



水健康循环原理与应用



Beijing, China



建设部科学技术司 组织编写

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内容提要

本书从地球上水的运动规律出发,研究了人类用水与水文循环的关系。从而指出人类用水即水的社会循环应服从自然水文循环的规律,实现社会用水的健康循环。只有如是,自然水环境才能维系,水资源方可持续利用。

全书共分9章。第1章研究地球上水资源及其循环规律;第2章介绍我国社会水循环现状与水环境退化的原因;第3章和第4章论述健康水循环的理念、实施方略与途径;第5章和第6章提出城市排水系统的现代观和人类循环型用水的新模式。第7章至第9章分别介绍了笔者在深圳、大连和北京等地,运用水环境恢复理论与社会用水健康循环的方法进行的城市第2供水系统——再生水供应系统、污水与海水资源有效利用、水环境恢复工程等方面的规划研究。

本书面对给水排水、水环境、水资源等学科的广大读者而著;是本科生与研究生必读的教学参考书;还可作为我国水事决策的技术基础。

Abstract

This book explores, with a view to the rules of water cycle on the earth, the relation between water utilization and water cycle, indicating that water utilization, i.e. cultural water cycle should be subject to natural water cycle, so as to enable healthy cultural water cycle. This is the only way to maintain natural water environment and ensure sustainable utilization of water resources.

This book comprises nine chapters. Chapter 1 probes into water resources on the earth and their cycle rules. Chapter 2 introduces the current situation of cultural water cycle in China and the causes of water environment degradation. Chapter 3 & 4 discuss the philosophy, practical strategies and approaches for healthy water cycle. Chapter 5 & 6 present the innovative idea of urban drainage system and the new mode of cultural water cycle. Chapter 7 to 9 respectively details the planning and studies made by the authors by applying water environment restoration theory and healthy cultural water cycle principles on the secondary water supply system for urban areas reclaimed water supply system, full utilization of wastewater and seawater, and water environment restoration projects in Shenzhen, Dalian and Beijing.

This book is prepared for readers majoring in water supply and drainage engineering, water environment and water resources engineering. It can also serve as a useful reference textbook for undergraduates and postgraduates and a technical reference for water-related decision-making.

序 1

由于中国工程院组织的“中国水资源”、“西北水资源”与“东北水资源”等咨询项目，我有机会认识张杰院士。在项目组的实地考察和研讨中，他的观点鲜明，给我以深刻印象。2006年两院院士大会期间，阅读了他和熊必永、李捷合著的“水健康循环原理与应用”草稿，看到他的观点已进一步系统化并上升为理论，很受教益。

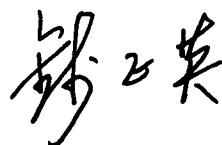
水是生命之源，是人类生存发展的最基本要素之一。从史前文明到农耕时代，从工业文明到现代社会，人类社会用水对自然界的水循环造成了越来越大的影响。世界范围内的水资源短缺、水污染加剧，全球性的水危机日益迫近。我国在近年来的经济迅速发展，许多地方的水危机已成为现实。迄今为止，我国的用水模式是上游城市从源头取水，污水排入江河，污染了下游河段，使下游河段的沿江城市也都力争从附近支流的源头引水，污水也同样就近排入江河。因此形成全国660个城市河段都受到不同程度的污染，流域水环境日趋恶化。长此以往，一些地方将陷入无水可用的困境。

张杰院士等面对我国水资源短缺，水环境污染的危机，进行了深刻的反思，提出一系列的新理念与新思路。书中提出了符合水循环规律的社会用水模式——社会用水的健康循环，并明确它的内涵是：上游地区的用水循环应不影响下游水域的水体功能，水的社会循环应不损害水的自然循环，从而维系或恢复全流域的良好水环境，达成流域内城市群间水资源的重复与循环利用，使有限的水资源保证全流域社会经济的持续发展。书中开创性地运用生态系统原理与系统科学思想，对社会用水系统健康循环理论及应用进行了系统地研究，从而描绘了一幅在以河流流域为单元的人与水和谐发展的美好景象。

该书在我国第一次系统地创建了一种包括水文循环与人类社会用水循环在内的和谐用水模式，为我们指出了一种新的水资源利用观和一个审视人与自然和谐发展的新视角，对改变我国现行的粗放用水模式，恢复碧水清流，具有重要参考作用。书中反复强调的主题是：水是可以再生循环利用的自然资源，水健康循环是一个开放的复杂系统工程，人类只有在系统地研究水的社会循环，并以水健康循环的观念和新的用水模式指导我国水事活动的实践，使社会水循环的“干扰度”处于自然水循环可承载的范围之内，建立起以流域为单元的社会用水健康循环，才能够维持水的自然循环与社会循环的动态平衡与协调发展，实现水资源的可持续利用。

