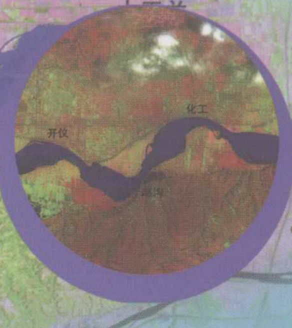
水科学前沿学术丛书

Remote Sensing Monitoring Technology for River Regime of Yellow River Downstream

黄河下游河势遥感监测技术研究

◎ 刘学工 张艳宁 韩琳 佘红伟 著



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内 容 提 要

本书共有12章，介绍了黄河下游水沙、工程及河势关系等水业务知识，阐述了河势监测要素及遥感监测作业流程；讨论了河道水域、水域边线、河道主溜（线）等关键要素的检测技术和方法；介绍了畸型河湾平面扭曲变形监测及河湾法向角概念，探讨了藕节河道变化定量分析方法以及河段河相监测和河段冲淤变化监测中遥感信息与水文观测信息结合应用的尝试。

本书可供水利行业遥感应用人员参考，也可作为相关专业硕士研究生参考用书。

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序

黄河水少沙多、水沙关系不协调，致使下游河床淤积升高，河道游荡摆动，河势变化剧烈，洪水期极易发生“横河”、“斜河”，冲毁滩区耕地和村庄，如果河道主溜直冲大堤，可能造成堤防决口，给下游人民生命财产安全带来巨大威胁。及时准确地获取河势变化信息，为黄河防洪安全提供决策依据，是下游河势监测的主要任务，同时，河势监测信息也是下游河道工程规划设计和下游河势演变规律研究的基础资料。

自20世纪末，在黄河尝试利用遥感技术进行下游河势监测，遥感以其宏观性强、获取信息快、不受现场条件限制等特点，在下游河势监测中发挥了重要作用。特别是近几年来，黄河遥感从业技术人员，在下游河势监测生产实践过程中，进行了大量的探索和实验，取得了可喜的进展。

《黄河下游河势遥感监测技术研究》一书结合黄河下游河势监测生产实践，系统地总结了近几年黄河下游卫星遥感河势监测的技术成果。本书作者以黄河下游水沙、工程、河势之间相互关系为切入点，系统分析、归纳了河势监测的基本要素，提出了河势遥感监测作业流程，讨论了河道主槽、水域、水边线、主溜线、心滩、汊流、串沟等动态变化要素的监测方法，并对黄河下游畸型河弯、藕节河道、河段河相等遥感监测方法进行了有益探索，其成果对促进遥感技术在黄河下游河势监测中的进一步应用研究具有很好的参考价值。

河道主溜线描述了河道中含沙量最高、流速最大、水深最深、动量最大的水流位置和流向，主溜线综合反映了河道主溜变化趋势，是河势图的灵魂，主溜线监测是河势监测的关键所在。由于河道主溜遥感成像机制复杂，河道主溜

线遥感识别困难很大，主溜线识别技术的应用研究尚处于起步阶段。本书深入分析了河道主溜的表象特征、主溜的光谱特征，阐述了可见光影像和 SAR 影像的主溜线检测方法，这在国内外河势监测中尚属首次，为河道主溜线遥感监测技术的进一步深入研究奠定了基础。

河势遥感监测的目的在于利用遥感影像监测河势变化，期待通过系统、长期、连续的遥感监测，早日提出信息丰富的河势变化分析成果；期待通过持续深入的应用研究，促进黄河下游河势演变规律研究取得重大突破。

2011 年 6 月　于北京

前　言

河道水流的平面形态及发展变化趋势称为河势，河势演变过程是河道水流平面形态的变化过程，是来水来沙条件与河床边界条件相互作用、相互影响的结果。黄河，世界泥沙之最的河流，下游河床不断淤积抬升，河道水流剧烈游荡，造就了黄河独特的河势变化现象。水流塑造河槽、河槽约束水流。不同来水来沙条件的组合，塑造出不同的河槽形态和比降，边界条件的改变反过来影响河道的排洪输沙，黄河下游河势就这样处于不休止的变化过程中。

