Northwest Research Station, USDA Forest Service, Olympia, WA 98512-9193

THOMAS L. BOTT (663) Stroud Water Research Center, Avondale, PA 19311

WILLIAM B. BOWDEN (381) Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT 05405

JOHN M. BUFFINGTON (23) Rocky Mountain Research Station, USDA Forest Service, Boise, ID 83702

JAMES L. CARTER (805) United States Geological Survey, Menlo Park, CA 94025

CHELSEA L. CRENSHAW (761) Department of Biology, University of New Mexico, Albuquerque, NM 87131

JOSEPH M. CULP (835) National Water Research Institute and Canadian Rivers Institute, Department of Biology, University of New Brunswick, Fredericton, NB, Canada E3B 6E1

KENNETH W. CUMMINS (585) California Cooperative Fisheries Research Unit, Humboldt State University, Arcata, CA 95521

CLIFFORD N. DAHM (119) Department of Biology, University of New Mexico, Albuquerque, NM 87131

JACK W. FEMINELLA (537) Department of Biological Sciences, Auburn University, Auburn, AL 36849-5407

STUART FINDLAY (239) Institute of Ecosystem Studies, Millbrook, NY 12545

KENNETH FORTINO (637) Department of Biology, University of North Carolina at Greensboro, Greensboro, NC 27402

FRANCES P. GELWICK (611) Department of Wildlife and Fisheries Science, Texas A&M University, College Station, TX 77843-2258

JANICE M. GLIME (381) Department of Biological Sciences, Michigan Technological University, Houghton, MI 49931

JAMES A. GORE (51) Department of Environmental Science, Policy, and Geography, University of South Florida St. Petersburg, St. Petersburg, FL 33701

STANLEY V. GREGORY (273) Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331

NANCY B. GRIMM (761) School of Life Sciences, Arizona State University, Tempe, AZ 85287-4501

JACK W. GRUBAUGH (249) Department of Biology, University of Memphis, Memphis, TN 38152

VLADISLAV GULIS (311) Department of Biological Sciences, University of Alabama, Tuscaloosa, AL 35487-0206

MORGAN J. HANNAFORD (805) Department of Biology, Shasta College, Redding, CA 96049

F. RICHARD HAUER (103, 145, 435) Flathead Lake Biological Station, Division of Biological Sciences, University of Montana, Polson, MT 59860-9659

ANNE E. HERSHEY (637) Department of Biology, University of North Carolina at Greensboro, Greensboro, NC 27402

WALTER R. HILL (103) Illinois Natural History Survey, Champaign, IL 61820

ALEXANDER D. HURYN (691) Department of Biological Sciences, University of Alabama, Tuscaloosa, AL 35487-0206

JOHN J. HUTCHENS Jr., (249) Biology Department, Coastal Carolina University, Conway, SC 29528-6054

GINA D. LALIBERTE (327) Wisconsin Department of Natural Resources, Madison, WI 53716

GARY A. LAMBERTI (273, 357, 537) Department of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556-0369

PETER R. LEAVITT (357) Department of Biology, University of Regina, Regina, SK, Canada S4S 0A2

HIRAM W. LI (489) Oregon Cooperative Fish and Wildlife Research Unit, Oregon State University, Corvallis, OR 97331

JUDITH L. LI (489) Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331

MARK S. LORANG (145) Flathead Lake Biological Station, Division of Biological Sciences, University of Montana, Polson, MT 59860-9659

REX L. LOWE (327) Department of Biological Sciences, Bowling Green State University, Bowling Green, OH 43403

WILLIAM J. MATTHEWS (611) Department of Zoology, University of Oklahoma, Norman, OK 73019

RICHARD W. MERRITT (585) Departments of Entomology and Fisheries and Wildlife, Michigan State University, East Lansing, MI 48824

G. WAYNE MINSHALL (721) Stream Ecology Center, Department of Biological Sciences, Idaho State University, Pocatello, ID 83209-8007

DAVID R. MONTGOMERY (23) Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195

PATRICK J. MULHOLLAND (187) Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831-6036

MARILYN J. MYERS (805) U.S. Fish and Wildlife Service, Albuquerque, NM 87111

ROBERT W. NEWBURY (79) Canadian Rivers Institute, University of New Brunswick, Fredericton, NB, Canada E3B 5A3

MARGARET A. PALMER (415) Chesapeake Biological Laboratory, Center for Environmental Science, University of Maryland, Solomons, MD 20688

BARBARA L. PECKARSKY (561) Department of Zoology, University of Wisconsin, Madison, WI 53706

BRUCE J. PETERSON (637) The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543

