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China's Water-Saving Irrigation Management System: Policy, Implementation, and Challenge

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Received: 1 November 2017; Accepted: 13 December 2017; Published: 15 December 2017

Abstract: In response to the increased competition for water, the Chinese government has determined to promote water-saving irrigation (WSI) followed by a range of institutional arrangements and policy goals. Three management mechanisms are analyzed in this study in terms of effectiveness, including the top-down regulation mechanism using direct control or economic instruments, the design-bid funding mechanism mobilizing local governments by competitive grants program, and the bottom-up participation mechanism transferring more irrigation management responsibilities to end-users. Although the WSI management has achieved notable improvements by the combination of different mechanisms, conflicts among different policy goals, uneven distribution of financial resources, and insufficient participation from water users caused the difficulty in aligning stakeholders' incentives. Approaches are needed to enable sustainable management by coordinating incentives from different stakeholders in the management, as well as incorporating end water users to assist decision-making.

Keywords: management reform; top-down regulation; design-bid funding; bottom-up participation; Shiyang River Basin

1. Introduction

China encompasses almost 20% of the world's population with only 6% of the world's fresh water [1], leaving it with much less water available per capita than most other countries. Over the past few decades, expanding agricultural production, increasing industrial output and growing population with more water-intensive lifestyles have all exacerbated the scarcity of China's available water resources [2]. Faced with growing competition from urban and industrial sectors, the agricultural sector is likely to experience serious water scarcity problems in the near future. These problems are aggravated by the low economic output per cubic meter of water. Furthermore, socioeconomic development will require more food production [3], leading to the further demand for water in agriculture. In the meantime, the agricultural sector still consumes the largest proportion of the county's water (62.4% in 2016) [1], but with a low level of water use efficiency. Specifically, the ratio of the volume of water used productively by crops to the total quantity of water supplied was 0.55 in 2016, far behind the developed world of 0.7–0.8 [1,3]. Thus, in response to the increased competition for water, there is great potential for water-saving irrigation (WSI) to achieve sustainable water use while maintaining agriculture development in China.

To address the above concerns, various WSI technologies have been developed to save water use in agriculture from the supply of irrigation water to its final use on crops. Wang et al. [4] made one of the earliest attempts to summarize the various technologies, and divided them into two categories: engineering measures, such as canal lining, drip irrigation, and intermittent irrigation; and agronomic practices, such as water-matched production, biological water-saving technology, and soil moisture conservation. Wang et al. [5], on the other hand, divided WSI technologies into three categories: traditional technologies, such as border irrigation and furrow irrigation; household-based technologies, such as using plastic sheeting and surface pipe; and community-based technologies, such as drip irrigation, using underground pipe and canal lining. Other studies have investigated the implementation of these technologies, their adoption, real impacts, and the problems encountered in carrying them out. For instance, Deng et al. [6] discussed various biological mechanisms of the WSI technology in the arid and semiarid areas of China; Chai et al. [7] analyzed the implementation of WSI technologies in China and its social, economic, and environmental impacts. Zou et al. [8], Ingman et al. [9], Tang et al. [10], Feike et al. [11], Khor et al. [12], and Mamitimin et al. [13] investigated the factors influencing the adoption of some of the widely-implemented WSI technologies. Undoubtedly, the practices of WSI technology are of broad interest, with much learned from these, and other, studies.

Nonetheless, the extent of WSI technology use remains low in China [4–7]. To facilitate a more successful adoption of WSI technologies, a set of policies have been pioneered by the Chinese government to foster management change. However, the administrative multi-level and multi-sector structure limits the effectiveness of these policies [5]. Additionally, financial shortfalls from the local governments [14,15] and insufficient participation of farmers [16] also affect the implementation and success of WSI policies [17,18]. As a response, WSI management has been reformed to intensify the connection among macro-level water-saving policies, meso-level policy implementation, and micro-level irrigation water users. For instance, the central government has issued policies to mobilize local governments by providing special funds to fill the fiscal gap for WSI investment [19,20]; Water User Associations (WUAs) have been promoted to take on the irrigation management responsibilities in rural China [21]. In the changing policy environment in China, it is essential to conduct more detailed and empirical assessment of the performance of WSI strategies taken by the government and farmers. Unfortunately, there have been relatively few studies focusing on the status of the WSI management system. There is almost no systematic information on management mechanisms of the WSI, its experience and lessons, although they are urgently needed.

This study aims to enrich the current understanding of the on-going WSI management policies, the mechanisms of how WSI policies have been implemented, and the challenges that the management system is currently facing, thus providing information for further sustainable WSI management. To this end, we have collected data and information on the way that agricultural water has been managed and the effectiveness of different management measures. A case study, carried out in the Shiyang River Basin, has also been analyzed in this paper to illustrate the consequences of the WSI management reform in practice. The research method used in this paper includes an extensive and critical review of academic literature on the technologies, institutions, policies, strategies, and progress involved in WSI. For the case study, we organized site interviews and focus group discussions with a variety of stakeholders from June 2016 to August 2017 to collect information on local water management regulations, government plans, and other relevant information on the studied area.

The remaining sections of this paper are organized as follows: Section 2 provides an overview of China's WSI management policies and its implementation; in Section 3, we give a more detailed discussion of the WSI management by providing empirical evidence for their implementation in the Shiyang River Basin; and Section 4 summarizes the findings and concludes the paper.

