水文信息技术与水库水资源模型研究

HYDROLOGY INFORMATION TECHNOLOGY AND WATER RESOURCES MODELS FOR RESERVOIRS

周振民
Zhenmin Zhou

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内容提要

本书包括两部分。第一部分包括降雨资料采集、河道流量测验和流量过程线分析、水文演算、降雨径流分析和设计洪水研究等。第二部分为水库设计和运行方案研究，首先研究了水库的供水功能，接着研究了水库的防洪和发电功能，最后将这三种功能熔于一个单一水库确定性模型。还研究了水库的多目标功能。对于一个新建或已建水库来说，分别用确定性和随机模型研究了供水、防洪、发电之间的水资源优化分配问题。本书全稿用英语完成，可作为水利类大学生和研究生双语教学的教材，对工程技术人员和研究人员也有很重要的参考价值。

本书是本人在米兰理工大学留学时，在导师 RENZZO ROSSO 教授指导下完成的英文稿。河南省水文水资源局王有振教授级高工、华北水利水电学院孟闻远教授、张丽、李秀芹、韩福乐副教授参加了本书的编著工作，参加本书编著的还有河南省建筑职工大学徐苏容、华北水利水电学院刘月、张世宝老师。本书全稿经英国爱丁堡大学博士、华北水利水电学院特聘专家 MARTIN. PARKES 教授审阅。梁士奎、吴昊、杨明庆、王铁虎、王贵彬、刘获、张晓丹同志参加了书稿校对工作，在此表示感谢。

作者

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作　　者：周振民　著
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序

为适应我国改革开放的形势、培养学生的对外交往能力，在当前高等院校的教学改革中，正在推广综合汉语和外语的双语教学工作。鉴于我国水情的特殊情况，水利专业的双语教学常常遇到的困难之一是难寻适当的教材。

为使水利专业的学生在学习专业知识的同时，又能提高专业外语的水平，周振民教授花费了多年心血，用英语编写了《Hydrology Information Technology and Water Resources Models for Reservoirs》一书。周教授曾经在水利部农田灌溉研究所、黄河水利委员会、以及水利部工作过，并且经过深造，取得了博士学位，具有丰富的实践经验和深厚的理论基础；又在国外留学多年，较好的完成了博士后研究课题，有着良好的英语造诣，他所编写的这本书具有以下特色：

1. 内容系统性强，适合我国水情，其承前启后性可以自然融入我国高等学校水利专业的课程体系中；

2. 既介绍了关于水文学的基本知识，又深入浅出地介绍了作者的最新科研成果；

3. 本书的内容既严谨地说明了原理，又结合实例介绍了具体的分析和计算方法，因而易于在工程实践中应用；

4. 书中各篇章的语言合乎英语语法和习惯表达方式，专业单词引用正确标准，语法现象和短语丰富，有利于学生提高外语水平。

总之，本书是一本不可多得的精品教科书，完全适用于水利专业的本科及研究生双语教学，也可以供水利科学研究人员、工程技术人员参考。

赵中极教授

高等学校水利学科教学指导委员会副主任委员

2004 年 12 月

ABSTRACT

The plan of this book covers two parts. The first part includes Chapter 1,2,3,4 5, and 6 in which hydrology information collection on precipitation, stream flow measurement and stream flow hydrograph, hydrology routing, rainfall – runoff relations and design flood have been studied. In Part Ⅱ, we begin with relatively established technology (models) for the design or operation of the surface water reservoir. The presentation will be by function, beginning with water supply proceeding to flood control, and then hydropower. These three functions will be integrated in a model of a single reservoir operating in a deterministic environment. In this part of the book, irrigation as well as its in – stream releases will be added to the list of functions. Through most of the discussion, it will be assumed that a division or allocation of reservoir services between these functions has already taken place.

Finally, we have shown how, in both a deterministic and random environment, to allocate services between functions for new and existing reservoirs that provide water supply, flood control, and hydropower. It is in Chapter 12 that we encounter the critical need for a new model of a water supply reservoir, a model that can in an efficient fashion ensure the reliability of the water supply function. Such a model is created and demonstrated in chapter 13. In Chapters 14 and 15, the new model is folded into the allocation and reallocation of reservoir services.

It is suggested that the fist part be used as a double language learning material for university students and graduated students. The second part may be as a reference for graduated students, senior engineers and researchers in the field of hydrology and water resources. I am sure that the practicing engineers, senior professionals, researchers and university students (including graduated students) who deal with hydrology and water resources should benefit from this book both in their language learning and their professional studies.

