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11 Irrigated Crop Production in the Syr Darya Basin: Climate Change Rehearsal in the 1990s

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Abstract

Future inflow to the irrigation scheme of the Syr Darya Basin is modelled under two climate scenarios, based on outputs of International Panel on Climate Change (IPCC) core models run under IPCC-SRES A2 emission scenario. Under the GFDL99-R30-based scenario, the mean annual flow (MAF) is likely to increase by 10–20%. Under HadCM3-based scenario, MAF is supposed to decrease by 10–20%. Simulating water allocation in the basin in 2070–2099 shows that 14–21% of water demands in the agriculture sector in a normal hydrological year and 28–51% in a dry year are likely to be unmet. The challenges expected from future climate change can be paralleled to those resulting from the political change due to the collapse of the USSR, which left 18% (normal year) and 46% (dry year) of agricultural water demands unmet in 1992–2001. The study stresses the point that the adaptation measures employed in the post-Soviet transitional period are likely to serve as a basis for the future climate change adaptation strategies, since the development of the agriculture sector under climate change impact will remain handicapped without a more efficient water management at all hierarchical levels.

11.1 Introduction

The Syr Darya (Fig. 11.1), one of the two major river basins belonging to the Aral Sea drainage, is today home to a multi-ethnic population of over 20 million, 73% of whom constitute an impoverished rural population. Livelihoods of these people depend mainly on irrigated crop production. Cotton, one of the principal cash crops, has been produced in the basin since prehistoric times. The first irrigation infrastructures, according to archaeological findings, had been built in this harsh desert and semi-desert environment more than 3000 years ago. Political tensions aimed at gaining control of access to water in this arid land are possibly as old as the first irrigation infrastructures. However, the strains imposed on the basin environment and its inhabitants in the past 50 years have been unparalleled in history.

In the Soviet times, the extensive irrigation schemes and capacious water reservoirs had been constructed in order to intensify the agriculture sector. This measure boosted cotton production, but eventually caused an unprecedented over-exploitation of water resources in the Syr Darya and the adjacent Amu Darya Basin, which resulted in environmental collapse of the aquatic system of the Aral Sea (Raskin *et al.*, 1992). The political collapse of the Soviet Union in 1991 and the emergence of the new post-Soviet states in place of the formerly strongly centralized country created new problems, or rather revived the old ones, since sharing water resources among water users with

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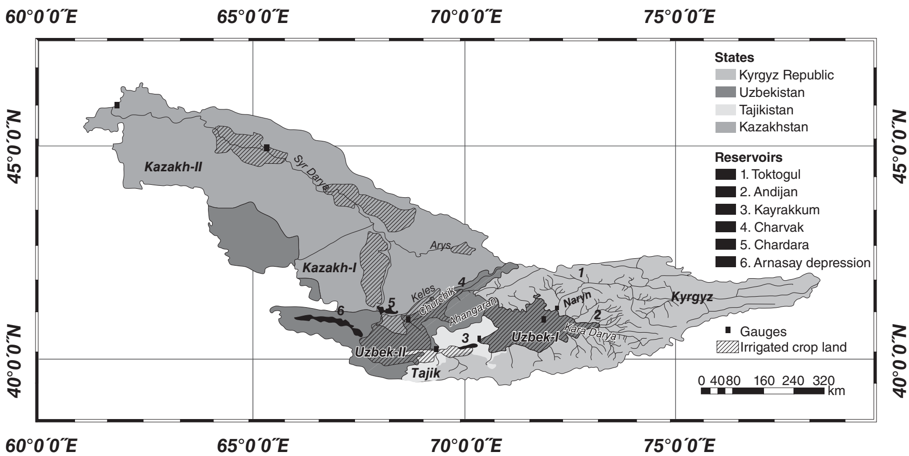

Fig. 11.1. Map of the Syr Darya Basin showing its political divisions, river network, major water reservoirs and location of the irrigated cropland.

competing interests has never been an easy task in the arid environment of Central Asia (Arsel and Spoor, 2009).

The new political and economic mechanisms for the regulation of transboundary water allocation in the basin established by the newly independent Central Asian states of Kyrgyzstan, Uzbekistan, Tajikistan and Kazakhstan in 1992 can hardly be termed very efficient since then (Ul Hassan *et al.*, 2004; Abdullaev *et al.*, 2009; Lerman, 2009); now yet another danger threatens the basin water security. Global climate change (CC) poses additional risks to the sustainable development of the region despite an increase in water availability projected by application of various hydrological models (Malsy *et al.*, 2012; Siegfried *et al.*, 2012; Sutton *et al.*, 2013). The study presented in this chapter examines the potential impacts of future CC in the Syr Darya Basin on the water availability for agriculture, based on modelling of water allocation in the basin under a set of two scenarios derived from General Circulation Model (GCM) outputs.

The key question is to what degree the agriculture sector in the basin is prepared to cope with the CC impacts. The objectives of the study have been: (i) to construct future climate scenarios, which would reflect the most plausible range of CC at the end of the 21st century; (ii) to simulate the changes in streamflow under future climate scenarios; (iii) to simulate water allocation under CC scenarios in order to see how much water will be available for agricultural water use in future; and (iv) to compare the simulated performance of a basin transboundary water allocation system in future with that of the last Soviet decade, 1982–1991, and the first post-Soviet decade, 1992–2001. This decade is of especial interest for this study since it was marked by an initial transitional decline in agricultural production in the Central Asian states, which was reversed, i.e. reached the level of 1991 only in 2003 (Lerman, 2009).

11.2 Constructing Scenarios of Future Climate

The climate scenarios based on the outcomes of GCMs were constructed following the standard protocol suggested by the IPCC guidelines (Parry *et al.*, 2007). The climatological variables used in the scenarios are the 30-year average monthly and annual air temperature and precipitation. The baseline period used as a reference line is 1961–1990.

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The future time slice of interest is 2070–2099. GCM runs used here are driven by the SRES A2 emission scenario (Parry *et al*., 2007).