21世纪是人与自然协调发展的世纪，人类社会只有建立起循环经济型的社会才能持续发展，而社会用水的健康循环将是循环经济型社会的重要基础。虽然这种理念的实现还任重道远，但从长远的观点看，这是人类可持续发展的惟一选择。希望这本专著的创新思想能够逐步应用到我国各地城市用水系统的取水、用水、排水、再循环等各个领域，更希望水健康循环的理念将培育我国水资源与水环境领域的新一代人才。

特为之序。



2006年7月8日

序 2

水孕育了人类。

伴随着人类社会的进步和经济发展，“生命之水”面临日益巨大的危机和挑战，如今，在世界范围内出现的水危机对人类的发展构成了严重威胁。保障水安全，促进水资源可持续利用，实现人类与水环境和谐共存是世界各国十分关注的重大课题。近二三十年来，我国政府通过实施相关科技计划，水行业管理部门，科研开发、工程设计和水务运营等单位共同努力，在分析国际水领域技术发展趋势和典型案例的基础上，开展深入研究和攻关，取得了一批具有理论价值和应用价值的成果，拓宽了解决水问题的思路，发展了水处理技术，在保障城镇供水，改善水环境等方面取得了显著成效，形成了适合中国国情的技术体系和管理模式，培养了一支由国际知名专家为学科带头人的专业队伍，使我国水领域的技术和管理水平大幅度提高，为今后的发展奠定了很好的基础。

2006年9月，建设部与国际水协将在北京举办第五届世界水大会。大会将为中外学者和工程技术人员搭建一个传播国际先进理念、交流研究成果和实践经验，探讨技术和管理创新的平台。为增进国际水业界对中国的了解，展示我国水领域的学术水平和发展成就，促进国际交流与合作，建设部科技司组织国内水领域的部分院士和知名专家编写了这套书籍。她包括学术理论、水处理工艺和工程应用以及水业管理等方面的内容，是对几十年来我国水领域所取得的成果和经验的总结，对我国城镇供水、节水和污水处理及资源化工作的开展，对促进我国水领域的跨越式发展和机制创新会有很好的参考作用。

在此书即将出版，第五届世界水大会即将召开之际，我们借用先哲老子的名言“上善若水，水利万物而不争”来表达对我国水领域科技工作者和致力于水资源永续利用、创造美好人居环境的广大同仁的敬意，感谢他们做出的无私奉献。

谨以此书献给第五届世界水大会。

建设部科技司
2006年5月9日

前 言

- 目前全球一半的河流水量大幅减少或被严重污染。世界上 80 个国家、或占全球 40% 的人口严重缺水。如果这一趋势得不到遏制，今后 30 年内，全球 55% 以上的人口将面临水荒；

- 水污染导致的死亡人数每年达 2500 万人，主要发生在发展中国家；
- 全球 50% 的湿地在 20 世纪因人类活动严重破坏了淡水生态系统而消失；
- 中国 2/3 城市缺水，大部分属于污染导致的水质型缺水；
- 每年水污染造成的经济损失约为中国当年 GNP 的 1.5%~3%；

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水是生命之源，然而 18 世纪产业革命以后，尤其是近半个世纪以来，人类社会无度消费、大量生产大量废弃的用水方式，致使水资源短缺与水环境污染日趋严重，地球上有限的水资源逐渐成为人类生存发展的桎梏。

早在 1972 年，联合国第一次环境与发展大会就指出：“石油危机之后，下一个危机就是水”。1977 年联合国大会进一步强调：“水，不久将成为一个深刻的社会危机”。1997 年联合国再次敲响警钟：“目前地区性的水危机可能预示着全球性水危机的到来”。进入 21 世纪，全球性水危机已经初露端倪，水资源紧缺与水环境恶化已经成为当今世界许多国家社会、经济发展的制约因素。如何应对日益严峻的水危机，实现社会、经济可持续发展已经成为各国 21 世纪迫切需要解决的首要问题。

时至今日，国际社会和各国为缓解水危机都付出了远久的巨大努力。发达国家的城市污水二级处理率已达到较高水平，许多国家已经或开始普及污水深度处理与回用，水污染控制由末端治理发展为清洁生产和污染预防的综合污染控制。其虽然极大地控制了水传染疾病，提高了居民卫生水平，但水资源短缺与水环境恶化问题仍困扰着世界各国经济的发展。

我国从建国初期就开始进行水问题的研究，但是我国水环境恶化的总体趋势还远未得到有效遏制。城镇缺水、地表水污染加剧、地下水严重超采、湖泊富营养化、城市型洪涝灾害等问题，不断威胁着人民生活、生产与生态的安全。

