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河流动力学与河流综合管理

River Dynamics and Integrated River Management

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内容简介

本书介绍有关河流动力学及河流综合管理的基本知识和新的研究方向。内容包括高含沙河流——中国黄河的现代和历史上的治理方略；河流生态与生态修复；水库、湿地及河口的管理方法和河流水质的检测、研究和管理，以及一些中国复杂环境下的独特问题。本书避免具体问题的详细数学描述，主要对河流研究的新思路、新概念和新技术进行综合介绍并提供很多研究实例，例如：河道阻力与河流稳定性之关系；河床结构与推移质运动的等价律；阶梯-深潭系统用于泥石防治和生态修复；生物栖息地的多样性与生物多样性的关系。书中一些新概念已经或者可能成为学科增长点，例如植被侵蚀动力学、流速极限定律、河流治理的基本方向以及泥沙概算方法等。

本书可用作研究生教材或相关科技工作者的参考书。

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河流动力学与河流综合管理

River Dynamics and Integrated River Management

Preface

In 1994, Dr. E. Plate and I initiated the Sino-German cooperation research on unsteady sediment transportation (known as GESINUS), which was supported by VW-Foundation and DFG of Germany and National Natural Science Foundation of China (NSFC). The bilateral cooperation achieved important results and shifted my main research interest from fluvial rivers to mountain rivers. The idea to study and write a book on integrated river management came to my mind when I found that the sedimentation problems in the lower reaches of rivers were essentially caused by riverbed incision in upstream reaches.

The writing of this book began in 1997 when Dr. G. Klaassen invited me to teach a short course in the IHE Delft with the main contents of the course focused on the Yellow River training and management and the Three Gorges Project on the Yangtze River in China. The notes from this short course have become the main contents of Chapters 6 and 7 of this book. In the same year I took part in a western China investigation organized by the Central Government, one of the themes was greening the mountains and hills and beautifying the landscape. To answer the question "if the bare hills in arid and semi-arid areas can be vegetated?" I studied the dynamic relations among vegetation development, soil erosion, and various stresses on the vegetation and established the theory and model of vegetation-erosion dynamics, which has become the main contents of Chapter 2. During the process of developing the model a discussion with Dr. J. B. Thornes was very constructive.

To study riverbed incision and control strategies my research group established field experimental stations on the Xiaojiang River in Yunnan, Mianyuan River in Sichuan, and East River in Guangdong. The results from the field investigations and field experiments at these sites have become the main contents of Chapter 3. I began to study debris flow in 1984 and visited the Dongchuan Debris Flow Observation and Research Station every year, where I witnessed debris flows. Dr. Z. Kang worked in the station for 20 years and was among my research partners. The great Wenchuan Earthquake occurred on May 12, 2008 and rekindled my research interest in landslides and debris flows. My research group studied landslides, avalanches, and debris flows in the earthquake area in the period 2008-2010, during which Dr. P. Cui supported us with valuable ideas and convenient access to data. The results from these studies enriched the contents of Chapter 4.

The main concepts of sediment transportation and fluvial processes in Chapter 5 are from Dr. Ning Chien. It was under the guidance of Dr. Ning Chien that I started my research in the field of sedimentation, especially hyperconcentrated flows. I worked with him for seven years with sincere and deeply friendly feelings. I was deeply saddened when he passed away in 1986. I here express a few words of both my grief and fond memories of my dearest professor.

I have collaborated with Dr. J.H.W. Lee on several research projects since 1999. We studied river ecology and the eutrophication and algal blooms in the Bohai Sea and Hong Kong waters. The discussion between us on various issues on the river management, especially deltaic and coastal processes, elicited valuable ideas for integrated river management. Dr. Lee contributed Chapter 8, which makes the book more complete.

Dr. Ben Yen, Dr. Tai Wai Soong, Dr. C. S. Melching, and I initiated Sino-U.S. cooperation on environmental sediment research in 1999. During my visits to the U.S. I contacted the Federal Interagency Stream Restoration Working Group and discussed stream restoration with various members of this group. The discussion was very constructive for writing Chapter 10. Since then my research team began to study aquatic ecology. In 2003, I was granted a research project from the Ministry of Science and Technology to study the ecology of Yangtze River, and in 2007 I was granted a research project from the NSFC to

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study benthic invertebrates. The research results from these projects have become the main contents of Chapter 10.

