Water Resource Development and Ecological Reclaim in Chinese Fen River Basin

Xiao-Hong Zhang and He-Li Wang

Abstract In this paper, the author put forward some views and suggestions on water resources utilization and management and the ecological environment protection process in the future, through a new historical perspective of Fen River basin water resources development and the governmental efforts to solve the ecological troubles it caused. Fen River is the largest river in Shanxi Province and number two of Yellow River's first-grade tributaries. Along with the development of the social economy and changes in the natural climate environment, Fen River basin appeared to have serious ecological environment problems, an increasingly serious shortage of water resources and pollution trouble which brought about the bottleneck of ecological and economic development in Shanxi Province, and affected the water quality and flow of Yellow River. Since the founding of new China, there have been four massive, systemic governances of Fen River focusing on surface water development, utilization of groundwater, flood control for security, and recovery of clean water flow, respectively. All have made some significant achievements; however, the governances have not been able to fundamentally solve the problems of the ecological environment under the limitation of temporal governing ideas and capital. During the twelfth five-year projects Shanxi Province launched, the "two longitudinal and cross ten" large water program, which aims at facing and solving the trouble of uneven spatial and temporal distribution and guaranteeing the entire province's economic development demand of water resources by connecting the six major rivers and their large and medium-sized reservoirs in the province, taking the north trunk stream of Yellow River and Fen River as the two longitudinal trunks. The ecological restoration planning outline (2015–2030) that Shanxi Province issued in July 2015 sounded the horn of large-scale administering in Fen River basin for the fifth time. This new round of river basin ecological management must include: ecology—resources—environment—society—economy, the five elements

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which should be balanced considerations, none of which are dispensable; from divided ruling to shared governance within basin, from passive decontamination to active anti-fouling, from focusing on engineering construction at master stream to balance controlling of whole basin, all relevant departments and personnel need to create new ideas and actions.

Keywords Fen River basin · Ecological environment · Water resource Ecological restoration

1 Introduction

Fen River is the largest river in Shanxi Province, and the second one of the first order tributaries of Yellow River (Fig. 1) [1]. It originates from GuanQin Mountain, which is in the east village Town of Ningwu County in Shanxi Province. The total length is 695 km, of which the upstream section (217.6 km) is from the source to Lan Village stone mouth, going through the Lvliang mountains; the middle section (266.9 km) is from Lan Village to the beach of Hongtong county, which basically belongs to the river basin plain; the downstream segment (210.5 km) is from Hongtong beach to the estuary into Yellow River, as one of the main agricultural bases in Shanxi Province. The whole river basin area is 39,741 km^2, involving 45

