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Systematic methodology and practice of a co-governance program for five waters in a typical area of China

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Abstract

A co-governance program for five waters (CPFW), including sewage treatment, flood prevention, drainage, water supply and saving, is an innovative concept in water resource management. It includes current and near future system projects and advanced management policies for water utilization and protection. In this paper, the scientific connotation of CPFW is explained by multidisciplinary theory. Based on current guidance and technology, evaluation targets and water management countermeasures are specified. Combining hydraulic engineering and their characteristics, operable approaches for CPFW are suggested for projects' designation and construction. These approaches of CPFW are applied in a typical area. Systematic projects are composed of sewage interception projects, efficient water supply projects and hydraulic projects with ecological engineering. With the guidance of CPFW, all projects are connected together and their integrated benefits are evaluated in water saving, sewage drainage, increase in environmental capacity and ensuring security. The results show the CPFW is valuable and available both in theory and in practice.

Keywords: Co-governance program for five waters; Integrated benefits; Operable approaches; Water resource management

1. Introduction

With the implementation of No. 1 Document in 2011, the significant concept of the function of water was enhanced as the life source, the key material of production and basis of the ecological system (Cao & Li, 2012). One year later, in No. 3 Document of the State Council of China, the implementation of the most strict water resources management regulation supported the constitution of an integrated system of water resource utilization and protection (Chen *et al.*, 2013a, b). In 2013, the Third Plenary Session of the 18th Central Committee of the Communist Party of China proposed a strategic concept named the

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'comprehensive deepening reform at a new historical starting point', which focused on the construction of an ecological civilization system (Jin *et al.*, 2006), a sound national spatial development, resource conservation, ecological and environmental protection, and promotion of the harmonious development relationship between humans and nature (Grillo, 2007, Chen *et al.*, 2013a, b). As for national demand, the government of Zhejiang Province proposed a strategic decision-making firstly in the co-governance of sewage treatment, flood prevention, drainage, water supply and saving (the co-governance program for five waters; CPFW) to establish a system of compensation for the use of natural resources and the subsequent impact on the ecosystem based on Deng Xiaoping Theory, the important theory of the 'Three Represents' and the scientific development concept in China. The final target is to establish ecological civilization and sustainable socio-economic development in Zhejiang (Zhao *et al.*, 2013, 2014). This is a crucial breakthrough in a new historical era. CPFW represents the understanding and accurate grasp of social development requirements, and the determination of the Chinese on integrated water protection. In this paper, the scientific connotation of CPFW and executable approaches are discussed, hoping to further grow the concept of CPFW.

2. Scientific connotation of CPFW

2.1. The essential support provided by CPFW is to implement the most stringent water management system

The most stringent water management system is a major shift of water management and strategic thinking in the new era (WWAP, 2012). It presents the implementation of 'three red lines' in water allocation, conservation and protection, such as 'water quantity control in the administrative region, total water emissions control into rivers and lakes, and water utilization efficiency control' (Ding *et al.*, 2011). This system achieves the change clearly from water supply management to water demand management, which provides a fundamental guarantee for sustainable water resources utilization and the construction of a water-saving society (Hill *et al.*, 2014). It provides a scientific system for the comprehensive improvement of water environment treatment as well (Hu & Cheng, 2013).

2.2. The important task of CPFW is to implement sewage treatment

The full implementation of a 'River Administrator (RA)' is a useful way to prevent river pollution, which can strengthen the management of the water environment. Integrated coastal zone management (ICZM), provides a holistic solution to all kinds of coastal problems including geographical and political boundaries in Shandong (Wu *et al.*, 2012). Since 2013, 811 eco-actions have continued for three phases in Zhejiang Province, which strengthen water pollution control and water protection totally with the help of the RA system. Each RA, the local chief administrator, should take charge of all issues related to specified rivers or lakes. This plan makes water quality better overall in the whole region. At the same time, parts of the rivers still have environmental pollution problems, especially in some of the major rivers. Similarly to plains and coastal waters pollution, serious dirty and messy phenomena exist in some urban and rural rivers (Cong *et al.*, 2014), which directly affect production and habitat. To comprehensively improve the management of the water environment, accelerate upgrading for industry and promote stable sustained social development, 'CPFW with

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priority of sewage treatment' should be considered. The major breakthrough for sewage treatment is to attach co-governance and coordination with all hydraulic projects and schedules, such as flood prevention, drainage, and water supply and saving. So, integrated water environment improvement is a strategic decision-making part of CPFW.

