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Enhancing resilience to water flow uncertainty by integrating environmental flows into water management in the Amudarya River, Central Asia

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ABSTRACT

The wetlands of the Amudarya River delta in Uzbekistan provide valuable ecosystem services to the local human population which has suffered severely from the loss of the Aral Sea, desertification and the post-soviet socio-economic transition. The region is also particularly vulnerable to the impacts of climate change as a recent severe drought has shown. In this contribution, we assess the potential and implications of incorporating environmental flows into management of the Amudarya River for improving the provision of wetland ecosystem services and enhancing resilience of the social-ecological system to river runoff uncertainty. Our assessment is based on analyses of 1) the current vulnerability of deltaic wetlands to years of low water availability, 2) expected regional climate change and its impact on water flows to the wetlands, and 3) alternative water use options to enhance environmental flows under a changing climate. The results provide a ranking of these options with respect to their benefits for the provision of environmental flows and implications for agriculture. Their realization, however, poses challenges that cannot be tackled by technical interventions of redistribution and efficiency increase alone but call for institutional changes and moves towards multi-purpose water use. The diversification of impacts and livelihood options would allow enhancing the resilience of the social-ecological system to climate or socio-politically induced changes in water flow.

1. Introduction

Environmental flows are the flow regimes needed to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on them (Brisbane Declaration, 2007). Particularly in the developing world livelihoods often strongly rely on a multitude of ecosystem goods and services provided by these ecosystems. Their provision of environmental flows, however, is often compromised by massive alterations to the hydrological regime for irrigation, flood protection, hydro-energy production or transport.

This is particularly evident in the Aral Sea Basin where the ecosystems of the Amudarya river delta and the Aral Sea have for centuries supported the local population with a multitude of ecosystem services (Fig. 1). These include, among others, the provision of fish, forage, reeds for fodder, heating and construction material, medicinal plants, hunting grounds, muskrat for fur production, protection from desertification, regulation of the groundwater table and more. In the past 50 years massive man-made alterations to the hydrological regime, mainly to support the Soviet cotton industry, have led to their serious decline. Many valuable ecosystem services have been completely lost or strongly impacted. These include the fish production in the Aral Sea which ceased in 1982, the muskrat and reed production in the deltaic wetlands, or the retention of the groundwater level. However, despite and in part due to this massive degradation the importance of the remaining deltaic wetlands as an additional income source and buffer against economic hardship has in recent times increased. Up to today, fish from deltaic lakes for example represent an important protein source for the diet of the local people as well as a valuable good for sale at local markets or for export to Russia.

Because of the massive extraction of water resources for irrigated agriculture most of the wetland ecosystems in the delta only irregularly receive freshwater input. As a result practically all of the aquatic ecosystems have undergone significant changes with respect to their hydrological and hydro-chemical regimes. The extreme drought event in 2000/2001 which was a strong disturbance to all wetland components has further caused degradation of the ecosystems up to

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Fig. 1. The Amudarya river basin in Central Asia. This study focuses on the northern delta area beyond the last irrigation intakes formerly bordering the Aral Sea.

the disruption of major ecosystem functions. It has given some indication of the vulnerability of the local communities and ecosystems to extreme events. During these two years the irrigation system in North Karakalpakstan in the Northern part of the delta 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. To stabilize the regime of the wetland lakes several of them are now regulated using a mixture of freshwater and drainage flows. However, little is known about the impact of collector drainage flows on water quality and organisms and the effect of high flow variability on biological interactions and aquatic ecosystems.

There is a broad agreement that Uzbekistan is among the countries most vulnerable to climate change due to the high sensitivity of its arid arable lands, high density of population and growing concern about food security (CACILM, 2009). A stable warming tendency is observed today in Uzbekistan and other Central Asian countries (MNPT, 1999; Republic of Tajikistan, 2002) with likely consequences for the regions' water resources. Average rates of warming since 1950 along the territory of the Republic have been 0.29 °C per decade, which is more than twice the world average (Chub, 2007; Second National Communication under UNFCCC, 2008). In combination with extreme weather events and other climate related natural disasters, climate change can become a major cause of declining food production, water contamination, and economic damages. Mitigating the consequences and adapting the country's land and water use to climate change have thus received increasing attention in national and regional policies. The delta ecosystems of the Aral Sea Basin are among the most vulnerable regions in the basin.

The aim of the paper is to assess the vulnerability of the ecosystems of the Amudarya river delta to climate change impacts in order to analyze the potential and implications of incorporating environmental flows into water management. These strategies would allow improving the provision of desirable ecosystem services and enhancing the resilience of the social-ecological system in the river delta. The given assessment is based on climate modeling, field survey data and reports of several development projects conducted in the delta region in the past years as well as expert knowledge elicited during field studies, consultations and an expert workshop. In the remainder of the paper we introduce the Amudarya river delta and the methods used in this study. We then proceed with an assessment of the current state and vulnerability of the deltaic wetlands and the potential impacts of climate change on water supply to the delta. This information forms the basis for a scenario analysis of possible options to meet environmental flow requirements for the benefit of ecosystem services other than crop production under climate change. We conclude by discussing the implications of the options for agriculture and other livelihoods as well as challenges of their implementation.

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2. The Amudarya River delta

The Amudarya river is the largest river of the Aral Sea basin with an average annual runoff of 78.5 km^3. It accounts for two thirds of the total water resources in the Aral Sea basin. It is a glacier/snowmelt-fed type of river. The main flow volume (85%) is formed by the Vakhsh and Pyandj tributaries in the high mountain ranges of the Pamir, Tienshan and Hindukush in Tajikistan and Afghanistan. It drains into the lowland desert plains of Uzbekistan and Turkmenistan. The catchment of the Amudarya River is 535,000 km^2 (ADB, 2010). Over 1000 km of the river borders with the states of Uzbekistan and Turkmenistan before it enters the Aral Sea. Along the river a significant quantity of water is abstracted for irrigated agriculture. The massive expansion of irrigated agriculture in the 1960s–1980s for cotton production has caused major alterations to the runoff regime with well-known consequences for the deltaic ecosystems and the Aral Sea. Today irrigated agriculture accounts for 90% of crop yields and consumes over 92% of the total water intake. About 64% of the population of Uzbekistan live in rural areas and are thus directly or indirectly dependent on irrigated agriculture. In the future the demand for water will grow even more in order to maintain the food security of a rapidly increasing population.

The delta of the Amudarya river, as an end user of the river flow, has been most severely affected by the massive alterations of the hydrological regime. It is located in the Turan subzone of the desert zone and has an area of approximately 28,500 km^2 with a length of 400 km and a maximum width of 250 km. 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. The climate of the delta is semi-arid with a mean annual precipitation of 80–120 mm/year. Evaporation is high with 1200–1600 mm/year caused by high temperatures and strong winds in summer. The northern part of the delta between 42°30 and 44°N that lies on the territory of North Karakalpakstan (PreAral) comprises most of the former wetland areas and remaining semi-natural ecosystems of the delta. Here exists a peculiar system of lakes and floodplains with a total area today of about 212,000 ha (Fig. 2).

Conflicts over water allocation in the Amudarya river 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 (Uzbekistan and Turkmenistan) and water needs for drinking water and to sustain fish enterprises in deltaic lakes in the northern part of the delta (Uzbek Autonomous Republic of Karakalpakstan). The water needs of the semi-natural ecosystems often conflict with water needs for agriculture. Ecological considerations are so far rarely included in hydrological assessments and temporal trend analysis. Moreover, competencies and responsibilities in water allocation are not clearly defined. For instance, 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.

River runoff to the Amudarya river delta 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 is used for irrigation (Schlüter et al., 2005). An analysis of past runoff volumes to the northern delta for the period of

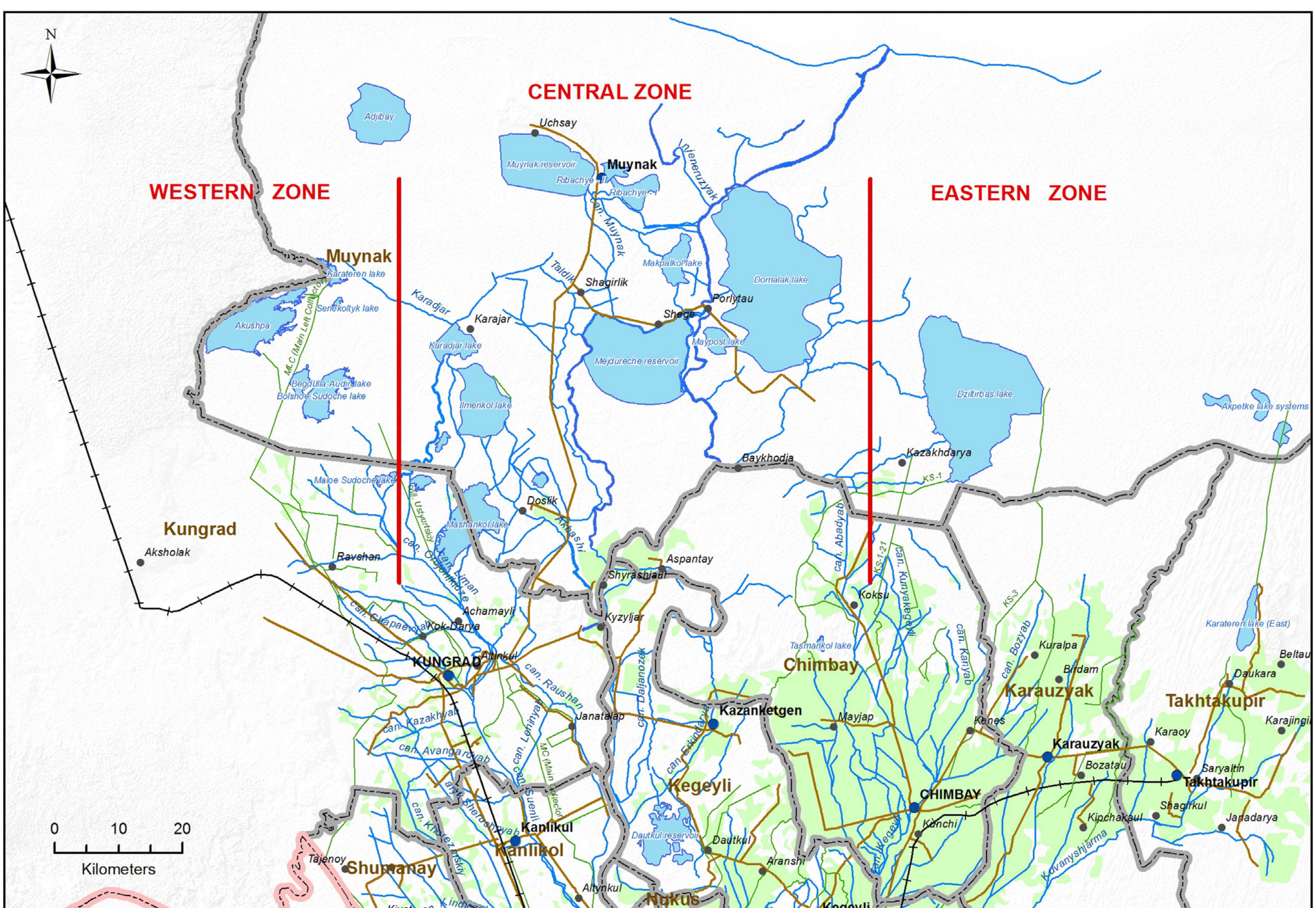

Fig. 2. Map of the northern Amudarya delta region.