2. Overview of Water-Saving Irrigation Management

2.1. Institutional Arrangements

The administrative structure of China's agricultural water management has grown into a vast and complex bureaucracy with overlapping competences and responsibilities [22,23]. China's political administration structure consists of five hierarchical levels: centre, province, prefecture, county, and township [24]. According to China's Water Law [25], the Ministry of Water Resources (MWR) has the primary responsibility for agricultural water management at the central level. The role of the MWR is to develop and enforce water government laws and regulations, and to supervise water-saving investments by providing technical guidance. In addition to the MWR, other central authorities in China are also involved in the management of the agricultural water management by law [25], including the Ministry of Agriculture which is responsible for developing local water allocation schemes and extending water-saving technology, the Ministry of Environmental Protection which plays a crucial role in water pollution prevention and control, the Ministry of Geology and Mining which provides the information about the groundwater level with respect to groundwater pumping permits, and the State Price Bureau which assists in setting irrigation water price guidelines at the provincial level.

Below the central government, many subnational water management authorities also influence the implementation of the WSI. The Water Resources Bureaus at the provincial level, and the Water Affair Bureaus at the prefectural and county level take most responsibilities for executing WSI policies [26,27]. Those bureaus all link vertically to the MWR to implement the decisions by a higher-level authority. Horizontally, the heads of local bureaus are appointed by local leaders of their own jurisdiction, and thus water management rules and policies were frequently carried out as influenced by local interest [5]. To deal with potential water use conflicts among different jurisdictions, water resources management opted for river basin authority that manage the whole basin's water across administrative boundaries [23,25]. Each of China's seven major river basins, such as the Yellow River Basin, has a National River Basin Conservation Commission, working on behalf of the MWR to manage the basin's water resources. For some of the important basins that lie within the same province, but across different prefectural levels, such as the Shiyang River Basin in Gansu Province, a Provincial River Basin Conservation Bureau has been set up to exert managerial responsibilities empowered by the provincial Water Resources Bureau. The key tasks of the river basin authority are to set an annual quota for water delivery, constructing WSI conveyance structures, and providing more reliable timely irrigation water deliveries of the river basin under their charge [25,26].

Most of the large and mid-sized Irrigation Districts (IDs) have specially set-up bureaus which are responsible for agricultural water conservancy facilities and agricultural water allocation [28]. The ID management bureau is a professional agricultural management organization and their leaders report to local water Resources/Affair Bureaus. Under the ID management bureau, the irrigation stations at township level are directly responsible for allocating agricultural water, maintaining irrigation facilities, and collecting irrigation water fees. Each village has coordinators with executive responsibility given by irrigation stations. Small IDs will be managed directly by a collection of village farmers, with the managers of the small IDs being either village leaders or informally chosen leaders by consensus.

2.2. Water-Saving Irrigation Policies

Agricultural water management has been changed from supply-side management to demand-side management since the revision of China's water law in 2002 [29]. Historically, projects focusing on exploiting more water to meet the increasing water requirements have been given the highest priority. Various surface water and groundwater exploiting projects were built to support the expanding of irrigation areas and the growing of water-intensive crops. However, the cost of exploiting new water resources is increasing especially where the groundwater table has fallen significantly, and massive reliance on irrigation has also produced adverse ecological outcomes [30]. It has become clear that a supply-side approach is insufficient to deal with the growing water demands [30,31]. Gradually, the management objective has shifted to stem the excessive rising demand by the more efficient use of irrigation water.

The 11th Five-Year Plan (2006–2010) [32] set out a series of policy goals for the WSI management. These included (a) shifting from supply-side to demand-side management and quota control; (b) adopting a more unified river basin management system and integrating it with regional development; (c) establishing a preliminary system of water rights trading; (d) developing the WSI to improve the water use efficiency to achieve a zero growth of agricultural water consumption; and (e) increasing the average agricultural water-use efficiency from 0.45 in 2005 to 0.50 by 2010. The 12th Five-Year Plan (2011–2015) [33] emphasized the following water-saving management goals: (a) implementing the strictest water resources management system with volume control and quota management, and perfecting the water allocation scheme; (b) reforming the water price system; (c) promoting WSI techniques and adding 5×10^7 mu (1 mu = 666.7 m^2) of high-efficiency WSI area; and (d) increasing the average irrigation water-use coefficient to 0.53 by 2015. The current 13th Five Year Plan (2016–2020) [34] also has plans for water resource management, which includes: (a) continuing to implement the strictest water resources management system; (b) limiting the production scale, which should be based on local water resource conditions; (c) increasing the average irrigation water-use efficiency to 0.55 by 2020 and 0.60 by 2030, respectively; and (d) reforming agricultural water price and promoting the practice of the WSI.

2.3. Three Management Mechanisms for Agricultural Water Saving

To implement national WSI policies, the traditional management mechanism is a top-down mechanism, which includes direct control and economic instruments [35,36] with responsibilities assigned over a range of vertically—and horizontally-interlinked government authorities. However, a lack of coordination inherent in China's administrative structure hampered the effectiveness of policy delivery [37,38]. In recent years, the central government has delivered WSI policies with greater reliance on task-specific governance. Instead of using a chain-of-command sense, the central government realizes WSI goals using the application model. Special funds have been designed at the central-level and reached to the basic-level directly [14,17,37], which bypasses the conventional hierarchy. Nonetheless, a lack of alignment and connection between the government and end-users of irrigation water led to the high cost and low efficiency in implementing WSI policies. These concerns have encouraged participatory irrigation management reform by introducing the Water User Associations (WUAs). The WUAs have been considered as a bottom-up organizational form of water governance aiming at enhancing better irrigation performance [16,19,39,40]. Below, we present the three management mechanisms: top-down regulation, design-bid funding, and bottom-up participation.

2.3.1. Top-Down Regulation

The top-down bureaucratic system empowers the central government to have more control over decision-making than lower-level governments. In the case of the WSI, this mechanism includes direct control and economic instruments [36], aiming at allocating water resources and increasing farmers' awareness of their irrigation costs.

