Restoring environmental flows and improving riparian ecosystem of Tarim River

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Recommended Citation
ZHANG, JieBin; WU, GuiHua; WANG, QiMeng; and LI, XiaoYan (2010) "Restoring environmental flows and improving riparian ecosystem of Tarim River," Journal of Arid Land: Vol. 2 : Iss. 1 , Article 7.
DOI: 10.3724/SP.J.1227.2010.00043
Available at: https://egijournals.researchcommons.org/journal-of-arid-land/vol2/iss1/7

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Cover Page Footnote
This research is carried out under the support of the UNESCO HELP program. The author gratefully acknowledges the support of K. C. Wong Education Foundation, Hong Kong. The author also thanks all members of HELP Tarim implementing team and supporting organizations, notably Xinjiang Institute of Ecology and Geography of Chinese Academy of Sciences and Tarim River Basin Management Bureau.
Restoring environmental flows and improving riparian ecosystem of Tarim River

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Abstract: Rapid population growth and artificial oasis enlargement did pose great threat to the natural riparian ecosystems of Tarim River and caused seriously ecological deterioration and greater desertification of the Tarim River Basin in the second half of 20 century. Restoration of the endangered riparian ecosystem requires that environmental flow should be restored through restricted and uncontrolled flow diversion irrigation in tributary areas. Implementation of such restriction needs further the basin-wide reallocation of water resources through a set of engineering and non-engineering measures taken to ensure the water requirement in the tributary and maintain effective flows in Tarim River. As one of evolving HELP (Hydrology for Environment, Life and Policy) basins, the article first presents an overview of hydrology, socio-economic development and ecosystem evolution of the Tarim River Basin. Then, those measures for restoring and maintaining environmental flow are reviewed and analyzed along with its applicability and validity. The issues emerging in implementing those measures are also explored, and then the conclusions were summarized. Lessons learned could provide a good example for other basins under similar conditions.

Keywords: environmental flow; IWRM; riparian ecosystem; Tarim River; HELP

1 Introduction

Located in the southern Xinjiang Uygur Autonomous Region (Xinjiang) of the arid region in northwestern China, the Tarim River is the longest inland river in China. The river flows in the plains, hardly any surface runoff, depend on the flow contribution of many tributaries, originating from the high mountains around Tarim Basin (Fig. 1). The riparian forest ecosystem, dominated by the species of Populus euphratica, is the most productive ecosystem in the Tarim River Basin. P. euphratica forest is largely distributed in strips along the Tarim River, depending on the river flows. However, this ecosystem has been degraded because of rapid population growth, economic and social development since 1950. Extensive reclamation, combined with a large amount of inefficient irrigation diversions in tributaries, has resulted in continued reduction of flows of the Tarim River and more than 320 km of the lower Tarim River along with Taitema Lake have dried up from 1972 to 2000 (Zhu, 2001). The ecosystem of the lower Tarim River known as Green Corridor has seriously deteriorated, with withering vegetation, parched land and expanding desertification along the lower reaches.

The issues have been a great concern for both the public and governments at various levels as well as the world organizations since the early 1990s. The restricted flow diversions for irrigation enlargement of tributary areas are recognized as the direct means to restore the environmental flow and reserve the ecosystem. Given the significance of irrigation to the socio-economic development of Tarim River Basin, an arbitrary decision will hardly help in restricting such escalating diversions. In order to reallocate water resources and restore the environmental flows, the integrated water resources management (IWRM) should be implemented through a set of engineering and non-engineering measures in whole Tarim River Basin. This article therefore focuses on exploring measures and their results as well as issues emerging from the implementing these measures in the whole Tarim.
River Basin. As one of evolving basins of the UNESCO HELP (Hydrology for Environment, Life and Policy), the lessons learned in designing and implementing those measures could provide a good example for other basins under similar condition in the world.

