Incorporating environmental flows into water management in the Amudarya river delta

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Introduction

Environmental flows are the flow regimes needed to maintain a river's ecosystems and the services they provide in the face of competing water uses (Tharme 2003, Acreman and Dunbar 2004). In the Amudarya river delta the incorporation of environmental flows into the current water management regime is especially important given that the livelihoods of the population, especially in the river delta, strongly depend on the provision of ecosystem goods and services from its semi-natural ecosystems. The importance of the deltaic wetlands as an additional income source and buffer against economic hardship has even increased after the retreat of the Aral Sea and the socio-economic changes following the independence of the riparian nations from the Former Soviet Union. This has become very evident during a severe drought in the years 2000/2001 were water deliveries to the northern delta were reduced to 18% of the mean.

In the past years water management measures have been implemented to increase the water storage capacity of the delta. They have created a system of deltaic lakes which support commercially valuable fish and muskrat populations, other game species (wild boar, water fowl, etc.) as well as reed production. Besides, measures have been undertaken to restore the Sudoche wetlands, a potential RAMSAR site of great value for migratory birds as well as for fish production. There are signs that following the restoration the socio-economic situation of people living in the vicinity of the Sudoche wetlands has improved. However, given the high consumption of water resources in irrigated agriculture (> 90%) most of the wetland ecosystems only irregularly receive freshwater input particularly in the Central zone of the delta. This strongly affects the chemical regime and biotic communities of the deltaic lakes, which depend on freshwater inflow to regulate flow dynamics, water levels, salinity and for fish reproduction. The spring floods act as a natural stocking mechanism that provides millions of larvae and young fish from upstream spawning habitats to the lakes. To stabilize the regime of the wetland lakes several of them are now regulated using a mixture of freshwater and drainage flows. The use of drainage flows to maintain wetlands is becoming increasingly important, however, there is little knowledge on their impact on water quality and organisms. Accounting for environmental flows in water management would increase the productivity of the deltaic wetlands, lakes and the irrigation system itself, e.g. by increasing fish production, improving habitats for reeds waterfowl and muskrat and contribute to the improvement of local livelihoods and poverty alleviation as well as the conservation of biodiversity. However, despite those benefits and the initial success stories of restoration activities, there have been few substantial and sustainable measures to include ecosystem water needs into water management practices, and institutions and legal arrangements to regulate water allocation amongst multiple users as well as institutions to facilitate a sustainable use of the biological resources of the delta are lacking.

The goal of the presented work is to assess the vulnerability of the ecosystems of the Amudarya river delta and determine the flow regimes needed to maintain the provision of valuable ecosystem services. We identify several water management options to satisfy ecosystem water requirements within the water limits of the delta region and give an outlook to the institutional measures and process needed to incorporate those flows into current water management.

Methods

Monitoring of the deltaic ecosystems of the Amudarya river and their exploitation is currently basically non existent, so that time series on the dynamics of the ecosystems and their exploitations are not available. There are a few snapshots of the ecological conditions related to project activities and long term observations of local scientists, but they are not sufficient to establish relationships between the river regime and the ecological conditions in the delta. In this situation expert judgment basically remains the best possible method for assessment of state and needs of the ecosystems. The given assessment is based on data and reports of several development projects conducted in the delta region in the past years, data bases and experiences of local scientists (Joldasova 2002), as well as expert knowledge elicited during a workshop of local experts in ecology and health, and representatives of water planning and management organizations and fishery enterprises. In the workshop the needs and main impacts on the state of the wetland ecosystems, indicators for assessment and monitoring of their condition and measures to improve the provision of ecosystem services to the local communities were discussed.

For an estimation of the impacts of different measures in years of different water availability the following representative years were selected. For a low water year: observed runoff in 1989 and two calculated hydrographs based on the years 1981 and 1984. A mean water year is represented by the actual hydrographs of 1985, 1995, and 1999. The year 1991 represents a high water year (Table 1).