The direct control relies on mandatory measures, such as reducing the area of irrigated farmland, restricting the cultivation of high water-consuming crops and introducing a water consumption permit system. The permit system, which was introduced to China's water law in 2002 [25], stipulates that river basin management authorities and local bureaus should set their irrigation quotas among different administrative regions. All water users should obtain their allocated water with permits from the water management authorities and should not exceed the allocated amount. The approved abstraction permit is formulated according to river basin' water allocation plans issued by the upper-level water administrative department or the river basin management authorities [41]. Permits for IDs are the amount of water that can be used for crop production. The implementation of, and emphasis on, the quota management in the agricultural sector began only in recent years and remains in the pilot phase [41,42]. In some of the pilot areas, water use permits have also been assigned to individual farmers and vary annually by water supply and crop type [31]. Farmers deposit money for the allocated amount according to the permit, and the irrigation stops once the allowed volume is acquired [30]. By the establishment of a permit system, individual farmers have de facto rights to agricultural water through their ownership of a permit. In theory, this kind of water right can be traded, but farmers hardly ever sell their water to others because of the high transaction cost in finding trading partners and the flat trading price determined by the IDs [30,31,42]. Mandatory measures negatively affected farmers' agricultural income, resulting in a low support rate of the policy enforcement [43,44].

Economic measures made based on market signals have also been introduced. The water price reform is the major part of economic instruments in China's WSI policies [5,22]. The first-time water pricing regulation was made in the early 1980s when the state council determined to build a water fee accounting system [22]. Since then, the pricing policy, which prescribed that agricultural water should be treated as market goods to adequately cover the water supply cost, has been reformed. In 2016, a comprehensive agricultural water pricing reform was initiated to gradually increase the water price to guarantee the operation cost of irrigation projects, adjust pricing strategies to encourage saving and punish wasting, and invest in water-saving infrastructure and facilities to lower the cost of the water supply [45]. The water price reform has caused an increase in the price of water to address the nation's water crisis. However, China's farmlands are highly fragmented and small-scale in nature [6,20], and infrastructure for monitoring flows at the individual user level is still unfeasible due to high cost. Thus, water fees are usually collected above the household level. That is, individual households pay a proportion of the total collected water fee based on the size of their irrigated land and regardless of the actual amount of water they have consumed [28]. Further, farmers' water demand is relatively inelastic under the current water pricing system [46], and raising the price will not likely decrease irrigation water use by a significant amount [11,12]. Only a tremendous increase in water price would lead to a significant reduction in farmers' water demand [47,48]. However, such a high increase in the water price occasionally conflicts with other policy goals, such as raising rural incomes and maintaining food security. All these difficulties impede the progress of water price reform.

2.3.2. Design-Bid Funding

In contrast to the central government's strong determination of promoting the WSI, local governments have responded slowly because of the institutional barriers inherent to China's administrative structure. Recently, a significant trend in management reform has been the direct allocation of WSI funds in grant programs [37,49–57]. The grant programs are designed by the central government with specific water-saving outcomes [20,52]. Local governments bid for the WSI program in order to obtain additional benefits other than general operating funds [20]. Thus, we refer to the designing and bidding of grants program as "design-bid funding" mechanism for the WSI management. One of the major factors driving the design-bid mechanism is the fiscal deficits of local governments [17,18,38]. Since China's revenue-sharing reform in 1994, the central government has increased its ability in collecting taxes by the recentralization fiscal control [49] and, thus, decreased the revenue for local government. Further, the complete elimination of agricultural tax in 2006 continued moving fiscal control away from local governments and shifted it to the central government [17]. Consequently, the provision of public services, such as WSI promotion, has increasingly depended on the funds provided by central governments' fiscal transfers [14,15]. The affluent central government also has the capacity and will to invest in the WSI by designing special funds, and asks local governments to apply for the funds by the competition with other local governments [20,56]. This design-bid mechanism in the WSI management is quite different from the top-down regulation, as local governments have the autonomy to decide whether they would like to apply for the funds or not. Meanwhile, this mechanism also provides the central government with an effective controlling power by a task-centred mode of mobilization [50].

The design-bid mechanism also makes a full use of the bureaucracy system while reducing the vertical and horizontal administrative barriers [54]. The central government addresses the nation's growing water shortages by designing competition funds for the investment in village-level irrigation systems. To offset the shrinking revenues, local governments will do the best to win the bid by setting up a team from different departments and integrating the information from these departments [17,37]. Additionally, getting the funds will also rebound to local officials' credit [52–55].

Thus, the design-bid mechanism realizes the water-saving goal through the coordination between the central and local governments. In local government's pursuit of external funds, vertical hierarchical institutions and horizontal departmental arrangements will be broken up and recombined for a short-term [50]. Additionally, the status of the WSI development will be synthesized and submitted to the upper-level government [56]. Consequently, local officers have the incentive to discover the potential water using problems within their jurisdiction during the application process [37,50,56].

The competition for funds from the design-bid mechanism play an increasing role in water conservation engineering and demonstration work [57]. However, the mechanism also faces with striking deficiencies in application and implementation. During the application, the central government will provide guidelines with specific objectives and strict rules on realizing the objectives [52]. Low-level governments have little voice in the formation of guidelines, such as the promotion of drip irrigation among smallholders, and a lack of understanding of the farming practice led to a wasteful use of funds [51]. Moreover, WSI funds were frequently allocated to highly-advanced water-saving technologies, such as automatic irrigation. The advanced technologies are usually favoured by large-scale operation farmers or enterprises because a considerable labour input can be saved together with saving water [53]. Those entities also have the power to lobby authorities and obtain financial support [56]. The government, on the other hand, is eager to create "highlights" in the shortest possible time, requiring that the project pilot units must have strength. This, in turn, means that the priority will be given to those with larger operation scales, and that little attention has been paid to smallholders who will contribute a more significant potential for water savings through water management [22]. Lastly, each of the funds has its specific objectives to the view of higher authorities, but all local affairs involve synthesis [37]. Thus, local governments always combine different funds into one area [57], leading to the uneven distribution of fiscal resources and widening development gap among regions.