At the first step, the performance of six core IPCC GCMs described in 2007 IPCC AR4 (IPCC, 2014) over the baseline reference period was examined in order to select the GCMs best suited for simulating the present-day climate in the study area (Table 11.1; Fig. 11.2). The criteria for the selection of the best-performing GCMs were the differences between observed and simulated air temperatures ($T_{mod} - T_{obs}$) and the ratio of simulated and observed precipitation (P_{mod}/P_{obs}). To assess baseline climatological variables in the study area, the re-analysis data set by the Climate Research Unit (CRU) with a resolution of 0.5×0.5 degrees has been used (http://www.cru.uea.ac.uk/data). At this stage, CRU data were up-scaled to match the GCM grid resolution. According to the data presented in Fig. 11.2 and Table 11.1, three GCMs have a good performance in the Syr Darya Basin. Out of the three good-performing GCMs, GFDL99-R30 and HadCM3 have been selected to represent a range of future CC in the study area. GCMs tend to have a poorer performance in the mountains compared to plains, particularly in simulating the precipitation regime. Therefore, an adequate performance of a GCM is of especial importance in this study, since the major part of the river flow in the Syr Darya area originates in the mountains.

The regional baseline climate model (Fig. 11.3) is based on the digital elevation map and data of long-term observations from 238 meteorological stations (De Pauw *et al*., 2004). It has a resolution of 1×1 km and was designed for the project presented by Savoskul *et al*. (2004). At the final step of the CC scenario construction, the statistical downscaling was done using the change factor method (Parry *et al*., 2007). The change field based on HadCM3 is presented in Fig. 11.4. Two sets of CC scenarios have been constructed by adding monthly change fields to the baseline regional climate model (Fig. 11.5; Table 11.2).

11.3 Simulation of the Inflow to the Reservoirs and Principal Gauges

With the construction of two new reservoirs in 2010, the total storage capacity of the water reservoirs in the basin increased to 105% of the Syr Darya MAF, of which active storage volume makes 87% of MAF. In the medium and low reaches of the basin, virtually all streamflow is regulated through an immense water storage and irrigation scheme. Because 85% of the flow is formed in the mountains that constitute roughly 20% of the catchment area, the simulation of inflow to the major reservoirs and irrigation schemes can be done using time series of natural flow measurements from the mountain gauges. A semi-distributed streamflow model has been applied for this purpose. A supplementary model block has been designed to account for the changes in contribution from seasonal snow cover and glaciers. Table 11.3 shows the data used for the baseline extent of glaciers and seasonal snow, glacier runoff and seasonal snowmelt contribution to streamflow as well as simulated future values. Snowmelt yields were modelled by the temperature-index approach for the 100-m elevation bands using the method proposed by Mukhin (1991). The glaciological approach described in detail by Savoskul and Smakhtin (2013) was used to model changes in specific glacier elevations, area, volume and glacier runoff. The major uncertainties of the streamflow simulations are inherent in the uncertainties of the CC scenarios, particularly in predicting future precipitation. In this respect, the use of two contrasting scenarios is a commonly recommended option for outlining the potential range of future changes (Parry *et al*., 2007).

The outputs of the streamflow simulation under the selected CC scenarios are presented in Fig. 11.6. The changes of flow regime under warm and humid GFDL99-R30-based scenario are characterized by a pronounced shift of spring maximum to earlier dates and increase of annual water flow by 27%. Under this scenario, the amount of water in summer months does not show

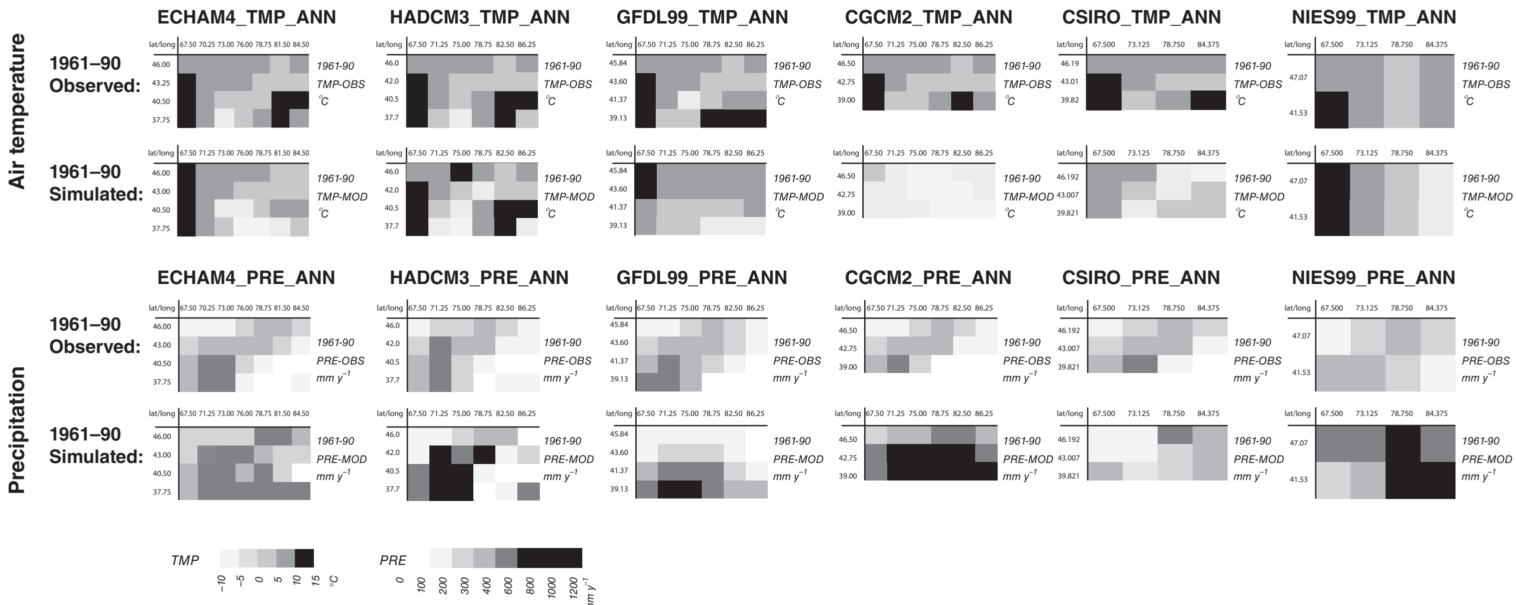

Fig. 11.2. GCM outputs for the baseline period (1961–1990) as compared with CRU observed climatology fields (upscaled to match GCM resolution). (Data sources: observed climatologies: CRU, available at http://www.cru.uea.ac.uk/data, accessed 7 March 2009; simulated climatologies: IPCC Data Distribution Center (DDC), available at http://www.ipcc-data.org/sim/gcm_clim, accessed 9 March 2009. The GCM abbreviations are adopted from the original data sources.)

