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Report

Chinese Water Resource Management and Application of the Harmony Theory

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Abstract: Chinese water resource management (CWRM) has passed through four stages: infancy, initial development, rapid development, and formation. In the last of these stages some problems persist and will affect management performance. CWRM was a decentralised, imperfectly codified and weakly implemented system that lacked a sound market policy, rational water prices, water conservation awareness, technical support and a performance appraisal system. The government of China proposed two new strategies in 2009: the Three Red Lines and the Interconnected River System Network (IRSN). This paper analyses these two strategies and reflects on new CWRM concepts. Both strategies strive for the sustainable utilisation of water resources and human-water harmony. The concepts, quantification method and application of harmony theory to water resources management is discussed. Applications of harmony theory to water resources management include (i) harmony between humans and nature; (ii) a harmony strategy for water resources management; (iii) a rational allocation model for water resources among different areas and departments based on harmony theory; (iv) harmony-based water allocation issues associated with transboundary rivers; (v) harmony-based interbasin water transfer problems; and (vi) harmony-based control of pollution discharge. We conclude by discussing how harmony theory and its applications provide an appropriate pathway for water resource management in China.

Key words: Chinese water resource management (CWRM); harmony theory; Three Red Lines; Most Strict Water Management System (MSWRMS); Interconnected River System Network (IRSN)

1 Introduction

Water is the essence of life, crucial to production, and the foundation of ecology. Building a reasonable management system for water resources is necessary and important. As water resource issues become increasingly prominent, emphasis is being placed on scientific water resource management (Zuo *et al*. 2008a). In 2011, the Central Committee First Document titled "CPC Central Committee and State Council on the decision to speed up reform and development of water conservancy" detailed the plan for comprehensive water conservancy reform, highlighted the importance of this issue to national development, expressed an adherence to human-water harmony and presented the Most Strict Water Resources Management System (MSWRMS) strategy.

Chinese water resource management (CWRM) has been on the agenda for some time. For instance, Xu (2000) advocated regional modern water resource management based on resource conservancy concepts. Quantification methods for water resource management with a focus on sustainable development were proposed by Zuo and Chen (2003). Water resource management gradually entered the stage of resource management and water demand orientation management, studied by Zhou (2004), who identified the goal, content, principles and countermeasures of a modern water resources management system. Zuo *et al*. (2008b, 2009) constructed a scientific set of quantification methods for human-water harmony, and researched an index system and evaluation system of a society that conserves resources, including water resources. Wang *et al*. (2009) analysed soil water resources and cost utility in the Yellow

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River basin and discussed the necessity and feasibility of an evapotranspiration-based modern water resources management strategy. Water conservancy, management philosophies, development types, and water use modes were advanced by Chen (2010). Liu *et al*. (2011) established conditions, an index control system and safeguard measures for the MSWRMS in Dezhou City. Last, Dou *et al*. (2011) discussed the concept and connotations of the Interconnected River System Network (IRSN), analysed its driving forces, constituent elements and inter connections paths, and built a primary classification system. Here, we build on previous research and examine the Three Red Lines and Interconnected River System Network strategies and new concepts in CWRM such as harmony theory. Our aim is to identify an appropriate pathway for Chinese water resource management into the future.

2 Development of Chinese water resource management

Water resource management is the management for water resource allocation and scheduling (Zuo *et al*. 2008a). To date, no uniform and standard definition of water resource management has been developed. The most cited definition of water resources management is by Chen Jiaqi in the water volume of the China Encyclopedia Press: "Water resources management is the organisation, coordination, supervision, and scheduling of activities associated with developing, utilising and protecting water resources". Water resources management includes (i) developing and utilising water resources, as well as preventing and controlling water disasters, by administrative, legal, economic, technological, educational and other means; (ii) coordinating the relationship between resource utilisation and socioeconomic development to address water conflicts among various regions and departments; (iii) supervising and limiting unreasonable overexploitation and other actions of harm to water sources; (iv) formulating reasonable water allocation programmes, using flood control and profit scheduling principles, and developing and executing the optimal scheduling of water supply systems and water engineering projects; and (v) monitoring changes in water quantity and quality and taking appropriate management actions (Chen *et al*. 1987). Above all, water resource management is a complicated set of water-related activities covering five key areas (Zuo *et al*. 2008a): (i) increasing publicity, education, public awareness, and participation; (ii) developing rational measures for the utilisation of water resources; (iii) formulating water management policies; (iv) implementing unified water management strategies; and (v) putting real-time allocation and scheduling into practice.