Zhenmin Zhou

24, Nov. 2004

Preface

In preparing this book the aim has been to provide an understanding of the theory and application of water resources measurement and optimization in reservoir. The past few decades have been vast developments in the technology of water resources, usable hydrology, stochastic processes, probabilistic methods, system engineering and decision analysis, most of which are aimed at conjunctive use of new theory and practice. New techniques have been developed and propounded in books and an increasing number of journals in the pure and applied sciences, but the complexity of the subject matter has encouraged authors to adopt styles which do not aid assimilation by the majority of potential users.

At the present time, there is a necessity for improved techniques to tackle the uncertainties and random effects, which pervade water resources design and planning. Knowledge about the mechanics of atmospheric processes, oceanic temperatures and other factors influencing climate is often inadequate. The same may be said about the land phase of the hydrological cycle. The practitioner cannot wait until mathematicians, climatologists and physicists solve the problems of engineering relevance. This book is designed to bridge the gulf that exists between the academic and the technologist and serves to introduce some useful techniques that may aid the design of water resources systems.

It is thought that the treatment in this book will be valuable to advanced students and practicing engineers. Prior requirements are an understanding of basic statistical theory and methods, and a background of elementary calculus and matrix algebra. Researchers, in particular, should benefit from the comprehensive reviews given here. It should also appeal to statisticians interested in practical applications.

Serious notice has been taken of the opinions of university students; in recent years they have had to cope with original sections of the text in the form of lecture notes. It is utmost useful for them to try to read and use directly the foreign press of scientific and technical books as well as magazines and other forms of articles to facilitate their advanced knowledge. This book may be extremely helpful for those who want to raise their special knowledge as they are learning English.

The fundamental components that make up surface water systems include not only reservoirs, but their withdrawal structures and spillways as well as associated pipelines, irrigation channels, and hydropower units, components that reflect the multiple functions of the reservoirs. These functions include water supply for municipal and industrial use, irrigation, flood control, recreation, hydropower, and flow maintenance for navigation or aquatic life. All these functions will be modeled in this book although water supply, flood control, and hydropower are emphasized.

The reservoir takes different structural forms depending on its design functions. If the reservoir is used only for flood control, it can be almost as simple in design as a bathtub, with a single, limited size, un - adjustable outlet structure as well as a spillway. Alternatively, the reservoir can deliver water through multiple hydropower units or through complex units such as a submerged tower with inlet ports at multiple levels of the reservoir. Such a tower might be used to mix water for temperature control or ever oxygen control.

The reservoir will be an impoundment created by either an earth dam or a concrete dam for our purposes. It will have a spillway to get rid of excessively high and unexpected flows—if it should become absolutely necessary to do so. And it will have one or more outlet structures, at least one of which discharges water to the stream below the reservoir, possible through gates, or through a turbine - generator.

The water discharged to the stream may be a planned release to the stream to maintain desired aquatic life or navigational flows, or the discharge may be used later for water supply withdrawal. Alternatively, this water released to the stream may be "wasted" from the reservoir through its gates to keep the reservoir sufficiently empty to prevent use of the spillway. Since most spillways are never tested (for fear of their destruction), this latter practice is only common sense. If the water used for water supply or irrigation is not drawn from the stream but from the reservoir, a separate structure will provide the means of withdrawal. The structure might be a submerged port connected to a pipeline that directs water to municipal and industrial use.

This basic reservoir structure provides the flexibility needed to begin to model the arrival of water at the reservoir, its storage in the reservoir, and its dispatch to various uses. Alternatively, this template of uses can be used to model the design process that determines a required reservoir capacity.

Therefore, The contents that we focus on in this book fall in two categories: (1) basic theory of hydrology engineering and hydrologic information collection, (2) deterministic and stochastic water resources models for reservoirs. The simplest of the deterministic models are the linear programming models that choose optimal releases or capacities and simulation models that experiment with various releases and capacities. Both model types deal with known inflows to the reservoir. Interestingly, the stochastic form we investigate in Chapter 12 reduces to the linear programming model as well.