Dr. C. S. Melching made great contributions to this book. He has visited China and collaborated with my research group every year since 2004. We worked together on sediment transportation, aquatic ecology, and water quality and published quite a few papers. Dr. Melching gave me valuable ideas for stream ecology and contributed Chapter 9. Moreover, he polished the English of all chapters several times. It is due to his efforts the English of book is at the international standard.

In the period from 2005 to 2010 my research group conducted several experiments on the Diaoga River and the Jiangjia Ravine in Yunnan, and the Mianyuan River in Sichuan and performed field investigations and measurement in the Yalutsangbu, Yellow, East, and Songhua rivers to search for methods of integrated river management for geological hazard mitigation, erosion and sedimentation control, and ecological restoration. Both theoretical and technical results were obtained and they have become the main contents of Chapter 11.

The style of the book is such that it should readily useable as a textbook for graduate students and also as a reference book for scientists and engineers. There were several versions of the book beginning from 2003, which were printed at Tsinghua University as a textbook for graduate and Ph.D. students. The main contents of the book were also used as a textbook at the University of Hongkong, IHE Delft, Bari University, and UNESCO training courses organized by the International Research and Training Center on Erosion and Sedimentation. I have been working as the Chief Editor of the International Journal of Sediment Research since 1996 and an Associate Editor of the International Journal of River Basin Management (IAHR). The experience of journal editor helped me to access new research results, which was helpful for completion of the book. Finally, it is a pleasant duty to express thanks to all my immediate collaborators over the years, who have contributed in different ways to the creation of this book.

Zhao-Yin Wang
May 2014, Beijing

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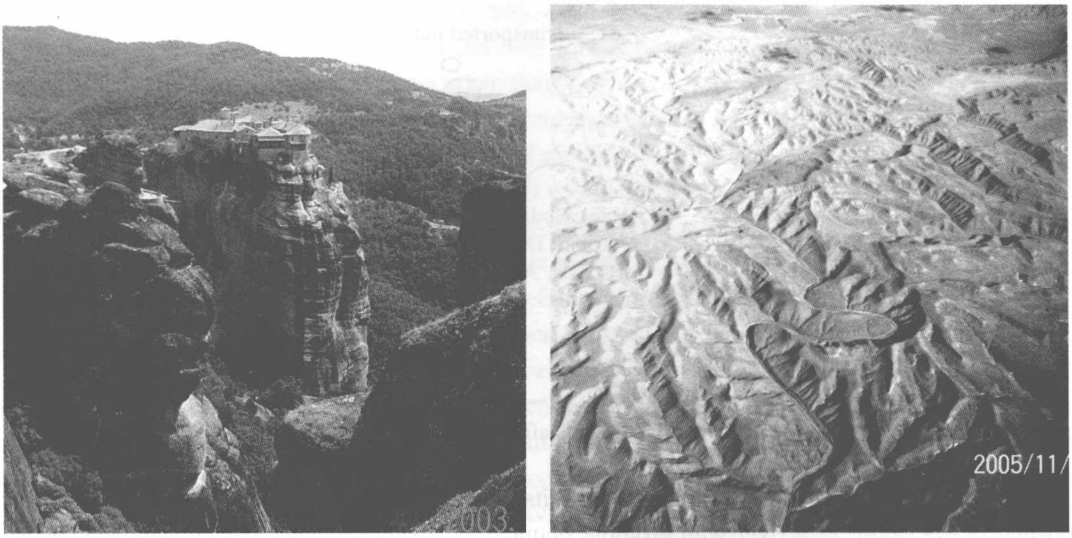
Introduction

All land is part of a watershed or river basin and the water, which flows over it and through it, shapes all landscapes. Figure 1 shows the landscape sculptured by erosion in Greece and the very dry land in Egypt. Indeed, rivers are such an integral part of the land that in many places it would be as appropriate to talk of riverscapes as it would be of landscapes. Rivers are much more than merely water flowing to the sea. Rivers carry downhill not just water, but just as importantly sediments, dissolved minerals, the nutrient-rich detritus of plants and animals. Their ever-shifting beds and banks and the groundwater below are all integral parts of rivers. Even the meadows, forests, marshes and backwaters of floodplains can be seen as part of the rivers—and the rivers as part of them.