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Table 1
Total discharge of surface water reaching the northern Amudarya delta, million m^3/year.

	Average discharge to northern delta	Collector-drainage water discharge	Total
Low water	1036	1222	2258
Mean water	2356	1759	4115
High water	9353	1929	11282

Source: Feasibility Study on "Creation of Small Local Water Ponds on Littoral zone of the Amudarya River Delta", Main report, IFAS, 2004.

1980–2002 has shown that in some low water years (95% probability) water practically does not reach the northern delta, but in high water years (5% probability) flooding can last up to 3–4 months. Table 1 gives the average river and collector drainage water runoff volumes in the northern delta for a low, mean (50% probability) and high water year.

2.1. Wetland ecosystems in 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 Uzbekistan and Turkmenistan. They are associated with a single source of water supply — the Amudarya river. Despite their common origin, the lake systems and wetlands of the Amudarya delta differ in their forms, sizes and ages, and are characterized by different relative depths, levels of littoral development and coverage with wetland vegetation. One of the major differences is whether the lake has an outflow and water can circulate or it is a runoff accumulator. A second major difference is the main water source of the lakes, which can be either river or collector drainage flow. As fluctuations of drainage water inflow are less pronounced than river water, lakes with drainage water inflow experience less water level fluctuations.

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 water levels can fluctuate by up to 1 m in spring and summer, which can seriously impact their ecological conditions. A decrease of the water level by 30–50 cm is already sufficient to kill the eggs of herbivorous fish that spawn on the littoral where water tables are shallow. The lake systems of the western and eastern parts of the northern delta on the contrary are fully or partly dependent on the volume and quality of collector-drainage runoff, which amounts to a total mean runoff of 1560 mln m^3/year.

The hydrochemical regime of the wetlands is not stable and completely depends on the volume and quality of the water inflow. The water salinity in deltaic lakes that have an outlet and water circulation (Karateren, Big Sudoche, Begdulla-Aydin) varies in the range from 3.5 to 7 g/l to 12.7 g/l on average; in stagnant terminal lakes the levels of values can reach up to 40–50 g/l (Taily, Akushpa). Differences in water salinity determine differences in fish population and the formation of the food basis. Water bodies with a salinity of up to 12 g/l are mostly inhabited by freshwater fish species; while only a few species can sustain high salinity — up to 30–35 g/l (e.g. Aterine, Amur goby, Medaka).

Stable wetlands (for example Sudoche, Djeltirbas, Mezhdurechye, Domalak and the Amudarya riverbed, the Sarbas and Muynak bay and others) can serve as objects of biological resource reproduction, biodiversity conservation, and provision of ecosystem services (fishing and hunting). The Sudoche weltands have been proposed for recognition as a potential Ramsar site. The shallow coastal zones of the Sudoche wetlands, Sarbas bay, Mezhdurechye and the Makpalkol, Khodjakul-Karajar, Domalak lake systems can provide valuable ecosystem services such as pastures, fodder and construction materials. Some lake systems have recreational and aesthetic values such as the Achikul lake, the Amudarya riverbed, Dautkul, Mezhdurechye and others.

2.2. Environmental water needs of the deltaic lake systems

Table 2 lists the main characteristics and water needs of the individual lakes in the delta (IFAS, 2004). The estimation of the water needs of each lake was based on the main parameters of the water objects and accounts for losses through filtration and evapotranspiration (calculated by using CROPWAT (FAO, 1998)).

With the adoption of the intergovernmental agreement on water management between the newly independent Central Asian states in 1992 the Amudarya delta region acts as an independent water user. The agreement prescribes an annual water flow from the Amudarya river to the northern delta of about 3 km^3 for basic needs and another 2.3 km^3 for farming needs. Those water resources are aimed for the conservation of the deltaic ecosystem, for maintaining

Table 2
Main parameters and water needs of the delta lake systems.

Lake/wetland	Main parameters			Water demand (mln m^3/yr)		
	Elevation [m]	Area [1000 ha]	Volume, [mln m^3]	Through flow	Including evaporation and filtration	Total
Western zone						
Sudochye	52.5	52	396	132	728	860
Mashankul-Karajar	57–53	24	352	352	336	688
Total		76	748	484	1064	1548
Central zone						
Mezdurechye	56	25	200	–	350	350
Muynak bay	52.5	9.75	161	161	136	297
Ribache bay	52.5	6.24	136	136	99	235
Makpalkol	54	3.8	63	63	53	116
Maypost	55	1.5	25	25	21	46
Domalak	54	35	580	580	490	1070
Total		81.29	1165	965	1149	2114
Eastern zone						
Jiltirbas bay	42	26.6	280	349	372	721
Other lakes and food-plains	55–52	30.8	308	–	431	431
Total		57.4	588	349	803	1152
Overall total		215	2501	1798	3016	4814

a regular water exchange in artificially regulated water bodies, for conducting forest amelioration and for other aims (IFAS, 2004). However, those limits are often neither observed nor enforced. And, as can be seen from Table 1, water flows even in a current mean water year are not sufficient to serve the needs of the lake systems. In a low water year only approximately 50% of the needed environmental flows are currently available.

3. Material and methods

3.1. Assessment of vulnerability of the lakes to low flow events

Our assessment of the vulnerability of the aquatic and wetland ecosystems in the Amudarya delta to extreme events is based on (1) available hydro-chemical and hydro-biological monitoring data from the Uzbek Hydro-meteorological Service, the Environmental Protection Agency (Goscompriroda) and the Ministry of Agriculture and Water Resources (MAWR), (2) results from field surveys and monitoring activities carried out over the past ten years within the framework of environmental and social assessment studies of the Sudoche wetland restoration project and others (e.g. IFAS, 2001; IFAS, 2004), and (3) our own field studies and expert consultations in participatory workshops in September 2007 (NeWater, 2007; Schlüter et al., 2007). No time series data of the aquatic ecosystems and their use are available because of the lack of monitoring programs for the deltaic ecosystems. Expert judgment thus remains the best possible method for assessment.

In order to assess the vulnerability of the lake ecosystems to low flow conditions, the current states of the lake during a year of average water flows and a year of low flow were compared. The states of the lakes under both flow conditions were determined using a system of indicators. Indicators include both key abiotic and biotic variables to provide a comprehensive assessment of the conditions of the lakes (Table A1). For instance the hydrobiological status was assessed using the saprobe index (SI) – degree of organic matter compositions and the F/S – ratio of freshwater and brackish water diatom species. Additionally spatial and temporal changes of abiotic and biotic characteristics were studied such as (i) the species composition of zooplankton biocenosis; (ii) phytoplankton; (iii) periphyton and (iv) zoobenthos. The community structure of this biocenosis is highly sensitive to changes of the hydrological and hydrochemical regime in the lakes. Freshwater species prevail in conditions of low or moderate water salinity, while moderate salinity leads to parity of the development of fresh- and brackish-water components. The presence of different trophic and ecological aggregations of organisms in the biocenosis testifies the availability of diverse ecological niches which is usually a characteristic for good ecological conditions.

For every lake the abiotic and biotic parameters of the aquatic systems and suitability of conditions for breeding of fish, muskrat, the reproduction and conservation of hydrophilic birds and vegetation under the two inflow flow conditions were assessed. The value of each indicator was classified into one of three classes: very good, good and bad. The sum of the classified indicators was then used to classify the overall condition of the lakes as very good, good and bad. In cases where there was a lack of data expert opinion was additionally consulted.

3.2. Assessment of climate change impacts on river runoff

The assessment of climate change impacts on water resources is a complex multivariate analysis based on various approaches and methods. The expected natural changes in water resources are mainly defined by changes in the parameters of the climate system. Climate change outputs of the global ocean and atmosphere circulation models are the most appropriate basis for development of regional climate change scenarios, which in turn serve as a basis for various regional assessments of vulnerability to the expected climate changes. The expected volumes of runoff depend on the models and scenarios selected. The assessments of climate change impacts on water resources according to the different scenarios of temperature and precipitation can thus vary within wide limits.

The given analysis of climate change impacts on river runoff to the delta is based on regional climate scenarios derived from the REMO model (Jacob, 2001; Jacob et al., 2007) and a regional hydrological model (Automated Information System for Hydrological Forecasting (AISHF), Denisov et al., 2000). The regional model REMO is driven by the global coupled atmosphere–ocean climate model ECHAM5/MPI-OM (Roeckner et al., 1996, 2006; Jungclaus et al., 2006). For the Amudarya river basin, REMO was applied with different realizations of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) (Nakicenovic et al., 2000). To assess future climate change for the purpose of this study a scenario simulation assuming greenhouse gas concentrations according to SRES A1B was performed.

