Water, Climate, Food, and Environment in the Syr Darya Basin

Contribution to the project ADAPT

Adaptation strategies to changing environments

July 2003

Oxana S. Savoskul, Elena V. Chevnina, Felix I. Perziger, Ludmila Yu. Vasilina, Viacheslav L. Baburin, Alexander I. Danshin A.I., Bahtiyar Matyakubov, Ruslan R. Murakaev

Edited by O.S. Savoskul

Table of Contents

1. Introduction

The Syr Darya Basin (Fig. 1.1) is one of two major basins belonging to Aral Sea Basin in Central Asia. It has an area of 402,760 km^2 divided between four ex-Soviet states; Kyrgyzstan, Uzbekistan, Tajikistan, and Kazakhstan (Fig. 1.2). Approximately 20 million people inhabit the basin, of which 73% live in rural areas, making their living from agriculture. 55% of the land is used as pastures supporting livestock of sheep, cattle, goats, horses and camels. 8% of the land is used for crop production. Climate in the basin is hot and arid, only in the mountains the climate is more cool and humid. Soils are thin and infertile, but can be productive for certain crops with adequate irrigation, which is not abundant in the region. An immense irrigation network inherited from Soviet times is still in operation but in part needs renovation, reconstruction and proper maintenance.

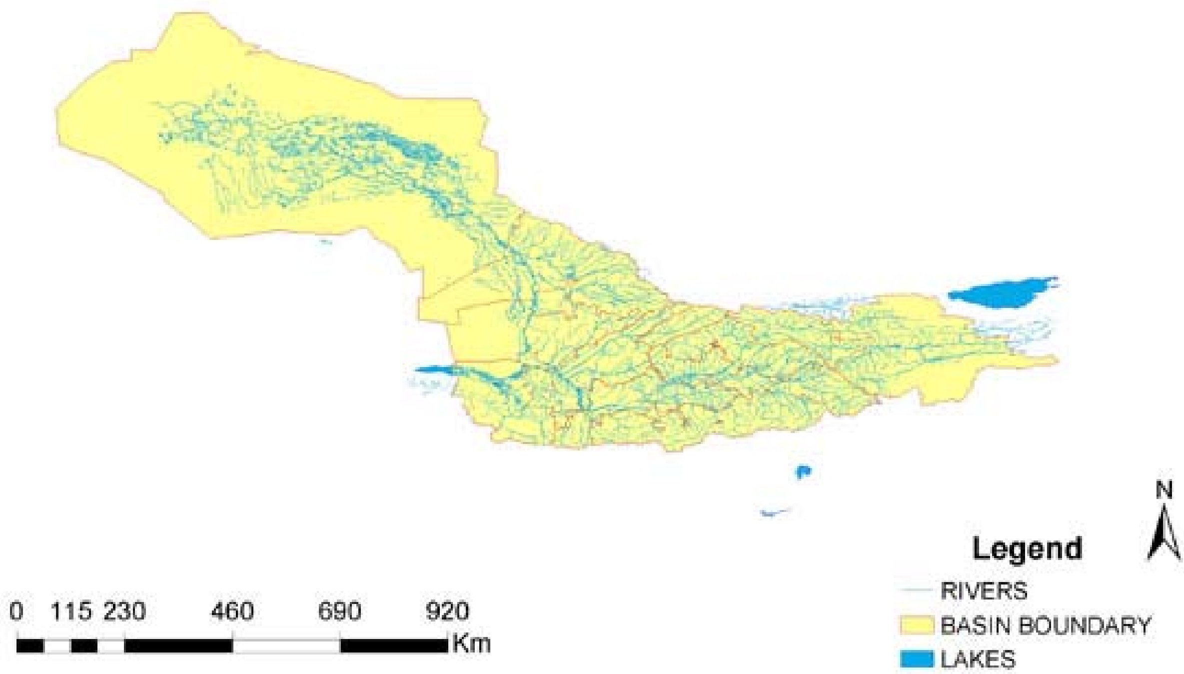


Fig. 1.1. The Syr Darya Basin.

After the disintegration of the USSR, the strictly centralised water management system came to an end, and the problems with co-ordination of water management became a hot issue in the region. Currently, a distinct conflict of interests between the states regarding the use of water has no effective solution. The centre of the dispute is huge Toktogul water reservoir in the upper Kyrgyz part of the basin. In the last decade, Kyrgyzstan has given the priority to hydropower production in winter thus creating serious water shortages downstream in summer, where the main agricultural land of Uzbekistan and Kazakhstan is located. Besides this, there are large environmental problems in the region: due to the overall overexploitation of water resources, Syr Darya outflow to Aral sea had significantly decreased since the 1960s, contributing to the unprecedented lowering of Aral lake levels leading to an environmental catastrophe in the region.

Besides these expected changes as a result of internal socio-economic and policy factors, external changes such as climate change, will have impact on water resources and thus also on the socio-economic situation. The Intergovernmental Panel on Climate Change (IPCC) described in one of their recent reports (IPCC-WG-I, 2001) the current state of understanding of the climate system and provides estimates of its projected future evolution and their uncertainties. In the global IPCC projections (according to CC scenarios considered below) some key points relevant to Central Asia and Syr Darya in particular, are:

- For the years 2070-99, the absolute increase of annual mean temperature will be 4 – 7 degree Celsius while annual precipitation will increase 7 to 16 per cent as compared to baseline (1961-90) interval
- The temperature variability is expected to increase remarkably: the standard deviation of temperature fluctuations might increase nearly double fold.
- Precipitation variability is expected to significantly increase only under scenario B2 over the period 2070-99 which also suggests a significant increase of the extremes.

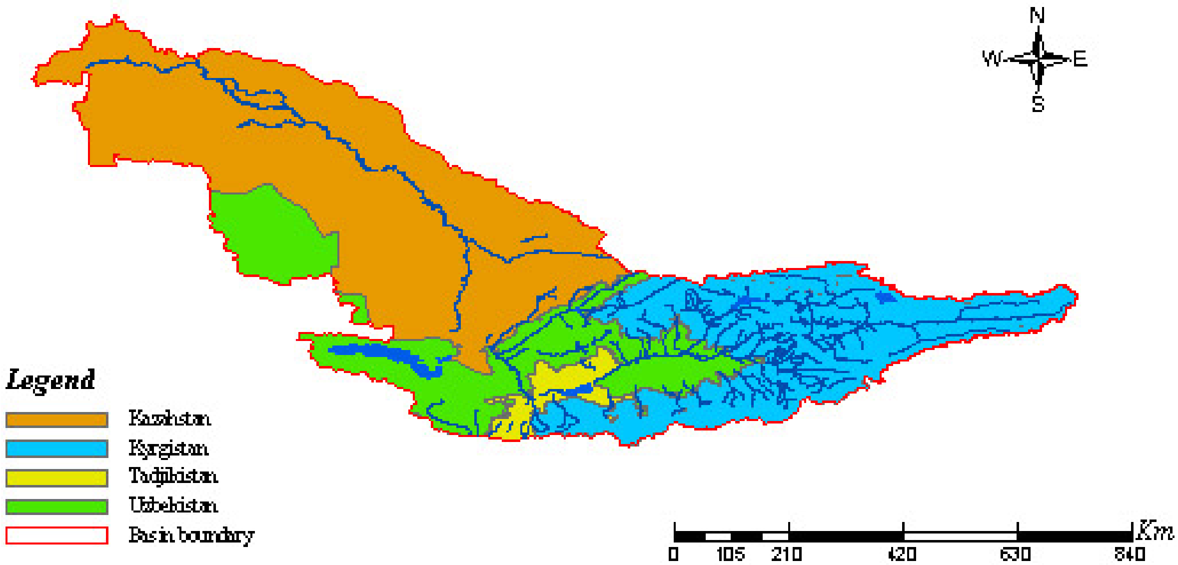


Fig. 1.2. Countries of the Syr Darya Basin. Note only parts of the countries lay in the basin.