Indeed, we are fortunate that many of the hydrologic optimization models that have been built fall naturally in the category of linear programming or into categories strongly related to linear programming. We are fortunate because these optimization models are the simplest to explain and the simplest to solve. We unapologetically emphasize linear programming models in this book because of the ease of problem statement and ease of solution, The analyst does not need to write a computer code for the solution of any particular linear programming model; multiple, easy – to – use solvers adaptable to all linear programming problems are already available in the marketplace. Further, solutions obtained are optimal to the problems at hand. Alternatives derived under multiple objectives can be generated easily. Finally, a linear programming problem statement is as much an explanatory device as it is a means of solution.

Zhenmin Zhou

24, Nov. 2004.

致谢

著书有各种理由，其目的各不相同。本书是1998～2000年本人在意大利米兰理工大学留学时，在RENZO·ROSSO教授的指导下所做的部分研究工作。RENZO·ROSSO教授是米兰理工大学的学科带头人。在赴意大利留学之前，一个问题一直在我的脑海中盘旋，即如何在中国大学生学习专业课的同时，使他们的外语水平有所提高，既如何以最有效的方式开展双语教学。我很快认识到，由于许多基础性的问题没有得到解决，开展双语教学工作尚有一定的困难。为了制定水利类专业双语教学计划，首先需要对许多基本水文水资源问题进行研究，其中包括水文信息技术和水资源数学模型问题的研究。ROSSO教授也认识到了这一点，他鼓励我开展这方面的研究工作，他从各方面给予我极大的支持，其中包括语言锤炼，数学问题研究以及充分给了我尽可能多地自由时间，让我集中精力来克服研究中的许多困难。在此，对于他的鼓励和支持，表示衷心地感谢。

如果说本书对于中国学生在双语学习和水文水资源专业技术学习有一定帮助的话，还要归功于我在米兰理工大学学习期间水文水资源界的许多同行们给予我的许多鼓励和支持。米兰理工大学有许多思想丰富、智慧非凡的同事们，他们十分乐意将他们在水资源研究领域以及双语教学方面的理论成果和实践经验与我一道分享。这里尤其要提及的是MARCO和MICHELE教授，他们都是米兰理工大学的骄傲。还有CHIARA教学秘书，她是米兰理工大学最优秀的教学秘书。同他们一起探讨当今社会面临的水资源问题以及如何提高工作效率和取得有用的研究成果，真是一大乐事。米兰理工大学是一所勇于创新和实践的始终站在学术前沿阵地的且人才层出不穷的大学，正是由于有一批像ROSSO、MARCO教授和CHIARA教学秘书这样的杰出的研究人员，使得米兰理工大学自1863年成立以来，取得了许多丰硕的成果，为意大利、欧洲以及世界的经济技术发展作出了卓越的贡献。

在此，还要感谢我国内的朋友，没有他们的鼓励，他们十分诚恳的建议，本人是难以较好地完成本书编著工作的。十分感谢英国爱丁堡大学博士、华北水利水电学院特聘外籍专家MARTIN. PARKES教授，感谢他对本书作了全文阅读审查，并提出了许多宝贵的意见。华北水利水电学院原副院长赵中极教授对本书做了审查，并提出了建设性意见。本书的出版得到了华北水利水电学院水文水资源学科的大力支持，在此对于多年来给予我学术上关心和帮助的老师、朋友一并表示感谢。作者对于书中的不足、遗漏、甚至错误负完全的责任。

周振民

2004年11月23日

ACKNOWLEDGMENTS

Books come about for numerous reasons: each has its own story of motivation. This book is a part of the research program I undertook in 1999 as a post – doctor student at the POLITECNICO DI MILANO (MILAN UNIVERSITY OF SCIENCE AND TECHNOLOGY) in Italy under the guidance of Prof. Renzo. Rosso, who heads the academic Policy and Special Studies Division of POLITECNICO. Before came in Italy I had been thinking, all the time in my mind, an urgent task that how to improve university language teaching efficiency at the same time when the Chinese students study their professional knowledge, which may be called at the present "double language teaching". I soon realized that the process was made especially difficult by the presence of a number of problems that remained unsolved in the general sense, and that in order to make progress on the scheme, I first needed to make progress on reexamining some fundamental water resources problems. Prof. Rosso realized this and let me proceed with the tasks, as I perceived it. I am enormously grateful to him for encouraging me to tackle these problems and for giving me the freedom to concentrate my efforts on them.