2.3.3. Bottom-Up Participation

Both the top-down mechanism and design-bid mechanism are nested in the authority system which excludes water users from the decision-making process. The Water User Associations (WUAs), as a public participatory organization, are considered as an effective entity for democratic decision-making at the lowest level [16]. The potential advantages of WUAs include better facilitating water-related affairs, such as water fees' collection and water delivery, improvement in resolving water use conflict such as opportunistic behaviour prevention, and lower costs of operation and maintenance of the irrigation system [16,40,43,58]. Since the mid-1990s, by introducing the WUAs, the participatory irrigation management reform has become the mainstream in China [43]. In 2005, the central government announced that the WUAs were a way for the effective water management [59] and determined to introduce the WUA over much of the country. However, in its implementation, increasing the number of WUAs or irrigated areas covered by WUA-based management has become the priority objective, and led to a rapid growth of the WUAs numbers [60]. By the end of 2014, 834,000 WUAs had been established and commanded 284 million mu farmlands, which comprised 29.2% of the country's effectively irrigated area [61]. With the establishment of WUAs, irrigation management responsibilities have been transferred from the government agencies to local water users to manage the agricultural water more effectively in a decentralization way. However, the performance of the WUAs varies considerably in water-saving [60,62–64].

The bottom-up WUAs formalized by the World Bank [40], and replicated in China with little attention to local context, resulted in a low success rate [39,40]. In China, the village is the lowest-level administration unit, and the leaders of village include both village committee head elected by village members and party secretary selected from above by the party organization. Since WUA has the identical administrative boundaries with the village rather than the established based on hydrological boundaries, the WUA board is usually comprised of the village leadership [58,64]. According to data from a large-scale survey during 2012 and 2016, it is estimated that 61% of the investigated WUA board was promoted by village leaders and that only 14% were elected through the democratic voting process [65]. The establishment of the WUAs can be considered as the provision of professional personnel for the responsibility of water-related coordination at the village level. Although participation by villagers has played only a minor role, it was found that the WUAs help increase the water use efficiency, as well as reduce water use conflicts [66,67].

3. Lessons from the Practice: The Case of the Shiyang River Basin

3.1. The Case Study Area

The Shiyang River Basin (SRB) is an inland river basin located in Northwest China, where water shortages are most severe, and the management measures are changed rapidly and dramatically. The basin (Figure 1), surrounded by the Baddan Jaran Desert and the Tenggli Desert, has an area of about 41,600 km^2 and annual runoff of 1.56 billion m^3. Due to the low precipitation and intensive evaporation, irrigation plays a critical role in local socio-economic development, and water conflict is quite serious among different sections. The upper stream of the SRB is the Qilian Mountain Range. Runoff, mostly formed from precipitation and snowmelt, provides surface water and groundwater for the whole basin. In the SRB, increasing grain production to meet the demands of the growing population and alleviating poverty used to be given the highest priority. The government statistics show the irrigated area increased by 30%, grain output increased by 45%, and the total amount of water use increased by 75% from the 1950s to 2003 [68]. Many dams have been built in the upper stream and middle stream to ensure sufficient water supply on their own account, causing the surface water flowing to the lower Minqin oasis to reduce rapidly from over 500 million m^3 in the 1950s to 98 million m^3 in 2003 [68]. In response to the increasing water demand and decreasing spring flow, those downstream greatly expanded their number of tubewells to pump groundwater for the expanded irrigation demand. In Minqin County alone, the number of tubewells peaked at 14,000, accounting for about 1/3 of Gansu Province's total amount [69]. The severe water conflict among different reaches caused the serious overexploitation of groundwater and a continuous decline in the groundwater table [70].

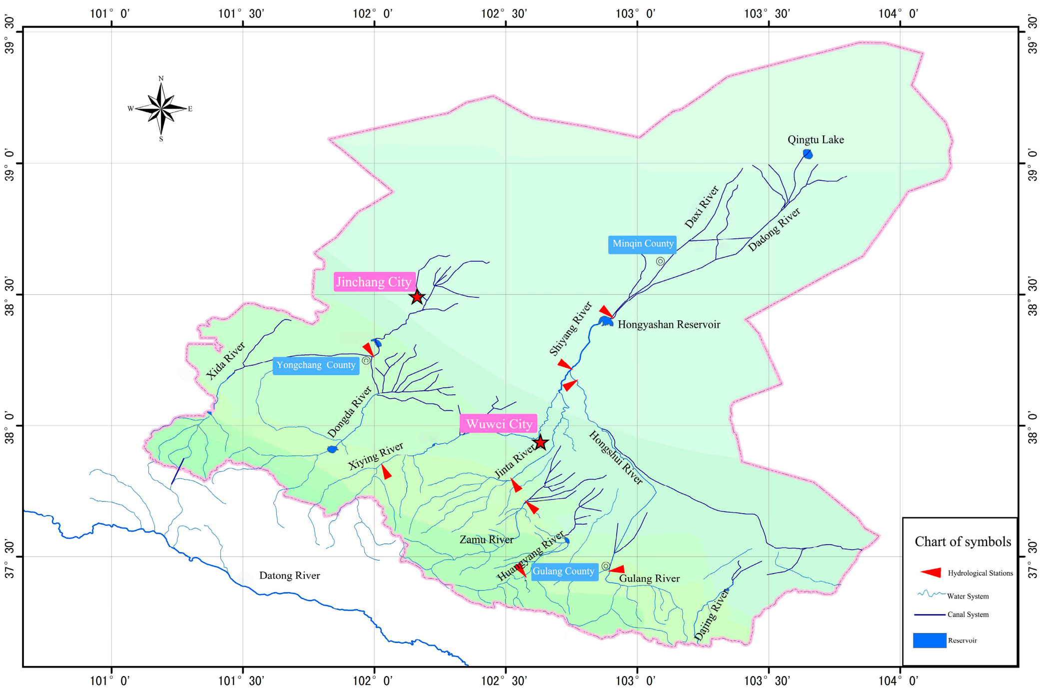

Figure 1. Shiyang River Basin, Gansu Province.