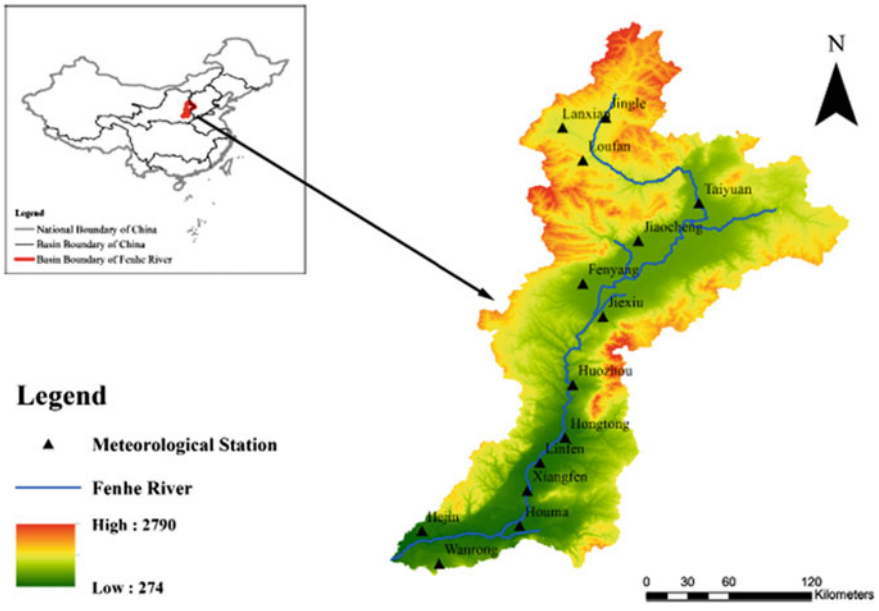

Fig. 1 Plane graph of the Fenhe River basin

counties (or city areas) of the 7 cities: Xinzhou, Taiyuan, Jinzhong, Lvliang, Linfen, Yuncheng, Changzhi. With less than a third of the entire water resources, it provides 41% of the water required for the population in the province and contributes half of the gross domestic product. Both coal reserves and coal production in Shanxi account for a quarter of China, and the province diversion volume accounts for 70% of the nation. Coal production, as the main mode of economic development for half a century, has brought about the cost of ecological environment deterioration within the scope of the whole province. As the focus of the economic development of Shanxi Province, the most developed area, Fenhe River basin has been facing a serious shortage of water resources, severe soil erosion and water pollution problems, which have become the bottleneck of the local development. To face and solve these problems correctly is crucial for the ecological economic development in Shanxi Province and even the comprehensive control of the Yellow River basin. The purpose of this article is to introduce constructive thinking and suggestions for the future management and utilization of basin water resources and ecological economic development through the observation and review of its changes in the quantity and quality of water resources and ecological environment problems co-existent with economic development, and the governmental responses to it.

This figure was quoted from the article of "The Impact of Climate Change on the Duration and Division of Flood Season in the Fenhe River Basin, China", which was written by Wang et al. [1].

2 Review of the Water Resources of Fen River Basin

The Fen River basin is often divided into two parts in the Shanxi Province water resources bulletin: the middle-upper stream and the downstream. The data that was found from 2007 and 2008 can represent the water resources status in the new century somehow (and the only shared data that could be found by a non-staff person of the water department), contrasted with an average of 45 years series (1956–2000).

2.1 Quantity of Water Resources

As shown in Fig. 2, the average total water resources quantity in Fen River basin for the 45 years series from 1956 to 2000 is 3.359 billion m^3, with a runoff of 2.067 billion m^3 and a groundwater of 2.409 billion m^3; the duplicated amount between surface water and groundwater account for 33.3% [2]. It is an important feature of surface water and groundwater to repeat for a larger proportion in the total water resources. While some large karst springs were used by wells, they are rapidly lowering, even cutoff in the clear water flow in the surface river. Compared with

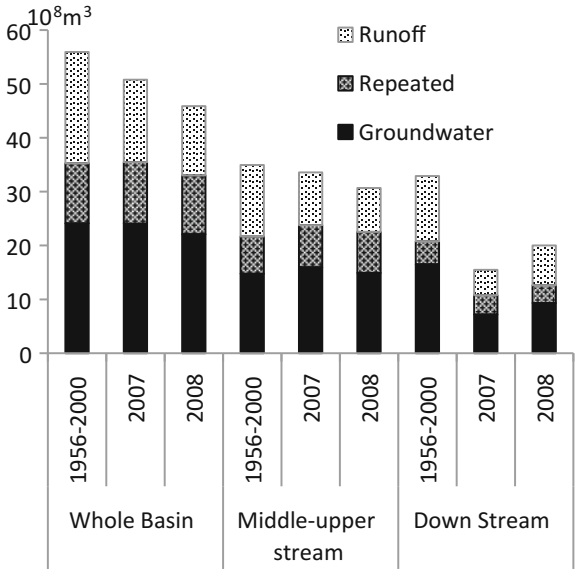

Fig. 2 The runoff and groundwater in Fen River basin

that of 1956–2000, the water resources quantity of Fen River basin in 2007 and 2008 had reductions, and the two annual amounts decreased by 17% and 28%, respectively, included in which the mid-upper stream damping were 15 and 27%, the downstream were 66 and 45% lower. The surface runoff decreased basin-wide, while the groundwater reduction only occurred severely downstream. However, in the mid-upper stream, it slightly increased.

All data were directly or indirectly from the Shanxi Province Water Resources Bulletin, which involves the quantity and quality of water resources sorted by basin and was found on the internet [2].

Basin water resources quantity and local climate, vegetation, topography and other natural conditions and social economic development are closely related. With the trend of global warming, for half a century Fenhe basin has had an obvious drying tendency; annual precipitation was in a declining trend, especially in the 1970–1990s of last century [3, 4]. This drying trend eased after entering the new century; in 2000–2013 the average rainfall was 510 mm, which rallied 10% of that in the 1990s (462.9 mm average) [5]. The selected 2007 and 2008 belong to the exceptional drought years, of which annual rainfall was only 45 and 34% of the average value in the new century, and far less compared with the average during 1956–2000 (Fig. 3).