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Table 11.1. Summary of the performance of six core GCMs in simulating present-day climate in the study area. Observed climatologies: CRU, from http://www.cru.uea.ac.uk/data (accessed 7 March 2009); simulated climatologies: IPCC DDC, from http://www.ipcc-data.org/sim/gcm_clim (accessed 9 March 2009). The GCM abbreviations are adopted from the original data sources.

GCM	$T_{mod}-T_{obs}$ (°C)	P_{mod}/P_{obs}	Performance in the study region
ECHAM4	0.1	1.4	Good
HadCM3	–1.0	1.3	Good
GFDL99-R30	–1.3	1.0	Good
CGCM2	–9.8	3.4	Very poor
CSIRO	–4.4	1.0	Poor
NIES99	–1.4	2.8	Poor

T_{mod}, mean annual air temperature simulated (°C); T_{obs}, mean annual air temperature observed (°C); P_{mod}, mean annual precipitation simulated (mm); P_{obs}, mean annual precipitation observed (mm).

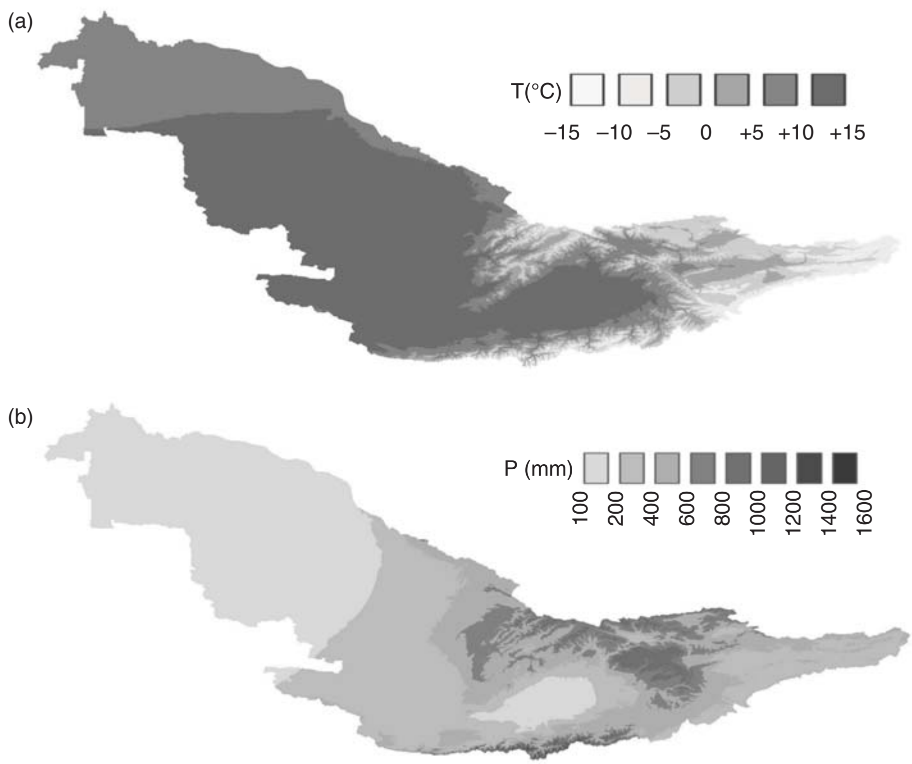

Fig. 11.3. Regional baseline climate model: (a) average annual air temperature in 1961–1990 and (b) average annual precipitation in 1961–1990.

significant changes. The significantly drier and hotter HadCM3-based scenario suggests a decline of annual flow by 18% and a shift of spring high-water season by even earlier dates than under the GFDL99-R30-based scenario. Shift of spring high waters will be due to the earlier onset of seasonal snowmelt, which will significantly reduce under both scenarios, but will still contribute around 10–20% of MAF to the river flow. However, a late summer peak in the discharge of rivers, which is a characteristic feature of baseline (1961–1990) hydrographs and is due to glacier runoff

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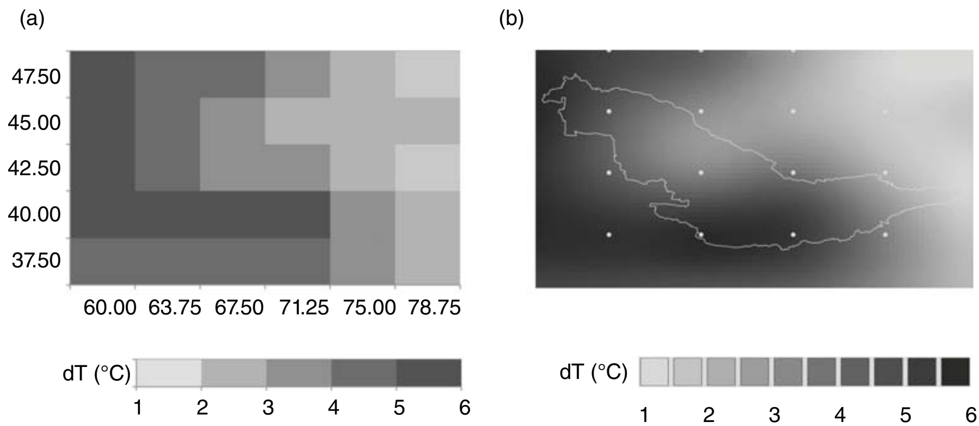

Fig. 11.4. (a) HadCM3 outputs for the air temperature change between baseline 1961–1990 and 2070–2099 periods in the study area (from GCM outputs, IPCC DDC, available at: http://www.ipcc-data.org/sim/gcm_clim/, accessed 9 March 2009). (b) Air temperature change-field based on the HadCM3 data.