To mitigate the ecological crisis in the SRB, a unified river basin management institution, the Shiyang River Basin Management Bureau (SRMB) was set up in Wuwei in November 2001. The SRMB takes on the primary responsibility for the development of water resources (both surface water and groundwater resources) in the SRB for all purposes and is responsible for the implementation, operation, and maintenance of large-scale water projects. Furthermore, a comprehensive water management plan (CWMP) was formulated and approved by the Ministry of Water Resources in 2006 [71]. The CWMP was mostly implemented in Wuwei municipality, which occupied almost 80% of the basin's water use and 70% of the basin's area. According to the plan, water consumption within the basin needed to be reduced from the peaked 2.88 billion m^3 in 2003 to 2.13 billion m^3 in 2010 and 1.97 billion m^3 by 2020. Another important goal was to prevent further desertification and salinization in Minqin County by reallocating surface water among different reaches of the basin and limiting groundwater exploitation of these regions. It was required that surface water flowing to the downstream Minqin oasis shall increase from 98 million m^3 in 2003 to 250 million m^3 in 2010 and 290 million m^3 by 2020; groundwater exploitation in the Minqin basin needed to decrease groundwater exploitation from 517 million m^3 in 2003 to 86 million m^3 by 2020; the middle basin needed to decrease groundwater exploitation from 972 million m^3 to 822 million m^3; the whole basin needed to lessen its groundwater exploitation from 747 million m^3 to 418 million m^3 during this period.

The Gansu government recently made an evaluation of CWMP in the SRB. According to the official evaluation report, positive results have been achieved after the implementation of CWMP; all the planned objectives were realized ahead of schedule in 2014, long before 2020, and the environment started to be managed in a sustainable way by integrating the ecological restoration with advancing social and economic progress. In all these efforts, a series of water-saving policies have been implemented to encourage farmers and local leaders to adopt water-saving practices, including water consumption permits, raising water prices, investing in WSI infrastructure, and establishing WUAs. During the eight years of the CWMP's implementation (from 2007 to 2015), the official evaluation report shows that the average agricultural water-use coefficient increased from 0.53 to 0.58; water used for irrigation reduced from 1.71 billion m^3 to 1.39 billion m^3, and for per acre irrigated land, reduced from 626.72 m^3 to 430.25 billion m^3. Thus, it is of importance to examine the effectiveness of water-saving policies and the lessons that need to be learned from the SRB case.

3.2. Quota Control and Economic Incentives

To reduce the agricultural water consumption, measures relying on direct control have been widely implemented. The most important measures have been water consumption permits and reducing irrigated areas, along with the closure of tubewells. In Wuwei municipality, those included closing 3318 tubewells and limiting the water exploitation in the remaining tubewells, reducing 663 thousand mu of irrigated area, and forbidding planting high water-consuming crops, such as onions (which would consume more than 1000 m^3 per mu), corn (which would consume more than 800 m^3 per mu), and wheat (which has a low economic output per cubic meter of water). Water consumption permits were granted to individual households, which were identified by the number of people in the household and the type of crops planted. For example, in Minqin County, the permit stipulated that each person can develop no more than 2.5 mu of irrigation farmland and the water available for the farmland was 415 m^3 per mu (300 m^3 groundwater and 115 m^3 surface water). For families having farmland more than 2.5 mu per capita, they could obtain additional water use by transforming land use to greenhouses or planning horticultural crops. For example, goji and grape could obtain 250 m^3 of water use permit per mu. Another essential tool for water use control was the Integrated Circuit card (IC card) technology, with which the consumption permit could be monitored by the electronic system installed in the tubewell. The IC card was usually held by a person from the WUA board. A farmer was allowed to purchase water tickets up to 415 m^3 per mu before irrigation, and the allowed volume of water pumped by a tubewell would be the amount of irrigation farmland multiplied by the allowed permit. The IC card holder coordinated water deliveries to his members. Farmers, together with the cardholder, supervised each other's water use time during the irrigation period, which guaranteed that irrigation water would be equally allocated. However, measures relying on direct control aroused complains. For instance, our interviewed farmers from the middle reaches were forbidden to do double cropping because their water supply had been reduced to ensure the water use in lower reaches, and farmers from the lower reaches believed that reducing the irrigated area lowered their potential incomes.

The water price has increased dramatically in the past ten years (from 2007 to 2017) in the SRB. The government of the middle reaches has increased its surface water fee for every cubic meter from 0.08 Yuan to 0.2 Yuan, while water fee in the lower reaches has been adjusted from 0.1 Yuan to 0.24 Yuan. Water fees collected in irrigation areas with groundwater only, or by mixing groundwater with surface water, would be charged by the two-part tariff system. The tariffs were divided into the basic part and the volumetric part. The basic part was a fixed fee, irrelevant from the level of consumption, which was 2 Yuan per mu. The volumetric part was charged depending on the volume of water consumed, which was 0.174 Yuan per cubic of water. Moreover, water price also differs by the cropping practices and the consumed amount. Water for greenhouses and drip irrigation would not only be exempted from the basic water fee, but also obtain a 20% and 50% discount for surface water fees and groundwater fees, respectively. For crops with high water consumption or low economic benefit, the irrigation fee would be risen by 50% for groundwater and 30% for surface water, respectively. In the case of water consumed exceeding the permit, the beyond amount would be charged at a higher rate, which is 150% for 0–30%, 200% for 31–50%, and 300% for more than 50% in excess of the allocated amount. If the water consumed was less than 90% of the allocated amount, a 10% discount would be given to the total irrigation fee. Other economic measures included: the government-subsidized 5000 Yuan per mu for greenhouse construction, 1300 Yuan per mu for wine grapes production in the lower reaches, and 300 Yuan per mu for growing fruit trees in the upper and middle reaches. Officials said those measures have encouraged local farmers to use water more efficiently and plant water-saving crops on agricultural land. The statistics from local government also showed the economic output per cubic meter of irrigation water has increased from 1.93 Yuan in 2009 to 9.33 Yuan in 2015.