(a) (b)

Fig. 1 (a) The landscape sculptured by erosion in Greece; and (b) River flow is the main force for development of geomorphology even in the very dry Egypt

The main **functions of rivers** are draining floods, supplying drinking water, maintaining ecology, irrigating farmland, transporting sediment, supplying power, providing habitat for fishes, assimilating wastewater, and providing navigation. Humans exploit the resources of rivers by constructing dams and water-diverting channels, developing navigation channels, and harvesting fishes, which result in changes in the river hydrology, runoff, sediment transport, riparian and stream habitats, and water quality.

Watersheds start at mountain peaks and hilltops. Snowmelt and rainfall wash over and through the high ground into rivulets, which drain into fast-flowing mountain streams. As the streams descend, tributaries and groundwater add to their volume and they become rivers. As they leave the mountains, rivers slow and start to meander and braid, seeking the path of least resistance across widening valleys with alluvial floors laid by millennia of sediment-laden floods. Eventually rivers will flow into a lake or ocean. Where the river carries a heavy sediment load and the land is flat, the alluvial sediments may form a delta. Estuaries, the places where the fresh water of rivers mixes with the ocean's salt water, are among the most biologically productive parts of rivers and of seas. Most of the world's fish catch comes from species that are dependent for at least part of their lifecycle on a nutrient-rich estuarine habitat.

Figure 2 shows the components of a river system, materials transported and the aspects affected by the rivers and transported materials. Rivers can be recognized as mountain rivers, alluvial rivers, and estuaries. A **mountain river** is the most upstream part of the river, including the river source and the upstream tributaries of the river, where the river system flows through mountainous areas and the flow is confined by mountains. Usually the channel bed of a mountain river is composed of gravel. Mountain rivers receive most of the sediment, nutrient-rich detritus of plants and animals, dissolved materials, and usually more than half of the water. For a large river the upstream reaches compose the input-part of the river and are closely affected by the watershed or drainage area. Erosion control and vegetation development are the most challenging tasks for researchers and watershed managers. Erosion induced landslides and debris flows are disastrous in the upstream reaches. Mountain rivers are quite often incised rivers and degradation of the channel bed causes many problems. Therefore, erosion control and vegetation development over the watershed, landslides and debris flows, and control of channel bed incision are major topics of mountain river studies.

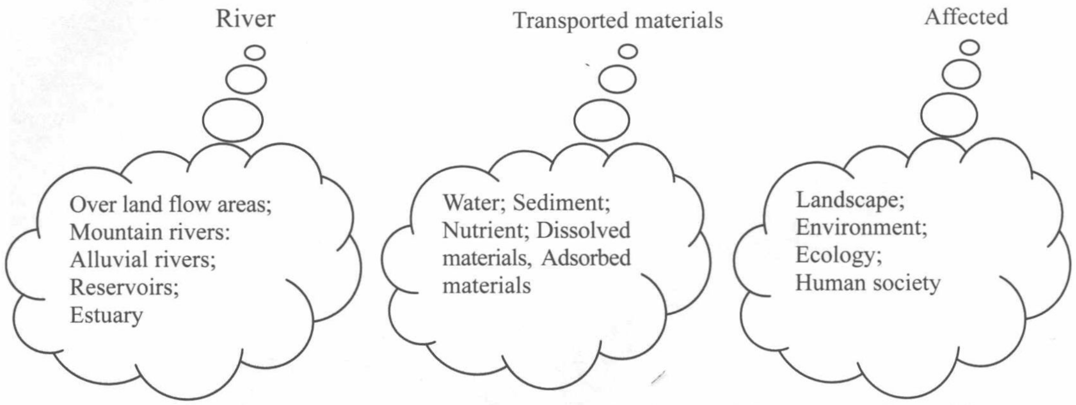


Fig. 2 River system, transported materials, and aspects affected by rivers and the transported materials