地球上的水在水圈、大气圈、岩石圈、生物圈不断地进行着往复循环，遵循着固有的运动规律。究其规律而言：水是循环性的资源，是可以再生的资源，但是参加水自然循环的水量又是极为有限的。人们的水事活动，即工业、农业、城市的取水、用水和排放，是置于水自然循环基础上的人为水循环，也称为社会水循环，它是自然大循环的支路。因此社会水循环的水量 and 水质与水的自然循环运动有着密切的联系。流域间水资源的随意调动和取用，水质的肆意污染，严重损害自然循环，造成水环境的退化 and 水资源短缺。往昔，50 年前，100 年前或者更久远，工业和城市不发达，人类用水分散、取水总量少，不足以干扰自然水循环的过程。于是人们漠视水的珍贵，误认为水与阳光、空气一样是取之不尽、用之不竭的。但时至今日在高度工业化和后工业化的时代，用水量剧增，污水水质恶劣，人们仍然随意取用，肆意排放，就超出了水自然循环所能承受的限度，出现了污染、断流、湿地干涸等现象，使水的自然循环陷入了病态，产生了水危机。要解决人类社会的水危机，经济和社会的发展必须与水资源、水环境相协调，必须遵守水自然循环的规律。规范人类社会的水事活动，使水的社会循环不致影响或损害水的自然循环。要充分体现水可再生使用的属性，

实现社会水系统的健康循环。

基于上述基本思想,本书系统剖析了水污染和水环境恶化的成因,从“社会水循环可持续性”、“排水系统现代观”、“水资源利用模式”、“污水污泥处理回用”、“水资源节约与循环利用”、“水环境恢复方略与措施”等方面对水健康循环理论作了初步探索,提出水资源利用、污水再生、污泥处理与处置的发展方向,给出了由水健康循环的基本原理、方略与途径、措施等组成的一幅系统的关于水环境恢复与水健康循环的全景画卷。为水健康循环研究提供新的视角与借鉴。

本书共分9章。第1章介绍了地球上水的运动规律与大气圈、岩石圈的互动关系。水资源贮量和在各国、各大洲的分布。水文大循环和水的社会循环。第2章介绍我国社会水循环现状与水环境退化的原因。第3章提出了水健康循环的理念。第4章指出了实现水健康循环的方略,详细阐述了实现水健康循环的途径和方法。第5章介绍了城市排水系统产生与发展过程,提出现今排水系统功能必须升华,使其成为城市用水循环和污水再生的纽带、土壤营养物质循环的桥梁,能量与物质回收的基地。第6章提出了人类用水模式的变革。第7章至第9章分别介绍了笔者在深圳、大连和北京等地,运用水环境恢复理论与社会用水健康循环的方法进行的城市第二供水系统——再生水供应系统、污水与海水资源有效利用、水环境恢复工程等方面的规划研究。

通过对水环境恢复与水健康循环理论与方略的系统探讨,可以了解水健康循环的建立与我们每一个人的观念、行为和生活方式的密切联系,从而为今后水环境恢复与水健康循环领域不可避免的革命提供动力和依据。

全书由张杰、熊必永、李捷共同撰写(第1、2章:李捷,3、4章:张杰、熊必永和李捷,5章:熊必永和张杰,6~9章:张杰、熊必永和李捷),戴镇生审阅。由于水健康循环是一个崭新的研究领域,国内外在这个领域的研究尚处于探索阶段,可资借鉴资料不多,加之作者水平所限,不当之处在所难免,希望得到广大读者的批评指正。

Preface

- 50% of all the rivers on the earth are greatly suffering low runoff or tremendously polluted. Some 80 countries, constituting 40 per cent of the world's population, are suffering from serious water shortages. If such a situation cannot be improved, 55% or more of the global population will suffer water shortage in 30 years;

- Each year, 25 million people die of water pollution, a large proportion of which occur in developing countries;

- About 50 per cent of the world's wetlands lost during the 20th century due to the serious damage of freshwater ecosystems by human activities.

- Two thirds of the cities in China are deficient in water, most of which are caused by because of water pollution;

- The economic loss resulted from water pollution each year is about 1.5% to 3% of the GNP of the same year in China

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Water is essential to life. However, water resources shortage and water environment pollution is turning worse due to the excessive consumption and unlimited waste of water by the production and living since the outbreak of the industry revolution in the 18th century, especially in the recent half of the century. The limited volume of water resources becomes the bottleneck for us to maintain survival and development.

Early in 1972, the first session of the UN Conference on Environment and Development stated, "Water crisis will occur following petroleum crisis". In 1977, the UN General Assembly further added, "Water will soon become a severe social crisis". In 1997, the UN warned again, "The water crisis currently occurred in some of the regions around the world is likely indicting the upcoming worldwide crisis". The global water crisis gradually came up in the 21st century. Water resources shortage and water environment deterioration has pulled down the development of the socioeconomy in many countries. The key problem of how to deal with the water crisis and enabling the sustainable development of socioeconomy is imminent for every individual country in the 21st century.