黄河下游水少沙多、水沙关系不协调，致使黄河下游河道游荡摆动，河床淤积升高，河势变化剧烈，洪水时极易发生“横河”、“斜河”，冲毁滩区耕地和村庄；如果洪水直冲临黄大堤，可能造成黄河堤防决口，严重威胁下游人民生命财产安全。河势变化信息历来是黄河下游防洪决策的重要依据之一。

河势监测的目的是及时为黄河防洪决策提供河势变化信息，防患于未然，减少灾害损失，同时，为分析研究河势演变规律和工程规划设计提供基础资料。河势监测的主要任务是进行河床平面形态、水流状态的观测。目前，每年汛前汛后采用乘船沿河人工查河的方式，根据经验和手持仪器观测河道主溜，在 1:5 万河道地形图上徒手勾绘主溜线，绘制河势图。每次查河动用大量的人力物力，耗费十多天。洪水期间由于河中行船安全问题，只能在险工岸边人工观测局部河道水流情况，结合汛前河势查勘的河势图，推测洪水期间的河势变化趋势，由此获得的河势信息具有很大局限性。

近年来，随着遥感技术的发展及其在水利行业的广泛应用，利用遥感监测河势已经成为必然的趋势。遥感以其宏观性强、获取信息快、不受现场条件限制等特点，在黄河下游河势监测中发挥了重要作用。根据近几年的工作情况分析，河势遥感监测过程主要包括：遥感图像采集、遥感图像预处理、河势信息解译、河势遥感监测制图、河势综合分析和河势监测报告编制等环节。其中，河势信息解译是关键环节，也是最为复杂和困难的环节。

河势信息解译过程也就是由遥感图像解译河势要素的过程，通过对几年来河势监测情况分析，考虑到防洪实际需求，河势遥感监测要素可归纳为动态跟踪、固定边界、特定河段三大类监测要素：（1）动态跟踪监测要素，主要包括河道主槽、水域、水边线、河道主溜、汊流、串沟和心滩等，随来水来沙条件变化而变化，是河势变化的重要信息；（2）固定边界监测要素，主要包括险工、河道控导工程、护滩工程、节点及天然边界（如天然山弯、胶泥嘴）等，以及河道内阻水物和过河建筑物（如铁桥、公路桥和浮桥）等，这些要素是较长期内固定不变的边界条件，一般每年监测一次；（3）特定河段监测要素，主要是特定河段中关键内容的监测，通常包括畸湾河段监测、藕节河段监测、河段河相监测、河段冲淤分析监测等。其中，河道水域、水边线、河道主溜等要素动态描述了河道水流的变化情况，尤其是反映河道主溜的主溜线，可称为是河势图的精髓，是掌握河势动态变化的关键。动态跟踪监测要素和特定河段监测要素是本书讨论的重点内容。

河道主溜是河道水流中流速最大、流动态势凶猛的水流带，反映了河道水流中最大动量所在的位置。在防洪工作中，常常用主溜带中心线表示主溜位置，这条主溜带中心线称为主溜线。由于河道主溜遥感成像机理非常复杂，主溜线遥感

监测技术需要更多相关人员持续进行深入研究，需要随着遥感技术的发展在长期的河势遥感监测实践中不断发展和完善。目前开展的“黄河防汛科技项目——基于多源遥感数据黄河下游河道主溜线解译技术应用研究（合同编号：2006I01，该项目由黄河水利委员会信息中心与西北工业大学计算机学院合作承担）”和“国家人事部2007年度留学人员科技活动择优资助项目——黄河下游河道主溜线遥感影像自动解译技术应用研究”及“高等学校科技创新工程重大项目培育资金项目——黄河自然灾害信息监测与预警网络系统（项目号708085）”项目取得的阶段性研究成果，在河势遥感监测中得到了初步应用。