AISHF is a model of runoff formation in the mountain region that has been developed in the Central Asian countries for runoff estimation and forecasting. For practical applications of this model an automated information system of runoff generation has been developed. It is widely applied today for solving tasks of applied hydrology, estimation of snow storage and run-off and for long term forecasting. The model approximates runoff based on past hydrological time series and an optimization approach. It describes the full cycle of run-off generation in the upstream mountainous river basins reflecting the main processes: (i) precipitation (liquid and solid), (ii) dynamics of snow cover, (iii) evaporation, (iv) impact of melt water and rain water on catchment area surface, (v) run-off from the glaciers, (vi) transformation and loss of run-off in the basin.

For the assimilation of the climate scenario data derived from REMO by the regional hydrological model an interpretation of the scenario data by gauging stations was required. The following model downscaling steps were carried out:

Step I Compilation of meteorological data for the periods 1960–1999 and 2000–2099
Step II Statistical local downscaling
Step III Runoff calculations using the regional AISHF model in accordance with climate scenarios for 2000–2099

The projected runoff into the Amudarya delta has been estimated using water balance calculations based on the forecasted flow at a midstream gauging station taking into account the inflow and water intakes along the river from the upstream areas to the Tuyamuyun reservoir. This only reflects one possible scenario based on current

Table 3
Proposed investments (mln US$) for measures to increase water use efficiency.

Year	Irrigation efficiency			Water demand (mln m³)			Investment (mln USD$)	
	Overall distribution efficiency	Field application efficiency	Overall water use efficiency	Agriculture	Ecosystems	Other water consumers	Rehabilitation of the irrigation infrastructure and land improvement	O&M
2030	0.52	0.70	0.36	14049	5300	2400	178	9
2050	0.58	0.74	0.43	12059	5300	3360	204	11

Table 4
Alternative options for changes in cropping patterns (RKK = Republic of Karakalpakstan).

	Description of option
Option 1	Decrease of cotton and rice by 5% in Khorezm and in RKK, increase in wheat
Option 2	Decrease of the cotton by 10% and rice by 5% in Khorezm and in RKK, increase in wheat
Option 3	Decrease of cotton by 10% and rice by 7% in Khorezm and in RKK by 3%, increase in wheat

extractions in the midstream, since information on intended future changes in water use in the midstream is not available.

3.3. Scenario analysis of environmental flow options under a changing climate

Three alternative policy options to secure environmental flows to the aquatic ecosystems under a changing climate have been developed. They are based on the implementation of alternative cropping patterns that lower the water use for irrigation and increase water supply to the northern delta in different ways (Table 4). No changes in the area of irrigated agricultural land are assumed, however, changes in the relative distribution of crops (cotton, rice, wheat) result in different predicted water demands. Scenario calculations were carried out for an average expected mean and low water year under climate change in 2030.

All three scenarios are also based on assumptions about future institutional and technical conditions that have been derived from recent studies and strategies about the development of water resources in the Uzbek part of the Amudarya river basin (GEF, 2001; UNDP, 2007). The projected water flows to agriculture and the lake system in the different scenarios have been calculated using hydrological balance calculations. Making assumptions about likely future changes in the water and agricultural sectors which may arise with the expected climatic changes and their impacts on the vulnerable deltaic ecosystems and human environment in the long-term future is difficult and subject to considerable uncertainty. Results thus have to be seen in light of the following assumptions about the future institutional and technical conditions. The detailed assumptions are given in Table A2.

With respect to the basin-wide institutional arrangements it is assumed that the inter-governmental agreement between the countries of the Amudarya River Basin will not be reconsidered until 2030–2050 and hence the Amudarya river run-off allocation between Turkmenistan and Uzbekistan is preserved in its current proportions — 50:50. The seasonal regulation of the runoff by the upstream Nurek reservoir and the operational regime of Tuyamuyun reservoir at the entrance to the delta are preserved at the current level. It is further assumed that government policy will be targeted towards agro-technical and drought mitigation measures including changes in cropping patterns in low water years to reduce the area with high crop water requirements or introduce draught tolerant crops (e.g. replacement of the rice by winter wheat, decrease in cotton in favor of food crops).

Furthermore we assume that the following measures to foster an integrated and adaptive water management have been implemented by 2030:

(1) construction of the Shorbulak reservoir in the delta (currently in planning)
(2) institutional measures to develop adaptive capacity, to improve inter-sectoral coordination, and to enhance compliance with inter-governmental agreements
(3) development of local environmental management, monitoring and mitigation plans
(4) other measures such as awareness raising, capacity building and knowledge management activities.

Future water demands of agriculture and other users are based on calculations performed for the “National Plan for Water and Salt Management” (GEF/WB, 2002). They were designed to meet the Millennium Development Goals (MDGs) for the sustainable management of water resources and environment and the prevention of natural and man-made disasters (UNDP, 2007). Those calculations assume investments of more than 200 million USD in physical measures to improve land and infrastructure as well as operation and maintenance to increase water use efficiency.

Table 5 shows the expected water demand by agriculture and the environment based on an assumed increase in water use efficiency in agriculture from 0.31 to 0.36. As a consequence water intake for irrigation decreases by 10%; however this comes at considerable costs as the column on investments shows. On the other hand the water demand of non-irrigational consumers, including potable, industry and domestic needs increases threefold. Expected water demand by other water users taking into account the social needs of the population by 2050 and the need for sustainable development of all sectors is estimated within 2400 mln m^3 for 2030 and 3360 million m^3 for 2050 (GEF/WB WEMP project, 2001).

It is assumed that the investments in infrastructure will also lead to an increase in yield by 17% for cotton, 34% for rice and 40% for wheat.

4. Results

4.1. Vulnerability of deltaic wetlands to low flow events

In a current mean water year wetlands of all three conditions can be found in the delta (Fig. 3).

The lakes of the successive lake chain located in the center of the northern delta – Mejdureche, Rybache I & II, Muynak reservoir – as well as several lakes of the Sudoche weltand in the western part belong to the category of wetlands in «*very good*» condition. They receive regular water inflows. Most lakes with low water circulation and water exchange have been classified as «*good*» such as Dziltirbas, Mashankol, as well as some lakes of the Karadjar and Dumalak system. Both wetland categories are characterized by low (0.97–1.03 mg/l) or moderate water salinity (1.55–5.00 mg/l), a high transparency of the water column (more than 1 m) and a diverse taxonomic structure of

Table 5
Expected changes in river flow in the Amudarya river basin estimated with the AISHF model (the river Vakhsh is one of the main contributaries to the Amudarya river).

River-gauge	Average multi-year *annual* discharge (million m^3) (1959–2007) (average multi-year *seasonal* discharge) (April–September)	% of multi-year *annual* (*seasonal*) discharge	
		2030	2050
Vakhsh — Komsomolabad (upstream)	19079 (15621)	95 (84)	88 (77)
Amudarya — Kerki (midstream)	61274 (47781)	97 (87)	92 (78)

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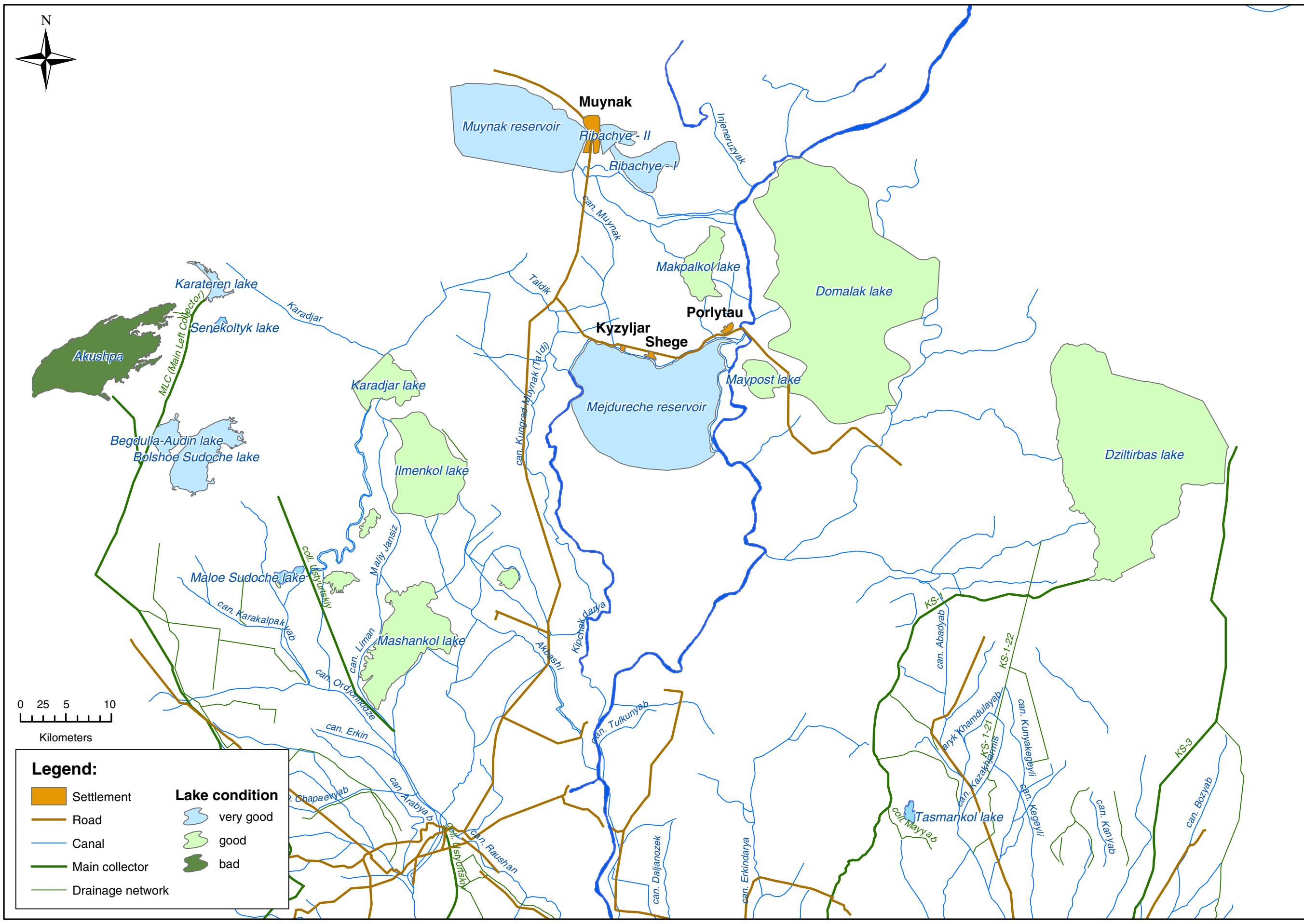

Fig. 3. Categorization of wetland ecosystems based on their vulnerability in a mean water year.

the biocenosis corresponding to a good ecological status. The wetlands categorized as «*good*», however, are more vulnerable to climatic and water management conditions (see below). Standing water lakes — terminal accumulators of drainage flow such as Akushpa belonging to the Sudoche wetland system have been categorized into the «*bad*» category. They are in a stage of ecological regress. This category of aquatic ecosystems has adverse characteristics — high salinity (17.5–47.5 mg/l), suppression of freshwater flora and fauna, simplified taxonomic structure of water biocenosis with single and mass development of highly tolerant species because of disturbance of trophic relations and absence of competition. The results for each individual indicator are listed in Table A3.