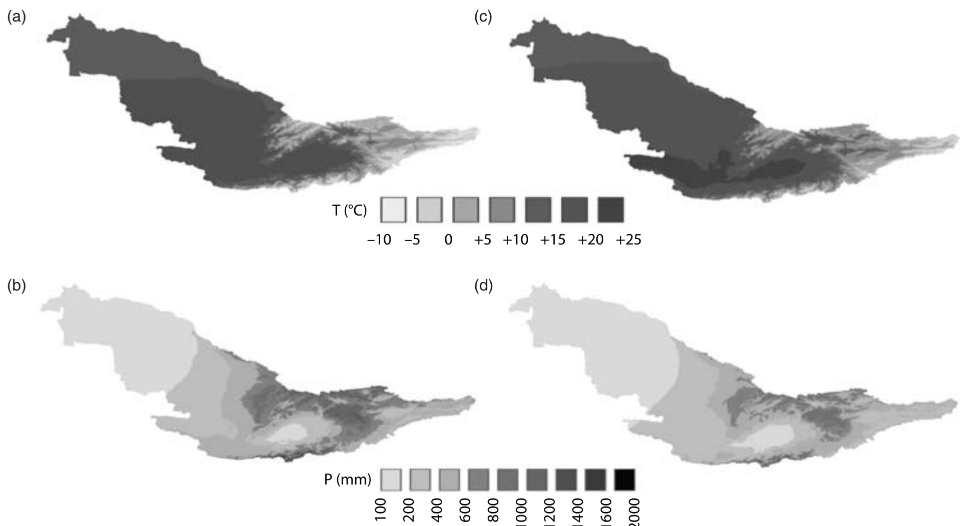

Fig. 11.5. CC scenarios for the period 2070–2099 used in this study: GFDL99-R30-based annual (a) air temperature and (b) precipitation; HadCM3-based (c) air temperature and (d) precipitation.

Table 11.2. Summary of the GCM-based scenarios used in this study. Climatologies: IPCC DDC, from http://www.ipcc-data.org/sim/gcm_clim (accessed 9 March 2009). The GCM abbreviations are adopted from the original data sources.

GCM	$T_{2070–2099} – T_{1961–1990}$ (°C)	$P_{2070–2099}/P_{1961–1990}$	Brief description
GFDL99-R30	3.7	1.34	Warm and humid
HadCM3	4.8	1.07	Hot and dry

$T_{2070–2099}$, future mean annual air temperature simulated (°C); $T_{1961–1990}$, baseline mean annual air temperature simulated (°C); $P_{2070–2099}$, future mean annual precipitation simulated (mm); $P_{1961–1990}$, baseline mean annual precipitation simulated (mm).

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Table 11.3. Data on glacier and maximum seasonal extent of snow and contribution to the flow used in the streamflow simulation (from Savoskul and Smakhtin (2013) and authors' estimate).

Control runs and CC scenarios	Area (km^2) covered by: Glaciers	Area (km^2) covered by: Seasonal snow at its maximum	Contribution to MAF (%): Glacier runoff	Contribution to MAF (%): Seasonal snowmelt
1961–1990	2,522	413,428	3.4	27.3
2000	1,967	349,358	3.2	19.7
2070–2099 GFDL99-R30	429	139,145	0.7	8.3
2070–2099 HadCM3	101	92,205	0.2	5.5

contribution at the peak of glacier ablation, under both scenarios of future climates, will be insignificant (around 1–2% of MAF under the GFDL99-R30-based scenario and below 1% under the HadCM3-based scenario).

11.4 Setting Water Allocation Model

Simulation of the water allocation was done using Water Evaluation and Planning (WEAP) model (http://www.seib.org/weap/; Savoskul *et al*., 2004; Chevnina and Savoskul, 2006). WEAP is a basin-scale water allocation model that allows simulating the water budget of a river basin at a reach-by-reach basis. The hydrological linear scheme of the Syr Darya Basin in this application (Fig. 11.7) includes the Syr Darya River and its main tributaries: Naryn and Kara Darya (forming Syr Darya at their confluence), Chirchik, Ahangaran, Keles and Arys. The main types of the WEAP elements are: R, resource; DS, demand site; TL, transmission link; RF, return flow link; O, outflow; and WR, water requirement point. The water resources in the Syr Darya scheme are presented by the five largest reservoirs: Toktogul (total storage capacity 19.5 Bm^3), Andijan (1.9 Bm^3), Kayrakkum (3.5 Bm^3), Charvak (2.0 Bm^3) and Chardara (2.9 Bm^3), which existed in the year of model validation (2000), and two recently constructed water reservoirs, Kambarata (4.7 Bm^3) and Koksarai (3.1 Bm^3), were included in the scheme only for the model runs under future scenarios. The additional local supplies are smaller tributaries, whose summary inflow is introduced at some reaches, the groundwater of Tashkent and Fergana areas and return water flows from agriculture and industrial demand sites.

Among the demand sites, three types are distinguished: agricultural, domestic and industrial. Transmission links, return flow links, outflow and water requirement points are shown in the basin scheme (Fig. 11.7). In this application, the basin is subdivided into six reaches, representing the key political and economic units of the basin (Table 11.4).

The water resources of the basin consist of around 50 Bm^3 per year, of which 39 Bm^3 are river flow, 3 Bm^3 are groundwater and aquifers and 8 Bm^3 are return flow. Approximately 50% of the water resources are consumed, 44% is transmission and return flow losses in the irrigation network and only 6% is the outflow to the Aral Sea, Arnasay and diversions to the desert in the lower Syr Darya reaches. The basin budget in the baseline period (1961–1990) for the dry, normal and wet hydrological years is represented in Table 11.5, along with the budget for year 2000 used for model verification. For the calibration of the WEAP model, simulated baseline (1961–1990) discharge was compared to the observed time series at nine gauges. The model calibration results presented in Fig. 11.8 demonstrate that within its accuracy range of +5%, the model performs satisfactorily in simulating observed flows at the principal gauges of the basin.

The assessment of water demands, consumption, return flow and transmission losses is based on national statistics bulletins and some other sources (Spravochnik, 1981;