Throughout the course of Chinese water resource management, changes in management thought have arisen alongside an increasing awareness of water resources. The evolution of thought on water resources management can be described by the following four stages (Fig. 1):

(1) The infancy stage of CWRM before the mid-20th century. When productivity was low in China people had limited knowledge of water resources, and suffered from floods, drought and other natural disasters while fetching and using water in simple ways. This period has been described as the "people avoid water, water violates people" stage (Zuo *et al*. 2008b), during which there was not a real sense of water resource management. This stage of CWRM was dominated by demand-driven activities pertaining mainly to drought and flood events, with water utilisation being in accordance with natural tendencies.

(2) The initial development stage of CWRM from the mid-20th century to the early 1980s. With increased human understanding of water resources, technological advancements, and increased productivity, human demand for water resources increased gradually during this period. This caused increasingly frequent and severe water resource problems and worsened human-water relationships. This period has been described as the "people fight for water" stage (Zuo *et al*. 2008b), during which water resource management was decentralised focused around water supply.

(3) The rapid development stage of CWRM from the 1980s to the late 1990s. Increasingly frequent and serious water resource problems aroused great attention. Public understanding of water resources gradually shifted from a unilateral view that water is inexhaustible to a more scientific understanding of water resources as being limited. More specifically, people began to appreciate that development and utilisation of water resources must be coordinated with socioeconomic development and ecological protection (Zuo *et al*. 2008a). During this period, management regulations such as the "Water Law" and the "Procedures for Water-Drawing Licenses" were issued and improved continuously. China was on a path of controlling water according to law and transforming from hydro-engineering conservancy to hydro-resource conservancy, i.e., from traditional water conservancy to modern and sustainable water conservancy. In this stage, CWRM advocated for the sustainable utilisation of water resources.

(4) The formative stage of CWRM from the late 1990s to the present. The growing human ability to reshape the world, continuous expansion of activity, and rapid population growth resulted in water shortages, environmental pollution and climate change. These became drivers of changes in water resource management (Zuo *et al*. 2008a). The idea of human-water harmony was put forward on the basis of integrated management and the sustainable utilisation of water resources. After 2009, two new water resource management strategies were proposed. Both outlined the latest concepts in CWRM. One strategy, proposed by the Ministry of Water Resources, was to implement the Most Strict Water Resources Management System, including the Three Red Lines strategy. A second strategy was the "Interconnected River System Network" strategy, which was first proposed by Minister Chen Lei during a working meeting for national water conservancy