With a sharp reduction of water inflow in a low water year most wetlands were classified as «*good*» pass into the «*bad*» category and practically dry out in extreme drought years such as 2001 (Fig. 4). These lakes are thus highly vulnerable to changes in water flow and suffer from persistent multi-year trends of increasing water salinity, are often overgrown with vegetation and accordingly show a worsening of the provision of ecosystem services. The lakes classified as «*very good*» are less vulnerable as are some of the lakes classified as «*good*» that are supplied mainly by drainage flows. The analysis shows that 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. Contrary to freshwater inflow from the river, drainage flow fluctuates less and thus provides a more stable water supply (Fig. A1).

The extreme drought event in 2000–2001 has dried up approximately 85% of the water bodies in the delta. In standing lakes the water salinity levels increased to 48–92 g/l, with a maximum in the stagnant zone of the Akushpa lake (121 g/l). Results of the assessment of abiotic and biotic parameters show that the drought had a strong effect on 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. Disturbance of migration and reduction of spawning areas of fish population, aggravated by an increase of fishing to meet the demand of the local human communities, have led to practical full exhaustion of the wetland fish resources. The quality of muskrat habitats also steadily worsened and they practically disappeared. The preserved cattail–reed and reed associations have significantly suffered and grass phytocenosis have been replaced with salt tolerant and drought-resistant species. Phytophagans, mainly big flocks of Asian locusts, have severely impacted the vegetation obliterating big parts of reed bushes and seedlings in adjacent agricultural lands. In all observed aquatic ecosystems, the reduction of species diversity and loss of productivity of the zooplankton biocenosis, connected with a loss of freshwater species from the plankton associations and the formation of a homogenous hemophilic and halo tolerant fauna have been noted.

4.2. Expected changes in climatic parameters in the Amudarya river delta

In accordance with forecasts of the change in meteorological factors a temperature rise and an increase of yearly precipitation are expected in the Amudarya river basin. The warming tendency can be seen both in the cold and warm half of the year. The average monthly temperature is expected to increase by 0.5–1.0 °C by 2030 and 0.5–2.3 °C by 2050, while in winter increases will be from 0.8 to 1.6 °C by 2030 and 1.7

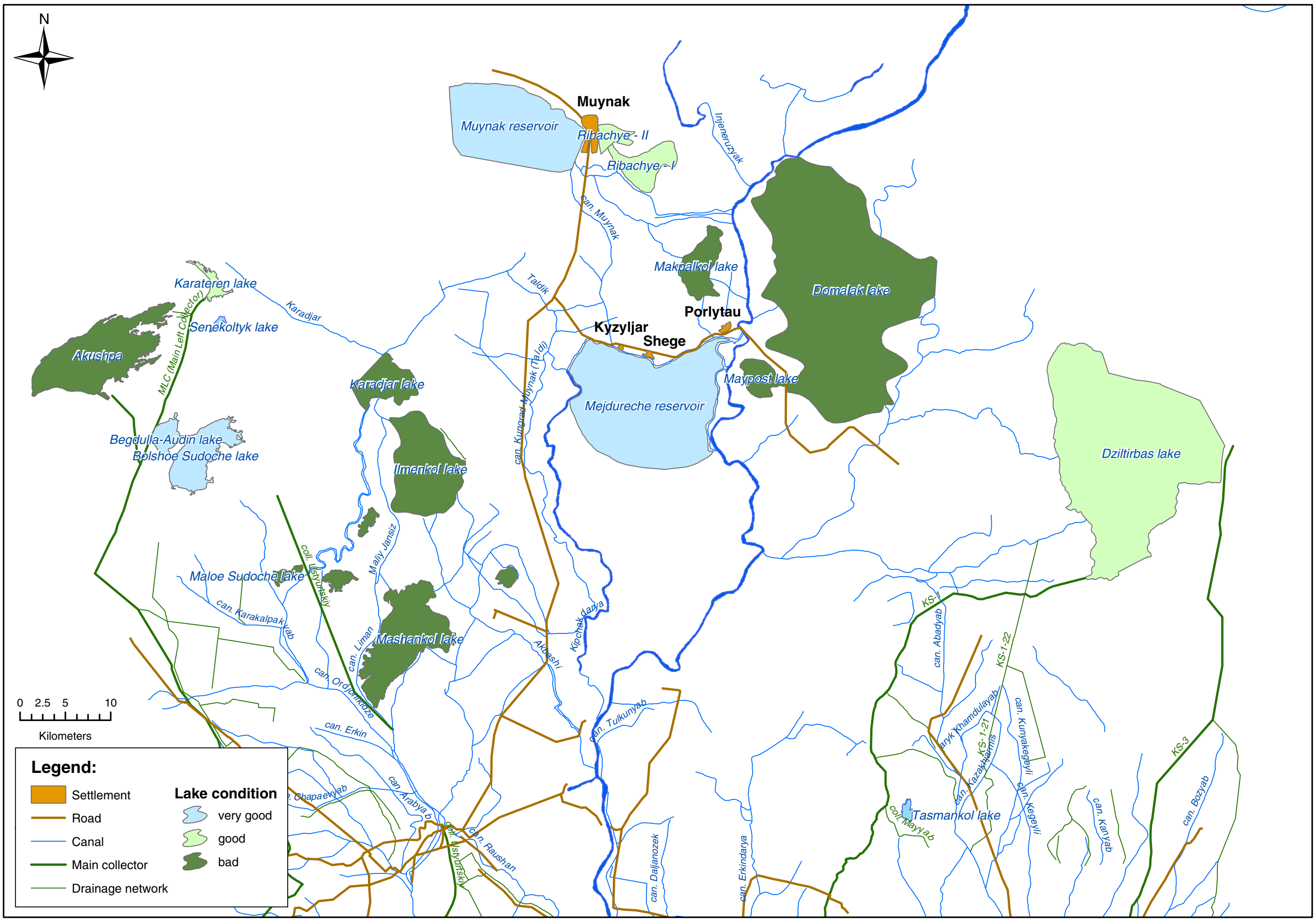

Fig. 4. State of the lake ecosystems during an extreme drought.

to 2.5 °C by 2050. Additionally the number of extreme weather phenomenon in summer is expected to increase (periods with droughts, winds and high temperatures).

In the lower parts of the Amudarya river a precipitation increase is expected of 12–14% by 2030–2050. However, given the low precipitation amounts (80–120 mm) and the increase in air temperature this increase will not have a significant effect on agriculture and ecosystems. A change in the precipitation regime is not expected – maximum precipitation will continue to occur in the autumn–winter–spring period, the minimum – in the summer period (Fig. A2).

The predicted temperature rise will increase the evaporation from soil and water surfaces as well as crop evapotranspiration. Under current conditions the transpiration of hydrophilous vegetation of the delta ecosystems exceeds the evaporation from the water surface by 1.7 times. As a result of further aridization, heat advection from the adjacent desert and an increase of the vegetation period, the transpiration of vegetation will exceed the evaporation from water surfaces by 1.8–1.9 times, which accordingly increases water losses. The expected increase of irrigation norms for agricultural crops will cause additional intakes of surface run-off for crop irrigation. Based on calculations using the CROPWAT program (FAO, 1998) the average annual potential evapotranspiration is expected to increase by 5% by 2030. The annual distribution of the potential evapotranspiration is similar to the temperature distribution.

4.3. Expected impact of climate change on river flow

In the upstream of the river, evaporation in the 30 year means is projected to increase as indicated above. As a consequence the water remaining for runoff will decrease by about 15% in the lower parts to 19% in the Pamir mountains (Starke and Jacob, 2009). These climate induced hydrological changes are reflected in a reduction of the natural river flow upstream (Komsomolabad) and midstream (Kerki) (Table 5). River flow will particularly be affected during the vegetation period. While by 2030 the multi-year *annual* discharge is projected to decrease only by 3–5%, the reduction during the vegetation period (multi-year *seasonal* discharge) is expected to amount up to 13–16%.

Despite this decrease in the seasonal runoff midstream until the end of the century intra-annual variation will remain high, although the extreme values decrease (Fig. A3). A similar trend can be observed for the inter-annual variation which remains high; however the magnitude of the variation decreases (Fig. A4). A comparison of annual hydrographs for inflow to the upstream Nurek reservoir and mid-stream Kerki gauge station shows that next to the shift in amplitude there is a shift towards a later onset of the summer floods which is particularly pronounced in the upstream area (Fig. A5).