How much of the precipitation transformed into basin water resources reflects the local underlying surface properties and human intervention on the process of water resources. From the calculation results in Table 1, compared with that of 1956–2000, the basin rainfall resource conversion rate of 2007 and 2008 were continuously improving. It was more than double the total water resources conversion, and the downstream area is 7–8 times higher due to the effect of

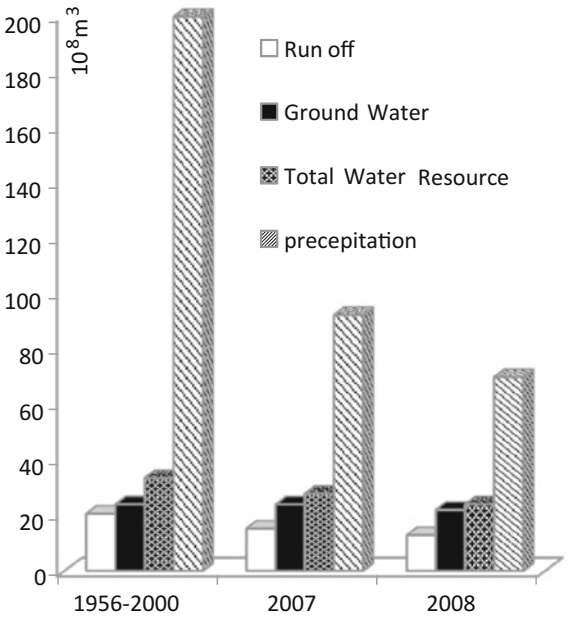

Fig. 3 Precipitation and water resources in Fen River basin [2]

Table 1 The conversion ratio of precipitation in Fen River basin (%)

		Runoff	Groundwater	Repeated amount	Total water resource
1956–2000	Whole basin	10.35	12.06	5.60	16.81
2007	Whole basin	16.59	26.03	12.39	30.23
	Middle-upper stream	20.65	33.70	16.60	37.75
	Down stream	74.50	108.59	48.21	134.88
2008	Whole basin	18.39	31.55	15.60	34.33
	Middle-upper stream	22.79	41.63	21.35	43.07
	Down stream	83.18	126.72	57.88	152.02

superposition of the upstream water. That should attribute to the continuous work of soil and water conservation and water storage management in Fen River basin after the foundation of the new nation.

2.2 Water Resources Utilization

Overload of water resources is the issue that has always been for Fen River basin, which is one of the causes of ecological environment deterioration. In the Chinese

Ministry of Water Resources' project planning for energy based in north China and Shanxi Water Resources Research in 1990, Fen River basin runoff utilization rate was 80% [6]. According to a study on the bearing capacity of water resources in Shanxi Province, Fen River basin water resources development has already reached its limits in 1998 [5]. The surface water utilization rates in 2007 and 2008 were between 63 and 85%; the 38.4% of 2000 was calculated by the temporal water resources utilization based on the average total water resources from 1956 to 2000 (Table 2). However, in fact, the amount of surface runoff was only 8.11 × 108 m^3 as a dry year and the actual temporal utilization rate was as high as 97.78%. Internationally recognized the rational development and utilization rate of surface water is 30–40% [7, 8]. Referring to the calculation results of the ecological water requirement [6, 9] to take 30% as the safe utilization rate for mid-upper stream and 40% for downstream, Fen River basin surface water resources was overloaded by 1–3 times.

The long-term unreasonable groundwater overdraft led to the declining of the underground water level and the formation of multiple urban funnel areas within Taiyuan basin and Linfen basin. For example, in 1965 the funnel area with closed area of 11.2 km^2 occurred and the buried depth was 16 m in Taiyuan city, while in 1987 the funnel area expanded to 298 km^2 and the buried depth dropped to 55 m. Although Taiyuan, Linfen, Lvliang, and Jincheng began to gradually implement the shut-in well and suppressing action to reduce the area of groundwater overdraft since 2003, and the groundwater level in some regions has stopped decreasing and even began increasing [10, 11], this recovery process was very slow, and had inversion because of the huge upfront overexploitation. According to Shanxi Province water resources evaluation, compared with 1986, 2010, Taiyuan basin and