Table 1. Representative river run-off in a low, mean and high water year

Year	Run-off probability, %	Annual inflow to northern delta (million m^3)
1989	Low water	1041
1985	Mean water P=54%	2358
1995	Mean water P=45%	2827
1999	Mean water P=37%	3880
1991	High water P=14%	9353

The Amudarya river delta

The wetland ecosystems in the delta of the Amudarya river represent a single hydrographic net of major irrigation canals, lakes and lake systems on the territory of the Autonomous Republic of Karakalpakstan and the Khorezm province of Uzbekistan and the Tashauz region of Turkmenistan associated with a single source of water supply – the Amudarya river (Figure 1). The river originates in the Pamir, Tienshan and Hindukush mountains in Tajikistan and Afghanistan and drains into the lowland desert plains of Uzbekistan and Turkmenistan where most of its water resources are used to sustain irrigated agricultural production. Before massive expansion of irrigated agriculture during Soviet times the Turan delta plain of the Amudarya was the second largest in the former Soviet Union after the Volga River by its size, productivity and biodiversity. Moreover, the wetlands were valuable spawning habitats for many fish species as well as habitats for breeding colonial waterbirds such as pelicans, cormorants, herons, egrets, swans and ducks and resting sites for migratory birds (Joldasova 2002, Kreuzberg-Mukhina 2006).

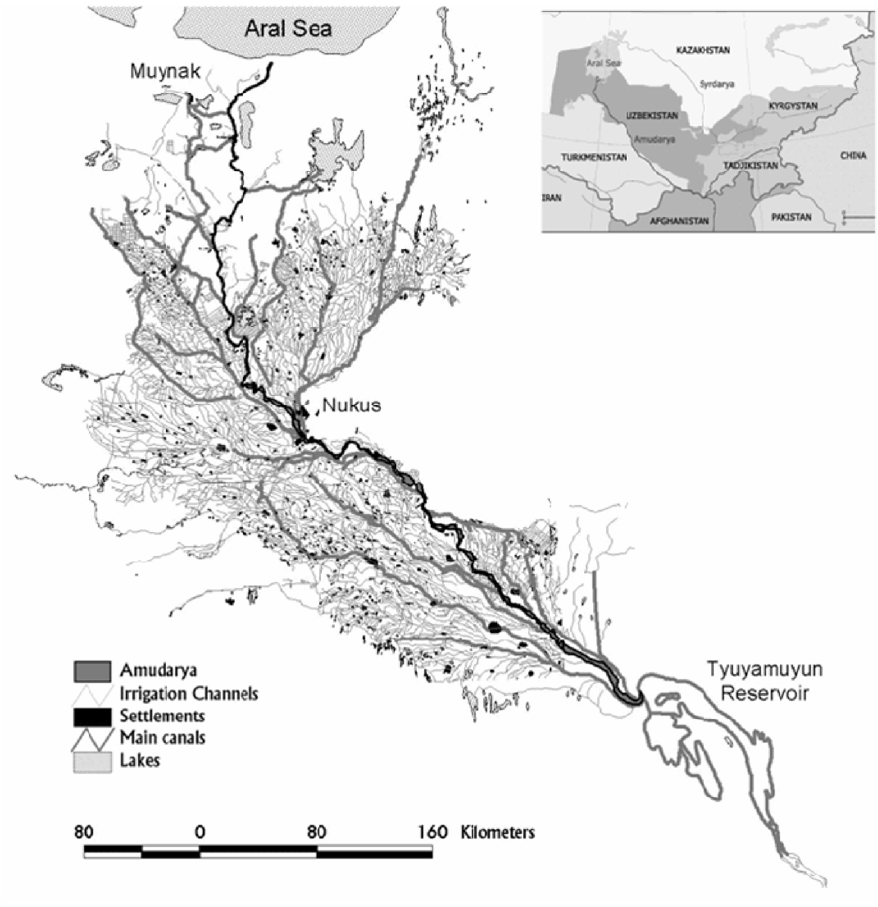

Fig. 1. The Amudarya river delta with the Tyuyamuyun reservoir and major irrigation canals in the irrigation areas of Khorezm, Karakalpakstan (both Uzbekistan) and Daskhouz (Turkmenistan) in the southwest. The shaded area of the Aral Sea is the dried out seabed. (Source: modified from Aral Sea GIS (Micklin et al. 1998)).