CATHERINE M. PRINGLE (537, 743) Institute of Ecology, University of Georgia, Athens, GA 30602

VINCENT H. RESH (435, 805) Department of Environmental Science, Policy, and Management, University of California, Berkeley, CA 94720

TENNA RIIS (381) Department of Biological Sciences, University of Aarhus, Aarhus, Denmark

SCOTT L. ROLLINS (785) Department of Zoology, Center for Water Sciences, Michigan State University, East Lansing, MI 48824-1115

EMMA J. ROSI-MARSHALL (213) Departments of Biology and Natural Science, Loyola University Chicago, Chicago, IL 60626

AMANDA RUGENSKI (721) Stream Ecology Center, Department of Biological Sciences, Idaho State University, Pocatello, ID 83209-8007

SIMON D. RUNDLE (415) Marine Biology and Ecology Research Centre, Department of Biological Sciences, University of Plymouth, Plymouth PL4 8AA, UK

LEONARD A. SMOCK (465) Department of Biology, Virginia Commonwealth University, Richmond, VA 23284-2012

JACK A. STANFORD (3) Flathead Lake Biological Station, Division of Biological Sciences, University of Montana, Polson, MT 59860-9659

ALAN D. STEINMAN (187, 357) Annis Water Resources Institute, Grand Valley State University, Muskegon, MI 49441

R. JAN STEVENSON (785) Department of Zoology, Center for Water Sciences, Michigan State University, East Lansing, MI 48824-1115

DAVID L. STRAYER (415) Institute of Ecosystem Studies, Millbrook, NY 12545

KELLER F. SUBERKROPP (311) Department of Biological Sciences, University of Alabama, Tuscaloosa, AL 35487-0206

JENNIFER L. TANK (213) Department of Biological Sciences, University of Notre Dame, Notre Dame, IN 46556-0369

FRANK J. TRISKA (743) Water Resources Division, United States Geological Survey, Menlo Park, CA 94025

AMBER J. ULSETH (637) Department of Ecology and Evolutionary Biology, Cornell University, Ithaca, NY 14853

H. MAURICE VALETT (119, 169) Department of Biology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0406

J. BRUCE WALLACE (249) Institute of Ecology, University of Georgia, Athens, GA 30602-2603

AMELIA K. WARD (293) Department of Biological Sciences, University of Alabama, Tuscaloosa, AL 35487-0206

JACKSON R. WEBSTER (169) Department of Biology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0406

WILLIAM W. WOESSNER (119) Department of Geology, University of Montana, Missoula, MT 59812

Preface

When the first edition of *Methods in Stream Ecology* was published in 1996, we hoped that it would prove useful to practicing stream ecologists, and perhaps as a supplementary textbook for aquatic ecology courses. However, we and our contributing authors have been delighted that the book has been accepted worldwide as the basic text in stream ecology. The first edition served well for ten years as a reference for both instruction and research. However, as in any dynamic research area, the book was in need of modernization to keep pace with important methodological developments. Unlike the first edition, which stressed exercises that could generally be completed within a few hours or an afternoon of intensive field work, the second edition provides both classroom-style exercises and research-level methods appropriate for the most rigorous investigations.

As we pointed out in the first edition, perhaps no other area of aquatic ecology requires a more interdisciplinary approach than stream ecology. Geology, geomorphology, fluid mechanics, hydrology, biogeochemistry, nutrient dynamics, microbiology, botany, invertebrate zoology, fish biology, food web analysis, bioproduction, and biomonitoring are but a few of the disciplines from which stream ecology draws. The science of stream ecology continues to advance at a remarkably rapid rate, as evidenced by the virtual explosion of publications in stream ecological research during the past two decades. Along with the rapid increase in research activity, we have seen a commensurate increase in the teaching of stream ecology at the upper undergraduate and graduate levels at major colleges and universities. Likewise, scientists, government agencies, resource managers, and the general public have grown keenly aware of stream ecology as an integrative science that can help societies around the globe grapple with environmental degradation of their water resources. Indeed, streams and rivers are fundamental to the human existence, and many organizations and user groups have emerged globally to protect these unique habitats that are so vital to global biodiversity, complexity, and sustainability. We hope that this book will also be of value to these groups.

Stream ecology has experienced many areas of rapidly advancing research, methodologies, and coupled technologies. The serious student or researcher will find that all chapters have been substantially updated and several topics not covered in the first edition have been added with new chapters, notably fluvial geomorphology, nitrogen cycling, dissolved organic matter, fungi, bryophytes and macrophytes, algal biomonitoring, and ecotoxicology. The book continues to provide the most comprehensive and contemporary series of methods in stream ecology, which can be used for teaching or conducting research. We hope that the book will be valuable to both the stream ecology student and the most seasoned scientist. Resource managers employed in the private sector or by federal or state agencies should continue to find this book an indispensable reference for developing monitoring approaches or for evaluating the efficacy of their field and laboratory techniques.