One of the main challenges for the near future is what kind of adaptation strategies in terms of water resources can be developed for Syr Darya in respond to these internal and external expected changes. As part of the Dutch funded project ADAPT (Aerts and Droogers, 2002), adaptation strategies to changing environments, river basins in several parts of the world have been selected to analyse and compare what kind of coping mechanisms can be developed. The seven basins selected are (see Figure 2):

- Mekong, South-East Asia
- Rhine, Western-Europe
- Sacramento, USA
- Syr Darya, Central Asia
- Volta, Western Africa
- Walawe, Sri Lanka
- Zayandeh, Iran

The development objective of the ADAPT project is defined as:

> *"Develop and promote adaptation strategies to alleviate the negative impacts of expected increased variability in precipitation on water for food and environment resulting from climate change and other stressors on water resources."* (Aerts and Droogers, 2002)

The intermediate objectives that will contribute to the development objective are:

"For selected river basins, ranging from wet to dry and from poor to rich, the impact and adaptation mechanism to increased variability in precipitation due to climate change will be developed and promoted. The set of river basins will function as reference for other non-studied basins. Results will contribute to the knowledge bases of the Dialogue on Water and Climate and the Dialogue on Water, Food and Environment." (Aerts and Droogers, 2002)

According to the project description (Aerts and Droogers, 2002) the following six research steps can be distinguished in the Syr Darya case study:

- Select a set of river basins ranging from wet to dry and from poor to rich across the globe.
- Collect existing climate change projections (GCM results) for the selected basins from IPCC datasets.
- Compare historic weather data with GCM results for the same period and adjust, if necessary, GCM results.
- Select simulation models at basin and field scale appropriate to the conditions of the basin considered.
- Assess base line reference and impact of climate change.
- Define and assess coping mechanisms to climate change.

This report describes the current status of water and other natural resources and related socio-economic aspects, the expected changes and current policy to these changes for the Syr Darya basin in Central Asia. Data, data sources, data availability and accessibility will be described as well. Possible adaptation strategies, food focused, industry focused and environmental focused, will be presented and discussed in comparison with business as usual, i.e. if no adaptation measures are taken.

2. Natural Resources

2.1 Climate

The southern part of the basin, where headwaters of Syr Darya are located, is situated in a subtropical climatic zone. The climate here is strongly determined by alpine vertical zonality, and because of that is moderately humid at high elevations to arid at the lower elevations. The northern part of Syr Darya Basin is located in maritime climatic zone and is characterised by extra-continental features. This part of the basin has extremely low precipitation.

The data from 238 meteorological stations, 140 of which are located in the Syr Darya Basin (Fig. 2.1) were analysed to create GIS-files of long-term (1961-90) average monthly air temperatures (Fig. 2.3-a) and precipitation (Fig. 2.3-b). Because of highly variable hypsometry of the basin, which is the main factor influencing the features of the climate, five elevation zones of equal area were outlined, each represented by one meteorological station (Fig. 2.2.). Tables 2.1-a and 2.1-b show the data from those stations. The average annual temperature in the mountainous part is between –10 to +5 ^{o}C, and rises to + 15 ^{o}C in the lower desert part of the basin. There is no drastic contrast in the monthly distribution of precipitation. In the lower part of the basin, maximum precipitation is in the cold period of the year, at higher elevations, maximum shifts towards the spring/summer months. In the mountains, annual precipitation ranges from 500-600 mm/yr up to 1500 mm/year in water equivalent. At elevations above 1000 m, i.e. over approximately one third of basin area, a considerable part of precipitation is snow, which forms a continuous cover over significant areas in the mountains during the cold period of the year. Annual precipitation drops to values between 100 and 200 mm/yr in the lower part of the basin. In summer these areas are hot and dry.

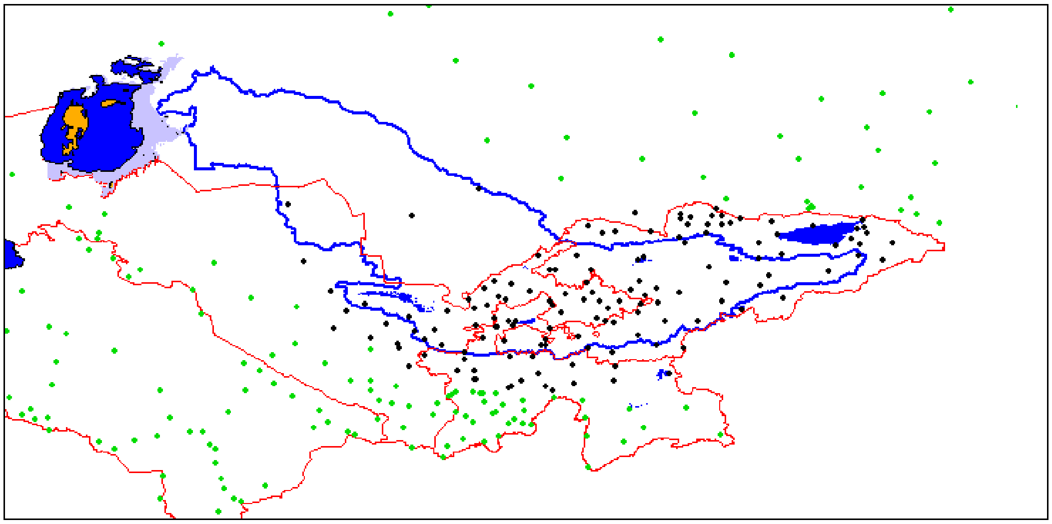


Figure 2.1. Meteorological stations belonging to the administrative units of the Syr Darya basin (black colour) and those located outside the basin (green colour), data from which were used to create GIS-files of temperature and precipitation in the region.

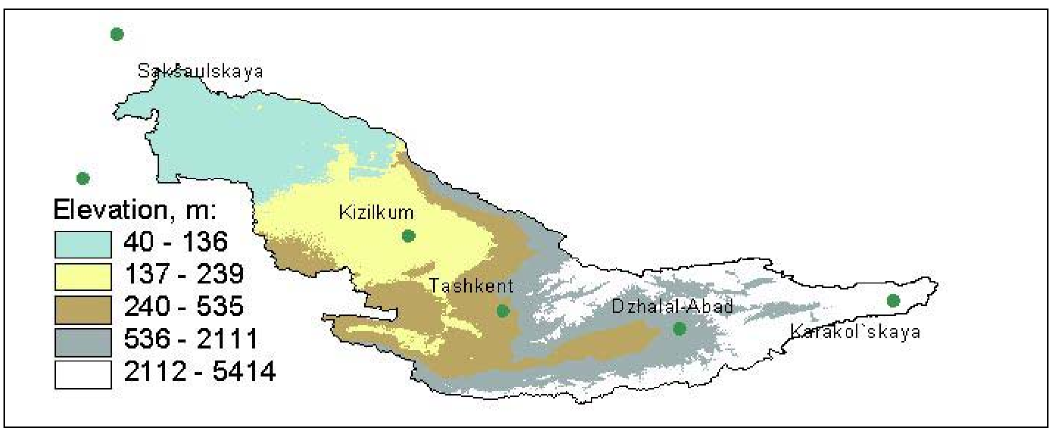


Figure 2.2. Hypsometry of the Syr Darya basin, five specific elevation zones of equal area and location of the representative meteorological stations.