The projected impact of climate change on the multi-year average annual river flow, despite its rather small magnitude, will further deduce the water available for environmental flows to the lake systems, if no adaptation measures are taken (Fig. 5). In an average mean water year in 2030 water releases into the northern delta will not be sufficient to satisfy environmental flow demands during the vegetation season. In a low water year water flows will not be sufficient to meet the demands of the lakes throughout the year; and will even not be enough to meet demands of agriculture. This will have serious impacts on the state of the vulnerable wetland ecosystems in the delta, as illustrated by our

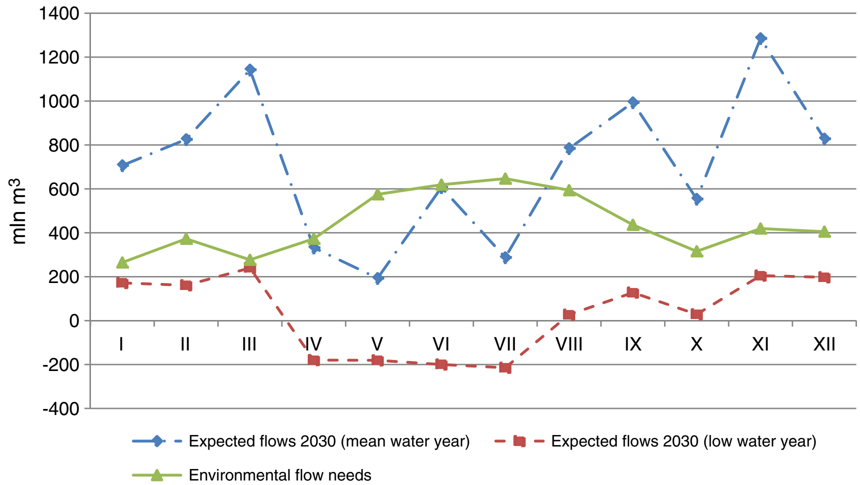

Fig. 5. Environmental water needs for lake systems and estimated flow to lake systems in low water year in 2030 without any adaptation measures.

analysis of an extreme low water event presented above. Based on the vulnerability assessment above it can be expected that the condition of vulnerable lakes turns bad. Only the non-vulnerable lakes that have been classified as good in a low water year, can potentially remain in a good condition if their water supply from drainage is retained at an acceptable level (i.e. not increasing salinity beyond ecologically sustainable levels). Environmental water needs are particularly not satisfied in the spring and summer seasons (April to August) when the ecosystems are most vulnerable to water fluctuations (e.g. because of spawning of fish in the shallow littoral) but water demand for agriculture is also at its highest. Thus the expected impact of climate change on the state of the deltaic wetlands is a worsening of the conditions particularly in the lakes identified as vulnerable above.

4.3.1. Scenario analysis of environmental flows under different climate change response options

Of the three alternative response options that aim at reducing water needs in agriculture to sustain water flows to the ecosystems under climate change impacts, only the third option is suitable to meet the required environmental water needs (Fig. 6). Here they are met throughout the year except for the winter months. It can thus be expected that most lakes remain in a very good and a good condition providing a multitude of valuable ecosystem services. Option 2 also gets close; however, water availability for the lakes during the vegetation period is very close or slightly below the needed volume and thus very sensitive to slight changes in runoff or water needs in agriculture. Note, however, that these environmental flows can only be achieved if the planned technical, institutional and policy measures and investments described above are implemented (Table 3).

On the agricultural side the most suitable option 3 translates into a decrease in water use by 17% in total and a shift of water use from summer (cotton) to fall (wheat). The shift in cultivated crops from cotton and rice to wheat leads to a decrease in cotton yield by approximately 30% compared to today, even when assuming an increase in productivity, and a substitution of wheat for rice (Fig. 7). Overall agricultural production, however, increases in all 3 options (under the assumption of improvements in yield/ha). This loss of cotton production would be offset by an increase in wheat production and productivity of other ecosystem goods and services such as fish, game birds, muskrat, and pasture. With the full implementation of all planed measures an increase in wetland area to 234,000 ha is expected. Together with an increase in productivity this could lead to a significant increase in ecosystem services produced (e.g. an estimated 5-fold increase in net benefits, Khasankhanova et al., 2008).

5. Discussion

The remaining wetlands of the Amudarya river delta still provide valuable ecosystem services and livelihoods to the local human

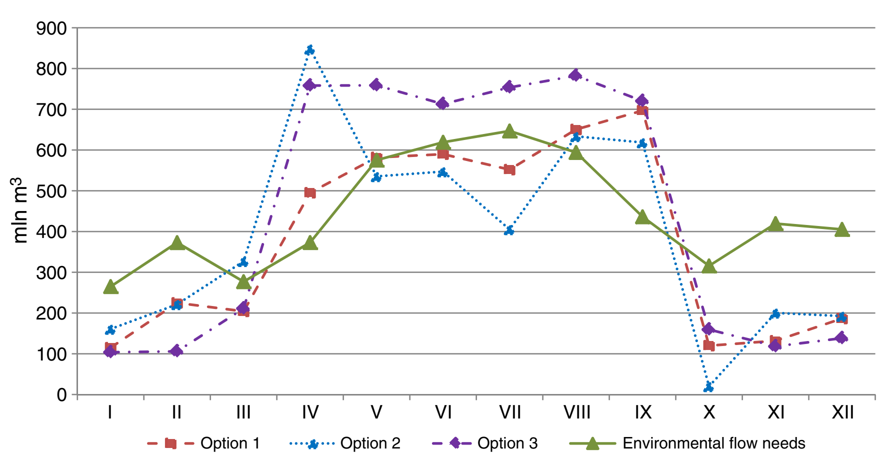

Fig. 6. Comparison of three alternative options to cope with climate change impact.

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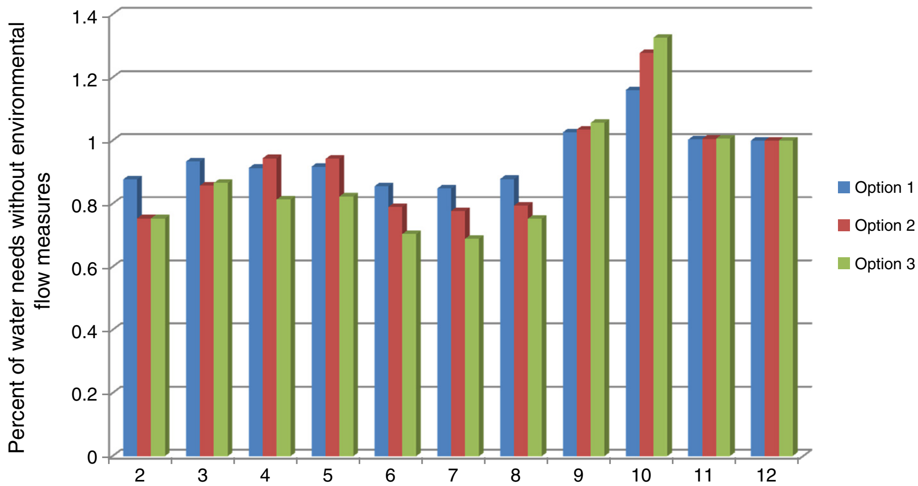

Fig. 7. Changes in agricultural water availability for the three options.

population despite their ongoing desertification. They are particularly important in the light of economic difficulties caused by the loss of the Aral Sea and the ongoing socio-economic transition in the former Soviet Union river basin states. The integration of environmental water needs into water management could provide significant benefits for the local population by mitigating desertification and enhancing the resilience of the delta region to uncertainty and variability of river runoff caused by climate and socio-economic change. With adequate management of the water supply in the Amudarya delta, stable and unstable, temporal and short-time water or marsh areas are formed which provide optimal conditions for the development of certain biological resources and ecological services. Taking the water needs of the wetlands into account thus can provide for a more diverse set of ecosystem services to sustain local livelihoods.

Our analysis of the current state of the wetland ecosystems has shown that in a mean water year most existing wetlands are in very good or good condition where they provide valuable ecosystem goods and services such as fish, reed, pasture, etc. As a whole, however, the wetlands and lake systems in the delta of the Amudarya are today unsustainable systems, as planned measures for their management, including the delivery of fresh and drainage water flows, construction of hydro-technical structures and supporting measures, are still not fully realized because of institutional, financial and organizational barriers. This is also reflected in their high vulnerability to low water years which can quickly move them into a bad condition as our analysis of the impact of a low water year has shown. When wetlands dry up or salinity severely increases the provision of ecosystem services is highly compromised. This has severe consequences for the local population which already suffers high losses in agriculture during drought (e.g. reduction in grain production by 54% in Karakalpakstan during the extreme drought in 2000, FAO, 2000). Climate change will most likely aggravate the challenges associated with water shortage and high variability of river flows as our analysis indicates.

Data of long-term hydro-meteorological observations in Central Asia show that climate change and the associated warming tendencies affect the trends of several components of the hydrological cycle. These include a decrease of snow accumulation and a significant reduction of the glaciation of mountain areas. Our modeling results, however, show that for the expected range of climate change parameters for the nearest 20 years, significant change in the total amount of water resources of the Amudarya river basin is not anticipated. All changes in the runoff are expected to be within the natural variability. However, projections indicate a shift in runoff patterns leading to significant reduction of river flows during the summer months. This is the time when both irrigated agriculture and the wetland ecosystems have highest water demands. This shift together with a later onset of summer floods can potentially have a severe effect on agriculture and wetland ecosystems. This is particularly concerning in light of the already prevailing water shortages in the downstream of the basin and will make the management of the tradeoff between different users even more challenging. Additionally, an increase in extreme events could severely impact the already stressed deltaic ecosystems. It will potentially render vulnerable wetlands currently in good condition permanently into bad. This will have severe consequences for the provision of ecosystem services and the associated livelihoods.

The three alternative options for incorporating environmental flows into water management under a changing climate tested in this paper show that the tradeoff between water use in agriculture and for other ecosystem services can be successfully managed. The options involve a change of cropping patterns in low water years and the implementing of a set of technical, institutional and governance measures to achieve a more integrated and adaptive water management. Reductions in cotton production of a certain level and substitution of wheat for rice can provide the needed environmental flows in an expected future low water year in 2030 under climate change. However, the options come at a cost for agricultural production that will have to be carefully balanced with other benefits derived from the deltaic ecosystems. Those benefits can be significant both in terms of actual value of the other ecosystem services provided and in terms of a diversification of livelihood options that enhance coping with river flow uncertainty. The decision on what ecosystem services to maintain with the limited water resources, however, has to be taken by society. More research is needed to understand the ecological, economic and social tradeoffs of different water management alternatives and the potential and obstacles of implementing them.