2 Hydrology, socio-economic development and ecosystem evolution of study area

With great distance separating it from moisture sources and surrounding high mountains, the Tarim Basin is subject to a typical desert climate with sparse precipitation, high evaporation, hot summers and cold winters and no particular seasonality for the scarce annual precipitation in the plains (Tang et al., 1993; Zhou, 1999). Such a relatively independent, closed and inland hydrological cycle causes a large portion of the basin (Taklimakan desert in \(340 \times 10^3\) km\(^2\) and the eastern Gobi) is extremely arid. Similar to other arid regions in the world, the surrounding mountains (Tianshan, Karakram, Kunlun and Altun Mountains) constitute the sources of flows of nine river systems (Table 1) (He, 1998), while the plain hardly produces any surface runoff and thus is naturally the area for runoff dissipation (Tang et al., 1993; Zhou, 1999). River flow is accumulated from the source to the tip of the piedmont alluvial fan, gradually reducing along the river due to seepage, overflow and evaporation. These processes indicate that many of the small rivers could not flow to the Tarim River except large rivers. Dominant in the summer period (60%—80%) and least in spring period (10%—15%), the river flow fluctuates greatly in year. Simultaneously, the annual flow does not change greatly because the great regulating function of melting waters from alpine glaciers Hydrological condition determines that most natural vegetation develops adjacent to the flowing rivers. contribute 25%—81% in the different rivers.

Hydrological condition determines that most natural vegetation develops adjacent to the flowing rivers. Elsewhere, the vegetation is sparse in such desert environments. The riparian forest ecosystem, dominated by \(P.\) euphratica, is the most productive ecosystem in the Tarim River Basin, largely distributed in strips along the downstream of tributaries and Tarim River. Naturally, its dimension and development depend much on the river flows and vary in extent with the migration of the river, the size of the flooded area and the situation of the local groundwater table (Wang et al., 2002). It was this riparian ecosystem that supported the human settlement and primary agricultural
activities in the Tarim River Basin, in particular the historical prospective communities at downstream deltas. Population growth changed this coexisting situation. It is proved by historical relics that human activities had gradually moved from the downstream deltas to the piedmont plains with advances in technology and population growth. The piedmont plains have become the location for modern human society and economic development because river flows can be easily and reliably tapped (Fan et al., 2001). The population migration finally caused formation and development of irrigated farmlands—artificial oases in the upper and middle plains. The Tarim River Basin, shared by five prefectures has rapid population growth, accelerated reclamation and large irrigation diversions in the productive areas of tributaries in the last 50 years. The population has increased rapidly from about $3 \times 10^6$ in 1949 to $8.5 \times 10^6$ in 2000 and irrigated land from about $0.8 \times 10^6 \text{ hm}^2$ to $1.36 \times 10^6 \text{ hm}^2$ in this period. It was such enlargement that began the great negative impact on the river system and then riparian forest ecosystem. The first effect is change of river regime and continued reduction of flows to the Tarim River. The Tarim River is gradually replenished only by the three big tributaries, i.e. Aksu, Hotan and Yarkant Rivers. The Yarkant River normally has no flows to Tarim River except in the extreme flood period since the early 1970s (the extreme flood caused by glacier dam breaking is the typical characteristic of this river) (Tang et al., 1998). The Kaidu-Konqi River, the nearest tributary to the lower Tarim River, was disconnected and only provides some flows to Tarim River through a canal. Investigations have shown that more than 320 km of the lower Tarim River along with Taitema Lake, the termination of the river, dried up following the construction of the reservoir Daxihazi at the beginning of the lower reaches of Tarim River in 1972. Accordingly, the riparian forest has decreased by about $219 \times 10^3 \text{ hm}^2$ along Tarim River (Gao and Fan, 2002). The area of degraded grassland enlarged to $850 \times 10^3 \text{ hm}^2$, resulting in an extreme fragile riparian ecosystem. The more serious situation is in the lower Tarim River, where the riparian forest has decreased from $54 \times 10^3 \text{ hm}^2$ in 1950s to $7.3 \times 10^3 \text{ hm}^2$, with the flow cutoff and the groundwater table sunk to below 8 m (Zhu, 2001; Gao and Fan, 2002). The local biodiversity has been nearly lost. The withered vegetation, parched land and desertification appear around the lower reaches and expand quickly (Chen, 1993; Song et al., 2000).