Table 2.1-a. Average baseline (1961-90) monthly air temperature at five representative meteorological stations in Syr Darya Basin (^oC)

Station	Saksaulskaya	Kizilkum	Tashkent	Dzhalal-Abad	Karakol`skaya
Long, ^{o}E	61.15	67.27	69.27	72.98	77.45
Lat, ^{o}N	47.12	42.87	41.31	40.93	41.52
Elevation, m	78	184	450	756	3069
J	-13.9	-5.8	0.6	-2.2	-19.6
F	-12.7	-2.8	2.5	0.5	-15.2
M	-4.2	5.3	8.5	6.8	-7.4
A	9.8	14.5	15.4	13.8	-0.3
M	18.7	21.3	20.3	19	3.7
J	24.1	26.8	25.6	23.6	6.9
J	26.7	29.5	27.6	26.7	9.1
A	24.4	27.1	25.5	25.6	8.7
S	17.4	20.3	20	20.8	4.4
O	7.4	11.1	13.3	13.9	-2
N	-1.9	2.6	7.8	6.2	-10.7
D	-9.4	-3.2	3.4	1.1	-17.1
Year	7.2	12.2	14.2	13	-3.3

Table 2.1.-b. Average baseline (1961-90) monthly precipitation at five representative meteorological stations in Syr Darya basin (mm)

	Saksaulskaya	Kizilkum	Tashkent	Dzhalal-Abad	Karakol`skaya
Long, ^{o}E	61.15	67.27	69.27	72.98	77.45
Lat, ^{o}N	47.12	42.87	41.31	40.93	41.52
Elevation, m	78	184	450	756	3069
J	11	20	55	45	4
F	9	20	47	64	3
M	12	29	72	105	7
A	14	25	64	82	14
M	10	16	32	66	31
J	11	5	7	36	41
J	13	3	4	12	41
A	10	2	2	8	35
S	8	1	5	6	17
O	13	10	34	47	6
N	11	14	45	75	5
D	12	24	53	57	5
Year	134	169	420	603	209

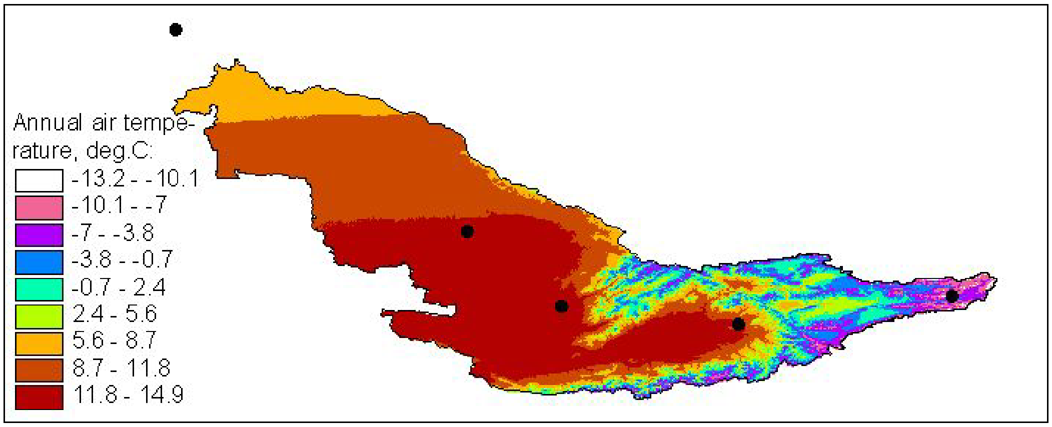


Figure 2.3-a. Annual temperature in Syr Darya basin (^{o}C).

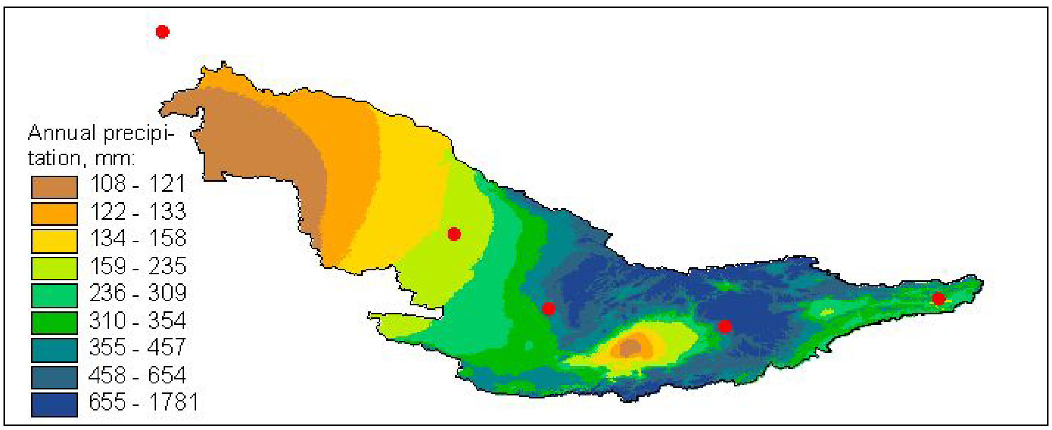


Figure. 2.3-b. Annual precipitation in Syr Darya basin (mm).

2.2 Topography

The topography of Syr Darya Basin (see also Fig. 2.2) can be roughly subdivided into two parts: the upper mountainous part, located in Tian Shan mountains (roughly corresponds to the zones 4 and 5 in Fig. 2.2). Here the valleys of rivers Naryn, Karadarya, Chirchik, Arys, and Keles form a network of runoff catchments with a typical alpine pattern of steep and narrow valleys, deeply cut into bedrock. The lower plain part of the basin (roughly corresponds to the zones 1-3 in Fig. 2.2) is basically built up of the erosion products of the nearby mountains, with loess in Golodnaya Steppe and sandy loess-like deposits in Kysyl-Kum desert. Here the Syr Darya river receives virtually no water from tributaries and has a relatively straight and broad valley stretching in the north-west direction towards the Aral sea. Fig. 2.4 shows the distribution of the basin according to elevation. Mountains, i.e. terrain above 1000 m, cover an area of approximately one third of the total basin area.
Digital elevation model image of Syr Darya Basin is based on GTOPO30, USGS models (Fig. 2.2)
The major geomorphologic features of Syr Darya Basin are:

- Naryn Syrts plateau which is slightly inclined westward at elevations of 2800-3600 m, located in the easternmost part of the basin, surrounded by mountain ranges
- Alpine ranges over 5000 m in height in the upstream part of virtually all major Syr Darya tributaries. The largest ranges are: Talas Alatau, Kyrgyz Alatau, Terskey Alatau, Fergana range, At-Bashi, Alay, Turkestan range

- Fergana valley, a waste alpine depression of tectonic origin in the mid part of the Syr Darya basin, located to the east of the Fergana range and encompassed by mountain chains to the north and the south;
- Syr Darya loess-like lowlands, so-called Golodnaya Step' (Hungry Steppe) at the foothills of Tian Shan mountains in the mid-low course of Syr Darya river
- Kysyl-Kum desert in the westernmost lower part of the basin

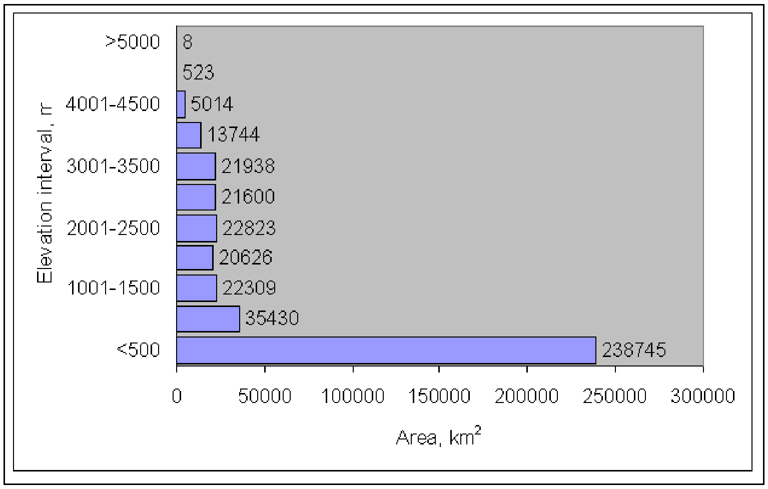


Figure 2.4. Distribution of Syr Darya basin area according to elevation

2.3 Land cover

Among the land cover classes (Fig. 2.5 and Table 2.2), the majority is represented by vegetation of arid and alpine type, like grass and shrubs, covering about 78% of area, forests covers about 8% of basin area and are specific for frontal alpine ranges, exposed to the main wind directions and receiving more precipitation. Swamps make about 7%, bare ground, rocks and other types of badlands contribute up to 5% of the total area, and the remainder includes water and perennial snow and ice.