The government believed that the water permit system, together with price reform, should provide conditions for the establishment of a water market. In practice, water permit trading did exist between the WUAs within the same ID, but traded less frequently (136 times comprising 9.44 million m^3 of water in 2015 and 70 times comprising 1.00 million m^3 of water in 2016). For farmers, they hardly sold their water to others within the WUA due to a lack of heterogeneity within the village, for example, the same plantation structure and same period for irrigation water distribution. At the national level, legislation and the necessary regulatory framework were still not ready to support the development of a water market. Moreover, those top-down regulations encouraged the cultivation shift from traditional grain crops to cash crops in the SRB, which substantially increased the benefit from every cubic meter of water use. Thus, farmers' average income was still doubled with the reduced water resources and increased water price. However, these successful experiences are limited in the SRB, where water scarcity is among the most critical issues on the government agenda. A higher water price will stimulate the planting of crops with higher revenues, which may hurt the nation's food security goal of achieving 95% self-sufficiency for all major grains in the short run. Hence, it is impossible for the policy-makers to increase water prices without hurting rural incomes [47] while maintaining food security [5]. Even with subsidy strategies to compensate famers' lost income because of increasing water prices, as in a pilot area of Taocheng District [72,73], there is still a significant shift in plantation structure from the traditional grain crops to the water-saving and high-value crops [74,75].

3.3. Specially-Allocated Funds

The comprehensive water management plan (CWMP) issued in 2006 itself is a major fund approved by the central government. The water crisis in the SRB was so severe that the central government decided to intervene and provide funds for water management directly. The fund allocated to the SRB did not follow a standardized design-bid mechanism, and the central government played an active role in mobilizing basic level units. Designing funds for only one application might be the case when they caught pervasive attention from the central government. CWMP was specially designed for the SRB by MWR with a total investment of 4.948 billion Yuan. The plan used a "matching funds" method, which required that the central government subsidize a major part of the investment; the provincial government provided a certain amount of matching funds; basic-level departments also needed to give assurances to invest when applying for the project. In the case of CWMP, 4.284 billion Yuan (86.6%) were from the central government, and 0.666 billion Yuan (13.4%) were from the local governments; 3.98 billion Yuan, accounting for 80.3% of the total investment, were primarily arranged for the WSI improvement project, such as water conveyance work and subsidies for WSI techniques. According to the government report, the main achievements made from the investment included, 824 km irrigation canal was reconstructed with concrete for preventing canal seepage; 117,300 ha of irrigated land was upgraded to use pipe or drip irrigation; drought-resistant crop varieties, including Chinese medicinal herbs, fruit trees, cotton, and sunflowers were widely planted; and the number of greenhouses was considerably extended by governments' subsidies.

Other funds also have been invested in SRB to promote the WSI together with the CWMP fund. One typical example is the on-going Sino-Israel Financial Cooperation (SIFC) program in the middle reaches. The central government fully funded the project by providing approximately 3000 Yuan/mu state loans to support the demonstration of high-tech technologies. The SIFC program was designed by the National Development and Reform Commission and Ministry of Finance in 2012 with the purpose of introducing Israel's high-tech WSI technologies and promoting China's WSI development. The program stipulated that all counties from China's northwest provinces, including Shaanxi, Gansu, Xinjiang, Ningxia, and Qinghai, were eligible to apply for the fund. Our investigated government in SRB applied and did not obtain the fund until 2016. According to the government's plan, 39,600 mu farmlands in the SRB would be equipped with highly automatic drip irrigation systems imported from Israel. The drip tape was freely provided in the initial stage, and local farmers needed to purchase it afterward. Training courses were conducted by technicians from companies, and representatives of farm members were trained on how to use the equipment. With the automated irrigation system, one person could control the irrigation and fertilization for approximate 3000 mu. The program also helped reduce one-third of the irrigation water, 10% of the fertilizer, and ensured quality consistency of the crops. Nevertheless, the machine increased farmers' electronic costs, which would offset the saved fertilizer expense.

The two design-bid cases mentioned above represent the category of engineering funds and demonstration funds, respectively, which are frequently designed for the WSI. In the first case, despite great achievements having been made, our investigation found that some funds were not sufficiently used, and even caused adverse consequences because the departmental ideas or expert opinions did not always connect the practice with scientific knowledge. For example, to increase the canal water-use coefficient, an irrigation canal had been reconstructed with concrete to prevent seepage. These measures may cause the death of trees and shrubs around the canal because of the reducing seepage. In lower reaches of the SRB, the dying plants are a critical component of the shelterbelt landscape, which protects the farmland against shifting sand. Thus, the enforced WSI measures could have been more effectively implemented by considering indigenous knowledge and the local context. The second case shows the WSI demonstration program is usually of high-tech with large investment. Outside the program, villagers will hardly adopt the automatic irrigation technology without lavish government support. The replacement of irrigation pipe will be quite burdensome after the project is implemented. If some farmers are not willing to buy new pipes after the SIFC program, the high-value equipment will be abandoned. Moreover, farmers have only been trained for how to use the machine. If some parts of the machine do not work, they are unable to fix it in time. This kind of problem has crippled many other similar projects because of the deficiency of after-funding services. Thus, overemphasizing the highly-advanced technology might be far beyond China's current small holder's stage and raises the problem of sustainability and replicability. Moreover, the funded villages in the SIFC program have always been linked to other funds, such as the fund for farmland leveling, which will provide the infrastructure conditions for the SIFC program. Our investigation indicates that the Matthew effect occurs during the implementation of WSI funding polices. Villages with the experience of implementing funding programmes will be given the priority for new funding programs. The phenomena of "fund linked to funding" may cause a project-made income disparity among villages.