在特定河段监测中，畸湾河段河势变化监测是一项重要内容。畸型河湾是多沙河流普遍存在的现象，是河道形态与来水来沙过程不相适应、河床平面形态自动调整过程中形成的中间产物。黄河下游畸型河湾对河势产生极大影响，往往造成工程脱河或半脱河现象发生，常常导致横河、斜河现象出现，严重威胁堤防安全。遥感监测表明，在畸型河湾发生、发展、消亡、再生过程中，河湾扭曲变形的程度决定了畸型河湾的演变过程。然而，在目前的河湾研究中，尚无河湾几何扭曲变形的研究成果。在黄河下游的畸湾监测研究中，首次引进了河湾法向角的概念，用于定量描述畸型河湾扭曲变形的程度，并对法向角在畸湾演变中的敏感性进行了定量分析。河湾法向角概念的引进将为研究畸型河湾演变规律提供新的思路。

在藕节河段遥感监测中，利用遥感技术的优势对黄河下游藕节型河道进行整体监测、定量分析，将促进藕节河段河势变化规律分析研究的进展。黄河下游铁谢—高村河段多处河道外形如粗茎细节相间的藕枝，河道宽浅，江心沙洲众多，

水流十分散乱，河势复杂。利用2002～2008年河势遥感图像，对花园镇一赵沟河段藕节形态河道特征进行分析，探索了藕节型河段河势变化分析的新方法。

在河段河相遥感监测中，河相反映了在一定来水来沙和河床边界条件下的河床形态，通过监测河相系数可简明地定量描述河道冲淤平衡状态的程度，在实际的应用中，由于常规观测资料所限，常常用断面河相系数来描述河道特性，受到了很大的局限。黄河下游河势遥感监测中，提出了基于遥感图像的河段河相系数概念，结合水文资料推求河段平均水面宽、河段平均水深，进行河段河相系数的分析研究取得了可喜的进展。

河道冲淤变化是导致河势变化的主要内在原因之一。河段冲淤分析遥感监测的基本思路是采集洪水期间某个时刻河流平面形态的遥感影像，并收集此时刻水位流量的观测数据，分析建立此时刻河道水位流量与河道平面形态的关系，对比以往不同时刻的相关关系，即可得知该河段河道的冲淤变化程度。此方法为洪水期间分析河段冲淤变化和河势变化提供了一条新的途径。

多年来通过遥感监测工作的实践深深体会到，当今遥感技术迅猛发展，国家资金投入逐年大幅度提高，各级领导十分重视遥感应用，然而，眼下的某些工作中往往看着遥感的优势，却难以发挥切实的作用，分析其原因主要是“最后一公里”现象所限，为了解决此类问题，国家层面正在倡导“遥感业务化”，促进遥感应用的快速发展。遥感在面对众多的业务应用领域时，并非“拿来”就能用，需要遥感从业人员面对特定的业务应用问题，踏踏实实地做具体的业务应用研究，使遥感技术尽快转化成为生产力。本书所讨论的动态跟踪监测要素技术是遥感图像解译洪水信息方面的应用研究，尤其是河道主溜解译研究进展，将在河势遥感监测方面打

通这“最后一公里”的距离。书中关于特定河段监测要素的讨论，主要是探索遥感信息与常规的水文观测信息如何结合，寻找解决实际问题的新途径，从而进一步拓展遥感信息的用途。

本书在结构上大致可分为四个单元：第一章至第三章为第一单元，介绍了黄河下游河势特性及监测要素等业务基础知识，概述了下游河势遥感监测流程及三类河势要素的监测内容，并针对河势监测实际讨论了图像增强处理方法；第四章至第七章为第二单元，介绍了水域、水边线及河道主溜等动态跟踪监测要素的监测技术，重点讨论了河道主溜光谱特性以及利用多光谱图像和SAR图像进行河道主溜线监测的方法和技术；第八章至第十一章为第三单元，重点讨论了畸型河湾、藕节河道、河段河相、河段冲淤等特定河段监测方法和技术；第十二章为第四单元，介绍了河道主溜线监测软件并给出了应用举例。其中，第二单元和第三单元是本书的重点。