Incorporating environmental flows into water management can be one measure to prepare for future changes of river runoff caused by climate change. Balancing water distribution among a diversity of water users increases the number of possible response options and spreads climate change impacts across several livelihood options. For instance the lake ecosystems that react slower to a short term reduction in inflows can buffer the impacts of a low water year by continuing to provide ecosystem services when agricultural production fails. This increase in adaptive capacity enhances the resilience of the delta to climate variability and change (Schlüter et al., 2009). Additionally, as most of the ecosystems are adapted to a highly variable arid environment their restoration potential after a low water year is rather high given that damages are not too severe and long lasting (Schlüter

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and Herrfahrdt-Pähle, 2011). A more stable provision of environmental flows may also increase the willingness of the local population to engage into maintenance and management of the wetlands. Recently the major water bodies of the delta have been leased to individual owners who try to establish fishing enterprises at the larger lakes or to secure the supply of reed as cattle fodder. The high vulnerability of the lakes and adjacent wetlands and the lack of access and management regulations, however, create high risks because of loss of fish and reed productivity. This acts as a disincentive to investing into improvement of the ecological conditions, biological productivity and a sustainable management of the water bodies.

Enhancing the resilience of the social-ecological system in the delta through a more balanced water allocation, an improvement of water use efficiency and reduction of water intensive crops can only be a first step towards more sustainable livelihoods in the Amudarya river delta. In the long run a transformation of the social-ecological system is needed that for instance includes shifting economic activities away from agriculture (Schlüter and Herrfahrdt-Pähle, 2011). Furthermore it will be necessary to develop institutional measures to ensure a balanced water allocation to sustain wetland services and improve collective water and land management. The indicators for the institutional and social dimension identified in the expert workshops (Table A4) confirm the importance of the institutional setting and of awareness rising among local communities and decision makers. Community measures to improve livelihoods focusing on recreational fisheries, demonstration of advanced technologies and best practices of wetland use and development of local handicrafts and commercial hunting enterprising, have been identified. The conducted expert consultations in the delta show that the development of local plans for lake conservation and collective management of deltaic ecosystems using local knowledge for monitoring and providing mitigation measures are critical for increasing the capability of the local human population to better cope with water and climate related uncertainties.

The massive ecological and social changes in the Amudarya river basin over the past few decades and the adaptation or lack thereof of the water sector (Schlüter et al., 2010) provide an instructive example for studying the institutional and governance changes needed to move the system out of a state that provides benefits to a few while depriving most of the ecosystem services they depend on. While the institutional and economic changes needed are inherently a political issue, a dimension we could not get into within the scope of this paper, we showed how careful consideration of the needs of other water users such as the wetlands and people that depend on the ecosystem services they provide can provide a first step forward to initiate change. The successful restoration of the Sudoche wetlands under the Aral Sea Basin Program has for instance initiated the feasibility study for a restoration of other deltaic wetlands presented here. Balancing the tradeoffs between water use for irrigation and other ecosystem services is a major challenge in many semi-arid and arid regions. There is much to be learned from studying the pitfalls and potentials of technical and institutional change in achieving this balance in case studies such as the Amudarya river basin.

6. Conclusions

In this paper we assessed the current vulnerability of the wetland ecosystems of the Amudarya river delta and tested different future management options to provide environmental flows to the wetland ecosystems under climate change. Results revealed a vulnerability of deltaic wetlands to fluctuations in river flow which varied depending on their location and hydrological characteristics. The presented approach for vulnerability assessment of deltaic ecosystem can support balancing and adapting the spatial–temporal water distribution between different water users and water-related ecosystem services. Our study also revealed that the impact of climate change over the next 20 years will lie within the current variability. However, shifts in runoff patterns will aggravate distributional challenges associated with the already scarce water resources in the downstream of the river. We tested alternative management options to better balance water use between agriculture and the deltaic ecosystems to provide the needed environmental flows. This would lead to a more stable and diverse provision of ecosystem services to the local population and thus enhances their resilience to water flow variability and uncertainty. In the long run, however, measures of adapting cropping patterns and improving water use efficiency fall short in providing long term opportunities for balancing these tradeoffs. For this a change of the economic emphasis away from irrigated agriculture is needed.

Acknowledgments

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Appendix A

Table A1
Key indicators for assessment of vulnerability and state of the aquatic ecosystems in the Amudarya delta.

Indicator	Characteristics	Possible consequences and RISKS
a) Abiotic Indicators		
1. Water exchange (outflow)	Flowing conditions	Intensive aging of the ecosystem and lack of water turnover and disturbance of productive functions
2. Depth of water bodies	Average depth of water — not less than 1.5 m	Risk of overgrowth of main water area with wetland vegetation when decreases depth of open reaches
3. Water level fluctuation	Water level variation/fluctuation in spawning and winter seasons not more than 0.3–0.5 m	Worsening conditions for fish reproduction and hibernation for coastal species
4. Water salinity for fish spawning	For fish spawning (April–May) — not more 5 g/l;	Decrease and cessation of food fish reproduction, muskrat and reed
5. Water salinity for other organisms	For muskrat, reed — not more 10 mg/l	

(continued on next page)

Table A1 (*continued*)

Indicator	Characteristics	Possible consequences and RISKS
6. Concentration of dissolved oxygen	Not less 4–5 mg/l	Inhibition of oxiphyle species
7. Open water surface		
2. Ecological flow demands: A. Mean water year; B. Dry water year	A — mean annual runoff volume B — 40–50% of mean annual runoff	Decrease of minimal water level and loss of main littoral and coastal biotopes
8. Water transparency	Transparency — not less than 1–1.5 m	Inhibition of macrophyte development when decreased transparency
9. Water color	Colorless in littoral and blue-green in open pelagic	Strongly marked green color of water – eutrophication of ecosystem; strongly marked yellow-brown color of water – waterlogging of ecosystem
b) Biotic indicators		
1. Development of wetland vegetation (helpohytes)	Well developed coastal reed–cattail associations but not more than 50% of water area Vegetative weight of reed/cattails (kg/m^2)	Decrease of protected habitats, spawning and food areas when semi-water vegetation poorly developed Upsilting, waterlogging, formation of hydrogen sulfide sites, shrinkage of fishing when intensive overgrowing of water area
2. Water vegetation (hydrophytes)		
3. Phytoplankton species diversity	A. Parity domination of fresh- and brackish-water forms.	High value of biomass — eutrophication of ecosystem
4. Saprobic zone (SZ) Saprobic index (SI)	Index SI – up to 2.5, biomass – not more 30 g/m^3 in summer season	Increasing SI — high content of organic matters and high level of trophic factor
5. Phytoplankton biomass	Not more than 30 g/m^3 in summer period	
6. Zooplankton species diversity	Part of halophilic species — 20–30%	Increasing % of halophilic species and drop-out from composition of zooplankton Cladocera — progressive salinization.
7. Zooplankton — taxonomic structure	Development of pelagic and thicket species (Rotifera, Cladocera and Copepoda)	
8. Zoobenthos — taxonomic structure	Development of species — Mollusca, Trichoptera, Ephemeroptera, Heteroptera, Coleoptera, Oligochaeta, Diptera, Chironomidae and Mysidacea	Decrease of common taxonomic and species diversity, especially chironomids and simplified trophic relations — ecological regress of aquatic system
9. Zoobenthos — trophic structure	Dominance of tangle forms and phyto-detritophage, increasing number of predators	
10. Periphyton — species composition and structure B — Indices SI and F/S	A. High diversity of species and generations when dominated by *Fragilaria*, *Diatoma*, *Achnanthes*, *Cocconeis*, *Rhoicosphenia*, *Synedra*, *Cymbella*, *Gomphonema*, and *Navicula*. B. SI volumes not more than 2.1 (slightly polluted); F/S –> 1.	Decreasing diversity of diatoms (*Fragilaria*, *Diatoma*, *Achnanthes*, *Cocconeis*, *Rhoicosphenia*, *Synedra*, *Cymbella*, *Gomphonema*) — ecological regress of aquatic system Development of epithemia, Rhopalodia — intensification of forming and accumulation of vegetation detritus. Increasing SI volumes — high content of organic substances and trophic level. Reducing of F/S volumes — increasing water salinity
11. Periphyton — ratio of fresh and brackish water species	F/S > 1 ; MH % — not more 20–25%	
12. Periphyton — saprobic zone, saprobic index	SZ — beta-mesosaprobic zone, SI — up to 2.4	
13. Ornithology (birds)	A sustainable presence of hydrophilic bird species in ornithofauna of the wetland	Reduction of relative quantity of hydrophilic birds — unstable and worsening hydrological conditions and ecological parameters of the ecosystem
14. Ichthyofauna (fish)	Parity presence limnophyte species in ichthyofauna (sazan, carp, mudfish, aral roach and others) and rheophilic freshwater fish species (grass carp, silver carp, pike-perch and others) and their baby fish and underyearlings.	Reduction of development of rheophilic fish when reduction of flowage or continuous inflow of the lake and absence of baby fish and underyearlings — points to unfavorable conditions for spawning and reproduction of ichthyofauna.

Table A2
Scenario assumptions.