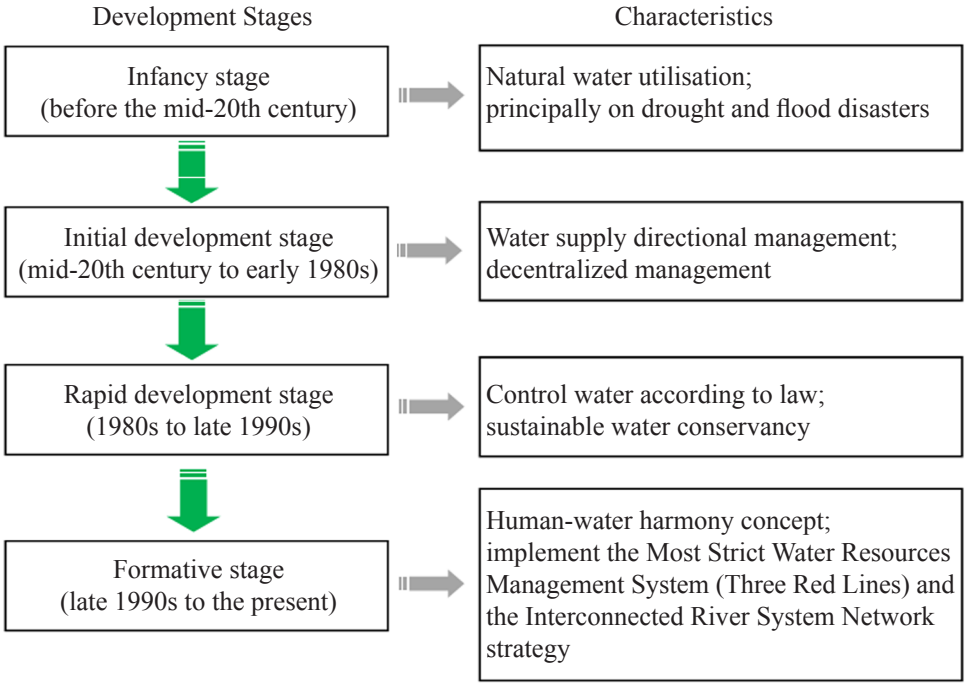

Fig. 1 Development stages and characteristics of CWRM.

development planning for 2011-2015.

3 New concepts in Chinese water resource management

3.1 Current problems with Chinese water resource management

(1) Decentralised management controlled by multiple departments. Water resources are managed provincially and the authority of river basin organisations is limited. Many departments in China are involved in water resource management and a central unified water management system is lacking (Zhang 2002; Yang *et al*. 2007).

(2) Incomplete laws and regulations, as well as weak enforcement efforts. Water laws and regulations must be more complete and include clear identification of responsibilities and high rigidity and operability. Water regulations must also be structured to adapt to the future needs of CWRM (Zhang 2002).

(3) Immature market-oriented policies and an irrational water pricing system. As a type of commodity, water resources should be included in the market economy. Water market economic entities should be cultivated to accommodate modern enterprise systems and promote the reform of water prices (Qi 2008).

(4) Incomplete enforcement of water-saving policies and weak water conservation awareness. Given increasing water consumption, growing water shortages and limited protection of water resources, China should develop a resource-conserving society and engage in water conservation, appropriate exploitation for new access to water sources, prevention and control of pollution, unified planning, and enhanced management (Qi 2008).

(5) Support systems for water resources management in need of strengthening. Some auxiliary systems, such as geographic information system and management information system, are powerful technologies that can be employed in water resources management (Qi 2008; Qin *et al*. 2011).

(6) The performance appraisal system for water resource management needs to be improved and strengthened. Water resource management results should be linked to the appraisal of competent leaders and governments.

3.2 New Concepts in Chinese water resource management

The Three Red Lines strategy, which characterises the Most Stringent Water Resources Management System, and the Interconnected River System Network strategy are the latest water resources management strategies developed to address water and socioeconomic development. Both strategies embody and elaborate the concepts of the sustainable utilisation of water resources and human-water harmony.

Three Red Lines refers to the control of water resources, water utilisation efficiency controls, and pollution controls in functional water zones. At its core is the implementation of the Most Strict Water Resources Management System proposed by the Ministry of Water Resources in 2009. Three Red Lines is intended to address three problems (excessive water development, low water utilisation efficiency and water pollution), covers three basic areas in the process of exploiting water resources (fetching, using and draining), and identifies three major requirements of water resources management (allocation, savings and protection) (Wang