本书由刘学工和张艳宁教授主笔。第一章由李旭东、刘学工编写；第二章由刘学工、韩琳编写；第三章由韩琳编写；第四章由张艳宁、佘红伟编写（其中第二节由刘学工编写）；第五章由韩琳、吴岩编写；第六章由张艳宁、佘红伟编写（其中第四节由韩琳编写）；第七章由张艳宁、李映、佘红伟编写；第八章由韩琳、刘学工、李旭东编写；第九章由韩琳、李旭东编写；第十章、第十一章由刘学工、李旭东编写；第十二章由张艳宁、佘红伟、段锋编写。其中：韩琳编写了约 9 万字、佘红伟编写了约 5.5 万字、李旭东编写了约 5.5 万字。

在本书编写过程中，得到中国科学研究院遥感应用研究所副所长王晋年博士的大力帮助和鼓励；在河势知识方面得到黄河水利委员会科技委副主任胡一三教

授的指导；在多年工作中得到黄河水利委员会防汛办公室张金良、王震宇、毕东升、李跃伦、张永、孙振谦、周景芍等多位专家教授的大力支持，得到刘贵芝、王德甫、宋志学等退休老专家的指导，在此表示衷心的感谢。

在本书编写过程中，黄河水利委员会信息中心遥感处的同仁做了大量的数据处理工作、西北工业大学计算机学院的师生给予多方帮助、黄河花园口水文站职工为观测研究数据付出了辛勤的劳动，在此一并表示衷心的感谢。

本书每章后已经尽可能列出了书中引用的论文著作，谨向原著作者表示感谢，如有疏漏，敬请原著作者谅解并联系补正；本书编写过程时间仓促，同时，由于水平所限，错漏之处在所难免，敬请读者批评指正。

作者

2011年5月于郑州

Preface

River regime refers to the plane form and development variation trend of river course flow. River regime evolution process is the plane form variation process of river course flow, and is also the inter-acted and inter-affected results from both inflow and in-sediment conditions and riverbed boundary conditions. The Yellow River, known as the top of sediment-laden rivers in the world, has a continuous deposition-induced riverbed rise and a great river course flow wandering in the downstream, resulting in the unique Yellow River regime variation phenomenon. Flow creates river channel while river channel restricts flow. Combination of various inflow and in-sediment conditions creates various channel forms and gradients, and change of boundary conditions affects flood and sediment discharge in river channel consequently. The downstream Yellow River regime is in such an endless variation process.

The Yellow River has less water and more sediment in the downstream, and the inharmonious water-sediment relationship leads to the wandering of river course, disposition-induced riverbed rise, and great river regime variation in the downstream. Such phenomenon as “transverse river reach” or “deflective river reach” is apt to appear at flood time with great potential, destroying farmland and villages in flood plain in the downstream. In case that flood strikes directly upon the Yellow River embankment, inrush will probably occur, which will drive the life and property of the downstream people into great danger. Therefore, information about river regime variation has always been one of the important basises for Yellow River downstream flood control decision.

River regime monitoring aims at providing information about river regime variation for the Yellow River flood control decision timely, preventing disaster in advance for the purpose of lessening loss, and providing basic information for river evolution rule study and engineering planning and design as well. The main task of river regime monitoring is to conduct observation of riverbed plane form and flow form. At present, river regime monitoring is conducted before and after flood each year in the way of inspecting river form by staff along river in boat, observing main current in river course based on previous experiences and in-hand observation instrument, drafting main current line manually on river course topography in scale of 1:50000, and producing river regime map. A great deal of people and materials as well as more than ten days are required for each inspecting. During flood, for the safety of boating in the river, observation of local river course flow form can conducted by staff only on the bank of vulnerable sections, and river regime variation trend during flood can be speculated with reference to the river regime map coming from inspecting which is conducted before flood. It can be seen that the river regime information obtained in this way is of great limitation.

In recent years, with remote sensing technology development and its broad application in water conservancy field, monitoring river regime with remote sensing technology has become an inevitable trend. Due to the characteristics of powerful macroproperty, quick information obtaining, non-restricted site condition, etc., remote sensing technology has played an important role in Yellow River downstream ministering. Analyzing the work of the recent years finds that process of remote sensing of river regime mainly includes acquisition of remote sensing image, pre-processing of remote sensing image, interpretation of river regime information, drafting river regime map by remote sensing monitoring, comprehensive analysis of river regime, preparation of river regime monitoring report, etc., in which interpretation of river regime information is the key link and also the most complicated and difficult link.