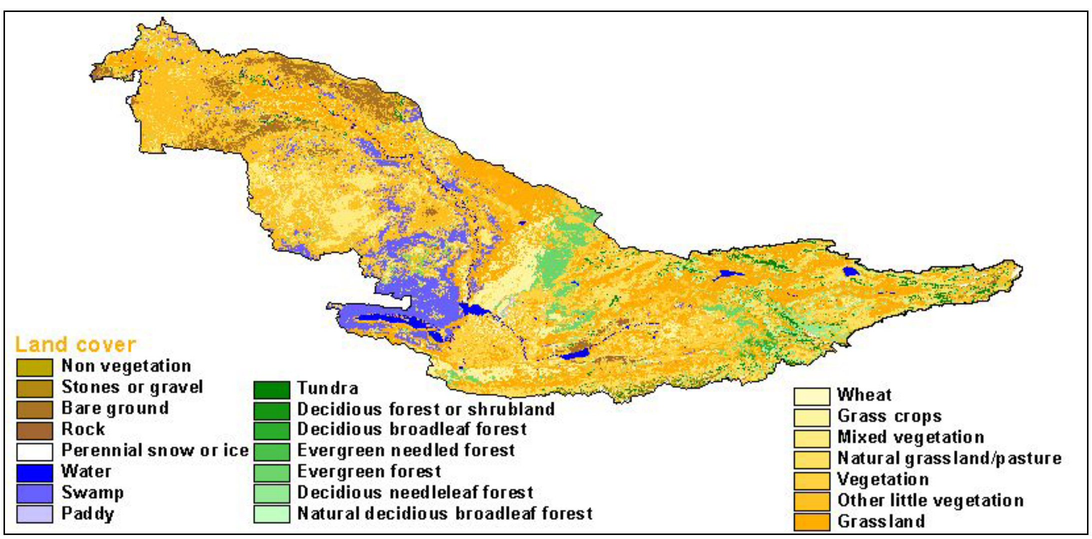


Figure 2.5. Land cover image of Syr Darya basin. Based on AARS Asia 30-second image, updated by inserting glaciers from 1:100 000, 1:200 000 (mainly), 1:500 000 topographic maps

Table 2.2. Distribution of Syr Darya basin area according to land cover classes.

CLASS	Code	Area, km^2	Share, %
Grassland	130	90161	22.4
Other little vegetation	184	91563	22.7
Vegetation	10	44799	11.1
Natural grassland/pasture	132	38221	9.5
Mixed vegetation	160	15645	3.9
Grass crops	140	30450	7.6
Wheat	142	2321	0.6
Natural deciduous broadleaf forest	76	3569	0.8
Coniferous forest	90	6950	1.7
Evergreen forest	16	13196	3.3
Evergreen needled forest	36	1636	0.4
Deciduous broadleaf forest	74	1009	0.3
Deciduous forest or shrub land	70	120	0.0
Tundra	182	7490	1.9
Paddy	141	271	0.1
Swamp	174	27932	6.9
Water	220	6278	1.6
Perennial snow or ice	200	1985	0.5
Rock	192	2349	0.6
Bare ground	191	13406	3.3
Stones or gravel	193	1334	0.3
Non vegetation	190	2047	0.5
Total		402732	100

2.4 Land use

Major agricultural land use types in Syr Darya Basin are depicted in Table 2.3. In total, 280,000 km^2 (55% of the basin area) is used as pasture. The livestock is represented by cattle, sheep, goats, pigs, horses and camels. Arable cropland land makes 35,000 km^2 (8% of basin area), of that about 80% is irrigated. Gardens, vineyards and other cultivated land are not accounted for. A substantial part of the cropland is located in Fergana valley (administrative regions: Djalal-Abad, Osh, Batken, Andijan, Namangan, Fergana and Sogd) roughly one tenth of the basin area. Here about 55% of the population is concentrated. Major crops in the basin are wheat, potatoes and cotton.

Table 2.3. Land use for agriculture in Syr Darya Basin. Data originates from national statistical data centres, and refers to 2000.

State	**Region**	**Area, x 1000 km^2**	**Pasture x1000 ha**	**Arable Cropland, x1000 ha**	**Percent irrigated**
Kyrgyzstan	**(all regions), incl:**	**(191.3)**			
	Naryn	46.7	2,512	130	80
	Djalal-Abad	33.6	1,191	150	50
	Osh	29.2	1,349	210	60
Tajikistan	**all regions, incl:**	**(140.6)**			

	Sogd	26.1	722	256	60
Uzbekistan	**all regions, incl:**	**(425.4)**			
	Andizhan	4.7	54	231	95
	Namangan	7.4	766	221	100
	Fergana	6.7	198	256	100
	Tashkent	15.6	42	339	100
	Syr-Darya	4.3	437	260	100
	Djizak	21.2	63	475	60
Kazakhstan	**all regions, incl:**	**(2669.8)**			
	South Kazakhstan	116.3	9,063	786	90
	Kysyl-Orda	228.1	11,868	124	100
Total regions of Syr Darya basin		**540**	**28,270**	**3,438**	**80**

2.5 Surface Water Resources

2.5.1. Pattern and formation of runoff

An overview of some key characteristics describing the state of surface water resources can be found in Table 2.4. The figures provided represents long-term averages. Variation within and between years is addressed below. Total annual average precipitation makes 129 km^3. Of this water, about 30%, approximately 39 km^3, reaches surface water runoff systems. Alpine glaciers are another important source of fresh water in the basin. There are 2863 alpine glaciers in Syr Darya basin covering an area of 1658 km^2 and containing 81,51 km^3 of ice (Kotlyakov, 1968). For the comparison, the natural lakes in the basin hold only 4 km^3 of water.

Table 2.4. Some key characteristics describing the state of surface water resources and the impact on society. Data originates from different sources and represents long-term averages.

Area (km^2)	402,800
Population (10^6)	19.5
Precipitation (mm y^{-1})	320
(km^3 y^{-1})	128.9
Surface runoff (km^3 y^{-1})	38.8
fraction (%)	30
Outflow to sea (km^3 y^{-1})	5.2
fraction from precipitation (%)	4
fraction from surface runoff (%)	14
Rainfall per capita (m^3 y^{-1})	6610
Surface runoff per capita (m^3 y^{-1})	1990

The main river of the basin, Syr Darya exceeding 2000 km in length, is formed in Fergana valley, from the confluence of the Naryn and Karadarya rivers. There are over 29,000 rivers in the basin, of these 1907 rivers exceed 10 km in length. The largest tributaries to the Syr Darya are Angren, Chirchik, Keles, and Arys' rivers. Table 2.5 shows the contribution of the sub-basins in the basin natural runoff.

Table 2.5. Syr Darya sub-basin runoffs (Basin team data).

Sub-Basin	Runoff, m^3/sec	Annual runoff, km^3/year
Naryn	448	13.8

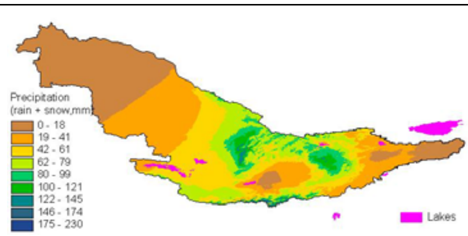
Fergana valley (main river Karadarya)	401	12.8
Chirchik	248	7.82
Arys'	64.2	2.02
Ahangaran	38.5	1.22
Karatau range	21.1	0.663
Turkestan range, to the west from Fergana	9.63	0.30
Keles	6.67	0.21
Total Syr Darya	1,237	38.83

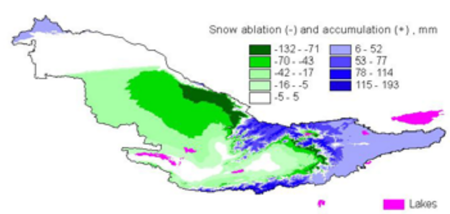
The rivers' nourishment is classified as mixed snow-glacial with prevalence of the snow part, and only in the uppermost parts of the basin, the glacial nourishment is dominant. Contribution of different sorces in river nourishment is shown in Table 2.6.