The climate of the delta is semi-arid with a mean annual precipitation of only 80-100mm/year. Evaporation is high with 1200 – 1600mm/year caused by high temperatures and strong winds in summer. The wetlands are strongly dependent on the freshwater inflow from the river to regulate the salinity regime and chemical composition.

Today the inflow to the delta area is largely controlled by the Tyuyamuyun reservoir at its entrance. The southern regions of the delta are mainly occupied by vast agricultural areas of the Khorezm, Dashkhauz and Southern Karakalpakstan provinces. The main source for irrigation of the ca. 750,000 ha lands is the Amudarya river and collector-drainage run-off blended with river water. The northern part of the delta between 42°30 and 44°N on the territory of North Karakalpakstan constitutes most of the former wetlands areas and remaining semi-natural ecosystems. The northern delta begins at Takhiatash dam after the last large irrigation intake at Nukus. On the west it is bordered by the Ustyurt plateau, on the north-east by an ancient channel net closely adjoining to the Kyzylkum desert, and in the north by the Aral Sea. Here exists a peculiar system of lakes and flood-plains with a total area of about 160,000 ha (Figure 2).

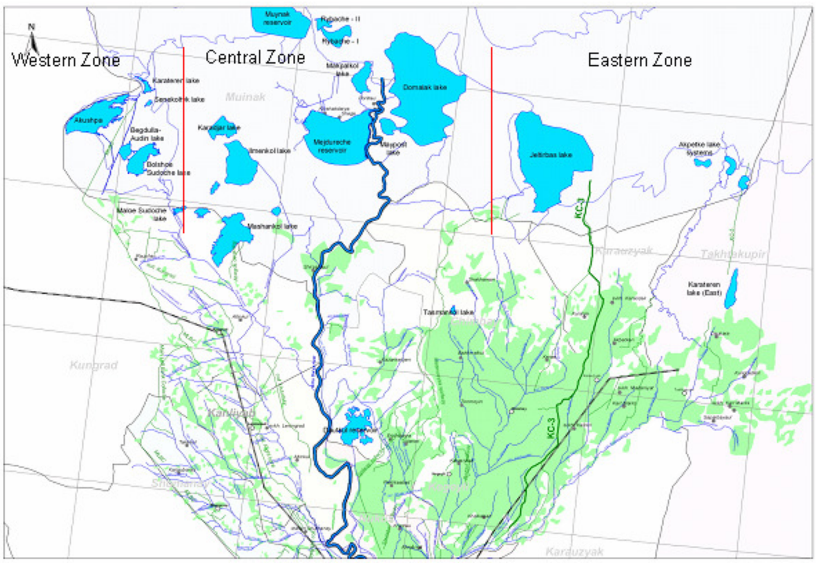

Fig. 2. Map of the northern delta region.

The lake systems of the western and eastern parts of the northern delta fully or partly depend on the volume and quality of collector-drainage runoff. Because variation in drainage water runoff is smaller than that of the river runoff and fluctuations in lake level are less severe, about 0.3-0.5m. The increase in water table happens mainly in April/May when the fields are leached and Aug/Sep when the water is released from the rice fields. The lake systems in the Central part of the delta closest to the Amudarya river are solely fed by freshwater inflow from the river itself. Therefore water quality in these water bodies is better; however, their inflow fluctuates stronger. Hence, their water levels can fluctuate by up to 1m in spring and summer. A decrease of the water level by 30-50cm is already sufficient to kill the fish eggs of fish that spawn on the littoral where water tables are shallow.

Current ecological and water management situation

The hydrological regime of the Amudarya river has been severely altered by the expansion of irrigated agriculture during the Soviet Union with well-known impacts on the deltaic ecosystems and the Aral Sea itself. Figure 3 shows the significant decrease in water volume reaching the northern delta region (Kyzyljar). However, it also shows that runoff is highly variable between years, e.g. in its extremes 17 km^3 in 2001 and 59 km^3 in 1998, of which 10 - 15.6 km^3 were used for irrigation (at the entrance to the delta at Darganata; Schlueter et al. 2005). In low water years water practically does not reach the northern delta, but in high water years the flood can extend 2- 3 months with a discharge of up to 2000 m^3/s. Thus water management has to deal with both severe drought events such as 2000/2001 and floods as in 1998. Winter flooding because of ice barriers in the canals is also a major issue.