The process of river regime interpretation is the process of interpreting river regime factor with remote sensing image. Based on the analysis of river regime monitoring in the recent years and with consideration of actual requirements for flood control, the remote sensing monitoring factors of river regime can be summed up as 3 major monitoring factors, namely, dynamic tracking, fixed boundary, and specific river reach.

(1) Monitoring factor for dynamic tracking mainly includes main channel of river course, water area, water margin line, main current in river course, braded flow, chute, and sand bar, etc. They change with the change of inflow and in-sediment conditions, and are the important information about river regime variation. (2) Monitoring factor for fixed boundary mainly includes vulnerable sections, river course control works, flood plain protection works, nodes and natural boundary (e.g. natural mountain bend, and bend with fine sediment), etc., and water retaining structures and over-river structures (e.g. bridges, floating bridges), etc. They are the fixed and certain boundary conditions in long term which shall generally be monitored once a year. (3) Monitoring factor for specific river reach mainly refers to the monitoring of key items in specific river reach, generally including monitoring of unusual-shaped reach, lotusroot-shaped reach, and river facies of river reach, river reach scouring-deposition analysis and monitoring, as well as bankful flow analysis (uncondcted yet), etc., in which water area of river course, water margin line, main current in river course and some other factors describe the variation of river course flow dynamically, especially reflecting main current line of river course main current, they can be deemed as the essentiality of river regime map and are

the key factors to know and control dynamic river regime variation. Monitoring factor for dynamic tracking and monitoring of specific river reach are the key items discussed in this book.

Main current of river course is the flow belt with maximum flow velocity and strong flowing form in the river course flow, reflecting the location where the maximum momentum in river course flow exists. In flood control, centerline of main current belt is often adopted to indicate the main current location, and the centerline of the main current belt is named as main current line. Because remote sensing imaging mechanism for main current of river course is very complicated, further continuous study on remote sensing monitoring technology for main current line shall be conducted by more related people, and the technology shall be continuously developed and improved through long-term practice of river course remote monitoring. At present, intermediate results have come from 2 projects, namely, Yellow River Flood Control Science and Technology Project—Study on Main Current Line Interpretation Technology for Yellow River Downstream River Course Based on Multi-sources Remote Sensing Data (Contract No. 2006I01. The Project is implemented jointly by Information Center of Yellow River Conservancy Commission (referred as YREC hereinafter)and Computer Science and Technology School of Northwestern Polytechnical University), and Returned Student Science and Technical Activity Project Financed by China Human Resource Department in 2007—Automatic Interpretation Technology Application of Main Current Remote Sensing Image for Yellow River Downstream River Course. The results have been preliminarily applied in remote sensing monitoring of river regime.

In specific river reach monitoring, river regime variation monitoring of unusual-shaped bend reach is an important item. The unusual-shaped bend is a common phenomenon in sediment-laden river, and it is a result from unharmony between river form and inflow and in-sediment process and from automatic adjustment process of riverbed plane form. Unusual-shaped bend in Yellow River Downstream has great impact on river regime, and it often leads engineering works away or half-away from the river, and creates transverse river reach and deflective river reach, greatly endangering the embankment. Remote sensing monitoring shows that during generating, progressing, vanishing, and regenerating of unusual-shaped bend, the degree of twisting-induced bend deformation governs the unusual-shaped bend evolution process. However, in the present bend study, result on twisting-induced bend geometry deformation has not been obtained yet. In the study on Yellow River downstream unusual-shaped bend monitoring, for the first time, the concept of bend normal angle is adopted to quantitively describe twisting-induced deformation degree of unusual-shaped bend and to quantitively analyze the normal angle sensitivity in unusual-shaped bend evolution. The application of bend normal angle concept will provide new thought for study on unusual-shaped bend evolution rules.