2.3. The important objective of CPFW is to improve the connection of rivers and lakes with comprehensive treatments

Healthy rivers are the basic guarantee for urban flood control, water supply and ecological requirements; they are the eco-carriers, which directly reflect urban living habits, image and economic status (Xu & Tan, 2002). Rivers are a source of urban civilization, whose historical and cultural heritage play a very important role in urban construction; so the river system in a region is the basis of urban development. Multi-level living services of rivers have laid a solid foundation for any hydraulic issues. Therefore, strengthening the comprehensive management of rivers and promoting connectivity is required to repair the ecological environment and comprehensively remediate black-odor rivers. According to the hydraulic projects set, maintaining a healthy and flood secure system, as objectives of CPFW, has important scientific significance.

2.4. The ultimate objective of CPFW is to construct an ecological civilization

The construction of an ecological civilization must establish a complete system of compensation for using natural resources and the subsequent impact on the ecosystem, delineate the control redline for ecological protection, and reform human behaviors to adapt to ecological protection. To respect, obey and protect nature are the keywords for constructing ecological civilization; at the same time, the basic state policy of resources' conservation and environmental protection are considered as well. Therefore, CPFW aims to set up the concept of ecological civilization, and integrate the ecological concept into water utilization, allocation, saving and protection, water pollution prevention and so on. The ultimate target aims to construct an ecological, beautiful and harmonious living environment.

2.5. The long-term guarantee of CPFW is to continuously improve theory and understanding in water science

CPFW is not only a profound understanding of social development in China, but also a water scientific connotation in a new era. It has in-depth understanding of the current development of water science. Nowadays, water science is related to the hydrologic cycle, water resources, the water environment, water ecology, water landscape, water culture, water tourism and water safety. Current water science is multidisciplinary and has multi-sectoral characteristics, which determine the guarantee and technical support of CPFW.

CPFW involves systematic project designation and optimization. It must use a multidisciplinary methodology: including hydrology, environment, economics, planning, municipal administration and meteorology, etc. At the same time, CPFW should be government-led with multi-sectoral cooperation for the innovative and scientific concepts.

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3. Innovative methodology for CPFW

3.1. Establish the concept of watershed management, avoiding the traditional pattern of water concentration only, and enhance the theory of water treatment

Rivers are complex ecosystems with a water body, riverside and land area. They are directly or indirectly influenced by the surrounding environment, especially human activities, urbanization and climate change (Woertz, 2013; Wang *et al*., 2014; Jeuland & Whittington, 2014), which has greatly changed the natural environment of water bodies. The water body in rivers accepts the watershed runoff with various physical, chemical and biological substances constantly, which impact on downstream aquatic ecosystems (Yeh & Lin, 2005). This principle suggests that the main water issues are from the basin. So, it is necessary to extend traditional water treatments to the watershed scale to avoid a lot of manpower waste, and material and financial losses (Dietrich & Funke, 2009; Du *et al*., 2011). Therefore, using sub-basins or regions as study units to utilize water resources or protect the water environment is a scientific and effective approach.

3.2. Strengthen the water conservancy concept by combining the basin and administrative regions, developing a water partnership team

A basin is composed of numerous administrative regions. In the current management system, each administrative region has relatively independent business accounting for all social statistical data and assessments in China, while the water flows at a watershed scale. Therefore, water conservancy or pollution control must be performed at watershed scale and enhance regional coordination. Then based on the water conservancy target, a partner team should be extended in all fields. These are key paths to solve the water issues within the watershed.