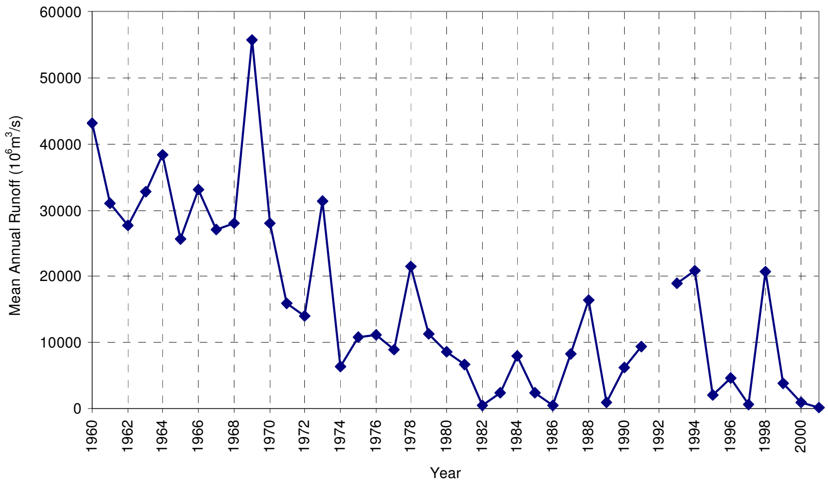

Fig. 3. Annual runoff at Kyzyljar at the beginning of the northern delta. There are some doubts in the accuracy of the values in some years; however the general trend is correct. (Source: Main Hydrometeorological Service of Uzbekistan)

37 % of the mean inflow to the delta or ca. 12 km^3 are withdrawn for irrigation, mainly in the southern parts of the delta (see table 2). Interstate agreements guarantee a minimum flow to the northern delta of 3.2 m^3/year (100 m^3/s) and 2.0 km^3/year for ecological and fish farming needs, mainly to support the Sudoche and Dautkul lakes. However, those limits are often not observed nor enforced. It is planned to increase the deliveries to 5.2m^3/year and up to 10 km^3/year depending on water availability of the year.

Table 2. Irrigation water needs in the delta area (Source: GEF/WB WEMP project, 2001, Ministry of Agriculture and Water Resources (MAWR), 2005)

	Khorezm	SK	NK	Delta Total
Irrigated area ('000 ha)	275	100	400	**775**
IrrigationMin (10^9 m3)	3.9	1.5	4.45	**9.85**
IrrigationMax (10^9m^3)	5.3	2.27	5.95	**13.52**
CDW min	3.2	0.54	1.12	**4.86**
CDW max	4.2	0.96	1.66	**6.82**

The lake systems in the delta are intensively used for fishing especially in Northern Karakalpakstan where before 1982 most people were employed in the fishing industry of the Aral Sea. Fish represents an important protein source for the diet of the local people as well as a valuable good for sale at local markets or in a few cases export to Russia. Recently the deltaic water bodies have been privatized and leased to individual people who try to establish fishing enterprises at the larger lakes or to secure reeds supply as cattle fodder. However, the insecure water supply, water quality problems and lack of a guaranteed minimum water inflow and of access and management regulations create high risks because of loss of fish and reed productivity. These difficulties and constrains were evident during the extreme drought years of 2000/2001, when the deltaic wetlands practically fully degraded and lost their environmental and social useful functions and services.