	Assumptions and uncertainties	Interventions/measures	Source
1.	*Background (present level)*		
	The existing system of water limits for irrigation. Low water use efficiency (0,48 × 0,65 = 0,31). Irrigation is a main water consumer. Environmental flows in to the delta are provided on residual principals depending on water year. Non-irrigational consumer downstream Tuyamuyun — 800 mln m^3	The contributions of IFAS and MAWR for rehabilitation of the irrigation and drainage infrastructure, O&M system and wetland restoration. Rehabilitation of main collectors is considered from the Government Ameliorative Fund of the country	Decree of the President of the Ruz УП-3932 dated October 29, 2007 "about measures on radical improvement of the system of the land ameliorative improvements" for the period 2008–2012
2.	*2030*		
	Intergovernmental agreement on water allocation between states in the Amudarya River Basin up to 2030 is realized. The Amudarya river run-off allocation between Turkmenistan and Uzbekistan, is preserved in former proportions — 50:50.	Water demand for irrigation in Turkmenistan was accepted in the range of 4412 mln m3 for future (in mean water year — 3291 mln m3)	GEF Water and Environmental Management Project (WEMP), Component A1: National and Regional Water and Salt Management. Regional Report (2002); Reporting BVO Amudarya, 2006, 2007
	Seasonal regulation of the run-off by Nurek and operational regime of Tuyamuyun is preserved in current level.	Construction of Shorbulak water reservoir for providing guaranteed run-off supply in to the Amudarya delta	FS of construction Shorbulak water reservoir (UZGIP) according to MAWR resolution (TOR)

Table A2 (*continued*)

Assumptions and uncertainties	Interventions/measures	Source
Water demand of non-irrigational consumers, including portable, industry and domestic needs have increased in 3 times. Water intake for irrigation has decreased to 10%, and the efficiency of water use have increased from 0,31 to 0,36 (0,52 × 0,70)	To satisfy needs of social demands for 2030 it is required 2400 mln m3	National and sectoral programs for the period up to 2015. The WB Strategical Study of Irrigation and Drainage Sector Development. Final report (2001).
Targeted investments in to I&D sector makes up 163, 8 mln $US	Technical interventions on rehabilitation I&D infrastructure and land improvements is 163,8 mln USD, from them about 15–20% contributions of WUAs for on-farm network rehabilitation Institutional measures (support of ADB, implementation of the training and consulting programs, improvement O&M and monitoring systems, etc) are realized	1. Scheme on the Irrigation Agriculture Development and Water Management of the Republic of Karakalpakstan for the period up to 2015 (2006) 2. GEF WEMP A1 Component. National Plan of Water and Salt Management up to 2025 (2002); 3. Master Scheme on Development of Irrigated Agriculture and Water Management of the Republic of Uzbekistan for the period up to 2015» 4. The WB Strategical Study of Irrigation and Drainage Sector Development. Final report (2001). 5. NeWater report (WP 2.3). 2007, 2008
Investments for rehabilitation and maintenance of the delta ecosystems — 30,0 mln $US	Rehabilitation of technical infrastructures and accomplishment of lake systems and wetlands and others were done	FS of creation local water ponds in the Amudarya delta IFAS/UZGIP; GEF/WB WEMP Component E. Sudioche Project (2002)
Institutional measures on support and management of delta ecosystems — 1,333 mln $US	Working out coordination mechanisms and participatory plans of lake system and wetlands management, creation of community-private firms and fishman associations on each wetland, support and consulting services	NeWater Reports (2007, 2008); Joint Decree of Kengash Legislative Chamber and Senate of Oliy Majlis of the Republic of Uzbekistan dated 3 July 2008» About measures on strengthening support of non-governmental non-commercial organizations and other institutes of civil society»
Activity of operation and monitoring service of water resources and lake ecosystems corresponds to demanded regimes and standards	Participatory monitoring of lake systems and wetlands has been adapted	NeWater Reports (2007, 2008)
Uncertainties connected with future change of climate and run-off		
Increasing average monthly temperature: in summer (to 0,5–1,0 °C) and in winter (to 0,8–1,6 °C), precipitations to 12–14% on the year; evaporation (from 60–120 mm)		UZGIP estimations, based on forecasts NIGMI
Change of river run-off: (a) in the upper zone — decreased to 29 mln m^3 and (b) in mean stream (Kerki) — decreases to 12%, (March–August) in comparison with norm (1961–1990);		UZGIP estimations, on the base of NIGMI forecasts
In mean water year environmental flow to the delta to 2030 will be observed	Environmental flow into the delta corresponds to hydrological and hydro-chemical demands	UZGIP estimations
In low water year wetlands demand is not satisfied — 3585 mln m3 against 5300 mln m3 (flow deficit — 1715 mln m3). The accepted mitigation measures and alternative options for providing environmental flows are as follows :	Selection of reasonable alternative options, based on benefit-cost analysis «irrigation — aquatic ecosystems»:	UZGIP estimations
Option 1. Cotton and rise decreasing to 5%	Option 1. Environmental flow — 4549 mln m^3	UZGIP estimations
Option 2. Cotton decreasing to 10% and rice to 5%	Option 2. Environmental flows — 4710 mln m^3	UZGIP estimations
Option 3. Cotton decreasing to 10% and rice (to 7% in Khorezm and 3% in KKR)	Option 3. Environmental flows — 5324 mln m^3	UZGIP estimations
Hydro-chemical regime of river run-off and CDW correspond to demands of sensitive lake ecosystems. Mineralization environmental flow in April–August varies from 0,77 to 1,11 g/l (river run-off) and 2,3 to 3,0 (drainage run-off)	Monitoring and controlling of regime and quality of the river run-off and CDW are conducted regularly in all levels.	Standards and procedures of the control and monitoring of responsible institutes and governing bodies
2050		
Interstate agreement on water division between states in the Amudarya river basin to 2050 corresponds to obligations of global Water Convention. Actual Amudarya river run-off distribution between Turkmenistan and Uzbekistan, including the delta, is preserved in former proportion — 50:50. Seasonal run-off regulation by Rogun and operation regime of Tuyamuyun is preserved in the current level.	Management mechanisms of water quality and environmental flows in Amudarya river downstreams were accepted and adapted	Decree of the President of the Republic of Uzbekistan dated August 9, 2007. "About joining to Convention on Protection and Use of Transboundary Water Courses and International Lakes", and "About Joining to Convention on Right on Non Navigational Use of Transboundary Water Courses".
Tradeoff between sectors and water consumers in down streams of the Amudarya river was reached: water intake of non-irrigational consumers has increased 4,2 times. Water intake for irrigation have decreased to 9%, and efficiency of water use have increased up to 0,43 (0,58 × 0,74)	Water demand of non-irrigational sectors is provided in the range of 3360 mln m^3 by 2050	GEF WEMP A1 Component. National salt and water management plan up to 2025 (2002); The WB Strategic Study of Irrigation and Drainage Sector Development. Final report (2001).
Investments in to I&D sector in the range of 190,5 mln $US, including O&M — 4,2% from the total costs	Technical interventions for rehabilitation and modernization infrastructure and O&M systems, and widely introduction innovations in water use, from them up to 30% contributions of WUAs and other land users for on-farm network rehabilitation	
Investments for institutional strengthening — 24,4 mln $US	Increasing of institutional capacity on approaches and mechanisms of AMWR with introduction innovations and advanced technologies (conservation of water and varieties, landscapes and conservation of natural ecosystems)	

(continued on next page)

Table A2 (*continued*)

Assumptions and uncertainties	Interventions/measures	Source
The investment for rehabilitation and support of delta ecosystems is 38,3 млн USD	Technical interventions for rehabilitation and maintenance of the lake system infrastructures, fish breeding and facilities of fish handicraft industry with using bio-technologies, and muskrat estuary	
Institutional and capacity building — 1,8 mln $US		
Activity of operation and monitoring services of water resources and lake systems correspond to demanded norms and standards	Participatory monitoring of lake systems and wetlands was adapted	NeWater Reports (2007) and Siderius et al. (2008)
Uncertainties connected with future run-off and climate change		
Increasing of average monthly temperature: in summer (to 0,5–2,3 °C) and in winter (to 1,7–2,5 °C), precipitations to 12–14% on the year; evaporation (from 80 to 150 mm)		UZGIP estimations, on the base of NIGMI forecasts
Change of river run-off: (a) in the forming zone — decreases to 69 mln m^3 in comparison with average multi-year (1961–1990.); (b) in mean stream (Kerki) — decreases to 14% from the average multi-year value, mainly from March to August.		UZGIP estimations, on the base of NIGMI forecasts
In mean water year environmental flow in to the delta is observed	Environmental flow in to the delta corresponds to hydrological and hydrochemical demands	UZGIP estimations
In low water year wetland demand is not satisfied — 3606 mln m^3 against 5300 mln m^3 (flow deficit — 1694 mln m^3). Possible mitigation measures and alternative options for providing the environmental flow:	Selection of reasonable alternative options, based on benefit-cost analysis «irrigation — water ecosystems»:	UZGIP estimations
Option 1. Decreasing of cotton and rice to 5%	Option 1. Volumes of environmental flows — 5155 mln m^3	UZGIP estimations
Option 2. Cotton decreasing to 10% and rice to 5%	Option 2. Volumes of environmental flows — 5246 mln m^3	UZGIP estimations
Hydro-chemical regime of river run-off and CDW correspond to demands of sensitive lake ecosystems. Mineralization environmental flow in April–August varies from 0,77 to 1,11 g/l (river run-off) and 2,3 to 3,0 (drainage run-off)	Monitoring and controlling regime and quality of the river run-off and CDW are conducted regularly in all levels.	The standards and procedures of controlling and monitoring of responsible institutes and governance and publicity

Table A3
Results of assessment of the current state of the lakes in the Amudarya river delta (selection of main indicators).