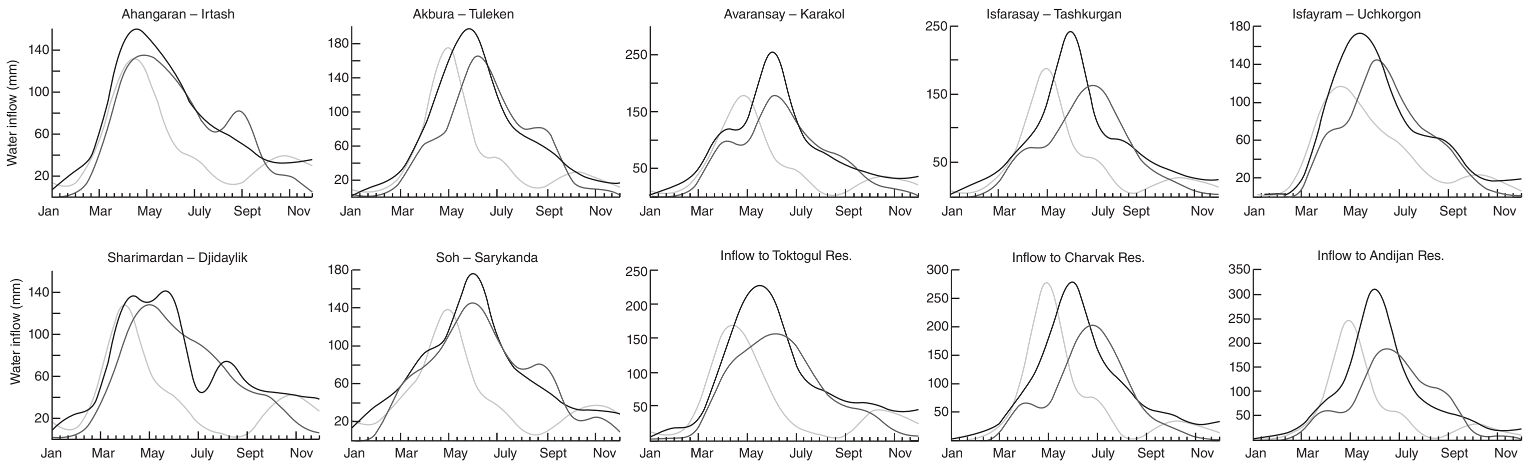

Fig. 11.6. Baseline and future simulated streamflow used to describe the changes of inflow to the reservoirs and irrigation scheme: medium grey line, baseline (1961–1990); dark grey line, scenario based on GFDL99-R30 outputs; light grey line, scenario based on HadCM3 outputs.

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Table 11.4. Subdivision of the Syr Darya Basin for WEAP application.

Reach	Hydrological elements	Administrative units (oblasts)	Area, $10^3 \times$ Bm^2	Boundary
Kyrgyz (Naryn)	Naryn River headflow, Toktogul and Kambarata reservoirs,[a] Kara Darya River headflow, Andijan Reservoir	Osh, Naryn, Djalal-Abad, Talas	104	Uchkurgan gauge at Naryn Andijan Reservoir water gate at Kara Darya
Uzbek-I (Fergana)	Lower reaches of Naryn and Kara Darya rivers, upper flow of Syr Darya River, tributaries from Fergana Range	Namangan, Fergana, Andijan	18	Akjar gauge at Syr Darya
Tajik (Sogd)	Middle flow of Syr Darya, Kayrakkum Reservoir	Sogd	13	Kzyl Kishlak gauge at Syr Darya
Uzbek-II (CHAKIR)	Middle flow of Syr Darya Tributaries: Ahangaran, Chirchik; Keles Charvak Reservoir (at Chirchik)	Tashkent, Syr Darya, Djizak	39	Chardara Reservoir water gate at Syr Darya
Kazakh-I (ARTUR)	Chardara and Koksarai[a] reservoirs Lower flow of Syr Darya downstream from Chardara Reservoir Tributary: Arys	South Kazakhstan	75	Tumen' Aryk gauge at Syr Darya
Kazakh-II (Kzyl Orda)	Lowest flow of Syr Darya from KzylOrdaup to the delta area	Kzyl Orda	116	Karateren' gauge at Syr Darya

[a]These two reservoirs were constructed in 2010. They were introduced into the basin scheme only in the WEAP runs under future scenarios.

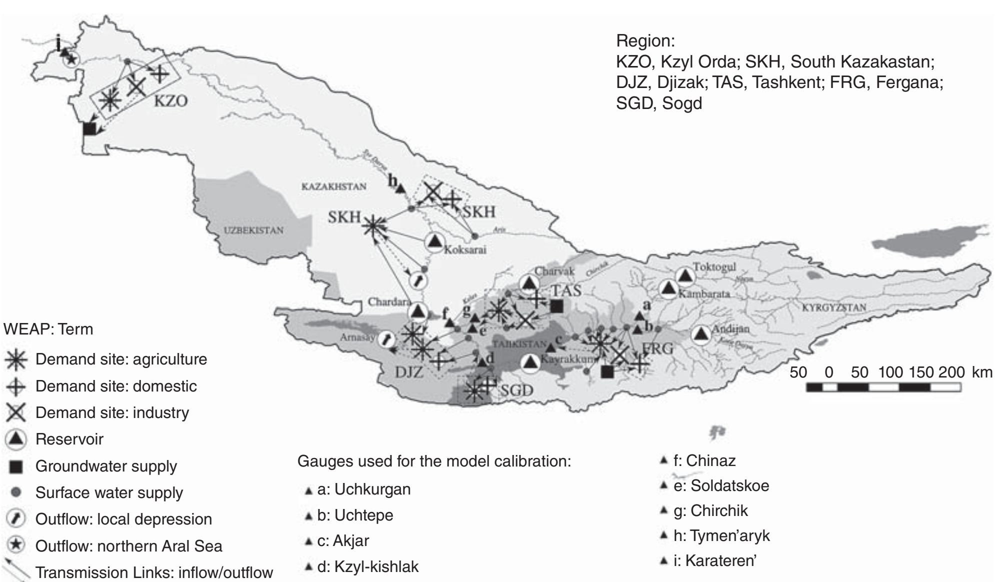

Fig. 11.7. The Syr Darya Basin water use scheme for WEAP application.

Minekonomstat, 2001a, b, c; Ministerstvo, 2001; Abdudjaparov and Toshmatova, 2002; GEF IFAS, 2002; Kipshakaev and Sokolov, 2002; Nurgisaev, 2002; Ryabtsev, 2002). The water demand in agriculture was estimated from crop areas and irrigation norms for the principal crops (Spravochnik, 1981; Minekonomstat, 2001a, b; Ministerstvo, 2001; GEF IFAS, 2002). Domestic water use demands were determined based on population at the demand sites and specific rates of water consumption per capita separately for urban