3.3. Focus on considering ecological engineering in hydraulic projects and developing ecological civilization construction

With the high-speed development of society and continuous increase of human material requirements, people are gradually acknowledging that water is not only a nature resource, but also a social resource. Using limited water resources more efficiently can support the ability for social and economic development. This requires hydraulic engineering to be considered fully with ecological requirements to match the construction design. Giving full consideration to ecological engineering and extending hydraulic engineering services may break professional or departmental limitations.

3.4. Combine ecology, landscape and culture in hydraulic constructions

Today, it is necessary to research the constructions of water ecology, landscape and culture at a higher level to satisfy human requirements. We need to build an ecological civilization system, investigate the traditional hydraulic culture and develop the modern water culture based on hydraulic carriers. As important carriers, lake landscape and waterfront environments should integrate into urban landscapes, and into coastal resident and tourist environments. This directly reflects the harmonious coexistence of

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humans and nature; it is also fundamental for economic development, and for the living environment's improvement under the needs of social development.

Being a strategic decision for hydraulic development in China, CPFW is an innovative idea to meet all water demands both nationally and locally. It needs systematic theory, technology, projects and management. Therefore, comprehensive planning for CPFW is available to execute all propositions in practice.

4. Case study

4.1. Study area and water issue diagnosis

Yuhuan County, an island, is located on the southeast coast of Zhejiang Province, China (Figure 1). With industrialization, Yuhuan's gross domestic product (GDP) has reached 40.047 billion (10^9) RMB and ranks 30th in 'China's comprehensive strength hundred counties'. Agriculture, industry and services account for 6.7%, 60.3% and 33% of GDP, respectively. There are 25 county rivers, 16 big reservoirs and hundreds of small rivers and pools in 13 small watersheds. The populations for each sub-basin are

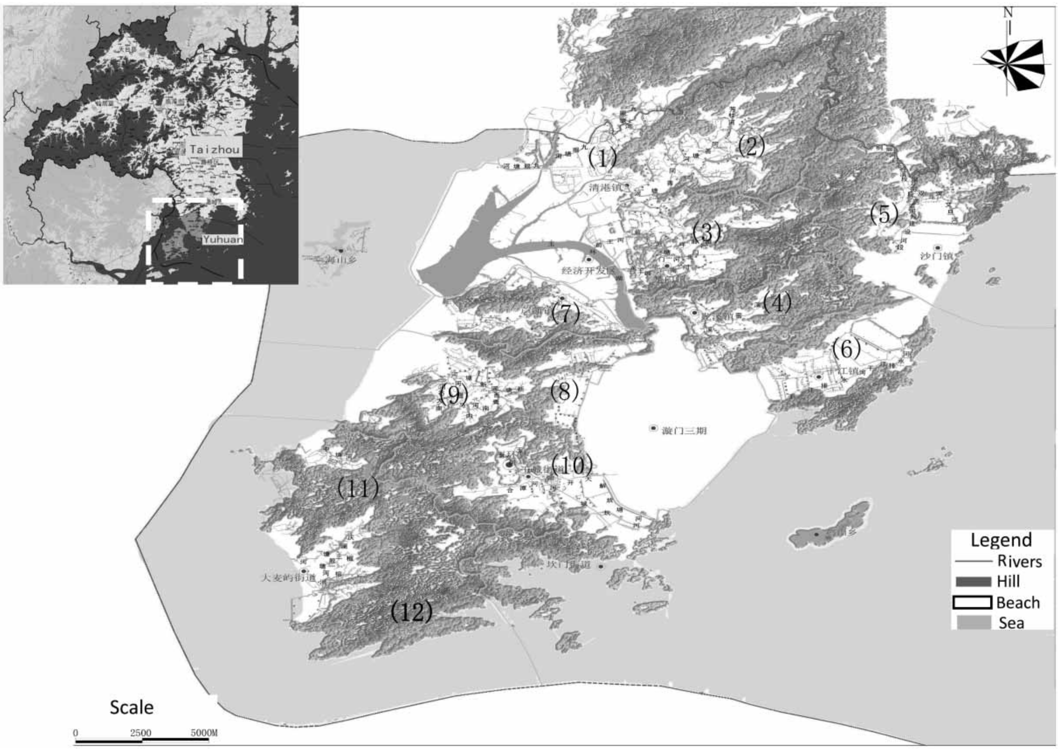

Fig. 1. The location of study area by CPFW.