Table 2.6. Contribution of different sources in river nourishment, at some of the primary tributaries of the Syr Darya.

River	Share of different sources in river nourishment, %			
	Basic ground	Snow	Glacial	Rain
Sokh	40	28	31	1
Naryn	44	42	10	4
Karadarya	42	48	5	5
Chirchik	41	52	3	4

The hydrological regime of the basin is to large extent determined by the climate in the mountains of Tian Shan, occupying approximately one third of the basin area. At the elevations over 1000 m, the period of temperatures below 0°C lasts one month, reaching up to over 6 months at the elevations above 3000 m, where annual temperature is below 0°C. Thus the mountains provide seasonal storage for snow and perennial storage of precipitation in form of the alpine glaciers.





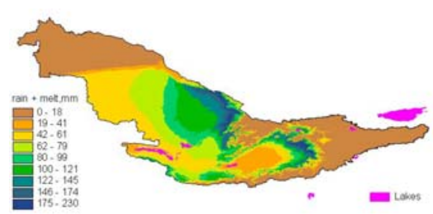


Figure 2.6. March precipitation (above), snow accumulation and ablation (upper right corner), total contribution into surface runoff (right)

Thickness, duration and stability of seasonal snow cover play the most important role in the inter-annual and spatial redistribution of precipitation income into surface runoff. A substantial part of winter precipitation makes its contribution to the runoff with a delay, as shown in Figure 2.6. The onset of snowmelt period shifts from early spring to early summer with increasing elevation. Because of this, the snowmelt water contribution to the runoff is distributed over a longer period, which is a factor stretching the duration of high water period and smoothening the height of its peak. Figure 2.7. shows the seasonal shifts of the zone of runoff formation. In January, this is mainly at the low altitudes in the middle part of the basin, where precipitation falls either in form of rain, or non durable snow cover is formed (less than a month), higher in the mountains and moving to the north there is a persistent snow cover at this time of the year. In April, the main contribution to the streamflow is provided by the snowmelt in the lower mountains. In July, alpine glacial runoff and snow melt at the highest elevations determine the pattern of runoff. In October, runoff is formed in the western periphery of the mountains nourished by the rains and early non-durable snow.

Second important regulators of inter-annual surface runoff distribution are the glaciers. Glacier ablation reaches its maximum in July-August and prolongs the period of high water. Due to combined effects of snowmelt and glacier runoff, the major part of the annual runoff in the basin, about 80-82%, occurs in the period from March to September. The alpine glaciers also play a specific role in the regulation of runoff from year to year. In the dry hot years, glacial nourishment compensates for the lack of precipitation, while in the wet and cold years the excess precipitation accumulates on glaciers compensating for the glacier ice loss. That balance is however disturbed by global warming: in the last century glacier mass-balance remained negative, causing retreat and disappearance of glaciers. According to our estimates (Savoskul et al., 2000), under various scenarios of climate change by 2070-99 the glaciated area will be 4 to 26% of its 1961-90 value.

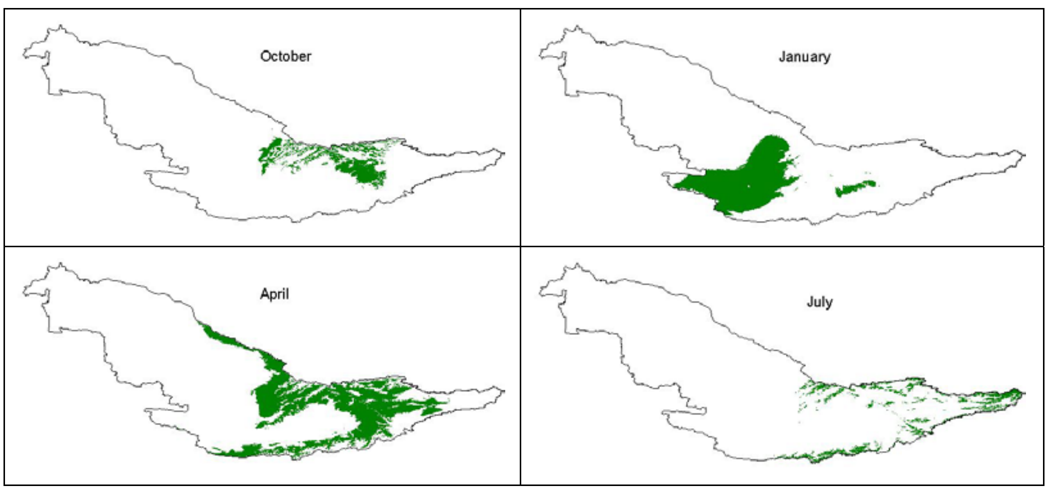


Figure. 2.7. Seasonal changes of the position of runoff formation zone (green area) in Syr Darya Basin

2.5.2. Water use and water development system

The water development system of the region is called “one of the most complicated water development systems in the world” (Raskin et al., 1992, p. 57). Six large artificial water reservoirs and a number of smaller ones constructed for the purposes of water storage for irrigation and hydropower production have in sum a water storage capacity of 35 km^3. The six largest reservoirs are:

Table 2.7. Largest water reservoirs in the Syr Darya Basin.

Reservoir	Country	Volume, km^3
Toktogul	Kyrgyzstan	19.5
Chardara	Kazakhstan	5.2

Kayrakkum	Tajikistan	3.4
CHAKIR	Uzbekistan	2.4
Charvak	Uzbekistan	2.0
Andijan	Kyrgyzstan	1.9

The maximum volume of the other reservoirs ranges from 400 to $40x10^6$ m^3. Besides water reservoirs, there is an immense network of canals (Fig. 2.8.), among which the largest are the Large Fergana canal, approximately 200 km long, with a maximum transfer capacity of 150 m^3/sec and the Northern Fergana Canal, which is 60 km in length.

The main water users in the countries where the basin is located are depicted in Table 2.8. In all cases, agricultural water demands by far outweigh those of industry and domestic needs. In the last four decades, the water resources were heavily overexploited what resulted in dramatic decrease of the Syr Darya outflow to Aral sea (see Table 2.9). That, together with overexploitation of water resources in the Amu Darya basin led to a dramatic drop of Aral sea level and environmental catastrophe in the delta areas of both rivers.

With average demands for irrigation 13,000 m^3 per ha of arable land, water demands for irrigation alone in the basin are estimated at 45 km^3. This figure is in close agreement with the estimates done by Raskin et al. (1992).

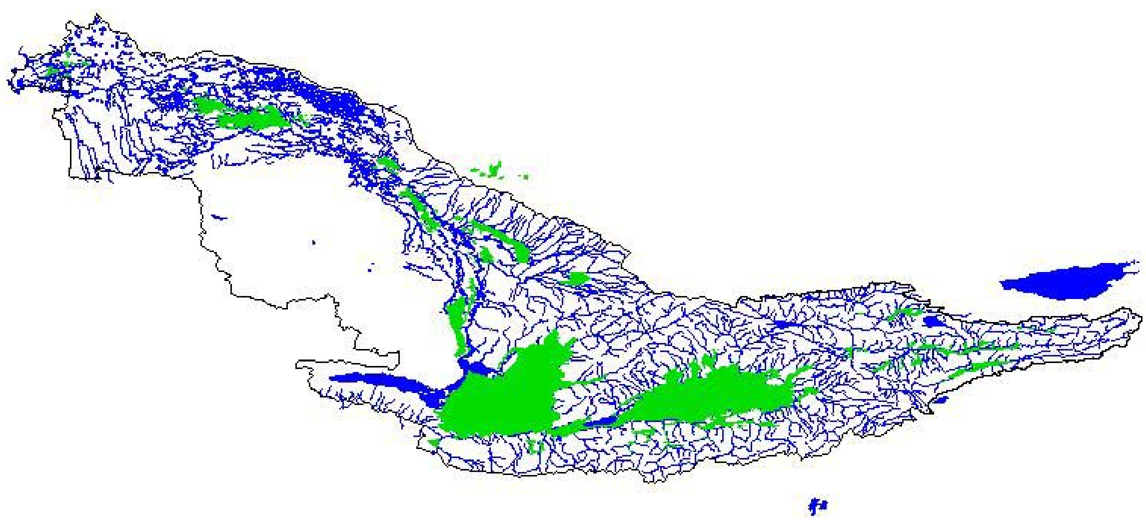


Fig. 2.8. Irrigation scheme of the Syr Darya Basin, main irrigated land is highlighted in green.