The main wetland ecosystem services of importance to the local population are

- Provision of fish
- Provision of forage grounds for livestock
- Provision of reeds as livestock fodder, heating and construction material
- Provision of wood for cooking/heating and construction
- Provision of medicinal plants
- Provision of hunting grounds (wild boar, water fowl, rabbit)
- Provision of muskrat for fur production
- Protection from wind and salt storms
- Protection from desertification
- Water purification and regulation of groundwater table

Conflicts over water allocation in the delta area occur between different water use sectors, mainly agriculture and other water uses, within the water management administration over water allocation for different purposes, as well as between upstream and downstream users. The main tradeoff in water use is between water use for irrigation in the southern part of the delta and water needs for drinking water and to sustain fish enterprises in deltaic lakes in the northern part of the delta. The water needs of the semi-natural ecosystems often conflict with water needs for agriculture. Competencies and responsibilities in water allocation are not clearly defined. E.g. it is the nature protection agency that distributes permits for water use for environmental purposes; however, the water is distributed by the ministry of agriculture and water management, which rarely agrees.

Major Problems

Table 3 summarizes the main problems for maintaining and improving the provision of ecosystem services as identified by experts and stakeholders at national and local levels. Obviously they are mainly connected with the availability and management of the available water resources. Water management is dominated by the demands of the agricultural sector and does not take the needs and dynamics of the wetland ecosystems into account. The fish populations in the lakes for example are dependent on an inflow of larvae and juveniles from suitable spawning habitats further upstream which then accumulate in the Tyuyamuyun reservoir. If water management ensures a sufficient inflow to the lakes during mid-May until mid-June this supply of offspring acts like a natural stocking mechanism. However, there is no interaction between the irrigation sector and the fisheries and wetland conservation sectors, which would facilitate coordination and balancing of spatio-temporal water needs. The ecological flows determined by the interstate agreement (see above) are only based on the needs of a few major lakes and are often not observed. Generally water management is in a bad condition, leading to large water losses and soil degradation. A few technical measures for wetland management such as overflow structures and dams have been implemented, however, they are often in bad shape or not finished. Financial resources for small measures, such as structures to prevent fish larvae from being spilt onto the irrigation fields are often lacking.

Table 3. Factors that influence state and provision of ecosystem services

Water supply	• Insufficient quantities • Bad quality • High fluctuations in inflow and water levels of lakes • No guaranteed water inflow to lakes • No regular flooding of floodplain Tugai forests
Water management	• Dominance of agricultural interests • Ecosystem water needs and dynamics not taken into account • No interaction between irrigation and fisheries/wetland conservation sectors • Flows for ecological purposes not observed • Bad water management • Insufficient finances for technical measures (e.g. fish gates) • Bad and incomplete construction of technical infrastructure • Environmental flows have to be addressed on the basin level

Designed technical interventions to rehabilitate deltaic wetlands

Technical and ecological interventions to rehabilitate the lake systems and wetlands have been started shortly after independence with the begining of massive donor assistance to the Aral Sea basin. Based on the good experiences with the restoration of the Sudoche wetland under a World Bank project in 1999-2002 an interstate program was defined in 2000 to create small local water bodies on the littoral zone of the Amudarya river delta. From 2004 – 2008 within the framework of the second Aral Sea Basin Project (Worldbank) the overall area of artificial lakes in the delta is planned to increase to 208,700 ha. This last project which is carried out by the government of Uzbekistan determined the following water needs for the maintenance and rehabilitation of the major water bodies in the delta zone (Table 4)

Table 4. Water requirements of water bodies in the northern Amudarya delta

Name	Main parameters			Water demand [million m^3/year]	
	Area [thou.ha]	Volume [million m^3]	Total water require-ments [mln. m3/year]	Evaporation and Filtration	Through-flow
Western Zone	76.0	748	1548	1064	484
Central Zone	81.29	1415	2564	1599	965
Eastern Zone	57.4	588	1152	803	349
Total	**214.69**	**2751**	**5264**	**3466**	**1798**

To improve the ecological situation and mitigate salt dust storms in the Amudarya river delta it is also planned to increase the flooding zone with riverine forests and vegetation as a green barrier to protect the irrigated lands from the harmful impact of the dry sea bed. Results of the GEF/Worldbank Aral Sea Basin Project suggest that minimum flow requirements of the deltaic wetlands of the Amudarya River, whose mean discharge is estimated at 74 km3 per year, amount to approximately 6 km3 per year (GEF, 2002). In low water years a minimum of 3.2 km3 should be maintained.