### Measures for restoring environmental flows

#### 3.1 Determining through comprehensive management plan

The water conservancy plans are available to each tributary, although a comprehensive water management plan has never been formulated successfully for the whole Tarim River Basin. One of the major difficulties is to plan flows required to discharge from each tributary to Tarim River. Several plans for the whole Tarim River Basin have been drafted and submitted for approval, but finally left in draft because they did not prove to have enough consideration of protection of ecosystem of Tarim River and explicit environmental flow requirement. The Xinjiang Competent Department for Water Administration (CDWA) shifted their conventional practices and considered that an ecosystem-based comprehensive management plan should be formulated. After several years of scientific discussions and preparation works, a consensus was reached and an Immediate-term Comprehensive Management Plan of Tarim River Basin (Immediate-term Plan) finally formulated which was formally presented to and approved by the State Council in early 2001. Notwithstanding its immediate-term characteristics, the Plan acknowledges the fact that socio-economic development should take full consideration of ecological water demand and not be at expense of ecological degradation, and the basin-wide IWRM is an effective approach to realizing such har-
monization. It clearly requires the stakeholders to take responsibility for the protection of ecosystem of Tarim River through rational and high-efficient utilization of water resources in the Tarim River Basin. Importantly, it sets forth the concrete targets as to make the lower Tarim River regain its flow, restore the ecosystem and control the desertification extension once the completion of the corresponding project under the Plan in 2008. In addition, the Plan also highlights the importance of evaluating the potential effects of the implementation on ecological protection and socio-economic development in tributary areas. It also outlines how these effects are to be addressed during the implementation phases (Xinjiang Government and Ministry of Water Resources, 2002). Environmental flow derived from this planning will provide guidelines for immediate-term comprehensive management and is planned to be maintained through a set of engineering and non-engineering measures.

3.2 Restoring through water allocation

Irrigation is the dominant water user accounting for about 90% of total river diversions and is the only way to sustain agriculture development in the Tarim River Basin. This leads to the customary concept that the more flow diverted, the higher yield of agriculture. Because of the seasonal and yearly fluctuation in river flows and poor regulating infrastructures, the local leaders in charge of agriculture regardless diverted the flow from rivers. This resulted in the flood irrigation mode in tributary areas and flow cut-off except the flood period in Tarim River. Water use for irrigation had customarily taken prior claim over ecosystem protection and the latter was often neglected. This situation can be shown in the official water use statistics in which ecological water consumption is estimated as water volume left after productive water use. Water for ecosystem was regarded as one kind of non-beneficiary uses until the degraded riparian ecosystem had negative impact on local communities in the 1980s. Especially, to reserve certain flows for downstream ecosystem requirements were widely accepted by senior water managers and scholars when IWRM concept was introduced in China in the early 1990s.

As for the Tarim River Basin the major issue remaining to be addressed in securing flows of Tarim River is to coordinate irrigation uses within the tributary areas and ecological use of Tarim River which depends in total on the flow contribution of each tributary. The Xinjiang CDWA decided to formulate a quantified water allocation scheme among the tributaries and define flow requirement of Tarim River in the early 1990s. An indicative plan for water diversion limit of each tributary was then formulated. However, it failed to implement this plan because of no real action taken to the effect by the prefecture’s administrators. The reason is that the prefecture’s administrators argued that who should be responsible for economic losses resulting in the irrigation reduction of this indicative plan. The arguments revealed the facts that the common responsibility for ecosystem protection was not widely convinced among prefecture’s administrators and a sound compensation system was also unavailable.