Table 2.8. Water resources usage in the countries of Syr Darya Basin. (1995, World Bank data)

	Water Resources per Capita (m^3)	Domestic Annual Withdrawals (%)	Industry Annual Withdrawals (%)	Agriculture Annual Withdrawals (%)
Kyrgyzstan	13003	3	7	90
Tajikistan	16604	5	7	88
Uzbekistan	5674	4	12	84
Kazakhstan	9900	4	17	79

Table 2.9. Syr Darya outflow to Aral sea.

(Basin team data)

Period	% of runoff
Before 1960	50-60
1961-1973	25-30
1974-1987	5-10
After 1988	10-20

Current disputes of water usage in Syr Darya basin are focused chiefly on regulations of large reservoirs outflows: Toktogul. Charadarya, Kayrakkum and Andijan. There is a distinct conflict of interests between the industrial and agricultural users, especially because the main stakeholders are in different countries, the major hydropower plants are in the upper stream Kyrgyz Republic, while main irrigated crop land is in the other three countries, thus downstream agriculture is in more vulnerable position. The largest reservoir in the basin, the Toktogul artificial lake (located on the territory of Kyrgyz republic) has the key position because of its location in the upper part of the basin and the water storage capacity of more than half of all artificial water storage in the basin. The lake supports a hydropower plant. Before the disintegration of the Soviet Union in 1990, Toktogul lake outflow and hydropower production was regulated taking into consideration the demands for water for irrigation downstream. After 1990, Kyrgyzstan started acting in its own interests, generating more hydropower for domestic needs in the cold period of the year, when the demands are higher, thus drastically reducing water supply to the agricultural areas of Kazakhstan and Uzbekistan in summer (Fig. 2.9). An attempt to settle the crisis was done when Kazakhstan and Uzbekistan both signed bilateral swap agreements with Kyrgyzstan to exchange coal and electricity for water. Though these states failed a number of times to meet the agreed targets, nevertheless, the existing institutions for the regulation of the transboundary water allocation may be considered quite effective in solving the problem (see Section 4)

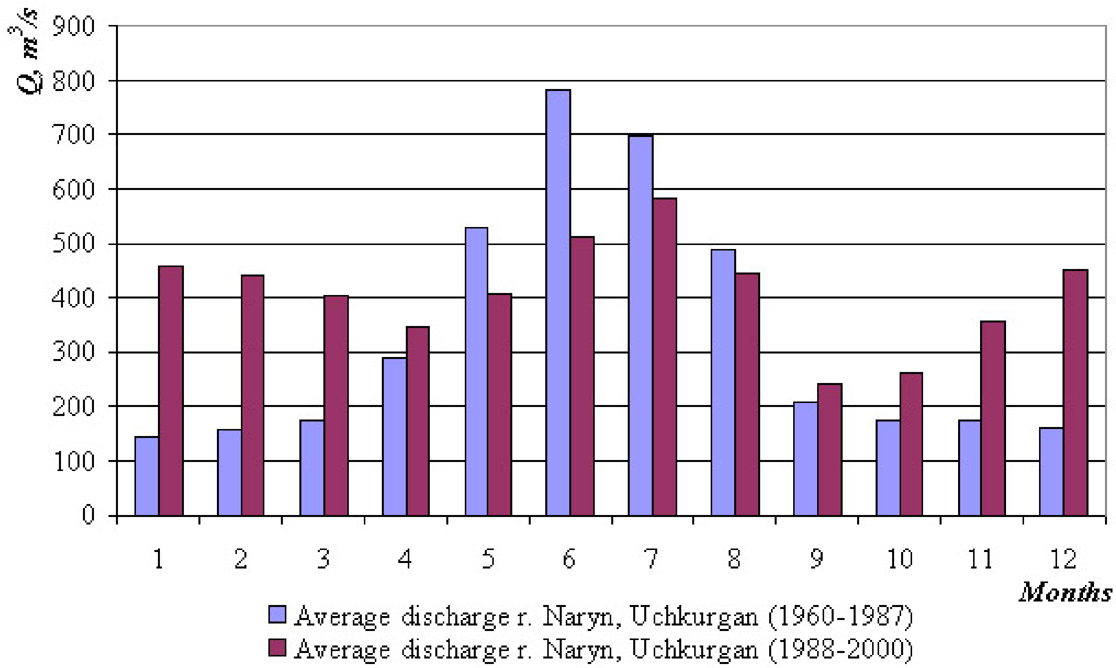


Figure 2.9. Average Toktogul lake outflow (vertical axis, m^3/sec) in 1960-87 (blue line) and 1988-2000 (purple line), horizontal axis: decades.

The last decade's changes in the regime of use of water reservoirs, had a consequence of creating not only downstream water shortages over summer, but also an excess water in wintertime that is not used for agriculture. However, the excess water in wintertime does not reach Aral Sea. The water flows into an isolated Arnaysay depression, creating there a system of lakes totalling 2000 km^2 in surface and raising the groundwater table. As a result, there are widespread newly formed swamps, covering an area of over 20,000 km^2 in the Arnaysay depression. The area is clearly visible on the land-cover image as a blue patch in the middle part of the basin (Fig. 2.5).

In the Syr Darya basin the typical wet years were 1921 and 1969, caused by high winter and spring precipitation (1,5-3,0 times higher than norm), when the Syr Darya runoff was twice its average. Dry years were 1974, caused by low winter precipitation and a hot summer, and 2000 caused by dry summer and insufficient water supply from reservoirs.

2.6 Groundwater Resources

Ground water resources are estimated at 11 km^3 by the basin team (L. Vasilina). Published data suggest a figure of 8 km^3 (Raskin et al., 1992). In Uzbekistan alone, the annual withdrawals are in order of 6,5-7 km^3 (Table 2.10). Due to excess water outflow in winter and extensive irrigation in summer, the groundwater table is raised. According to Rust et al., 2001, the 31 % of the irrigated area has a water table within 2 meters of the surface.

Table 2.10. Groundwater withdrawals in Uzbekistan in 1995 ($x10^6$ m^3) (Basin team data)

Domestic	2462.5
Industry	612.5
Agriculture	1502.4
Vertical drainage	2075.5
Other	22.1
Total	6675

2.7 Soils

There is a great variety of 34 soil types in the Syr Darya Basin as derived from the Digital Soil Map of the World (FAO, 2002). The dominant soil classes are various Lithosols (I) (covering 31% of basin area), Podzoluvisols (D) (20%), Yermosols (Y) (17%) and Xerosols (X) (13%) (Fig. 2.10, Table 2.11). Nearly 14% of the basin area has no soil cover, being represented either by bare rock, open water surface, or glaciers. Approximately 18% of the basin area are covered by aridic desert soils (Yermosols, Solonchaks and Solonetz), unsuitable for use either as pasture or for crop production. Shallow and stony Lithosols developed mainly in alpine zone. They are mainly used for cattle pasture. Relatively fertile soils with hydromorphic humidity regime (Fluvisols and Histosols) cover approximately 5% of the basin area and are concentrated along the rivers. Mostly aridic Xerosols, covering 13% of basin area, and in part Gleysols and Podzoluvisols with moderate humidity regime, that cover in total 20% of the basin area, are referred to as “although thin and infertile, ... [they are] easily tilled and productive for certain crops with the application of supplementary water. These favourable conditions provide the natural base for intensive irrigated agricultural development, particularly the large scale production of cotton in the Aral region” (Raskin et al., 1992). However, particularly in the last decade, the arable soil is losing in fertility due to salinization. Crop yields in the affected areas have declined by 20-30% and an estimated $137x10^6$ tons of salt is the average discharge from the irrigated lands (Rust et al., 2001).