Table 2 The water resources utilization in Fen River basin (10^8 m^3)

Year	River segment	Runoff			Groundwater		
		Water resource	Output of supplying	Use ratio (%)	Water resource	Output of supplying	Use ratio (%)
2007	Whole	15.3199	9.7062	63.4	24.0365	15.9466	66.3
	Mid-upper	9.7679	6.2232	63.7	15.9439	10.593	66.4
	Down stream	5.552	3.483	62.7	8.0926	5.3536	66.2
2008	Whole	12.8737	10.0685	78.2	22.0819	15.7927	71.5
	Mid-upper	8.1561	6.877	84.3	14.8955	10.9407	73.4
	Down stream	4.7176	3.1915	67.7	7.1864	4.852	67.5
1956–2000	Whole	20.67	7.93*	38.4	24.09	17.02*	70.7
	Mid-upper	13.27	–	–	14.76	–	–
	Down stream	7.4	–	–	9.33	–	–

Note *the data was for 2000

Linfen basin in plain groundwater level still fell cumulatively by 8.15 m and 3.81 m, respectively [12].

2.3 Water Quality of Fen River Basin

The environmental quality information posted on the website of China Public Environmental Research Center [13] showed that Fen River is one of the most polluted tributaries of the Yellow River. According to the report of the water resources in Shanxi Province in 2006–2008 [2], down from Taiyuan Shop Bridge the Fenhe River quality was all worse that can just be used as agriculture use water and general landscape water. Actually, back by 10 years, from 1998 to 2007, it had always been like this [14]. Upstream Lan Village and Jingle water quality was relatively good, except for individual year individual items slightly exceeding the standard, and could basically achieve II and III class standard. However, on the village cross section, which is in Gujiao city, the water quality was always worse. Regarding Fen River pollution, its mainly exceeded standard items are ammonia nitrogen, petroleum, chemical oxygen demand (COD) and volatile phenol, which are mainly from effluent sewage of coal gas, coking, petroleum, chemical, steel and paper industry, synthetic materials, food, livestock and poultry feed and other factories. According to the statistics, from 1998 to 2006 Shanxi Province annually discharged effluent sewage by an average of 8.45 $\times$ 108 tons, of which industrial effluent accounted for 77.5% and Fen River basin accounted for 40.1% [14].

3 Review of the Water Resources Development and Ecological Economic Harnessing

3.1 Traditional Development Processes

As one of the most important forefronts of industrial and agricultural economic development in Shanxi Province, Fenhe basin reflected the characteristics of a different era of water resources development pattern and intensity with its economic and social development process. Before the metaphase of the 1960s, it mainly held the characteristics of retaining surface water, and had a large number of medium and small reservoirs and irrigation areas. Although the water resources development growth is larger, it was overall on a smaller scale, and water resources utilization rate was less than 30%, which belongs to a low-level water consuming pattern. In the mid-1960s to mid-1980s, priority was given to large-scale development of groundwater with drilling supporting, and different degrees of water shortage areas began to appear. That limited the further development and potential of regional water resources. Therefore, industrial and agricultural production water consuming

began to transition to a water-saving style, which started the attention to the integrated management of water resources. Since the mid-1980s, it became a water resources comprehensive development period to meet the energy-based construction and the economic and social development in Shanxi Province. The water resources utilization rate had reached 70%, and the groundwater resources development degree was higher. It was close to a threshold by the end of the 1990s; the whole Fenhe basin had none or small further development and utilization potential [7]. This period development approach gave priority to deep development and optimizing configuration, and the integrated water resources management reached quite a high level. The deep-water resources development lasted until the early 21st century, as the results of Zhang and Feng [15]. Using the method of ecological footprint to research Shanxi Province water ecological carrying capacity, in 2001–2010 Fenhe basin showed ecological footprints that were greater than the water resources carrying capacity and presented a water deficit over the years [15].