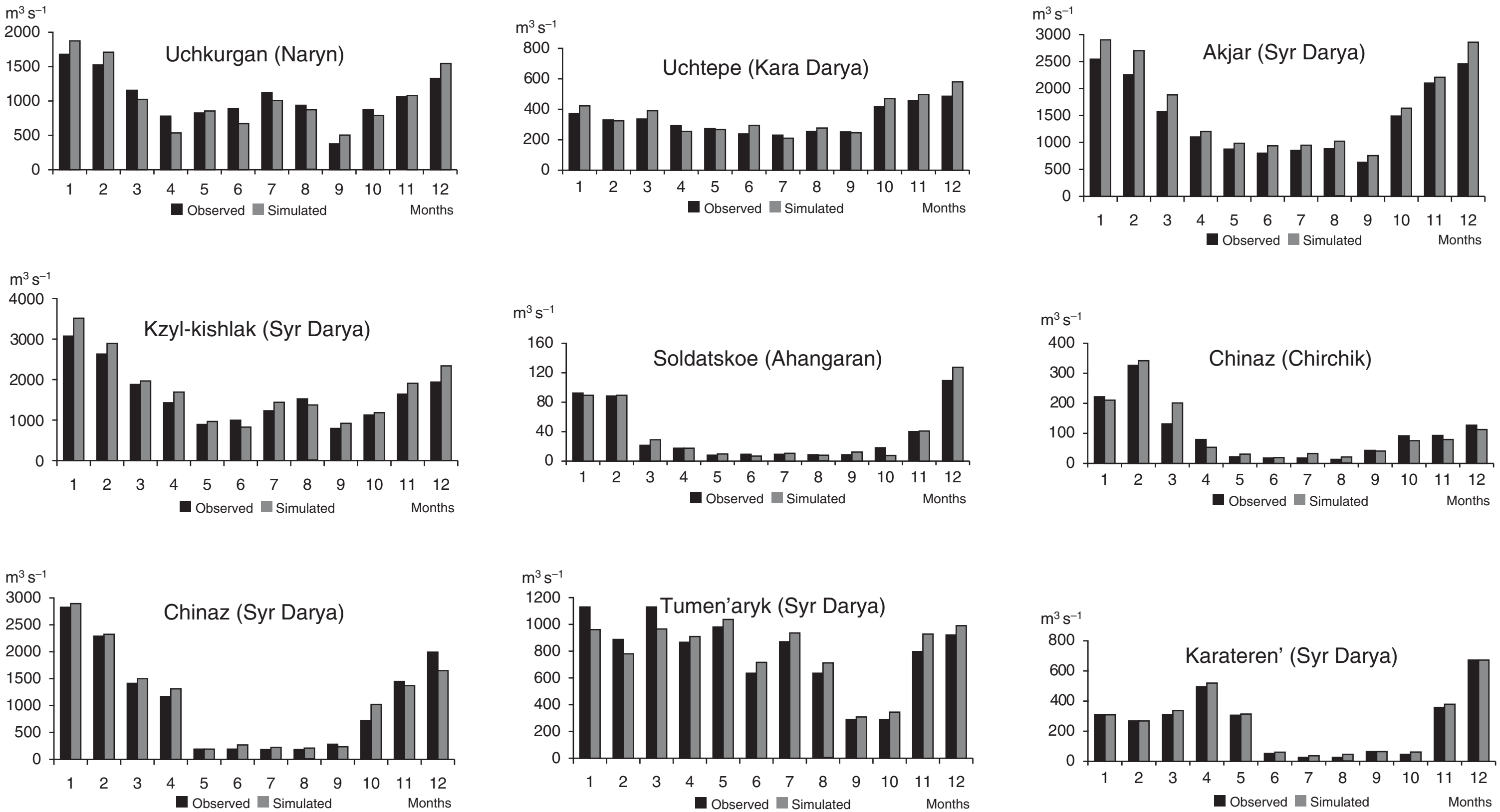

Fig. 11.8. Observed and simulated discharge at the gauges used for the calibration of the WEAP model.

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Table 11.5. Basin water-use budget in dry, normal and wet years during the baseline (1961–1990) period, and in year 2000, used for WEAP verification (from Spravochnik, 1981; Minekonomstat, 2001a, b, c; Ministerstvo, 2001; Abdudjaparov and Toshmatova, 2002; GEF IFAS, 2002; Kipshakaev and Sokolov, 2002; Nurgisaev, 2002; Ryabtsev, 2002; Bucknall *et al*., 2003).

Balance items ($10^6 \times m^3$)	Year			
	1975 (dry)	1985 (normal)	1979 (wet)	2000 (used for model verification)
Streamflow	29,750	41,991	53,943	42,076
Groundwater	3,115	3,115	3,115	3,115
Return flow	5,627	8,126	9,931	10,908
Inflow total	38,492	53,232	66,989	56,099
Consumption subtotal	18,257	26,116	31,851	28,751
Agriculture	14,708	22,488	28,151	24,976
Domestic	2,414	2,422	2,426	2,430
Industry	1,135	1,206	1,275	1,345
Losses subtotal	14,312	21,363	26,835	24,457
Transmission losses	11,465	17,109	21,525	19,627
Return flow losses	2,848	4,254	5,310	4,830
Outflow subtotal	7,156	7,344	10,227	7,568
to Northern Aral Lake	3,029	3,049	5,698	3,072
to Arnasay	2,839	2,839	2,839	2,735
Diversion to desert	651	772	882	901
to groundwater	637	684	808	861
Outflow total	39,726	54,823	68,914	60,775
Balance (Bm^3)	–1,234	–1,592	–1,924	–4,677
Balance (%)	–3	–3	–3	–8

and rural populations (Minekonomstat, 2001a, c; Abdudjaparov and Toshmatova, 2002). The estimate of industrial water demands was based on the value of production and annual water use rate (Minekonomstat, 2001). A detailed breakdown of water demands and consumption assessment for each WEAP unit is given in Chevnina and Savoskul (2006).

The principal water user in the basin is the agriculture sector (86% of total water consumption), which by far surpasses other water users: industry (5% of total consumption) and domestic users (9% of total consumption) (Table 11.5). The agriculture sector, apart from the direct consumption, uses water indirectly. It is almost solely responsible for the enormous water losses in the basin, equalling 44% of total water resources, which are due mainly to the transmission seepage in poorly maintained irrigation infrastructure. The water losses in the irrigation network are assessed here based on values provided by GEF IFAS (2002), which are more moderate than the estimate given by Raskin *et al*. (1992).

The highest priority to water use in the model setup runs is given to agriculture to reflect the economic and political reality of the Soviet era. However, since in the post-Soviet period the water use in the basin has switched to the power regime, the highest supply priority in the WEAP runs under future scenarios is given to industrial and domestic demand sites, and the lower one to the agriculture sector. The domestic sector in all WEAP runs has second priority.