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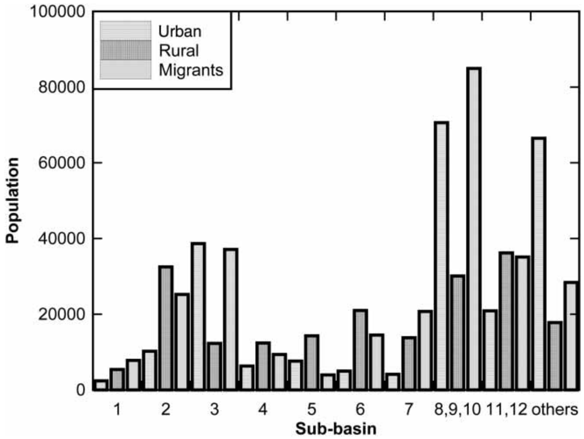

Fig. 2. The population statistics for each sub-basin.

listed in Figure 2. The total water area at normal water level is 13.04 km², and the water ratio is 3.5%. As a typical industrialized and urbanized area, meeting the water demand is major task for industry and commerce, which is achieved via water diversion projects. Ecological and agricultural water comes from local water storage.

With the high urbanization in Yuhuan County, the rivers and lakes are becoming worse and worse. According to field investigation, the key issues are listed as rapid increasing of sewage, lagging construction of sewage treatment plants and network, unreasonable water consumption and shortage of water supply, water pollution in urban regions, and safety pressures on flooding and urban drainage under extreme climate events. These issues seem independent for water management; actually they are in the same system for hydraulic protection.

4.2. CPFW planning and projects design

CPFW is a new water management concept, which is divided into five major water issues – sewage treatment, flood prevention, drainage, water supply and saving. The goal of CPFW is to keep water safe and clean. We calculate two equilibriums to reach the goal mentioned above. One is to keep equilibrium among water resources, water supply ability and water consumption. We consider the growth of the population and social-economic forecasting for water supply. Then, the potential water saving, water consumption structures and water supply projects are optimized together. With the stringent water management system in China, water-saving indices, such as irrigation water use efficiency, the Water Quota per person, water use per 10,000 RMB, GDP and so on, are used to adjust water consumption in each industrial field. Therefore, water supply-demand and the contaminants from industrial and domestic sewage are recalculated in each planning scheme. The other requirement is to keep equilibrium among contaminant emissions from all fields (agriculture, industry, services, etc.), the capability of wastewater treatment plants in each region and the environmental carrying capacity. The study area is divided into four regions with 13 sub-basins. Each study unit is calculated to decide the environmental

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goals and project capacities. So the water supply, water consumption and sewage are optimized and recalculated.

At the end, the rivers and lakes are the containers for all water. The planning discloses the desilting and ecological restoration in river bank and aquatic systems when considering flood and drainage projects. The connection for rivers and lakes can enhance the water flow and make up ecological water demands. So, these projects will add new environment carrying capacity and fresh water, to then save the water resources and decrease sewage treatments.

To achieve the goals, three project systems are listed in CPFW planning to take charge of each equilibrium. The relationships and interests for each scheme are obvious. The river hydraulic projects include 33 artificial rivers, four reconnected rivers and more ecological and hydraulic updating, which enhance the flood safety guarantee, environmental carrying capacity and water storage in the river-net. The pollutant abatement system includes three parts for sewage treatments with 41 projects and enhances the recycled water utilization. Pollution controlling engineering with 17 projects could decrease the point and non-point source pollutions by using forecasting technology. Those pollutant control projects increase available water resources. The water security system includes 37 projects as shown in Table 1. These projects are based on water demand forecast and water supply capacity with standard methods and urban planning results. According to systematic planning, the potential relations among the 'five waters' can be understood. It is more convenient to execute the combined water management policies than to execute them separately.