2011). Before being presented at the national level in the Central Committee First Document, the MSWRMS was selected for implementation via a pilot project in Shandong, Jiangsu, Hebei, Zhejiang, Shanghai, Tianjin, and in the city of Beijing. Shandong province set up a control index system for the Three Red Lines that operated at the provincial, city and county government levels. Other provinces and experts involved in the pilot project also expended considerable efforts in construction of the Three Red Lines index system. For example, the technical framework for research on regional and industrial water use efficiency evaluation systems was developed in Yunnan, where a centre for the study of regional and industrial water use efficiency was established (Yunnan Institute of Water Resources and Hydropower Research 2010). Hunan developed provincial control indexes based on national water use efficiency control indexes (Hunan Province Hydrographic Office 2011). Wang (2011) analysed eight key technical support components associated with implementation of the MSWRMS. The central goals of the Three Red Lines strategy, concerning water exploitation, water utilisation efficiency and water pollution control, were outlined by He (2010). To further implement Three Red Lines, a "work plan on practicing the MSWRMS" was released by the Ministry of Water Resources. Compared with traditional water resources management, MSWRMS is centred on Three Red Lines, and is more strict, refined and systematic. It identifies an appropriate pathway for integrated Chinese water resources management and identifies key issues (Wang 2011).

The "Interconnected River System Network" strategy was first proposed by Minister Chen Lei during the working meeting for national water conservancy development planning for 2011-2015. Also in 2011, the Central Committee First Document proposed the construction of a group of water resource engineering projects and proposed IRSN to improve the regulation level of water resources and water supply support capacity. IRSN is defined as engineering projects that connect rivers, lakes, reservoirs and other water supply network components. Its purpose is to construct a network of interconnected water resources to meet the needs of sustainable socioeconomic development and ecological civilisation construction, with the functions of improving integrated allocation ability, improving the status of the water environment, protecting against flood and drought damage, to eventually achieve harmony between humans and water (Dou *et al*. 2011). A number of IRSN engineering projects have been built in China and worldwide and have generated huge socioeconomic benefits, in addition to improving the regional ecological status and the human environment. Meanwhile, some unconscionable engineering projects have had profoundly negative economic, social and ecological effects. To fully appreciate IRSN engineering projects, the negative influences of some other projects should be given more attention (Cui *et al*. 2011). IRSN is influenced by natural factors (such as floods, earthquakes, river bed deposition, topography change and climate change) and human factors (such as water demand and approaches to water utilisation), which mainly include four basic elements and six interconnected ways. The four basic elements are water resources carrier systems, man-made engineering projects, water resources conditions and management scheduling rules. The six interconnections paths are of the urban water network type, river dredge type, waterbody update type, river regulation and storage type, flood diversion type and new water source supply type (Cui *et al*. 2011). Frequent flooding, water shortages and environmental degradation of water resources have become water-related bottlenecks that restrict the socioeconomic development of China, and it is urgent for China's socioeconomic development that IRSN strategies be implemented to address too much, too little, too dirty water (Xu *et al*. 2011).

4 Harmony theory and its applications

4.1 Harmony

The essence of Chinese water resource management is human-water harmony. China's new Plan for 2011–2015 explicitly proposes making water conservancy a priority of national infrastructure construction and advances an insistence on human-water harmony and scientific development to implement the Most Strict Water Resources Management System. The question remains, what is harmony? Harmony has been defined as "coordination, consistency, balance, completeness and adaptation" (Zuo2009a, 2012).By studying the theory and methods of achieving harmonious behaviour, harmony theory reveals the nature of harmonious relationships (Zuo 2009b, 2009c). Harmony theory is viewed as correct, positive, consistent with dialectical materialism, and helpful in addressing social, economic, political, cultural and religious problems (Zuo 2009b).

Harmony concepts are everywhere and evidenced by (i) advocating "peace is most precious"; (ii) rationally understanding contradictions and conflicts existing in various relationships, accepting diversity and differences, and dealing with all types of inharmonious factors and problems with a harmonious attitude; (iii) solving every type of problem with a human-oriented, comprehensive, coordinated and sustainable scientific development approach; (iv) insisting on dialectical materialism, paying close attention to the dialectical materialist relationship between humans and nature, and advocating living in harmony with nature; and (v) advocating development of harmonious relations with systematology.