3.4. The Development of WUAs

In the SRB, the WUAs have been widely established since the early 2000s upon the requirement of local governments. The government statistics in 2014 showed that the WUAs were developed in 77.6% of the villages in Wuwei municipality, in which 874 WUAs accommodated 2517 managers, 308,000 households, and 2.37 million mu of irrigated farmland. The primary duties of the WUA were to help the collection of irrigation fees, to resolve water conflicts among households, to purchase water from water supplier, and to allocate agricultural water at the village level.

The WUA board in SRB, supposedly elected by villagers, was composed of one director and two deputy leaders according to the local government's requirements. During our investigation in more than 30 villages, none of the board members were elected following the procedures in establishing the WUAs and the directors of the board were normally the current or previous leaders of the villages. Moreover, the director usually took all the responsibility for agricultural water management, and the deputy leaders only assisted water allocation during the busy irrigation period. The funding sources of the WUAs included two parts: a fixed part, which is 3000–4000 Yuan provided by the county government, and a profit-sharing part, which is decided by the total water fees collected from famers, total irrigation area, and the director's performance. Those two parts would amount from 12,000 Yuan to 16,000 Yuan, and the director would receive around 70% of the total. In our interviews, the directors, also as village leaders, were quite glad to take the duties of agricultural water management. This was because they were required to stay in the village as the village leader, which enabled them to have enough time to take the responsibility as well as receive additional remuneration beyond their regular salaries. WUAs had successes in filling the vacancy for a specialized water manager at the village level. For example, the duty of taking care of the irrigation infrastructure, which used to be ignored in rural management, has been assigned to the directors of WUAs; both our interviewed government officials and villagers believed that water has been more efficiently allocated to individual farmers because they know whom to turn to if they have problems with the allocation; according to the government documents, the rate of water fee collection increased from less than 60% to over 90% and the number of water conflicts decreased from over 10 cases per village to nearly zero after the establishment of WUAs. Although water management has been improved in general, the implementation of WSI policies was carried out without consultation with, or participation of, farmers. Water use permits were pre-determined by the government and WUAs deliver government orders from the top. Our interviewed farmers attended WUA meetings mostly because they cared about the official decisions of the irrigation quota, fees, and time, rather than participating in water use decisions.

The failure of public participation in WUAs of the SRB, just as in other places in China, comes with the question: Are farmers able, or are willing to, participate in WUAs? China has a centralized tradition, and the government shall take all responsibilities. It is the government's intention, instead of the farmers', to establish the WUAs. It is the government officials' and experts' decision, rather than the farmers', of how to make use of the water resources. The purpose of empowering WUAs is only to make it easy to complete official tasks, such as allocating water use permits, promoting WSI techniques, and collecting water fees. The performance evaluation on WUAs is based on how well the government's tasks have been complemented, which has nothing to do with farmer's participation. The formation of the WUAs becomes an effective tool for the government monitoring and controlling water use at the village level [76], rather than an open platform for farmers defending their own interest. The WUAs fail to represent the interest of their members, and the information exchanged between the government and non-state beneficiaries remains to be a one-way and top-down manner. Under the intense controlling power from the elite officials, the WUAs, as well as their members, normally have little autonomous power. On the other hand, farmers are reluctant to win them with more responsibilities and rights in water management. Our interviewed farmers expressed their inclination of relying on the authorities for irrigation management rather than self-governance. Invariably, famers do not believe that their advisory participation, such as allocating spare water to the trees and shrubs around the canal after its lining, will be considered by policy-makers. A lack of political participation consciousness makes it difficult to encourage farmers to take the extra responsibilities and costs in realizing effective self-governance. There is also a lack of incentive for participation. Farmers have more access to off-farm employment and have depended less on irrigation than before. According to the government's statistics, over 60% of the prime working age farmers migrated out of their village for off-farm employment, and the proportion of farmers' non-farm income increased from 26% in 2007 to 43% in 2015 [68,77]. This situation makes famers have less interest in running the public affairs of the village.

3.5. Discussion and Future Directions

The ecological crisis in the SRB used to be severe due to the exhaustive exploitation and non-sustainable use of water for irrigation. In the context of the national WSI policies by which to stem the rising demand for irrigation water, the water management reform in the SRB is of both success and failure in the WSI. WSI policies have been implemented by the combination of all these three management mechanisms, which involves top-down regulations through the administrative hierarchy, design-bid funding for local governments' competition, and bottom-up participation by irrigation water users. The effectiveness of the WSI management will be determined by the performance of all relevant stakeholders, including the central government, local governments, village level organization, and famers. Different WSI management mechanisms are on target for different stakeholders to convey incentives for behavioural change.