In order to govern unregulated water diversions from tributaries and restore seriously degraded ecosystem, the Xinjiang Government had to resort to legislation. Therefore, the Regulations of Tarim River Basin on Water Resources Management was adopted in 1997 (the Tarim Regulations). The provisions on water allocation under the Tarim Regulations are accepted by the prefecture’s administrators because it provides a participatory approach in that the water allocation scheme should be formulated in full consultation with all prefectures (Legislation Committee of Xinjiang People Congress, 1997). The water allocation principle was then agreed among administrators of five prefectures in compliance with the Regulations. The principle of water allocation should consider existing uses, meet potential needs and ensure the environmental flows for maintaining the riparian ecosystem. Water uses in 1998 was selected as the landmark for water allocation because no available water right system has ever been established. The water for socio-economic development of each prefecture should be based on the increase of efficiency and water-savings other than increase of diversions. A water allocation scheme was agreed among the prefecture’s administrators and finally approved by Xinjiang Government in 1999. It also makes clear enough that the annual mean flow contributions of all four major tributaries to Tarim River should amount to 4.9 km$^3$ and the annual total diversion from each tributary is
quantified and allowed to be adjusted in terms of a proportionate quota based on actual river flows (Xinjiang Government and Ministry of Water Resources, 2002). However, the three trial allocation implementations from 2000 to 2003 revealed the difficulties in achieving the targeted contributions of tributaries to Tarim River until the water-saving target of tributary irrigation is achieved. It could be argued that such a water allocation scheme could be left merely as an indicative one, if the relevant measurers for water-savings and high-efficient irrigation water uses are not taken in tributary areas.

3.3 Interim restoring through intra-basin water transfer

Comprehensive investigations and researches explored that riparian forest ecosystem was in imminent danger due to local groundwater table fallen down far below the threshold that vegetation can access after the drying-up of Tarim downstream for about 30 years. Given the difficulties in achieving the targeted flows under the water allocation scheme, it was agreed that an urgent measure should be taken to immediately restore the environmental flows and rescue the ecosystem before it fully loose its vitality at the end of 1990s. The initial idea was to directly divert water from the Bostan Lake of the Kaidu-Kunqi river system to the lower Tarim River via existing canals once the water years appear in this river system. This measure named Emergency Water Transfer Project was finally inaugurated in 2000 and designed to gradually replenish groundwater and raise water tables up to levels where the natural vegetation can thrive and the endangered ecosystem can be restored (Xinjiang Government and Ministry of Water Resources, 2002).

The first successful transfer encouraged the Xinjiang CDWA to continue and prioritize this project among those major projects to manage the Tarim River Basin. The documented Emergency Water Transfer Project still reserves the interim transfer from Kaidu-Konqi River but claimed to replace it by stable flows from other three tributaries through water-using limit and water-saving measures. Up-to-date, nine consecutive water diversions to the lower reaches of Tarim Rive have yet been fulfilled and total amount of 2.259 km³ has been transferred downstream, of which three recent transfers were implemented partially through the upper reaches of Tarim River. The transfers have resulted in the obvious environmental improvement of the lower reaches of Tarim River. However, the transfers much depend on the hydrological condition of the Kaidu-Kunqi River system. It is impossible to maintain a stable water transfer from Bostan Lake in case the drought years happen in Kaidu-Konque River system. Recent transfers have also indicated that it is necessary to change from the interim to functional water transfer. Long-term secured environmental flows of Tarim River should be subjected to water-saving and reduction of irrigation consumption in the tributaries.

3.4 Enhancing through river improvement and reservoir modification

Tarim River is a meandering river, in particular the upper and middle reaches where large amount of overflows appear frequently due to flat geomorphic conditions and man-made effects by temporary dams and random outlets dug by farmers for water diversion. Embanking of these sections is considered to be an urgent measure to gain river flows vital to the downstream ecosystem. It started in 2001 and envisioned that total 766 km embankments will be constructed along the both sides after the completion of the Interim Comprehensive Management Project. It has been recognized embanking could result in reduction of local riparian water supply and have negative impact on the existing riparian ecosystem. The proper sluice gates (so named ecological sluice gate) therefore have also been designed for ecological flow release when monitoring indicates the riparian ecosystem needs irrigation (Xinjiang Government and Ministry of Water Resources, 2002).

It has been proved by the completed embankments that the overflows have been reduced and accordingly the increased flow was recorded in the lower reaches of Tarim River. However, with further extension of embankments, much more concerns were raised in terms of layout and operation of those ecological sluice gates during flood period. The river regulation can increase the river flow downstream and thus replenish the downstream ecosystem, while on the contrary, the hydrology upstream and mid-stream could be altered substantially by such management activities, which will result in extensive changes in the local ri-
parian forest ecosystem. In particular, the reduced flooding flows could affect its function and structure as well as breeding process and habitat for seedling establishment. Therefore, the updated assessment and monitoring of new constructions and their management should be implemented. The proper operation and management of those gates play an important role in the spatial and temporal distribution of riparian forest and a healthy riparian ecosystem.