Harmony theory in Chinese water resource management embodies the following five characteristics: (i) assuring a harmonious state between humans and water; (ii) the popularisation of human-water harmony concepts; (iii) distributing water use and sewage volumes reasonably in different areas and different sectors and among different users; (iv) researching humans and water from the

perspective of humanistic systems and water systems (or the human–water system); and (v) establishing human-water harmony concepts, and dealing properly with the relationship between water resource protection and development.

4.2 Quantifying the degree of harmony

To achieve a reasonable expression and a quantitative description of harmony theory, five elements of harmony theory are proposed. They are harmony participants, harmony objectives, harmony regulations, harmony factors and harmony actions (Zuo 2009c). All of these elements interact and form harmony theory.

The harmony degree equation for a single factor is as follows:

$$HD = ai - bj \quad (1)$$

where, HD is the harmony degree. If $HD < 0$, HD is considered equal to 0, otherwise $HD \in [0,1]$. a is the uniformity degree and b is the difference degree; a, $b \in [0,1]$, and $a+b \leq 1$. i is the harmony coefficient, which reflects the degree to which a harmony goal is met. $i \in [0,1]$. If the research problem can satisfy the harmony goal completely, i is equal to 1; if not at all, i equals 0; otherwise, i has a value between 1 and 0.The harmony coefficient curve or function can be defined in terms of the harmony goal satisfaction degree. j is the non-harmony coefficient, which reflects the degree of opposition among harmony participants facing differences and is determined by the difference degree. $j \in [0,1]$. When harmony participators oppose each other completely, j is equal to 1; if not at all, j equals 0; otherwise, j has a value between 1 and 0. The non-harmony coefficient curve or function can be defined in terms of the degree of difference or opposition among harmony participators facing differences.

The harmony degree equation discussed above is just for a single factor. However, in practical applications, there are multi-factor and multi-order harmony questions. Thus, a comprehensive harmony degree can be calculated by the weighted average or weighted index methods. Based on quantification of the harmony degree, the harmony participants' states and the degree of harmony can be evaluated.

4.3 Applications of harmony theory to Chinese water resource management

The application of harmony theory has a robust future. Its applications can be divided qualitative and quantitative. Qualitatively, it can be applied to interpersonal harmony relationships, collective (area) harmony relationships, economic problems (such as investment consultation), political problems (multi-party cooperation), sociological problems (such as family harmony and societal harmony) (Zuo and Ma 2010), legal systems, culture, authority and ideas. Quantitative applications of harmony theory mainly involve harmony quantification and interdisciplinary perspectives. Research on harmony theory and its related applications mainly include calculating the degree of harmony and evaluation, harmony theory modelling and problem solutions, and optimal harmony behaviour choices (Zuo 2009c; Zuo *et al*. 2011). Harmony theory can be applied to Chinese water resources management via the following:

(1) Harmonious interactions between humans and nature (Zuo 2012). With increasingly serious water problems, people have accepted human-water harmony and its importance. Theoretical research and practical applications of human-water harmony (or the relationships between humans and nature and humans and water) are intended to coordinate solutions to currently worsening relationships between humans and water, address problems of flood disasters, droughts, water shortages, soil erosion and water pollution, and finally identify an appropriate path to sustainable water resource utilisation (Zuo and Zhang 2009). Zuo and Zhang (2009) put forward a set of research methods for quantitative indexes, criteria and methods of human-water harmony. In fact, this is still true of the "evaluation" concept of the human-water harmony state, which does not actually use harmony theory concepts. It is necessary to apply harmony theory concepts to the relationship between humans and water and between humans and nature (Zuo 2009b).

(2) Harmony theory strategies for water resource management (Zuo 2012). We often encounter such coordination questions, for example human-human, group-group, and human-water harmony. Under the circumstances, harmony theory thought is introduced. We can develop a scientific and reasonable water resource management strategy using harmony theory concepts (Zuo 2009b). A harmony theory-based model of water resource management with the objective of maximising the degree of harmony was developed by Guo (2011) who used system, region and department management factors as constraints. In the end, water resource management strategies were derived from the five elements of harmony theory and the harmony degree equation.