Indicator	Unit	Western part						Central part				Eastern part
		Akushpa	Karateren	Begdulla-Aydin	Big Sudoje	Mashankol	Khojakol	Mezdurechye	Muynak	Makpalkol	Ribachye	Dziltirbas
Mean water year												
Water exchange (outflow)		Low	High	Intermediate	Intermediate	High	High	High	Intermediate	High	Intermediate	Intermediate
Depth of lake/reservoir	m	1.2–1.3	1.5–1.8	0.6–0.8	1.2–1.4	0.8–1.2	0.8–1.1	0.8–1.5	1.0–2.0	0.5–0.8	1.5–2.0	0.5–1.0
Water level fluctuation	m	0.3–0.35	0.3–0.35	0.3–0.35	0.3–0.35	0.2–0.4	0.2–0.4	0.3–0.5	0.4–0.5	0.2–0.3	0.4–0.5	0.3–0.4
Water salinity	g/l	21.3–48.3	3.7–12.9	3.79–7.0	3.48–10.47	1.3–3.5	3.0–4.7	0.97–1.03	1.55–3.57	1.1–1.2	2.4–2.8	2.3–3.5
Dissolved oxygen	mg/l	9–11	8–9	9–10	9–10	8–9	8–10	5.9–9.6	4.4–10.6	5.8–9.0	6.0–9.0	5.5–8.6
Free water surface	%	0.6	0.5	80–90	0.9	70–80	70–80	50–60	70–80	10–20.	40–50	30–40
Water-marsh vegetation (helophytes)	%	40.	50.	10–20.	10.	20–30	20–30	40–50	20–30.	80–90	50–60	60–70
Water vegetation (hydrophytes)	Type	Brackish	Limnetic	Limnetic	Limnetic	Limnetic	Limnetic	Limnetic	Limnetic	–	Limnetic	Limnetic
Phytoplankton	g/m^3	25.7	36.8	24.2	36.2	–	–	10–80	30–100	20	23	–
Birds	% of hydrophilic species	49.	43.	94.	100	50.	55.	50–60.	40.	40.	50.	60.
Fishes	Dominant species	Lack of commercial fish	Limnophil species	Limnophil species	Limnophil species	Limnophil species	Limnophil species	Limnophil species	Limnophil species	Limnophil and rheophil species	Limnophil species	Limnophil species
Fish reproduction	Presence of young fishes	Absence of freshwater species	Limnophil species	Limnophil species	Limnophil species	Limnophil species	Limnophil species	Limnophil and rheophil	Limnophil species	Limnophil and rheophil species	Limnophil species	Limnophil species
Dry water year (2001)												
Water exchange (outflow)		Dried	Low	Low	Dried	Dried	Dried	Intermediate	Low	Dried	Low	Dried
Depth of aquatic	m	Dried	0.2	Dried	Dried	Dried	Dried	0.2	0.7–0.9	Dried	0.9–1.0	Dried
Water level variation/	m	1.3	1.5	0.8	1.4	1.2	1.1	1.3	1.1	0.8	1.0	1.0

Table A3 (*continued*)

Indicator	Unit	Western part						Central part				Eastern part
		Akushpa	Karateren	Begdulla-Aydin	Big Sudoje	Mashankol	Khojakol	Mezdurechye	Muynak	Makpalkol	Ribachye	Dziltirbas
Water salinity (for fish spawning and generation adult)	g/l	35.6–83.0	8.2–54.0	5.9–39.2	Dried	Dried	Dried	2.4–2.6	14.6–21.0	–	8.9–14.0	6.3–13.2
Birds	%	1–2.	6.	4–5.	7.	2.	5.	10.	7.	3.	5.	2–3.

Table A4
Social indicators of wetland conditions.

Indicator	Characteristics	Possible consequences and risks
1. Sustainability of water management	A. Availability of plans for lake conservation and planning of water body productivity B. Availability of an owner or a renter of the water body C. Availability of a monitoring and control system, and protection from poachers.	Maintenance of intergovernmental agreements Readiness and participation of local administration and community in planning and management of wetlands.
2. Social dimension	Income and family budget of local population and their participation in management and reception/sharing of the benefits	Insufficient awareness and knowledge of the local communities on adaptive wetland management and alternative sources of livelihoods

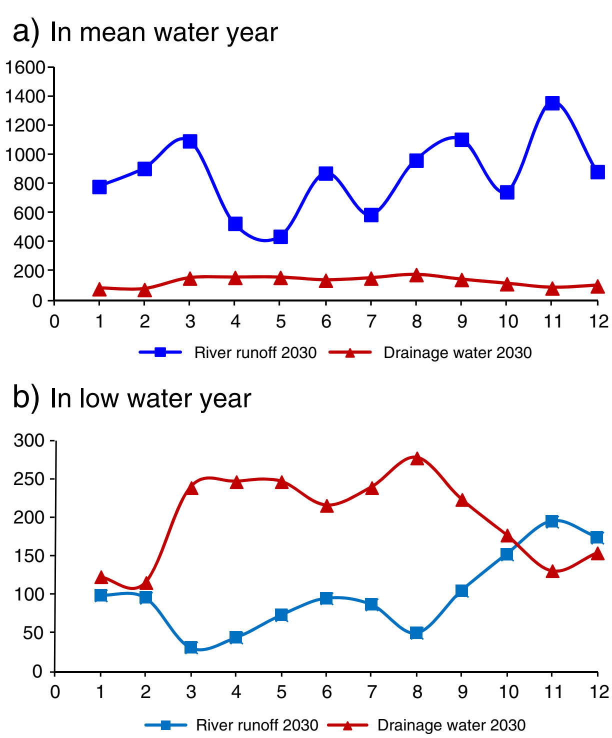

Fig. A1. Ratio of river runoff and drainage water discharged into the delta.

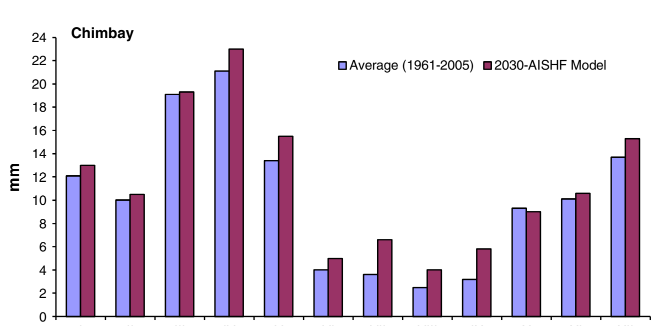

Fig. A2. Predicted change of average monthly precipitations for the period up to 2030.

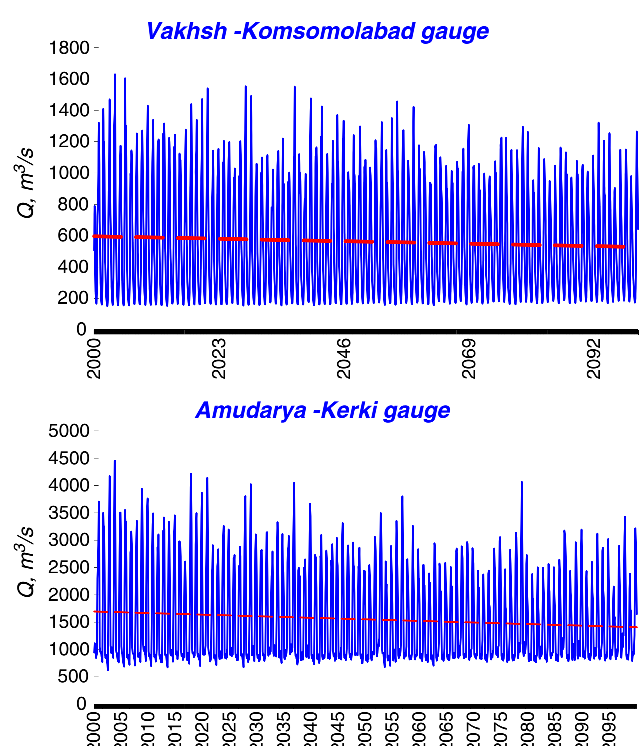

Fig. A3. Intraannual variations the discharges for Vakhsh — Komsomolabad (upstream) and Amudarya — Kerki (downstream) gauge station.

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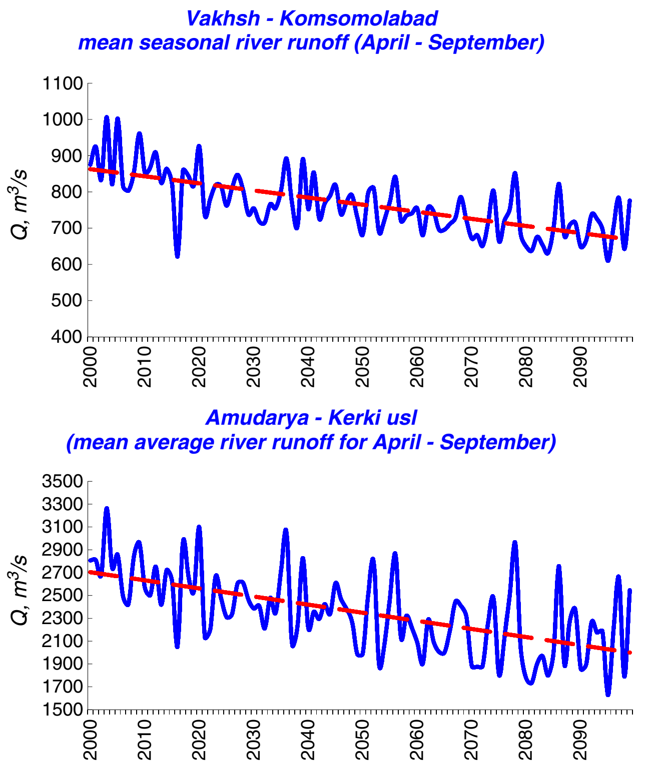

Fig. A4. Interannual variation of the seasonal discharges for Vakhsh — Komsomolabad (upstream) and Amudarya — Kerki gauge station.

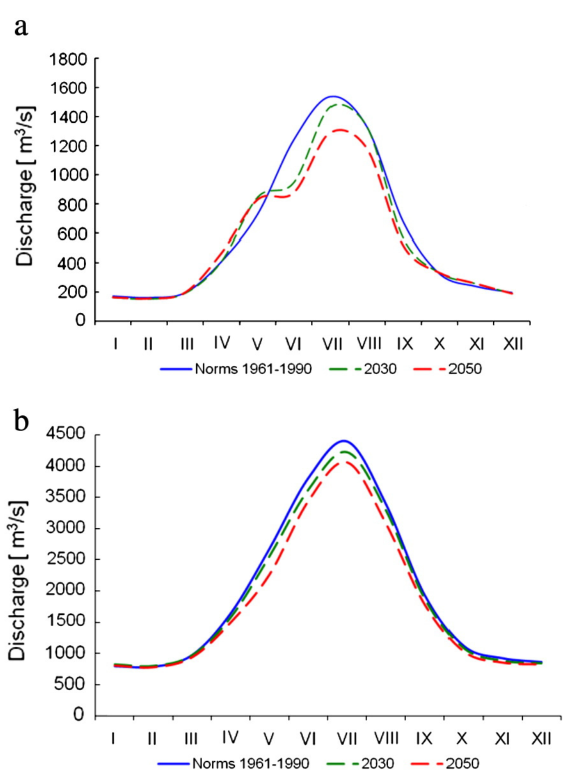

Fig. A5. a) A comparison of predicted annual runoff with long-term inflow norms at Nurek (upstream); and b) Kerki (midstream) gauging stations under climate change conditions.

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