If this book proves to be all enduring contribution to water resources management and double language learning for Chinese students, it will in no small measure be due to the support and encouragement that I received at the POLITECNICO in the field of Water Resources. I had numerous thoughtful and congenial colleagues with whom I was able to work and who were willing to share their expert knowledge on the conceptual and practical issues that confront water resources decision makers as well as double language teaching. I would particularly like to note the intellectual contributions of Prof. Marco. and Michele. Who are leading research fellowships in POLITECNICO and Chiara who is the best secretary of the POLITECNICO. It was a pleasure to participate with them in an exploration of ideas on the problems of water resources management confronting society today and how to get the high working efficiency. The POLITECNICO is the university that the regularly transforms concepts to practice, and it is a tribute to the academic leadership of such individuals as Prof. Rosso and Marco that POLITECNICO has become a leadership in implementing the best innovations in water resources and environmental management in Europe as well as in the world.

Appreciation must be expressed here for who, by their encouragement, constructive criticisms and advice in my home country, have helped in the preparation of this book. Thanks are due to those who provided the data. The author accepts full responsibility for any omissions, shortcomings or mistakes that may remain.

Zhenmin Zhou

24, Nov. 2004

CONTENT

PART I

HYDROLOGY ELEMENTS MEASUREMENT AND CALCULATION

Part I of the book, consisting of Chapter 1 through 6, considers the most important hydrology information collection related to hydrology and water resources research. Chapter 1 discusses the measurement methods of precipitation, including instruments of precipitation measurements (non – recording rain gage, recording rain gage), testing and adjusting precipitation record, extending point rainfall records, calculation methods of regional average precipitation, etc. The average depth of precipitation over a specific area on a storm, seasonal or annual basis is required in many types of hydrologic problems. The simplest method of obtaining the average depth is to average arithmetically the gauged amounts in the area. This method yields good estimates in flat country if the gauges are uniformly distributed and the individual gauge catches do not vary widely from the mean. These limitations can be partially overcome if topographic influences and area representative are considered in the selection of gauge sites. The Thiessen method attempts to allow for non – uniform distribution of gauges by providing a weighting factor for each gage. The isohyetal method, when it is used by an experienced analyst, is the most accurate method of averaging precipitation over an area. Various hydrologic problems require an analysis of time as well as area distribution of storm precipitation. Depth – area – duration analysis of a storm is performed to determine the maximum amounts of precipitation within various durations over different areas. The method discussed here is widely used. The procedure has been computerized. Chapter 2 deals with stream flow measurements, which includes water stage measurements, discharge measurements, storage – discharge relations calculation and analysis and interpretation of stream flow data. Water stage changes continuously with the time owing to the influence of the factors such as rainfall, snow – melting, ice – melting, evaporation, diversion and drainage. The change of stage is an important ground for hydraulic engineering construction, navigation, flood control, drought defying, etc. Therefore, there is a need to carry on a long term and continuous observation on stages. The stage record is transformed to a discharge record by calibration. Since the control rarely has a regular shape for which discharge can be computed, calibration is accomplished by relating field measurements of discharge with the simultaneous river stage. Chapter 3 deals with stream flow hydrographs, including analysis of complex hydrographs, total runoff calculation, unit hydrograph and its application. Chapter 4 analyzed the rainfall – runoff relations which play the important ground for hydraulic facilities design and planning. Through Chapter 5 to 6, we dealt with hydrologic routing and flood design, including reservoir routing, routing in river channels, design flood based on stream flow data and estimation of design flood based on rainfall data. Finally, we introduced the empirical methods of flood design which is normally a very important method dealing with no data and small – sized basin.

The fist part of the book is a basic knowledge for the next part. Therefore, it is strongly suggest that readers read the first part before deepening the second, especially for those whose original specialty is not hydrology and water resources.

CHAPTER 1 PRECIPITATOIN

1.1 Measurement of Precipitation

The precipitation is a basic element in hydrology study. The measurement of precipitation plays very important action both in hydrology and water resources researches. A variety of instruments and techniques have been developed for gathering information on precipitation. Instruments for measuring amount and intensity of precipitation are the most important.

1.1.1 Types of Rain Gages

Rainfall and other forms of precipitation are measured in terms of depth, the values are expressed in millimeters in most countries in the world.

Rain gages are based on the simple idea of exposing in the open . A hollow cylindrical vessel is used with a bottom but no cover. Rain or other forms of precipitation falls into the vessel, and its depth (or volume or weight) is measured. Snow or other frozen forms are melted before the measurement.