(3) A rational allocation model for water resources among different areas and departments based on harmony theory (Zuo 2012). Water allocation models have been proposed for different situations and for various types of factors. However, few studies or models have considered the harmony relationships among areas or departments or even between humans and nature. Zuo Qiting established an optimisation model for water resource allocation based on human-water harmony quantification theory, in which water harmony relationships were considered. The model considers not only economic objectives, social objectives, environmental objectives, but also the harmony relationships of different areas, different departments, and human-water harmony. A mathematical description of harmony theory makes this optimisation possible (Zuo 2009b).

(4) Water allocation issues pertaining to transboundary rivers based on harmony theory (Zuo 2012). Transboundary rivers refer to rivers that cross different areas, such as different provinces (e.g. the Yellow River and Yangtze River), and different countries (e.g. the Danube).Because of limited water availability, the total amount of water must be controlled to protect the health of the river. Nevertheless, every area (or every country) wants to obtain more water resources and obtain benefits from access to water resources. Differences between different areas over water resources can lead to conflict, and even war. To address these problems and achieve human-water harmony, we must the consider the water utilisation of other areas when developing water resources (Zuo 2009b).

(5) Interbasin water transfer problems based on harmony theory (Zuo 2012). Interbasin water transfer projects, which can be effective in addressing the irregular allocation of water resources and imbalances between supply and demand, are always implemented to promote national economic development and comprehensive water resource exploitation in water-deficient areas. Many countries (China, the USA, Russia, Canada, France, Australia, Pakistan and India) have constructed interbasin water transfer engineering projects, and some of these have yielded great benefits (Zuo 2009c).

In general, interbasin water transfer engineering projects can produce considerable benefits, including economic, social and environmental benefits. However, such projects involve large investment, large risks, and management difficulties. Managing such an operation involves balancing engineering investment, benefit sharing, water allocation, and the capacity of water areas. Coordination of export zones and import zones, different water units in import zones, different departments, benefits to the economy, society, and the environment, socioeconomic development and water resources protection, can be considered by building a harmony theory model (Zuo 2009c).

(6) Control of pollutant discharge based on harmony theory. Water resource management considers the union of water quantity and quality, and requires protecting and conserving water resources. Through the process of water resource protection, in which it is very important to control water pollution emissions and distribute controlled emissions among stakeholders reasonably. For the purpose of maximising the degree of harmony, Zuo and Pang (2011) constructed a total water pollution quantity control model limited by water pollution emissions control, management technology and economic investment. This model provides technical support for a reasonable control scheme for water pollution emissions in the basin.

5 Conclusions

Based on the research and development of Chinese water resource management, many problems in CWRM have been noted, such as a decentralised system, imperfect laws, incomplete market policies, lack of rational water pricing, weak water-saving awareness, insufficient technical support, and an imperfect performance appraisal system. Improvements to CWRM are needed for several reasons, including stimulating China's socioeconomic development, solving water resource problems, managing the relationship between government macro-regulation and market regulation, achieving sustainable development and ensuring human-water harmony. We have examined connotations of the Three Red Lines and Interconnected River System Network strategies. Concepts, quantification methods, and applications of harmony theory to water resources management have been discussed and it is clear that perfecting CWRM is very important and difficult and requires constant innovation.

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中国水资源管理新思想及和谐论应用

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摘 要：水资源管理已进入一个全新的阶段，现代水资源管理理念应运而生。在总结水资源管理发展历程，指出其存在问题的基础上，阐述了构建现代化水资源管理体系的必要性，剖析了反映水资源管理新思想的"三条红线"和"河湖水系连通战略"内涵，介绍了和谐论理念、量化方法及在水资源管理中的应用，包括构建人与自然和谐相处的和谐论途径、水资源管理的和谐论策略、分区分部门水资源合理分配的和谐论模型、跨界河流分水问题的和谐论模型、跨流域调水问题的和谐论模型、水污染物总量控制的和谐论模型等，为水资源管理工作指明了方向。

关键词：水资源管理；和谐论；三条红线；最严格水资源管理制度；河湖水系连通战略