5. Discussion

As an integrated methodology for all water issues, this approach could be of increased interest compared to separate plans. Based on the systems mentioned above, the optimized scheme discloses great valuable benefits.

Based on water budgets in each planning year as shown in Table 2, the total amount of available water is guaranteed by water supply projects and regional diversion projects. The reservoirs and water diversion projects in Yuhuan offer sufficient fresh water of 112 MCM in 2016, 156 MCM in 2020 and 210 MCM in 2030 at a high assurance rate of 95%. Comparing with the future water-demand prediction, the water budget in each year is almost at equilibrium with the help of these projects as shown in Table 2. Water-saving projects in all fields can save water amounts of 6.3 MCM in 2016, 11.5 MCM in 2020 and 23.1 MCM in 2030. The highly efficient utilization system keeps the total water usage within the proper range designed by CPFW.

Based on a balance control between water environmental capacity and sewage emission in each planning year, the total amount of contaminant draining into rivers, e.g. chemical oxygen demand (COD), is restricted by sewage interception projects and water recycle systems. The sewage treatment plants with a network system in urban areas and non-point source pollution control in agricultural areas could decrease COD drainage into rivers of 4.6 M kg/yr in 2016, 5.4 M kg/yr in 2020 and 3.2 M kg/yr in 2030, reaching the designed emissions targets. The sewage controlling system keeps the total contaminant sources in reasonable range as shown in Table 3. The actual COD emissions into rivers are kept lower than the maximum allowed and river capacity.

Based on the hydraulic security guaranteed rates in each planning year, the rivers are reconnected systematically, and hydraulic projects with ecological engineering are set to keep flood safety and

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Table 1. Planning project systems for different years.

Project system	Major projects	Project number and schedule			Total
		2016	2020	2030	
Pollutant control system	Urban sewage treatments	17	6	6	29
	Rural sewage treatments	7	4	2	13
	Industrial, agricultural pollution control engineering	9	5	3	17
Water security system	Construction of water sources	2		3	5
	Water supply system	5	3	2	10
	Industrial water-saving measures		1	2	3
	Agricultural water-saving measures	1	1	1	3
	Urban water-saving measures	3	2	1	6
	Desalination		1	1	2
	Seawater utilization		1	1	2
	Rainwater harvesting project		1	1	2
	Overseas diversion project	1	1	2	4
Hydraulic and ecological restoration system	The river widened and connected project	13	14	6	33
	River landscape	7	1	3	11
	Water ecological restoration	13	3	5	21
	Hydraulic narrow renovation	40	4	1	45
	Ecological water supplement	1	1		2
	Seawall upgrading	1	2	4	7
	Dredging	14	12	10	36
	Revetment construction	13	14	6	33
	Gate construction	12	3	1	16
	Reservoir and pond reinforcement	4	3		7
	Creek pit stone dam	14	7		21
	Ecological wetlands	2	7	4	13
	Eco ponds		2	2	4
	Reservoir comprehensive renovation	5	4	4	13
	Waterfront cultural park		2	3	5
	Total	184	105	74	363

regional drainage operating smoothly. The river-connection projects are composed of connecting the local river-net, extending width, cleaning sediment, rebuilding river banks and embankments, recovering the ecological system, which can achieve the designed security targets. The project system will reform 77 rivers, more than 16 local river-nets and several reservoirs located in four planning hydraulic conservancy partitions in planning years. After that, the water area is increased by 0.3 km^2 and the water cycle is active. The environmental capacity of COD is to be increased by 210 ton/yr in 2016, 15 ton/yr in 2020 and 23.8 ton/yr in 2030. There are plenty of ecological projects to restore potential environmental capacity and beautify the hydraulic structures.