WEAP model constraints are of two kinds, related either to the limitations of the model itself or to the data availability. Since the model is designed as a water allocation accounting tool, it is not suited for the evaluation of the changes in crop water requirements due to future rises in air temperature, which will lead to potential increases in evapotranspiration. A glimpse of the potential effects of these factors can be obtained only from application of physically based

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models (Droogers *et al*., 2004; Malsy *et al*., 2012). The study by Sutton *et al*. (2013) indicates that a 10% decline in yields is likely to occur without implementation of adaptation measures. The changes in crop yields of a similar range due to increase in evapotranspiration are projected in Savoskul *et al*. (2004). Malsy *et al*. (2012) suggest that evapotranspirative requirements under CC may increase by 12%. Based on these figures, the constraints of WEAP in accounting for the physically based future increase in water requirements may be roughly estimated as being within a range of 10–15%.

Due to the limitations in data availability for the model calibration, the basin scheme does not include the minor tributary rivers in the middle and low flows of the Syr Darya; those in some instances (e.g. Fergana valley) have been accounted for as an aggregated entry into the unit. Likewise, accounting of the water demands in agriculture is reduced to the major crops (cotton, wheat, potato, fruit and vegetables).

11.5 Simulated Changes in Water Availability for Agriculture in 2070–2099

WEAP simulations of water allocation in the future, under different CC scenarios, are used to quantify the unmet demands of agriculture in order to evaluate the potential range of water deficiency in the future for the three types of hydrological years; dry, normal and wet. Under the GFDL99-R30-based scenario, by 2070–2099 the unmet demands of agriculture are expected to be 28% in a dry year, 14% in a normal year and 2% in a wet year. For comparison, at present, i.e. in 1992–2012, 46% (dry year), 18% (normal year) and 3% (wet year) of agricultural demands are not met. WEAP run under the HadCM3-based scenario suggests a slight increase of unmet demands relative to the present, i.e. 51% (dry year), 22% (normal year) and 5% (wet year) (Fig. 11.9).

Modelling CC impact on future water availability for agriculture is constrained mainly by the uncertainties in future climate projections (Parry *et al*., 2007). However, these uncertainties with high probability will fall into the range outlined by the two scenarios considered here. Under a more favourable GFDL99-R30-based climate scenario, more water will be available for agriculture in 2070–2099. A second climate scenario based on the HadCM3 model suggests a slight decrease in water availability. However, both scenarios suggest that under business-as-usual water allocation policies and practices, from 14% to 22% of agricultural water demands will remain unmet in a normal year. In a dry year, these values are likely to be between 28% and 51%. A question is 'to what degree the agriculture sector is prepared to cope with the projected changes?' To answer this question, a closer look at recent developments in the water sector might be helpful.

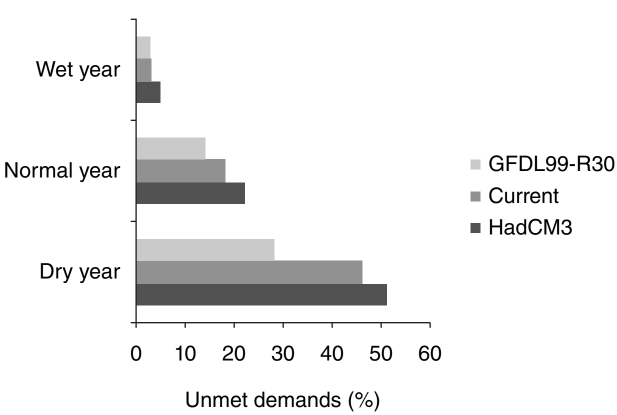

Fig. 11.9. Unmet demands of agriculture at present (1992–2001) and in future (2070–2099) under GFDL99-R30 and HadCM3-based scenarios.

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11.6 Climate Change Rehearsal in the 1990s

The total water storage capacity of the water infrastructure in the basin is equal to 105% of MAF. In principle, high intra- and inter-annual regulation capacity of currently existing water reservoirs in the basin allows for the effective optimization of water use in favour of the agriculture sector. Under the centralized Soviet government, the first priority among the water users was given to agriculture. However, after the disintegration of the USSR, the pattern of water allocation in the basin has changed drastically due to the emergence of a conflict of interests among the newly independent states. The focal point of the conflict is Toktogul, the largest water reservoir in the basin, located in Kyrgyzstan, with a total storage capacity of 19.5 Bm^3 of which 14.5 Bm^3 are an active storage. The outflow from Toktogul Reservoir supports a cascade of hydropower plants, which became a vital source of cheap electricity for the Kyrgyz Republic. Under Soviet government, in 1982–1991, 60% of water was released from Toktogul Reservoir during the irrigation season, i.e. between April and August. Starting from 1993, due to high demands of Kyrgyzstan in hydropower in the cold part of the year, from November to March, the outflow from the reservoir in winter months has almost doubled compared to the outflow in the Soviet time, and only 38% of annual flow was released during the irrigation season (Fig. 11.10). Because of high winter water releases the inter-annual water regulation capacity of the Toktogul Reservoir has decreased too.

In the new political situation, every year, starting from 1993, the agriculture sector in downstream countries of Uzbekistan, Tajikistan and Kazakhstan has faced the challenges comparable to what might be expected under the less favourable of the CC scenarios considered here. The water release from Toktogul during the irrigation season in 1992–2003 had declined, on average, by 3 Bm^3 against the release in 1982–1991. In 1992–2001, water demands of the agriculture sector were met only in the wet years, whereas in the dry and normal years, considerable parts of the demands, 46% and 20%, respectively, were left unmet (Fig. 11.11). A closer look at the response of the water sector to this challenge provides an insight into the pathways the CC adaptation strategies are likely to follow in the future.