Table 2.11. Soil types in the Syr Darya basin, summary

Class		Humidity regime	Depth	Area (km^2)	% of basin area
YERMOSOLS	Y	aridic	shallow	66,984	17.1
XEROSOLS	X	aridic	medium	49,402	12.6
SOLONCHAKS	Z	aridic	shallow	4,508	1.1
SOLONETZ	S	aridic	medium	2,251	0.6
LITHOSOLS	I	aridic to moderate	shallow	125,178	31.9
PODZOLUVISOLS	D	moderate	medium	79,977	20.4
GLEYSOLS	G	moderate to hydro	medium	15,179	3.9
FLUVISOLS	J	hydromorphic	shallow	15,014	3.8
HISTOSOLS	O	hydromorphic	medium	5,975	1.5

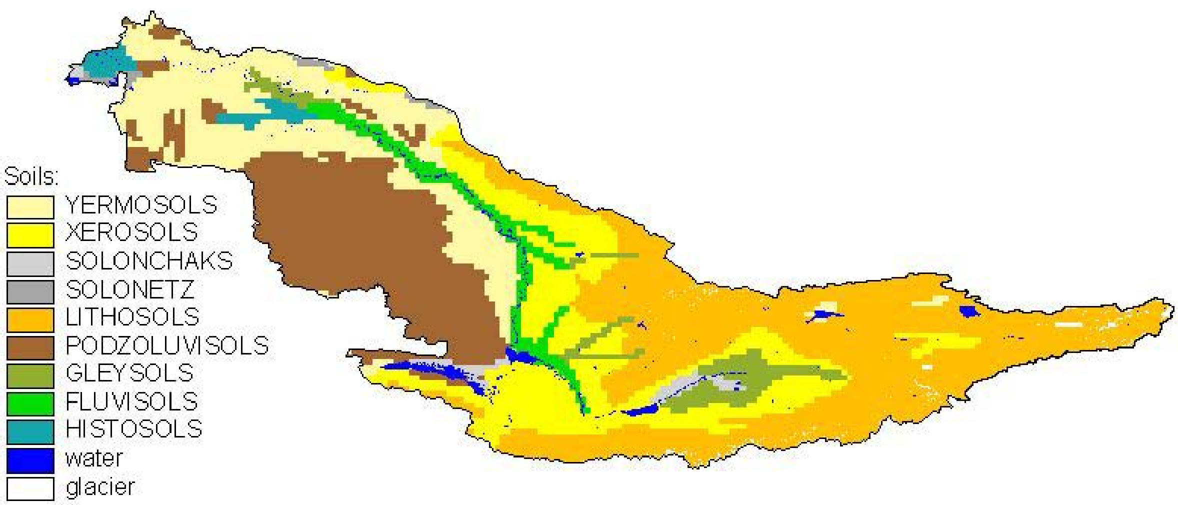


Fig. 2.10. Soil map of the Syr Dary Basin

2.8. Water quality and water-related environmental issues

The main pollutant of the water in the basin is its main user, i.e. crop agriculture. Since drainage infrastructure discharges some of its effluent back into the river, the downstream water quality gradually aggravates. Water salinity increases up to 2 g/l in the deltas of the Syr Darya (Rust et al., 2001) or up to 2.9. The use of pesticides and insecticides estimated at (38 – 57) x10^3 ton and (570-1140) x10^3 ton of mineral fertilisers, the chemical pollution of the water is also a serious problem in the region. The number and capacity of the sewage water treatment plants is also not sufficient.

The main environmental issue in the Syr Darya Basin remains the collapse of natural ecosystems in the area of the Syr Darya delta. Here, once productive wetlands, turned into a drying bed of Northern Aral Sea since 1960s. As a consequence, the fish population of the lake was drastically reduced, virtually eliminating the commercial fishing industry in the region. Furthermore, the exposure of the dried-up bed of the Aral sea allowed strong winds to erode the underlying sediments contributing to deterioration of air quality for the nearby residents and soil quality due to salt-laden particles falling on arable land. Salinization and waterlogging due to irrigation represent a serious treat to irrigated land. The area affected has increased during the last decade from roughly 25% to 50% of irrigated land (Raskin et al., 1992, Heaven et al., 2002). According to Rust et al. (2001) presently, 31 % of irrigated area has a water table within 2 meters of the surface and 28% of irrigated area suffers from moderate to high salinity levels, which results in crop yield decline by 20-30%.

In the late winter/early spring there is a danger of flooding in the lower course of Syr Darya around Ksyl-Orda city. The problem rises due to seasonal ice formation in the lower course of the river, which restricts the transporting capacity of the river channel, while in the upper stream too much water is used for hydropower production at e.g. Toktogul reservoir. To avoid flooding part of the excess water is diverted to Arnasay depression. However, since high degree of stream flow regulation and extremely low longitudinal freedom of Syr Darya (there are 29 major dams in the basin), the danger of flooding is rather a question of proper water management at transboundary level, than a real environmental problem. The excess water is diverted to the Arnasay depression since 1960s, but at the regular basis only in the last decade (at average up to 3 km^3 of water is being translocated to Arnasay depression annually in the period from 1990-2000). As a result, over a territory of about 20,000 km^2 there was created an ecosystem of man-made wetlands with unique flora and fauna, which already became a popular place for going game and fishing, as well as small-scale farming. Therefore, perversely enough, it became already an ecological issue to meet the demands of this newly created ecosystem, which means to continue the practice of translocation of the water into the depression, i.e. to deploy Northern Aral Lake of that water.

3. Socio-economic issues

3.1 Administrative subdivision

The Syr Darya Basin is divided among four ex-FSU states: Kyrgyzstan (28% of basin area), Uzbekistan (13%), Tajikistan (6%) and Kazakhstan (53%) (Fig. 1.2). Further subdivision of the territory into eleven *oblasts* or provinces is reflected in Fig. 3.1 and Table 2.1. Those were the single units used for the collection of socio-economic data. However, while counting the percentage and other indices, the figures were corrected based on the *oblast* area weight in the basin as based on DEM boundaries.

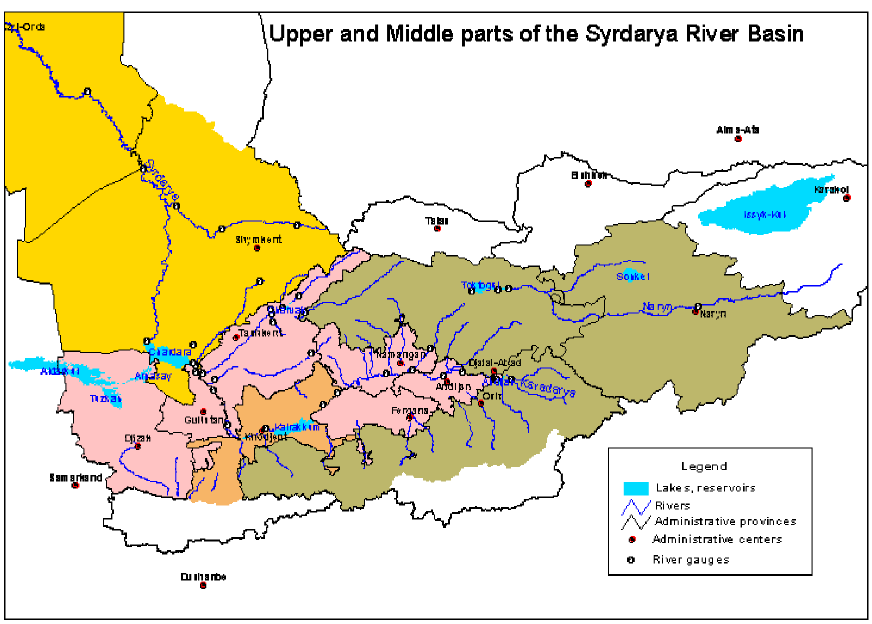


Figure 3.1. Administrative subdivision of Syr Darya basin into the states and *oblasts*, lower most part of the basin is not shown. Kyrgyzstan territories are highlighted in grey, Uzbekistan in pink, Tajikistan in orange, and Kazakhstan in yellow colour. *Oblast* centres are marked in red.