Vulnerability of deltaic ecosystems

For an assessment of the health of the aquatic and floodplain ecosystems in the delta area a set of hydraulic, hydrochemical, biological and socio-economic indicators have been identified in cooperation with local experts and stakeholders. The indicators include e.g. maximum acceptable water level fluctuations in the lakes in spring (spawning period) and winter, acceptable water salinity levels during spawning period, oxygen contents, the composition and diversity of aquatic as well as bird communities, indicators of productivity and food availability, but also the existence of management plans for water bodies, income levels of the local population and the proportion of wetland services in local livelihoods. Most of the indicators can be easily monitored by the local population which should be included into monitoring activities.

Analysis of the major characteristics of the wetland water bodies in the delta area show a wide variety of conditions, states and demands of those ecosystems. Some water bodies have a good water exchange; others are terminal lakes with very little exchange. The latter are more vulnerable to climatic and water management impacts, especially during dry years. The current situation in the delta area is unsustainable, both from a water supply as well as management perspective. Under the current water management regime in low water years the water quantity and flow demands of the water bodies can only be met for lakes which also receive significant drainage inflow. Moreover the existing management system and monitoring of aquatic ecosystem remains unsatisfactory. Monitoring is only conducted sporadically during the project life of international projects and scientific research programs.

The drought of 2000/2001 has given some indication of the vulnerability of the local communities and ecosystems to extreme events. During those two years the irrigation system in North Karakalpakstan received only 18% of the needed water deliveries (compared to 80% water delivery further upstream). The flow to the wetlands of the northern delta was reduced to zero for two years. However, besides its massive impact on agricultural production (loss of all major crops in North Karakalpakstan, aggravated situation of drinking water provision) as well as the state of the wetland ecosystems (e.g. loss of most fish populations), the drought in 2000/2001 has also shown that the wetland ecosystems have a high restoration potential. While up to 85% of the water bodies in the delta zone dried out most of the diversity of the deltaic ecosystems was reestablished during the next 2-3 years of sufficient water flow. It will take more years and rational use of the biological resources though until the ecosystems are also restored quantitatively to their former state. One of the mechanisms that facilitated quick restoration of the fish fauna is the large inflow of larvae and young fish with the spring floods from spawning grounds in the river further upstream.

The deltaic ecosystems are adapted to a fluctuating hydrological regime. Large flooding events such as e.g. the one in 1998 that flooded large areas of the floodplain in the northern delta initiate massive rehabilitation of the floodplain ecosystems such as the Tugai forests. However the long reoccurrence times of floodplain flooding and low groundwater levels prevent an establishment of the juvenile vegetation which is subsequently replaced by more drought and salt resistant plants such as salt cedar.

Technical options for the realization of environmental flows in the delta region

In the following we present a first assessment of infrastructural measures to increase environmental flows to the northern delta area. We develop and analyze several future water management scenarios and assess their implications for the provision of environmental flows and effects on the state of the deltaic ecosystems. The scenarios represent planned technical and management measures for water flow regulation in the northern delta area (for details see Khasankhanova et al. 2007).

Two different alternatives of regulation and run-off redistribution in the delta to provide guaranteed ecological releases into the lake and wetland systems were considered: (i) observation of the current design parameters of the systems, and (ii) development of a new improved system of regulation. The implications of both alternatives for the regimes of the lakes and the floodplains were assessed for a representative high, mean and low water year.

The calculations show that with a total area of lake systems and floodplains in the range of 214,700 ha in low water years the water bodies of the central zone that feed from the Mezhdureche reservoir remain vulnerable under both scenarios. Moreover, the western and eastern zones will experience severe water shortage (Figure 4). In mean water years water demand in the western and eastern zones will be satisfied by 80-100% given that all technical measures are perfectly realized. No water deficit in the central zone is observed. In high water years, water reserves are large, which can be used for the creation of new flooded zones.