A lot of plain reservoirs have been built with small capacities, whereas lack of the large mountain reservoirs to regulate river flows in the Tarim River Basin effectively. The plain reservoirs have big loses of water owing to large evaporation and seepage in an extensive area, in particular those along Tarim River. Several mountain reservoirs have been investigated and designed since the 1970s, of which Xiabandi in Yarkant River is the largest and Dashixia in Aksu River is the second. The Xiabandi reservoir commenced with a total storage volume of $867 \times 10^6$ m$^3$ in 2004. The Dashixia reservoir in Aksu River is proposed to be constructed next year. Those mountain reservoirs could be advantageous for stable irrigation and hydropower generation owing to their effectiveness in controlling and regulating the runoff and use of water in the tributaries. However, such reservoirs should be carefully managed for releasing environmental flows of the Tarim River. The joint operation of these reservoirs will be the key to produce adequate periodic floods to ensure the projected flooding areas upstream and midstream and replenish downstream with water. The operational strategy will depend much on better understanding of the natural flood characteristics and more accurate flood forecasting technology. It will be a great challenge for the local water managers. On the other hand, the abandonment of some inefficient reservoirs in the plains could save as much as 50% of water lost through evaporation and infiltration in all reservoirs (Tang et al., 2002). Conversely, the exposed reservoir bottom and seriously salinized land around it may become the source of constant wind-blown silt and salts, and thus affect the local environment.

3.5 Maintaining through irrigation water saving

Irrigation water use is much wasteful. The estimated average water conveyance efficiency of the canal system is only about 40%—45% (Fan et al., 1998) except the losses produced in many flat reservoirs with large area in the plain. This means much water was lost in the process of water transportation through canals by seepage and evaporation, although some lining engineering has been used. Such low irrigation efficiency is one of major causes for reduced river flows and degraded ecosystem downstream. Water-saving irrigation application is not new and always encouraged by various governmental policies in the Tarim River Basin. However, extending irrigation production is one of the most important applications. For example, the farmers welcome on-farm water-saving application because the charge of water fees is the same but can extend irrigation through the water saving. The most available technology is drip irrigation under plastic film with a low-pressure pipeline system, which has been approved the adaptability and high on-farm water-saving realities in crop production. However, the improvement of water storage and conveyance infrastructures lies on the governmental investment or subvention. In other words, water-saving irrigation for enhancing environmental flows can only lie on the government. The Immediate-term Plan improves the occasion by adopting a principle to encourage the extension of existing on-farm water-saving technology and highlight the improvement of irrigation facilities. The Plan sets forth its target to increase water-saving irrigation area by $647 \times 10^3$ ha and save water by 1.565 km$^3$ for downstream ecosystem (Xinjiang Government and Ministry of Water Resources, 2002). Different to past practice, the Plan also support establishment of incentive mechanism to encourage farmers to save water in addition to collection of water resources fees and slight increase of water prices. Water-saving applications are welcomed by farmers and implemented successfully. In despite of large amount of water to be saved, the likely impact of large-scale of such applications on the soil and farmland ecosystem seems not clear and some researches are being employed to support the right implementation.