With the help of three systematic designations, the CPFW is executed by real projects with theoretical guidance. All works take charge of major concerns in water management and treat them properly. The potential benefits of CPFW prove that systematic consideration of all water issues could solve complex water management puzzles with the help of administration policies.

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Table 2. Water balance between supply and demand in each planning year $\times 10^4\ m^3$.

Planning years			2016				2020				2030			
Water budget	Classification	Assurance rate	50%	75%	90%	95%	50%	75%	90%	95%	50%	75%	90%	95%
Available water supply	Conventional	Surface water	6,626	5,952	5,072	4,548	6,626	5,952	5,072	4,548	6,626	5,952	5,072	4,548
		Water diversion	3,190	3,190	3,190	3,190	5,690	5,690	5,690	5,690	7,690	7,690	7,690	7,690
		Ground water	270	270	270	270	270	270	270	270	270	270	270	270
	Unconventional	Recycled water	1,095	1,095	1,095	1,095	2,190	2,190	2,190	2,190	3,468	3,468	3,468	3,468
		Seawater desalination	2,040	2,040	2,040	2,040	2,340	2,340	2,340	2,340	3,040	3,040	3,040	3,040
		Other	220	157	62	30	1,102	786	609	550	2,203	1,571	1,143	1,000
	Total		13,441	12,704	11,729	11,173	18,218	17,228	16,171	15,588	24,902	23,407	21,863	21,008
Water demand	Domestic demand		3,730	3,730	3,730	3,730	4,184	4,184	4,184	4,184	4,503	4,503	4,503	4,503
	Manufacture demand	Agriculture	1,928	2,640	3,271	3,679	2,074	2,844	3,548	4,005	2,174	2,984	3,734	4,224
		Industry	5,510	5,510	5,510	5,510	5,994	5,994	5,994	5,994	6,720	6,720	6,720	6,720
		Services	1,058	1,058	1,058	1,058	1,008	1,008	1,008	1,008	1,066	1,066	1,066	1,066
	Ecological		335	335	335	335	605	605	605	605	692	692	692	692
	Total		12,561	13,273	13,904	14,312	13,865	14,635	15,339	15,796	15,155	15,965	16,715	17,205
Supply-demand analysis	Water deficiencies		/	1,329	2,935	3,899	/	/	753	1,793	/	/	/	/
	Deficiency ratio (%)			4.29	21.11	27.24			4.90	11.34				

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Table 3. The maximum and actual admitted COD emissions comparing the environment carrying capacity in planning years.

	2016			2020			2030		
Sub-basin No.*	Maximum (ton/yr)	Actual (ton/yr)	Environment carrying capacity (ton/yr)	Maximum (ton/yr)	Actual (ton/yr)	Environment carrying capacity (ton/yr)	Maximum (ton/yr)	Actual (ton/yr)	Environment carrying capacity (ton/yr)
1,2,3,7	1,673	1,035	1,611	1,465	924	1,288	1,493	1,021	1,288
9,11,12	2,247	1,315	2,196	1,844	1,131	1,756	1,831	1,122	1,756
5	693	483	673	577	412	538	559	432	538
4,6,8,10, other	2,400	1,574	2,355	2,062	1,295	1,883	2,075	1,244	1,883

*Sub-basin numbers are the same as in Figure 1.

6. Conclusion

According to current water policy and technology, the evaluation targets and water management countermeasures of CPFW are specified in several aspects. Each part is well explained by classic theory and are then combined together by related hydraulic projects or management systems. The three systems are separately constructed; however, their functions are integrated. Combining with hydraulic engineering and their characteristics, operable approaches for CPFW are suggested on each project's designation in Yuhuan County. Sewage interception projects, efficient water supply projects and hydraulic projects with ecological engineering are combined together systematically. Owing to the serious pollution here, the integrated benefits of CPFW projects are obvious in contaminant control, which proves that the CPFW is valuable and available for guiding hydraulic issues. With a systematic planning and optimizing scheme, all hydraulic projects are enhanced to integrated functions and produce more potential benefits in sewage treatment, flood prevention, drainage, water supply and saving.

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