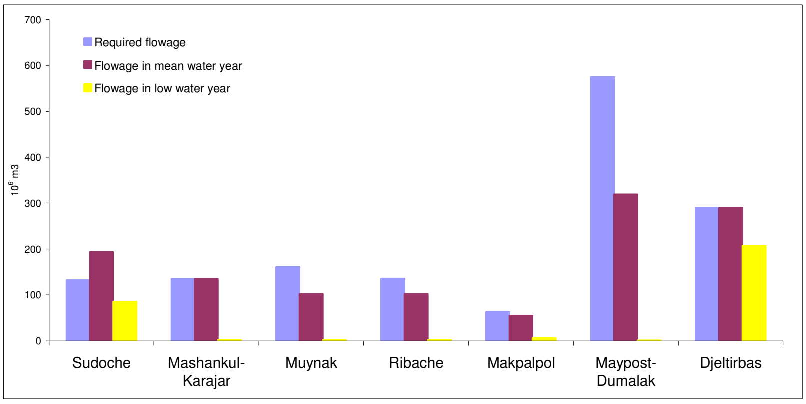

Fig. 4. Fluctuations of flowage on delta lake systems in the years of different water availability

With an increase in water use efficiency in agriculture which is a priority area of water management in Uzbekistan next to the introduction of water saving measures more water could be made available for the provision of those environmental flows. An increase in water use efficiency by 4% (from 0.3 to 0.34) by 2010 and 14 % by 2025 an additional amount of $185*10^6$ m^3/year in mean water years and $165*10^6$ m^3/year can be released as environmental flows. In the long term until 2025 $504*10^6$ m^3/year could be released given the ambitious efficiency increases were realized. However, the deficit in low water years amounts to approximately 800 – $850*10^6$ m^3/year, thus 300 - $350*10^6$ m^3/year would still be missing.

Hence, an expected future increase in the efficiency of water use in agriculture can improve the provision of environmental flows, however, even with significant increases in efficiency the needs of the lake systems cannot be fully met in low water years. Moreover, it remains doubtful whether those ambitious goals can be met with the planned measures of water saving and technical improvement of the irrigation system alone. It is thus necessary to devise additional approaches e.g. through changes in reservoir management or basin scale changes in water distribution and water use. Besides, the technical measures of redistribution and efficiency increase need to be accompanied by institutional changes and a move towards multi-purpose water use that recognizes the needs and benefits of other water users besides agriculture.

Discussion

Recent experiences have shown that technical measures to rehabilitate wetland ecosystems in the lower Amudarya delta and increase the provision of valuable ecosystem services are feasible and successful (e.g. restoration of the Sudoche wetland, construction of polders in former bays, etc.). In principle there are sufficient water resources in the Amudarya river basin to provide water for ecosystem services other than agriculture, however they need to be managed in a more integrative way taking the needs of different users such as the deltaic wetlands into account. This study is a first attempt at a more comprehensive assessment of ecological water requirements and the health of the deltaic ecosystems as well as technical, institutional and management measures needed for their maintenance and rehabilitation. While the hydraulic water demands of the lake systems in the delta are easy to estimate there is less knowledge on the ecological water demands of the floodplains and lakes. However, there is considerable local knowledge on indicators and ecosystem dynamics available which could be used to determine the flows and monitor the development of the wetlands at rather low costs.

The main challenge for the incorporation of environmental flows into water management in the Amudarya river basin is to address the tradeoffs in water allocation between different users, especially agriculture and other water users, upstream and downstream users, which are often perceived as conflicts (however they do not have to be). This challenge goes beyond the realization of infrastructural measures to provide improved drainage and freshwater flow to the water bodies and floodplains. The wetland restoration measures as well as their privatization run short without a legal and institutional basis for their management and exploitation and a stable, sustainable water supply. There are some rudimentary agreements between the riverine countries for the provision of environmental flows to the lower Amudarya delta region (ICWC 1998); however, the flow of these waters is often not realized. Among those responsible for water management there is no awareness of the short and long term benefits of allocating water to sustain environmental flows nor do the advocates of environmental flows have the power to enforce those releases in the face of a strong and traditional agricultural sector. To a large extent this is the results of the historically strong dependence on irrigated agriculture which created rents and vested interests that prevent any substantial change of the status quo (see Schlueter and Herrfahrdt-Paehle, this issue).