3.2 Clear Water Reoccurring Engineering of Fenhe Water Streams

Continuous development caused Fenhe basin to face water resources shortage and poor water quality, as well as ecological environment deterioration problems, which had become a bottleneck restricting the further development of the local economy. Since 2008, a systematic engineering involving many departments and multi-disciplines, Fenhe Water Reflowing Engineering, officially started the ecological environment governance with repair and protection work in the new century. It also was an important part of the Large Water Project in Shanxi Province. Shanxi large water network aimed at constructing an engineering skeleton covering the entire province's six big basins and major economic centers, taking the north natural trunk of Yellow River and Fen River as the two main longitudinal lines and plus the ten key traverse water supply system, to focus on the uneven distribution of water resources and realize sustainable utilization efficiently. As one of the two main lines, Fenhe streams in engineering played a vital role. According to the serial dissertation reported [16], NingWu of Xinzhou, where Fenhe source lies, was focusing on soil and water conservation and rational utilization. It was proposed by implementing in stages of recent (2 years), medium (5 years) and forward future (10 years) repairing, immigration reclamation and water conservation projects, to reduce soil and water loss. In the middle stream Taiyuan and Jinzhong have expanded and constructed new sewage treatment plants for sewage purification, shut-in wells to compress groundwater consumption, and constructed artificial wetlands to realize water body restoration. All these actions obtained certain effects; for example, the underground water level of two water sources of LAN Village and Xizhang had stopped decreasing and realized an increase again for the first time since 1987. Linfen City, the downstream segment that was facing serious water

pollution, started unprecedented governance within 3 km of Fenhe range by closing down or relocating polluting enterprises that did not meet industrial policy or affect Fen River water quality. In 2012, Linfen City began constructing "Fen River Ecological Economic Zone in half hundred kilometers". It took ecological restoration as the starting point and implemented construction of roads, industrial parks, cultural tourism and urban areas.

3.3 Further Ecological Restoration Plan in Fen River Basin

The new century's Fen water reflow project has achieved initial progresses: surface water regulation and storage functions have been significantly improved; the histories of the drying of the Fenhe have ended; part of the local groundwater table also achieved a cease in the decrease and a rebounding. However, the whole Fen River Basin is still faced with falling water tables, reducing surface runoff, decrease and degradation of vegetation, soil erosion and other outstanding issues. The watershed's own "blood" production and flow function have not been restored. In July 2015, Shanxi provincial government formulated the "Fen River Basin Ecological Restoration Plan (2015 to 2030)". It can be said that this is the fifth large-scale governance program of the Fen River in Shanxi Province. Its overall goal is with multi-investment of ¥130 billion, after five years of construction and 10 years of natural restoration, that is after a total of 15 years of effort, to make a substantial increase in groundwater reserves and the area of vegetation in Fen River basin, to effectively control erosion and water pollution and make the groundwater level rise, so as to have the reappearance of the splendid scenery of Fen River. There are six specific measures included: 1. adhere to the principle of water-saving priority through scientific configuration of land and water resources, vigorously promote a water-saving society and encourage efficient use of water resources; 2. rely on the built programs of Wanjia Village Yellow River Diversion, Yumenkou Water Lifting, Citing Qin Water to Fen River, and the under-constructed Guiding Yellow River in Central, Dongshan Water Supply Project, implement the "Giving assistance to Fenhe with five waters", increase the amount of surface water resources and to protect the watershed healthy economic and social development through the water transfer network in Fen River basin; 3. restore and build a number of regulating water storage projects such as "string of pearls", "bunch of grapes" in low-lying areas on both sides of the Fen River, to make full use of flood resources and make efforts to increase groundwater recharge; 4. define according to law the Fen River and its major 9 tributaries' source protection areas, closing off to restoring vegetation, so as to achieve water conservation and increasing streams and greenery; 5. strictly control the exploitation of groundwater in the basin, shut down coal mines within protected spring fields and the nine tributary source protected areas according to the law, strengthen the protection of eight large karst fields and groundwater systems; and 6. in mountainous areas vigorously implement the building of clean small watersheds; in plain areas control sewage discharge,

strengthen pollution prevention through comprehensive treatment and sewage interception at the 10 tributaries in Taiyuan City to utilize water resources [17, 18].