The SRB was one of the important grain producing regions in China before 2006. The inaction of the CWMP indicated that the central government relaxed the food security and agriculture development requirement in this area, with reducing agricultural water use being given the highest priority. Under the top-down mechanism, local officials' performance in the SRB was greatly evaluated by their fulfilment of water-saving duties. Mandatory WSI regulations, such as quota control and price adjustment orders, were enforced effectively by local governments. However, this was sometimes at the expense of agricultural production and famers' income, which was also the central government's concern. Although most farmers had changed their plantation to water-saving and high-value crops, they were still inclined to increase irrigation water use and expand their irrigation areas. As a result, some farmers managed to have access to more water by stealing water and colluding with local officials in charge of water use, which was reported by the local media. Moreover, there was a very large implementation gap of the top-down mechanism when comparing the SRB with other regions. This was mainly because the WSI has not been considered as a priority for most local governments, compared with other policy goals, such as ensuring food security and poverty reduction. Under the design-bid mechanism, the vertical level and horizontal scale of the institution had been restructured to adapt the task-centred mode of management. Local governments had been motivated and had the decision-making power in carrying out and organizing the grants program. At the same time, the central government gained an effective mobilizing power in the design and allocation of special funds, other than relied solely on the bureaucratic system. For non-state stakeholders, they played no role in drawing up the plan, and they were largely excluded from decision-making processes. More often than not, a lack of communication between government and water-users obstructed the "quality" of WSI decisions. Under the bottom-up mechanism, the WUAs had been established to promote the WSI theoretically based on the participation of farmers. As an individual was chosen to be accountable for the WSI management at the village level, governments increased their controlling power over ensuring the implementation of WSI decisions. In contrast with the traditional form of leader-run management, directors in the WUAs were paid a bonus based on their performance, thus faced with better incentives. For farmers, fewer efforts had been made to encourage their participation in the management.

As demonstrated above, the managerial incentives created by the management mechanism reform led to the consolidation of government authority. However, too much government control and the near-absence of famers' participation affect the ability to deliver high quality WSI policies and to improve the implementation and compliance. The current management mechanisms tend inevitably to devolve into "trade-off of money and water-saving", where all relevant stakeholders attempt to pledge economic interests instead of pledging the consensus of public interest. The WSI management is faced with the risk of frangibility in the case that an external disturbance occurs, such as the government's budget reduction, climate change, and free-riding chances. Clearly, if policy-makers want to better solve China's water crises in water-scarce areas, additional policies will be required to better align stakeholders' incentives. Indeed, there are cases where farmers may have greater incentives than government agencies to ensure the effective water conservation, such as in the cases in Nepal [78], the Philippines [79], and Bali [80]. Implications derived from those cases indicate that a reliable and robust WSI management should be community-based with external assistance needed to be provided upon a request of the community. It is vital to mobilize water users participating in the process of establishing WSI rules, and to ensure that their implementation, as well as supervisory practices, is user-motivated, other than external controls from the performance-based management system. A future management reform should focus on bringing meaningful water users' participation for the improvement of decision-making process. Those include the shared perception of environmental problems by water users and government officials, the collective monitoring of mutual accountability, and the establishment of trust for designing rules, so as to promote cooperation and to resolve the conflict of interest among different stakeholders [5,40,44,64,78–81].

4. Conclusions

To feed the increasing population under the conditions of keeping sound ecosystems and environment, there is an urgent need for China to produce more food with less water, which makes the effective WSI management more critical. For saving irrigation water, China has changed its management from the supply-side to demand-side by a range of institutional arrangements and policy goals. Nevertheless, the fragmented bureaucratic responsibilities led to conflicts between upper-level and lower-level agencies, as well as between government and water users, which undermines the enforcement of WSI policies. In response to the growing managerial conflicts, this paper also explores how WSI can be achieved by highlighting the three management mechanisms. The top-down regulation mechanism, by either direct control or economic instruments, helps determine the allocation of, and the pricing strategies for, irrigation water. The design-bid funding mechanism provides an effective way to achieve the central government's WSI intension by reducing the barriers between the government's different departments and different levels. The bottom-up participation mechanism, although remaining nominal to a large extent, plays a key role in improving water management at the village level by the linkage between government and local water users. Throughout the process of WSI management, different combinations of these mechanisms have been used as an attempt for aligning stakeholders' incentives to achieve the planning objectives.

For the time of policy flux over the past decade, the implementation of WSI practices can rely on regulation, funding, and participation, with their respective advantages in mobilizing different stakeholders. However, there are challenges faced by all three management mechanisms because of the pervasive institutional and economical inefficiency and the continuing near-absence of end-user participation. Our field research shows that a wide diversity of measures has been used during the implementation, which provides an effective method to realize WSI objectives in SRB. At the same time, there are conflicts among different policy goals, uneven distribution of fiscal resources, insufficient participation from farmers, and unchanging, if not the aggravating, authoritarianism of the bureaucratic system. Thus, the WSI management should consider providing more incentives not only to policy-makers, but also to the affected population in constructing participatory institutions and governance.

Our analysis enriches the current understanding of WSI management in China and supports the conclusion that the government should continue to support management reform. Neither the highly-bureaucratic irrigation institutional arrangement, nor the involved enthusiasm of local governments' applying for funds, nor the nominal involvement of local water users, are sufficient for successful WSI management reforms. Problems it encountered in implementation have rendered the importance of facilitating meaningful participation of stakeholders with the well-defined regulatory powers and aligned water-saving purposes. Meanwhile, different management strategies, rather than a favorite cure-all mechanism should be considered to provide WSI solutions based on the understanding of local contexts. The research findings seeking for the attainment of the sustainable WSI management can also be applied to other countries facing similar water shortages.

Acknowledgments: Our research was part of a major project supported by National Social Science Foundation of China, "The Design of Natural Resources Management System under the Background of Ecological Civilization Construction" (no. 15ZDA052).

Author Contributions: Liuyang Yao and Minjuan Zhao conceived the framework; Liuyang Yao and Tao Xu collected the materials; and Liuyang Yao and Tao Xu wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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