The new political situation has called for an immediate reorganization of water management in the basin. At the level of the interstate relations, starting from 1992 the transboundary water allocation is regulated via barter arrangements. Downstream Uzbekistan and Kazakhstan provide upstream Kyrgyz Republic with fossil fuel in exchange for guaranteed water releases in summer and restricted water releases in winter. This measure alone, however, could not solve the problem of water deficiency in agriculture. The annual multilateral agreements are not observed fully by all partners. In 2007, the countries entirely failed to sign the multilateral agreement (Abdullaev *et al.*,

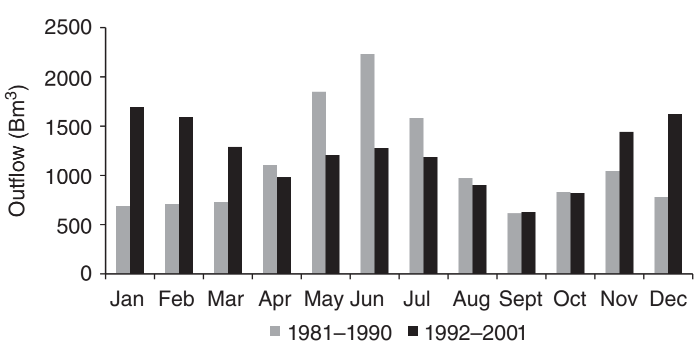

Fig. 11.10. Water releases from the Toktogul Reservoir under centralized Soviet government (1982–1991) and in the first post-Soviet decade (1992–2001).

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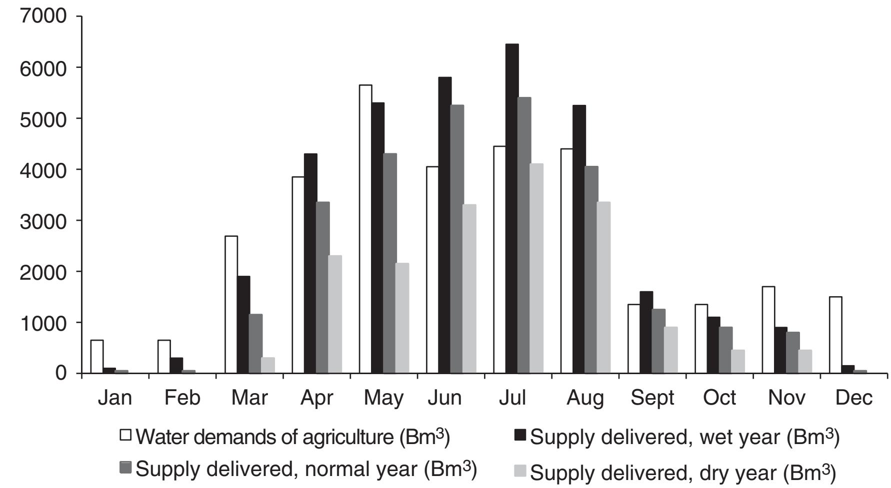

Fig. 11.11. Water demands of the agriculture sector in 1992–2001 and supplies delivered in the dry, normal and wet years. WEAP simulation.

2009). On average, the fossil fuel is delivered with delays, and in response the Kyrgyz Republic releases 2.4 Bm^3 more water in winter than agreed, depleting water storage for summer months (Antipova *et al*., 2002). There are other challenges the governments had to face in the new economic situation. After disintegration of the Soviet Union, due to drastic reduction of government budgets in the transitional period, maintenance of the water infrastructure in many places came to a standstill, resulting in endangered dam security, silting canals and reservoirs, with gates, barrages and pumping station partly damaged, missing measuring equipment, etc. Other problems in agricultural water management are related to deterioration of water quality and land degradation (Abdullaev *et al*., 2009).

A number of measures aimed at a more efficient water management had been applied in the first decade of independence (Dukhovny and Sokolov, 2005). A breakthrough initiative was the establishment of the Interstate Commission for Water Coordination in 1992, which is currently the highest water decision-making body in the region. Governments showed interest in the application of high-cost investment measures, such as construction of new storage and hydropower-generation facilities, rehabilitation and better maintenance of the water-allocation infrastructure, which depended mainly on the support from the international donor community (Savoskul *et al*., 2004; Rakhmatullaev *et al*., 2010).

At district level, some success was achieved by reorganization of the local water management on an integrated basis, establishment of water user associations (WUAs), installing monitoring facilities, and improving control over water quality, flows and diversions (Sokolov, 2006; Karimov *et al*., 2012). Responses of the small-scale water users in the agriculture sector to regular water shortages in the 1990s followed three principal pathways: (i) cultivation of cash crops less dependent on irrigation; (ii) application of more efficient water use practices aimed at increasing water productivity; and (iii) reduction of water losses in the irrigation network (Savoskul *et al*., 2004). All these efforts enhanced the understanding of the importance of improved water management as a principal means to cope with water shortage and related problems (Antipova *et al*., 2002; Heaven *et al*., 2002) but, in general, adaptation measures and reforms in the water sector are quite insufficient to solve the current problems of water shortages in the basin (Bucknall *et al*., 2003; Ul Hassan *et al*., 2004; Arsel and Spoor, 2009; Sutton *et al*., 2013).

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Application of the models employed in this study is constrained by a range of uncertainties inherent in the business-as-usual type of future scenarios, which do not account for changes in water requirements due to increased crop demands, population growth, industrial development, application of adaptation measures, changes in political environment, etc. Some of these unknown factors will definitely work to increase the capacity of the basin to cope with CC impact. For instance, recent construction of the Koksarai Reservoir significantly increased the capacity of Kazakhstan to accumulate water in the winter to alleviate flooding in the lower reaches of the Syr Darya River and to reduce water shortages for downstream agriculture during the irrigation season. Other factors, like increased evapotranspiration, soil evaporation, increased pressure from future population growth, etc., will impose extra challenges for the transboundary water management (Siegfried *et al*., 2012; Sutton *et al*., 2013). However, the use of the models employed in this study is justified by their capacity to help us answer the question asked at the beginning of this chapter, i.e. to what degree is the agriculture sector in the Syr Darya Basin prepared for the challenges imposed by future CC impacts?

Looking in this light at simulated water allocation in 2070–2099 under two different climate scenarios invites some surprising conclusions. First, the CC impacts on the water availability for agriculture in the future will be comparable with the impacts of recent political change in the region due to the disintegration of the USSR. Second, under one of the considered CC scenarios, water deficiency in the basin is likely to be somewhat reduced. Under another scenario, water deficiency in the basin is not likely to significantly exceed that of 1992–2001. Third, the agricultural water users in the basin have already tested some adaptation measures, which might serve as a basis for the development of future CC adaptation strategies.

The study presented here stresses the point that the challenges imposed by CC on the agriculture sector in the Syr Darya Basin will be in many respects comparable to the challenges it faced in the first post-Soviet decade, and their solution will call for a more efficient water management at all hierarchical levels.

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