The principal difficulties are as follows: the presence of the gage may disturb the wind field so that the free fall of precipitation is interfered with, piled – up snow or ice on the opening of the cylinder also may interfere; trees, buildings, a roof serving as a catchment area, or other objects may make the exposure site unrepresentative; some of the precipitation may be lost by evaporation or by wetting the sides of the gage or the measuring tube; various other factors such as dents in the rim of the receiver or the measuring volume may give false answers; in extreme cases, splash into or out of the objects may modify the true value of rainfall. Most of these causes may be minimized with proper care.

Types of gages are as following:

(1) Non – recording Gages. The gage consists of a copper vessel, a receiver (or funnel), and a measuring tube whose cross – sectional area is one – tenth that of the gage. During warm weather the measuring tube is placed in the gage and the receiver is fitted on the top of it. If the depth of precipitation is less than one – tenth of the height of the gage, it is simply measured in the tube by dividing the actual depth in the tube by 10. In case of that the measuring tube overflows, the water must be poured back from the gage into the tube in successive filling until the total depth is measured. During cold weather the receiver and tube are removed from the gage so that they will not interfere with the accumulation of snow.

The rainfall is measured every day at 08:00 a. m. During heavy rains, it must be measured three or four times in the day. The total amount of all the measurements during the previous 24 hours is recorded as the rainfall of the day in the register. Thus the non – recording rain gauge gives only the total depth of rainfall for the previous 24 hours (i. e. daily rainfall) and does not give the intensity and duration of rainfall during different time intervals of the day.

It is often desirable to protect the gauge from being damaged by cattle and for this purpose a barbed wire fence may be erected around it.

(2) Recording Gages. In order to know the intensity of rainfall or the amounts of shorter durations that can be obtained by manual measurements at a regular rain gage, recording gages are used, which gives a continuous pen trace on a clock – driven drum. Several mechanisms are provided for moving the pen: floats, weighing devices, or the tipping bucket. It is usually desirable that the total rainfall be retained so that manual measurements can provide a check on the total rainfall and a means of calibrating the rates of fall.

There are three types of recording rain gauges: tipping bucket gauge, weighing gauge and float gauge.

Tipping bucket rain – gauge consists of a cylindrical receiver of 30 cm in diameter with a funnel inside, see Fig. 1 – 1. Just below the funnel a pair of tipping buckets is pivoted such that when one of the bucket receives a rainfall of 1mm it tips and empties into a tank below, while the other bucket takes its position and the process is repeated. The tipping of the bucket actuates on electric circuit, which causes a pen to move on a chart wrapped round a drum which is revolved by a clock mechanism. This type cannot record snow. The tipping – bucket type (Figl –2) is especially adapted to remote recording and has been in use in China since 1960'S.

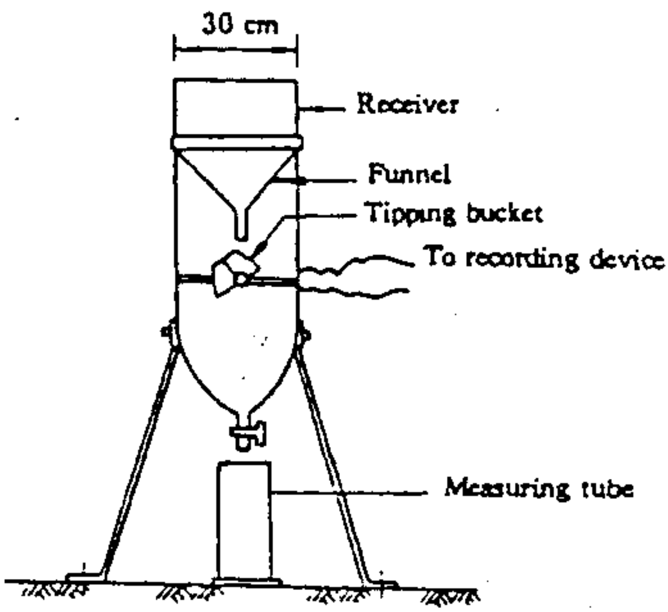

Fig. 1 – 1 Tipping Bucket Gauge

In case of weighing type rain – gauge, when a certain weight of rainfall is collected in a tank which rests on a spring – lever balance, it makes a pen to move on a chart wrapped round a clock – driven drum, Fig. 1 – 3. The rotation of the drum sets the time scale on which the