Nevertheless the consultations carried out within the framework of this study revealed a number of areas and possible solutions that should be addressed to move towards an integration of environmental flows. In table 4 we present the challenges and next steps as identified by the consulted experts and stakeholders.

We see the necessary next steps especially in raising awareness among water managers and decision makers for the benefits of wetland ecosystems and the services they provide for the livelihoods of the local population and the economy at large. The wetlands act as buffer in low water years by storing excess water from high water years but also by providing additional income sources during low water years. The former is one motivation for the recent extension of the lake systems in the delta. We aim to convince stakeholders in upcoming workshops about the possibilities of integrating environmental flows into water management by pointing out the potential benefits and by jointly developing and assessing scenarios of environmental flows and their potential impacts. In the long run the perception among decision makers and the local public that water is too scarce or valuable to “waste” it to the environment has to change towards a view that allocating water to the wetlands can produce valuable ecosystem services for all. Moreover, feasible ways have to be demonstrated of integrating environmental flows into water management in the river basin or parts thereof with respect to water availability, benefits and costs.

Table 4. Challenges and next steps for the realization of environmental flows and an improvement of the health of the wetlands in the Amudarya river delta as identified by local experts and stakeholders.

Water allocation (technical measures)	• Better balance water allocation between different users • Realization of water distribution infrastructure for wetland restoration and conservation • Definition of operational rules for provision of environmental flows
Water allocation (institutional measures)	• Negotiation of international water sharing protocols • Reduction of dependence on agricultural production • Legal basis for water sharing among sectors and interaction of users and suppliers • Definition of responsibilities of different organizations, enforcement, etc. • Development of institutions for collective use of wetland ecosystem services • Basin level agreements • Creation of associations of fishermen on lake systems for management and monitoring • Development of a monitoring framework
Water use in agriculture	• Increase water use efficiency • Awareness rising among representatives of agricultural and water sectors about the value of ecosystem services • Introduction of incentives for water saving
Water management (Public participation)	• Development of community level management plans and their integration into national environmental management programs • Involvement of local population in monitoring and conservation, control of sanitary conditions • Use of local knowledge for monitoring and development of measures • Awareness raising among local population on sustainable use of wetland ecosystem services

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References

Acreman M, Dunbar MJ (2004). Defining environmental river flow requirements – a review. Hydrology and Earth System Science 8(5):861-876

GEF (Global Environmental Fund) WEMP (2002). Water and Environmental Management Project. Subcomponent A1. Regional Report No 2. 1-62.

ICWC (Interstate Coordination Water Commission) (1998). Bulletin no 16. Scientific-Information Centre of the Interstate Coordination Water Commission, Tashkent, 53 pp

Joldasova, I., L. Pavlovskaya, S. Lyubimova, Temirbekov R. (2002). Fisheries reservoirs in the delta zone of the Amudarya River and problems of the sustainable use of their resources. Bulletin (Vestnik) of the Karakalpak Branch Uzbek Academy Sciences 5-6:3-9.

Kasankhanova G, Taryannikova R, Talskikh V, Abdullaev U. (2007). Adaptive Water Management under Uncertainty – the Amudarya Case Study. Report of activities of WP 2.3 in the Amudarya river basin. The NeWater project. 20pp.

Kreuzberg-Mukhina, E. A. (2006). The Aral Sea basin: changes in migratory and breeding waterbird populations due to major human-induced changes to the region's hydrology. Pages 283-284 *in* G. C. Boere, C. A. Galbraith, and D. A. Stroud, eds. Waterbirds around the world. The Stationery Office, Edinburgh.

Schlueter M., A. G. Savitsky, D. C. McKinney, H. Lieth (2005). Optimizing long-term water allocation in the Amudarya river delta—A water management model for ecological impact assessment. Environmental Modelling & Software 20:529–545

Tharme R. E. (2003). A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications, 19:397-441.