An **alluvial river** is defined as a river with its boundary composed of the sediment previously deposited in the valley, or a river with erodible boundaries flowing in self-formed channels. Over time the stream builds its channel with sediment it carries and continuously reshapes its cross section to obtain depths of flow and channel slopes that generate the sediment-transport capacity needed to maintain the stream channel. Alluvial rivers are mostly perennial streams and the channel bed is composed mainly of sand and silt. A large river usually originates from mountains and flows over floodplains before it pours into the ocean, therefore, it is a mountain river in its upper reaches and an alluvial river in its lower reaches. Many alluvial rivers are large rivers or flat-land sections of large rivers, such as the lower reaches of the Yellow River and the middle and lower reaches of the Yangtze River. These alluvial rivers are confined within the valley defined by human constructed or artificially reinforced levees. The river morphology and river patterns depend mainly on the sediment transportation and deposition. Rivers are the main source of water resources for agriculture, urban use, and industry. River floods are major natural disasters accounting for 1/3 of the total loss due to natural hazards. The quality of river water is important for human health. Flood and sediment transportation are natural processes in these rivers and water diversion, channelization, and navigation are human disturbance to the rivers. Thus, sediment transportation, water resources development and flood defense are the most important issues in the alluvial river management.

The **estuary** is the connection part of a river with the water body (lake, sea, or ocean) into which it flows, including the river mouth, a river section affected by the tide, and the water body area affected by the river flow. Sediment is deposited for land creation and very often a delta develops in the area. In recent years, the need for sustainable development of coastal cities and marine resources has given rise to challenging environmental problems. Examples include the environmental impact assessment of dredging and sludge/spoil dumping and the transport and transformation of nutrients and heavy metals at the sediment-water interface. Urban development including large-scale land reclamation and population growth induced increase in sewage discharge puts the estuary ecosystem under stress. Red Tide is a phenomenon in which the seawater is discolored by high algal biomass. Some algal species produce potent toxins, which accumulate in shellfish that feed on those algae, resulting in poisoning in human consumers. There has been a significant expansion of red tide episodes and impacts throughout the world over the last several decades. Very unusual red tides have occurred in the Bohai, East China, and south China seas in the past decades. Delta and coastal processes, eutrophication, and algal blooms are the major challenges for the management of estuaries.

A variety of **river-uses** was the driving force of societal development in the past and now is even more important in economic and cultural development. Rivers, and the rich variety of plants and animals which they sustain, provided hunter-gatherer societies with water for drinking and washing, and with food, drugs and medicines, dyes, fibers, and wood. Farmers reap similar benefits as well as, where needed, irrigation for their crops. For pastoral societies, who graze their herds over wide areas of often parched plains and mountains, perennial vegetation along the banks of rivers provides life-sustaining food and fodder during dry seasons and droughts. Towns and cities use and misuse rivers to carry away their wastes. Rivers also served as roadways for commerce, exploration, and conquest. The role of rivers as the sustainers of life and fertility is reflected in the myths and beliefs of a multitude of cultures.

Many countries have taken an increasing interest in **river dynamics and integrated river management** coordinating various sectors of river issues. A developing country, like China, now strongly emphasizes the goal of flood control, water resources development, and protecting environment in addition to reducing poverty by supporting efficient and sustainable development of agriculture and light industries. Water is acknowledged to have a significant impact on the economic development potential of individuals, through agriculture, water supply and sanitation, public health, power generation, flood mitigation, etc. In addition, water sustains ecological systems, which also have economic value, and in turn generate a healthy hydraulic system. Poor people can improve their welfare by having access to water. In turn, people who are wealthier and better educated are better able under stress conditions to make cautious use of water, thus, not pre-empting the next generation from having similar benefits from the same water system.

Integrated river management aims at reconciling the provision of safety to the people dwelling by the river and sustainable use of the land and water. It also aims at making water use economically productive, socially equitable, and environmentally sustainable. These goals can be achieved in principle in many ways, but the fact that the water system is characterized by important externalities and unusually high transaction costs (as compared to the power sector, for instance) limits the options for workable institutional arrangements. It is attractive to concentrate on a hydrographically coherent region such as a river basin, catchment, or drainage or *polder* area, as all key actors and all decision-making can be brought under one purview.

Where water users have managed to put their common long-term interest ahead of their desire for quick personal gain, and, thus, engaged in collective action, 'catchment based' water management has been practiced in many places around the world. For integrated river management, one has to understand the whole river system very well, including all issues of a river, and all aspects of the natural and human-impacted system and their interconnections.

In China, there are more than 50,000 rivers each with a catchment area larger than 100 km^2, including more than 1,500 rivers with a catchment area larger than 1,000 km^2. Most of the rivers are located in the eastern and southern parts of the country. The seven most important rivers are the Songhua, Liaohe, Haihe, Yellow, Huaihe, Yangtze, and Pearl Rivers.