This second edition covers important topics in stream ecology organized within six major sections: Physical Processes; Material Transport, Uptake, and Storage; Stream Biota; Community Interactions; Ecosystem Processes; and a new section on Ecosystem

Quality. Six new chapters have been added to the book, which now contains 36 chapters written by leading experts, and all existing chapters have been substantially revised and updated. Each chapter consists of (1) an Introduction, (2) a General Design section, (3) a Specific Methods section, (4) Questions for the student or researcher, (5) a list of necessary Materials and Supplies, and (6) relevant References. The Introduction provides background information and a literature review necessary to understand the principles of the topic. The General Design presents the conceptual approach and principles of the methods. The Specific Methods generally begin with relatively simple goals, objectives, and techniques and increase in the level of difficulty and sophistication; Basic Methods are suitable for the classroom, whereas Advanced Methods are applicable to high-end research projects. Each method is explained in step-by-step instructions for conducting either field or laboratory investigations. The methods presented are of research quality, and while it is not our intention to produce an exhaustive manual, we present rigorous methods that provide sound underpinnings for both instruction and research purposes. In each case, the methods presented are used frequently by the authors in their personal research or instruction. The Questions listed at the end of each chapter are formulated to encourage critical evaluation of the topic and the methods that were used to address a particular stream ecology issue. The comprehensive list of Materials and Supplies itemizes equipment, apparatus, and consumables necessary to conduct each method and is generally organized by each specific method to allow simple checklists to be made.

If this book is being used for course instruction, we recommend that instructors carefully consider the chapters and methods that they wish to use and plan carefully to budget the necessary time for setup, sampling, and analysis to complete individual or group research projects. Generally, classes should begin with Basic Methods and then delve more deeply into Advanced Methods as time and resources allow. We hope that all of the chapters will enrich the field of stream ecology as a rigorous scientific discipline. As before, we encourage the use of this second edition to assist in the formulation of exciting ecological questions and hypotheses and, to that end, the chapters present sound methods for discovery.

For course instruction, we recommend use of moderate-sized streams from 3 to 12 m wide that are easily waded. Smaller streams should be avoided by a large class, such as 10–20 students, because of the impacts incurred on a small environment. Large rivers are limiting to class instruction because of safety concerns and the inherent difficulties associated with sampling deep, flowing waters.

Reviewers and users of the first edition found this book to be particularly "user friendly." Once again, this was one of our primary goals. As in the first edition, we have attempted to present a book with a logical flow of topics and a uniform chapter format and style, an approach that our authors embraced and implemented. We deeply thank our contributing authors and co-authors from the first edition, who once again gave of themselves and their time for the benefit of our science. We also welcome the authors of the added chapters and likewise thank them for their remarkable efforts. All of them tolerated with (mostly) good humor the fits and starts that characterized the production of this second edition. Chapter reviews were mostly conducted by authors of other related chapters, but several external reviewers also provided us with helpful reviews: Dominic Chaloner, Dean DeNicola, Paul Frost, Brian Reid, Dave Richardson, and Don Uzarski. We are grateful for their assistance.

The inspiration for this book arose from our own research and teaching. Numerous colleagues and students also encouraged the preparation of this second edition, often with suggestions of new chapters or methods that were not treated in the first edition.

We are thankful for their input. Our graduate and undergraduate students continue to be a source of inspiration and encouragement to us even as this book has robbed from our time with them. Our own graduate and postdoctoral advisors (Jack, Art, Vince, and Stan) continue to support our endeavors even as they ruefully concede that "we have become them". We gratefully acknowledge the assistance and financial support of our outstanding home institutions, the University of Montana and the University of Notre Dame. The highly professional staff at Academic Press/Elsevier was a pleasure to work with during this project. Finally, and most importantly, we thank our families for their continued love and support. Our wives, Brenda Hauer and Donna Lamberti, and our children, Andy and Bethany Hauer and Matthew and Sara Lamberti, have energized and inspired us throughout this endeavor and we will be forever grateful to them.