In lotusroot-shaped reach monitoring, the advantages of remote sensing technology are adopted to conduct integrated monitoring and quantitive analysis to lotusroot-shaped river course in the Yellow River downstream, and the technology will promote analysis and study on river regime variation rules of lotusroot-shaped reach. In Tiexie-Gaocun reach in the Yellow River downstream, there exist many lotusroot-shaped reaches in various widths, with wide and shallow river courses, many islands, quite dispersive current, and complicated river regime. The remote sensing monitoring images for 2002 - 2008 river regime map are adopted to analyze the characteristics of lotusroot-shaped reach from Huayuan Township to Zhaogou, and new analysis method for river regime variation of lotusroot-shaped reach is developed.

In remote sensing monitoring of river facies of river reach, river facies reflect the riverbed configuration under the conditions of a certain inflow and in-sediment and riverbed boundary. The monitoring of river facies coefficient can briefly describe scoring-deposition balance degree of river course quantitively. In actual application, due to limited routine monitoring information, river facies coefficient of cross-section is often adopted to describe characteristics of river course, leading to great limitation. In remote sensing monitoring of Yellow River downstream, the conception of river facies coefficient for river reach based on remote sensing image is proposed to speculate the average water surface width and average water depth of the river reach with reference to hydrologic information, and the analysis and study on river facies coefficient of river reach have a remarkable progress.

Scouring-deposition-induced river course variation is one of the internal reasons for river regime variation. The basic thought for analyzing and remote sensing monitoring of scouring-deposition river reach is to acquisition the remote sensing image of river flow plane form of a certain time during a flood, collect observation data about level and discharge at this time, analyze and establish the level and discharge relationship of river course and plane form of river course at this time, and the comparison of previous relevant relationships at various times can lead to the knowledge of river course scouring-deposition variation degree of the river reach. This method provides a new approach for analyzing scouring-deposition variation and river regime variation of river reach during flood.

The deep impression resulted from practice of remote sensing monitoring for many years is that the present remote sensing technology is in a rapid progress. The State

Government has been increasing fund input into this aspect year by year, and great attention has been paid to remote sensing application. However, the advantage of remote sensing technology is obvious in some work while difficulty for actual application still exists. The main reason for the difficulty comes from the phenomenon of "the last kilometer". To solve such problem, the State Government is proposing "popularizing remote sensing as business" and promoting quick progress in remote sensing application. When remote sensing technology is facing multiple aspects of application business, "bring-in" of the technology does not mean effective application. For the purpose of the effective application, remote sensing personnel shall carry out careful and specific business application study on specific business application problem to transmute the technology into the productive forces as soon as possible. The technology of monitoring factor for dynamic tracking discussed in this book is an application study on interpreting flood information with remote sensing image, especially the study on interpreting the main current of river course will solve the problems referred to as "the last kilometer" in remote sensing monitoring of river regime. The discussion on monitoring factor for specific river reach in this book is to explore the way for combining remote sensing information and routine hydrologic information, find a new approach for solving the actual problem, and further extend the application of remote sensing information.

This book is in 4 units for documentation structure. Unit 1 includes Chapter 1, Chapter 2 and Chapter 3. In Unit 1, the basic knowledge of river regime characteristics and monitoring factors and other business for Yellow River downstream is introduced, remote sensing monitoring procedures and monitoring items for Type III downstream river reach factor are briefly described, and processing method of image enhancing is discussed for monitoring practice of river regime. Unit 2 includes Chapter 4, Chapter 5, Chapter 6 and Chapter 7. In Unit 2, monitoring technology for dynamic tracking monitoring factor is introduced, such as water area, water margin line, main current in river course, etc., and specific characters of main current spectrum of river course and method and technology to monitor main current line of river course with application of multi-spectrum image and SAR image are discuses. Unit 3 includes Chapter 8, Chapter 9, Chapter 10 and Chapter 11. In Unit 3, monitoring method and technology for specific river reaches are discussed, such as unusual-shaped bend, lotusroot-shaped reach, river facies of river reach, river reach scouring-deposition, etc. Unit 4 includes Chapter 12. In Unit 4, software for monitoring main current in river course is explained with examples from application. Unit 2 and unit 3 are the focuses of this book.

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Articles and works cited in this book have been attached to each chapter as much as possible. The authors would like to thank the authors of the cited articles and works, and show apology in case of the missed attachment. Advices from readers are expected.

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