3.6 Ensuring through legislation and institutional framework

A relevant legal framework was essential for the IWRM of the Tarim River Basin, in particular to ensure restoration and maintenance of the environmental
flows of Tarim downstream (Wouters et al., 2000). The Tarim Regulations was adopted by Xinjiang People’s Congress and simultaneously came into force in 1997. The Regulations have several breakthroughs in water legislation practices in that it contains a set of regulations applicable to an ecosystem-based water management of a whole river basin, which are not provided under the first National Water Law adopted in 1988 and the Procedures for the Implementation of National Water Law of Xinjiang (Wouters et al., 2000). Firstly, the Regulations provide a substantial principle requiring the economic development should harmonized with ecosystem protection. Secondly, the Regulations have a scheme for annual ecological water uses of Tarim River. Thirdly, the Regulations enumerate seven factors in making the basin-wide water allocation scheme, of which three aspects are directly related to the environmental flow requirement of Tarim River, i.e. (1) flows required from each tributary to Tarim River, (2) ecological water uses in tributary areas and along Tarim River, (3) annual main flow and fluctuations along with their impacts on ecosystem of Tarim River, as well as the flow thresholds with no negative impacts on ecosystem of Tarim River. The enforcement of the Regulations reveals that they are lack of provisions regulating the reclamation and water diversion for new irrigation areas. The revised Tarim Regulations were adopted in 2005 and added a series of provisions on restricting reclamation and augmentation of non-ecological water use, enforcing water-saving and protecting the ecosystems. The revised Tarim Regulations could lay foundation for the implementation of the IWRM of the whole Tarim River Basin. Given the framework characteristics, the effective enforcement of the Regulations needs the detailed procedural rules. Especially, the detailed procedures are required in formulating and approving annual water allocation scheme and real-time distribution under the changing hydrological conditions, as well as in settling disputes and punishing the violators. The rules are being drafted by Xinjiang CDWA and will be submitted to Xinjiang Government for approval in the second half of this year.

Management Bureau of Tarim River Basin (TMB) was established in 1992. As an agency of Xinjiang CDWA, the TMB was empowered to represent it to exert the functions of water management and supervision of whole Tarim River Basin. Similar to Xinjiang CDWA, the TMB focused mainly on the design, construction and management of water conservancy projects, but little in the management of environmental flows crucial to ecosystem protection (Zhang, 2006). The reason is that the ecosystem protection was assigned to the Xinjiang Environmental Protection Bureau (EPB) and all prefecture’s EPBs in the Tarim River Basin. This situation was changed as coming into force of the Tarim Regulations in 1997. The Regulations require establishing the Tarim River Basin Water Resources Commission (TWRC) responsible for unified management and supervision of water resources over whole Tarim River Basin. Importantly, the Regulations provide that the Standing Committee of the TWRC should be the decision-making body with commissioners of the directors of all stakeholders, including relevant departments of Xinjiang Government and all five prefectures. Under the Tarim Regulations, the TMB is empowered to have concrete management and supervision functions of water resources over whole Tarim River Basin. The operation of the TWRC approves that it should play more roles in water allocation other than examination and approval of water demand plans formulated by each prefecture. The revised Tarim Regulations enhance the TMB on this regard by providing that the TMB should be responsible for formulating the basin-wide water allocation scheme, preliminary plan for water distribution under draught conditions and annual water distribution plan as well as for real-time distribution and water transfers to lower reaches of Tarim River. It indicates that the TBM could play key role in restoring and maintain the environmental flows of Tarim River. However, lack of expertise and capacity building impede the TMB in effective environmental flow management. The TMB needs to build such capacity through the training programs and partnership with other professional institutions.

4 Conclusions

As an arid river basin, the irrational water use could lead to serious conflict between upper and downstream, the losses are subjected to downstream where water shortage is aggravated and finally riparian eco-
system is degraded. The degraded ecosystem indicates the unbalance between socio-economic development and ecological protection, and the IWRM along with measures for restoring and maintaining the environmental flows is necessary to achieve their coordination at a basin level. The Tarim River Basin is an excellent case experiencing such processes. The on-going measures taken to restore the environmental flows approves that water reallocation should be the core measure in Tarim River Basin. Such water reallocation should be implemented by increase of water use efficiency through various engineering and non-engineering measures, of which the legislation and proper institutional framework can play essential role. The implementation of environmental flows in Tarim River has also demonstrated the huge cost, scientific uncertainties and managerial difficulties. Therefore, it is essential to gaining the awareness and support from all governments and the public along with the full participation of all stakeholders in order to restore and maintain the environmental flows in the large rivers.

Acknowledgements
This research is carried out under the support of the UNESCO HELP program. The author gratefully acknowledges the support of K. C. Wong Education Foundation, Hong Kong. The author also thanks all members of HELP Tarim implementing team and supporting organizations, notably Xinjiang Institute of Ecology and Geography of Chinese Academy of Sciences and Tarim River Basin Management Bureau.

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