F. Richard Hauer
Gary A. Lamberti

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Section A

Physical Processes

Landscapes and Riverscapes

Jack A. Stanford
Flathead Lake Biological Station
University of Montana

I. INTRODUCTION

Streams, rivers, and groundwater flow pathways are the plumbing of the continents. Water coalesces and flows downhill in surface channels and subsurface pathways in response to precipitation patterns and the dynamic form of river basins (*catchments*). Uplift of mountain ranges, caused by continental drift and volcanism, is continually countered by erosion and deposition (*sedimentation*) mediated by the forces of wind and water. Catchment landscapes are formed by the long geologic and biological history of the region as well as recent events such as floods, fires, and human-caused environmental disturbances (e.g., deforestation, dams, pollution, exotic species).

The term *landscape* is used extensively, referring generally to the collective attributes of local geography. An expansive view of a stream or river and its catchment, including natural and cultural attributes and interactions, is the "riverscape." For a stream ecologist, a riverscape view of a catchment (river) basin encompasses the entire stream network, including interconnection with groundwater flow pathways, embedded in its terrestrial setting and flowing from the highest elevation in the catchment to the ocean, with considerable animal and human modifications of flow paths likely along the way (Fausch *et al.* 2002). For example, the earth's largest catchment, the Amazon River basin, occupies over half of the South American continent. Headwaters flow from small catchments containing glaciers and snowfields over 4300 m above sea level on the spine of the Andes Mountains to feed the major tributaries. The tributary rivers converge to form the mainstem Amazon, which flows from the base of the Andes across a virtually flat plate covered by equatorial tropical forest to the Atlantic Ocean. The altitude change is less than 200 m over the nearly 3000 km length of the mainstem river from the base of the Andes to the ocean. Because of the enormous transport power of the massive water volume of the Amazon River, some channels are >100 m deep. In other places along the river corridor the channel is >5 km wide, relatively shallow, and filled by sediment deposition (*alluviation*). Flood waters spread out over huge and heavily vegetated floodplains that support a myriad of fishes and other animals (Day and Davies 1986).

The riverscape of the Amazon River, as among all rivers, was molded over time with the river cutting steep canyons through mountain ranges while building (*alluviating*) expansive floodplains where the slope of the river valley decreased. Rivers drain the continents; transport sediments, nutrients, and other materials from the highlands to the lowlands and oceans; and constantly modify the biophysical character of their catchment basins. These processes occur in direct relation to a particular catchment's global position, climate, orography, and biotic character, coupled with spatial variations in bedrock and other geomorphic features of the riverscape.

Within a catchment basin, stream channels usually grow in size and complexity in a downstream direction (Figure 1.1). The smallest or first-order stream channels in the network often begin as outflows from snowfields or springs below porous substrata forming ridges dividing one catchment from another. Two first-order streams coalesce to form a second-order channel and so on to create the network (Strahler 1963). A very large river, like the Amazon, often has several large tributaries, and each of those river tributaries may be fed by several to many smaller streams (Figure 1.1). Thus, each large catchment basin has many subcatchments.

Erosive power generally increases with stream size. Boulders, gravel, sand, and silt are transported from one reach of the stream network to the next in relation to discharge and valley geomorphometry (e.g., slope and relative resistance of substrata to erosion). Expansive deposition zones (floodplains) form between steep canyons, where downcutting predominates.

All rivers feature this basic theme of alternating cut and fill alluviation. Floodplains occur like beads on a string between gradient breaks or transitions in the altitudinal profile of the flow pathway (Leopold *et al.* 1964). Rivers of very old geologic age have exhausted much of their erosive power; mountains are rounded, valleys are broadly U-shaped, and river channels are single threads in the valley bottom with ancient, abandoned floodplains called terraces rising on either side. Whereas, in geologically young, recently uplifted catchments, stream power and associated erosive influence on valley form is great; mountains are steep-sided, valleys narrowly V-shaped, and the river spills out of many interconnected channels on alluvial floodplains in aggraded areas during flooding. Of course, no two rivers are exactly alike, but a general longitudinal (upstream to downstream) pattern of cut and fill alluviation usually exists (Figure 1.1A). Many small and usually erosive streams coalesce in the headwaters to form a main channel that grows in size and power with each primary tributary. The main channel alternately cuts through reaches constrained by bedrock canyons and spills water and sediments onto aggraded floodplain reaches where the river may be quite erosive (cutting) in one place and time and building sedimentary structures (filling) in another; thus, creating a suite of dynamic habitats for biota.

The riverscape at any point within the stream network is four-dimensional (Figure 1.1B). The river continuum or corridor from headwaters to ocean is the longitudinal (upstream to downstream) dimension. The second dimension is the transitional area from the river channel laterally into the terrestrial environment of the valley uplands (aquatic to terrestrial dimension). Except where rivers flow over impervious bedrock, some amount of porous alluvium is present within the channel owing to erosion at