4 Thinking and Proposing

From the point of historical exploitation of water resources and ecological environment management view, Fen River Basin watershed has also experienced the old route of resource over-exploitation, environmental degradation and then ecological restoration. More than 50 years of development after the founding of the nation almost depleted its groundwater resources and caused it to face the problems of surface runoff which is shrinking year by year, vegetation cover reduction, exasperation of water quality and environmental degradation. Fortunately, at the dawn of the new century, with the rise of the concept of sustainable development, people began to awaken. Starting in 2008 the Water Flow Reoccurring up until introduced in 2015 "Fen River Basin Ecological Restoration Plan (2015–2030)" [18], the Fen River Basin governance and economic restructuring and development organically combined, makes the future completely effective ecological recovery of Fen River basin to be just around the corner. However, looking at the several developing governance actions in Fen River Basin, there are two major issues to note: first, it pays more attention to the development of resources but lacks effective water pollution prevention and controlling; second, too much rely on the government-leading and less popular participation.

4.1 Resolving the Importance to Water Pollution Problem

Water scarcity is a big problem throughout Shanxi Province, so it is natural that several decades of governance of the Fen River basin was mainly centered on how to get more water. The design of "Five Waters Assisting Fen River" in Shanxi Large Water Network Engineering is mainly aimed at solving the uneven distribution and shortage of water resources in the basin. In the "Fen River Basin Ecological Restoration Plan (2015–2030)" the treatment of sewage discharge on 10 tributaries in Taiyuan was mentioned, but obviously the water pollution problem was not the topical subject. It cannot be neglected that Fen River water quality has not been resolved, especially, so far most of the time the middle and lower reaches of the river were inferior class V, while the "Fen River Basin Water Pollution Prevention Act" [19] has been issued and began to be implemented in 2005. It is considered that in the early stages of the management of the water reflow project, implementation of flood control, environmental protection, afforestation, landscaping, leisure and entertainment as one integrated work in Taiyuan, Linfen, etc. basically avoided the sewage governance [20]. It is time for Fen River to take

unified action on trunk and tributaries for pollution control, learning from the experiences of River Thames and others.

4.2 Integrating Departments to Comprehensive Management Within the Basin

To improve the antifouling and pollution control, it is necessary to pay much attention to it and take action from the top to the bottom. The Government should not just focus on GDP development overlooking and winking at contaminant enterprise; those who created the pollution are responsible for treatment and it should not be just a slogan as well. To urge its real action, it is rational to proceed supporting subsidies to enterprise that have the ability to perform pre-sewage treatment and to charge those with reasonable fees based on the number and nature of emissions for sewage treatment plants' operation and maintenance. Comprehensive management of the whole basin requires breaking the boundaries within administrating departments and industry sectors, having good communication and coordination on technology, policy, action and benefits, moving from divide and conquer to basin cohabitation. A comprehensive management committee of Fen River basin could be established on the basis of the original relevant departments, such as the Upstream and Downstream Water Management Sites, Fenhe Reservoir Authority and the Fen River Irrigation Authority, to discuss and decide the allocation and utilization of water resources. Environmental Protection Departments should be given sufficient regulatory powers for illegal sewage investigating and treating. The Water Information Department should organize and release information dynamically for the convenience of water use, management and conservation.

4.3 Monitor and Open Dynamic Information to Common Participation

Automatic monitoring stations built on municipal boundaries of Fen River basin have been put into use. Relevant departments should make full use of this new dynamic monitoring platforms to keep abreast of the changes in water quality and to provide information supporting water pollution control, not only to the water departments, but also to the public. Basin water governance requires the top-down driven auspices, but also the bottom-up supporting and participation of the popular. In terms of water pollution monitoring, if the public could immediately report to the environmental protection department as soon as an abnormal condition occurred in the river or they found some secretly sewage discharging, it would greatly improve the efficiency of supervision. To increase public participation in the initiative, in

addition to a good publicity and education program, more open and transparent information is necessary. Bulletining on schedule the changes of water quality and quantity, associated with development and utilization planning and implementation progress basin-wide, so that all interested people can learn readily and conveniently, thus to actively participate in governance of the basin.

5 Summary

As the largest river in Shanxi Province and number two of Yellow River's first-grade tributaries, Fen River is confronting serious ecological environment problems; increasingly serious shortage of water resources and pollution trouble; and it is bringing about the bottleneck of ecological and economic development in Shanxi Province, and affected the water quality and flow of Yellow River. A new round of river basin ecological management measures are imperative, which must include: ecological—resources—environmental—society—economy. The five elements should be balanced in consideration; none are dispensable; from divided ruling to shared governance within the basin, from passive decontamination to active anti-fouling, from focusing on engineering construction at the master stream to balanced controlling of the whole basin, all relevant departments and personnel need to create new ideas and actions.

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