Chapter 1 of this book summarizes the basic concepts and major issues of river management in China, providing a base for the book. Chapter 2 discuss erosion, vegetation and presents the vegetation-erosion dynamics model. Chapter 3 describes the phenomena and impacts of channel bed incision, with emphasis on management strategies for mountain rivers. Chapter 4 discusses landslide and debris flow and related management strategies. Chapter 5 provides a conceptual framework of alluvial rivers, including sediment transportation and fluvial processes. Chapter 6 describes flood defense and fluvial river management strategies with the Yellow River as an example. Chapter 7 discusses the impacts of impoundments on rivers, including dam construction and dam removal, sedimentation and strategies. The Three Gorges Project on the Yangtze River is discussed in detail as an example. Chapter 8 presents the issues, laws and management strategies of estuaries. Chapter 9 presents the basic knowledge of water quality management. Chapter 10 introduces the main theories of river ecology and methods of ecological assessment and restoration. Chapter 11 presents new theories and practices of integrated river training and management, including the principles of river training, methods of sediment budget, artificial step-pool system for incision and debris flow control and ecological improvement.

Readers may learn the basic knowledge of all aspects of rivers from this book, which pays no attention to the mathematical details of technical description but focuses on comprehensive and modern concepts and new methods of river management. Researchers may also obtain inspiration from the discussions such as the relation between resistance and channel stability, ecological functions of step-pool system, the relation between the habitat diversity and biodiversity, and vegetation-erosion dynamics. These discussions and many new concepts may shed light on the study of river dynamics and management.

1 Basic Concepts and Management Issues of Rivers

Abstract
Basic concepts are introduced in this chapter to help the readers understand the contents of the other chapters in this book. The water cycle and modes of stream network development, Horton's laws, sediment and sediment load, and various river patterns are defined and presented. Concepts of the water environment and stream ecology are briefly introduced. The major river management issues, such as water resources management, flood defense, reservoir management, river bed incision and geological disasters, erosion control, and river uses are also discussed.
Key words
Water cycle, Stream order, Sediment load, River patterns, Ecology, Management issues

1.1 Basic Concepts

1.1.1 Hydrological Cycle

Precipitation is the water falling over the land from the atmosphere primarily in the form of rain and snow. Precipitation can return to the atmosphere; move into the soil; or run off the earth's surface into a stream, lake, wetland, or other water body. More than half of the precipitation falling over the land of China evaporates to the atmosphere rather than being discharged as stream flow to the oceans. This "short-circuiting" of the hydrologic cycle occurs because of the two processes, interception and transpiration. A portion of precipitation never reaches the ground because it is intercepted by vegetation and other natural and constructed surfaces. The amount of water intercepted in this manner is determined by the amount of interception storage available on the above-ground surfaces.

Transpiration is the diffusion of water vapor from plant leaves to the atmosphere. Unlike intercepted water, which originates from precipitation, transpired water originates from water taken in by the roots of plants. **Evaporation of soil moisture** is, however, a much slower process due to the capillary and osmotic forces that keep the moisture in the soil and the fact that vapor must diffuse upward through soil pores to reach surface air at a lower vapor pressure. When calculating the hydrologic budget of a watershed the transpiration from vegetation and the evaporation from the soil typically are considered together as evapotranspiration.

Infiltration—Close examination of the soil surface reveals millions of particles of sand, silt, and clay separated by channels of different sizes. These macropores include cracks, "pipes" left by decayed roots and wormholes, and pore spaces between lumps and particles of soil. Water is drawn into the pores by gravity and capillary action. Gravity is the dominant force for water moving into the largest openings, such as worm or root holes. Capillary action is the dominant force for water moving into soils with very fine pores. Infiltration is the term used to describe the movement of water into soil pores. The infiltration rate is the amount of water that soaks into soil over a given length of time. The maximum rate at which water infiltrates into a soil is known as the soil's **infiltration capacity**.

Ground water—The size and quantity of pore openings also determines the movement of water within the soil profile. Gravity causes water to move vertically downward. This movement occurs easily through larger pores. As pores reduce in size capillary forces eventually take over and cause water to move in any direction. Water will continue to move downward until it reaches an area completely saturated with water, the phreatic zone or zone of saturation. The top of the phreatic zone defines the **ground water table or phreatic surface**. In mountainous area the channels are incised very deep and lower than the phreatic

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