So far, the international community and each of the countries have been making great effort to alleviate water crisis. The secondary treatment of urban wastewater in developed countries is extensively applied. Many countries have already or begun to widely apply advanced treatment and reuse of wastewater. The control of water pollution has transited from the end-of-pipe treatment to a

comprehensive level of cleaner production and prevention against pollution, which has largely helped constrain the disease infection by water and improve the health status of citizens. However, the water shortage and water environment deterioration still holdbacks the economic development of such countries.

Although China has commenced the study on water resources since its establishment, the deterioration of water environment has not yet been effectively restrained. The living condition, production and ecosystem have been being threatened by water shortage in cities, worsening of surface water pollution, excessive extracting of ground water, eutrophication and flood occurred in urban areas.

Water keeps cycling from the hydrosphere, atmosphere, geosphere and biosphere by following its immanent cycling rules, which indicates that water is a kind of recycling renewable resource. Yet, only a small part of the water involves in hydrologic cycle. Human activities that are related to water, i. e. the extraction, consumption and drainage of water by industries, agriculture and cities are based on the natural cycle of water. Such activities are called cultural water cycle, which is a branch of the natural cycle. Therefore, the volume and quality of the water from the cultural water cycle closely relate to the natural cycle of water. The random transfer and use of water resources in a basin and water pollution will severely affect the natural cycle of water, resulting in water resources deterioration and shortage. In the past 50 or 100 years or more, the industries and cities were not developed, and only a low percentage of water was consumed in different locations. Thus the natural cycle of water was basically unaffected, based on which people believed by mistake that water resources were, just like sunlight and air, inexhaustible and available for use all the time. But now, we are stepping into a highly developed industrialization and post-industrialization era, the consumption of water sharply increases and the quality of wastewater gets worse. However, water is utilized and drained at our pleasure, which oversteps the threshold of the natural cycle of water. As a result, water crisis is eventually occurred for the water cycle is interrupted, leading to pollution, zero-flow of rivers and dry-up of wetlands. The development of economy and society must correctly correlates to water resources and water environment by following their natural cycle rules, ensuring human activities are under control to avoid the interruption of the cultural recycle of water, so as to overcome water crisis. The used water should be efficiently recycled to enable a healthy cultural water cycle.

On the basis of the above ideas, this book probes into the causes of water pollution and water environment deterioration from a systematic point of view, launching a rough study on the theory for healthy water cycle by discussing “Sustainability of Cultural Water Cycle”, “Innovation in Drainage System”, “Utilization Mode for Water Resources”, “Treatment and Reuse of Wastewater and Sludge”, “Water Conservation and Recycle” and “Strategies and Measures for Water Environment

Restoration”, and presenting the development trend of water resources utilization, wastewater reclamation, sludge treatment and disposal as well as the basic principles, strategies and approaches, and measures for healthy water cycle, which gives an overview of water environment restoration and healthy water cycle. We hope that this book can be used for reference by offering a new insight into the study on healthy water cycle.

This book comprises nine chapters. Chapter 1 gives an overview of the relation between water cycle and the atmosphere and geosphere; the reserves of water resources and their location in different countries and continents; and hydrologic cycle and cultural water cycle. Chapter 2 introduces the current situation of cultural water cycle in China and the causes of water environment degradation. Chapter 3 presents the theory for healthy water cycle. Chapter 4 point out the strategies for healthy water aycle and addresses the practice and approaches for healthy water cycle. Chapter 5 introduces the brief history of urban drainage system and strongly proposes to upgrade the drainage system in order to allow it to serve as a link between the urban water utilization and wastewater reuse, the media for the nutrient cycle in soils, and the base to reclaim energy and substance. Chapter 6 focuses on innovations of water utilization mode. Chapter 7 to 9 respectively details the planning and studies made by the authors by applying water environment restoration theory and healthy cultural water cycle principles on the secondary water supply system for urban areas-reclaimed water supply system, full utilization of wastewater and seawater, and water environment restoration projects in Shenzhen, Dalian and Beijing.

The close relation between each individual's notion, behaviour and life style and the establishment of healthy water cycle system is unveiled by the systematic discussion of the principles and strategies for water environment restoration and healthy water cycle, which hopefully will be helpful to an inevitable revolution for water environment restoration and healthy water cycle in the future.

This book is jointly composed by Jie Zhang, Biyong Xiong and Jie Li (Chapter 1 & 2: Jie Li, Chapter 3 & 4: Jie Zhang, Biyong Xiong and Jie Li, Chapter 5: Biyong Xiong and Jie Zhang, Chapter 6~9: Jie Zhang, Biyong Xiong and Jie Li), and reviewed by Prof. Zhensheng Dai. Any comments, criticisms, suggestions for improvement will be gratefully received.

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