3.2 Population

Syr Darya Basin is inhabited by approximately 20 mln. people. Population density is 48 pers/km^2 at average, ranging from over 500 pers/km^2 in Andijan region to 2,6 in Ksyl-Orda region. Table 3.1. represents population of the *oblasts.* Approximately 55% of the population is concentrated in Fergana valley (*oblasts*: Djalal-Abad, Osh, Sogd, Fergana, Andijan, Namangan), i.e. approximately on one tenth of basin area. Rural population makes 73% of the basin population. There are over 3 mln farms in the basin. GDP per capita in the Syr Darya basin varies from $700 in urban areas to below $200 in rural areas. In the last decade, due to political and economic reasons there was a very significant migration flow of highly qualified urban population of Slavic, Jewish and German (specifically for Kazakhstan) origin from the newly established states of the Aral region, which resulted in lack of qualified specialists in all socio-economic spheres, including health care, science and education.

Table 3.1. Population of the Syr Darya basin. Territory units used are *oblasts*

State	*Oblast* (administrative centre if different)	Area, x1000 km^2	Population, x1000 pers	Population density, pers/ km^2	Urban Population, % of total
Kyrgyzstan:	**(all *oblasts*), incl:**	**(191.3)**	**(4,850)**	**(24.3)**	
	Naryn	46.7	249.1	5.3	18
	Djalal-Abad	33.6	871.4	25.9	23
	Osh	46.2	1551.3	33.6	23
Tajikistan	**(all *oblasts*), incl:**	**(143.1)**	**(6,200)**	**(43.3)**	19
	Sogd (Khodjent)	26.1	1824	69.9	35
Uzbekistan:	**(all *oblasts*), incl:**	**(447.4)**	**(24,900)**	**(55.7)**	
	Andijan	4.2	2205.1	525.0	30
	Namangan	7.9	1920.3	243.1	37
	Fergana	7.1	2709.7	381.7	29
	Tashkent	15.6	2559.6	164.1	40
	Tashkent, town		2118.7		
	Syr-Darya (Gulistan)	5.1	697.2	136.7	32
	Djizak	20.5	963.6	47.0	30
Kazakhstan:	**(all *oblasts*), incl:**	**(2724.9)**	**(14,950)**	**(5.5)**	
	Southern Kazakhstan (Shymkent)	116.3	1976.7	17.0	37
	Kysyl-Orda	228.1	596.3	2.6	61
Total Syr Darya Basin *oblasts*		**537.4**	**20,120**	**43**	**27**

3.3. Food production

It should be noted that after the disintegration of the Soviet Union, the Central Asian states of the FSU went through a complicated transitional period. During the first four to five years there was a sharp decline in production, the total number of livestock reduced, the productivity of livestock breeding and the yield of crops went down. Approximately in 1995 the production decline was stopped and since then agricultural outputs gradually increased. However, the reformation of the agrarian sector, particularly the massive privatisation does not pay off yet. This slows down the reforms, since market regulation mechanisms are still not quite effective and input and output prices remain distorted over most of the region (Rust et al., 2001).

Main crops in Syr Darya Basin are wheat ($3x10^6$ t produced in 2000), potato (approximately 2 $x10^6$ t) and vegetables (1,3 $x10^6$ t) more details are given in Table 14. Apart from those, important crops are foraging grass and cereals, rice, sunflowers (both specific for Kazakhstan), fruit, grapes, tobacco and spices. In the last decade, the export of fruit, wine grapes, vegetables, melons and spices chiefly to Russia, has substantially gained in importance as source of rural population income. Traditionally, the main commercial culture highly profitable in large scale farming projects in the region, is cotton. However, in the last decade, there is a distinct change in the structure of crops: Uzbekistan, Kyrgyzstan and Tajikistan switched from water-consuming cotton to less demanding wheat and other cereals. This is due to two factors: irrigation water shortages and increase in domestic need for locally produced food, induced by economic and political changes of the early 1990s. In the shadow economy of the region, illegal production of poppy, cannabis, and other plants used for drug production certainly plays a role.

The livestock breeding in the Syr Darya basin is of high importance in agriculture, judging merely from the prevalence of pastures in land use (55% of basin area). Livestock is represented by sheep, cattle, goats, horses, pigs and camels. Sheep breeding is especially common for Kyrgyzstan, sheep stocks here outweigh cattle stocks, the second common domestic animal seven times. Camel breeding is most typical for the Kazakh steppe and deserts of the lower basin. Typically for regions with dominance of Muslim cultures, pig stocks are small compared to other animals. Due to collapse of national economies after the disintegration of the Soviet Union, the livestock numbers plunged down two to three folds when compared to the Soviet times, and now are gradually increasing. Anyhow, agricultural products of animal origin especially from small and mid scale farms are very important food source in the local diet. Meat production in the basin is 0.5 $x10^6$ t, milk production is 2.85 $x10^6$ t, eggs - 900 $x10^6$ (Table 3.2). Apart from purposes of meeting food demands, animal breeding for commercial wool, fur and leather production is of relative importance in the region.

Table 3.2. Production of major crops, meat, milk ($x10^3$ t) and eggs ($x10^6$) in the Syr Darya basin, 2000 (Data from national statistical agencies)

Region	Grain	Potato	Cotton	Vegetables	Meat	Milk	Eggs
Kyrgyzstan:							
Naryn	100	140		25	50	120	4.8
Djalal-Abad	240	77		120	45	176	23
Osh	294	100	33	140	72	220	32
Batken	85	24	1	39	28	91	18
Tajikistan							
Sogd	110	85	252	150	35	170	100
Uzbekistan:							
Andizhan	519	338	342	65	33	335	96.8
Namangan	258	244	282	80	32	262	39.5
Fergana	325	363	269	83	39	378	84
Tashkent	339	256	528	127	63	347	316
Syr-Darya	186	175	91	11	16	120	28
Dzhizak	356	12	155	59	35	195	35
Kazakhstan:							
Southern Kazakhstan	282	88	287	299	57	383	23.6
Ksyl-Orda	197 (rice)	62		61	12	55	111

Total regions	3,291	1,964	2,240	1,259	517	2,852	913

Table 3.3. Land Productivity for three major crops in the Syr Darya Basin. (data from Rust et al., 2001)

Crop	Land Productivity t/ha
Cotton	2.89
Wheat	2.82
Rice	3.99

Productivity of land and water in Syr Darya basin was estimated by Rust et al. (2001). Land productivity calculated on the basis of three major crops (cotton, wheat, rice) combined is 714 USD/ha, and water productivity is 0.11 USD/m^3.

4. Institutional arrangements

It has to be recalled, that during Soviet regime, the institutional dealing with water management was strictly centralised and co-ordinated by the Ministry of Land Reclamation and Water Resources in Moscow. In 1987, a locally based Basin Valley Organisation for the Syr Darya (BVO Syr Darya) was created to co-ordinate water management functions. After the disintegration of the Soviet Union in 1990, newly formed states, found themselves in a state of budget decline that led to the deferred maintenance and degradation of the vast infrastructure assets created during Soviet times. Nearly instantly the conflicts over water sharing among new states surfaced and the BVO Syr Darya at this time became virtually irrelevant in solving the disputes. IWMI research report by Rust et al. (2001) cited below represents a perfect overview of the current state of water management institutional arrangements.

"The institutional framework for water management is a hierarchy with five levels of authority/ responsibility (Bandaragoda, 1999). The levels of management responsibility are divided into interstate or regional, state, province, district and farm.
Currently, the highest decision making body concerned with the regional water supply is the Interstate Commission on Water Coordination (ICWC) established under the agreements of the newly independent states' heads in 1992. Relevant deputy ministers for water are appointed as ICWC members. ICWC is entrusted with responsibilities of policy formulation and allocating water to the five states of the Aral basin. IWCW holds annual planning meetings scheduled towards the end of each calendar year to discuss preliminary plans and agreements for the following year's water supply and conducts working meetings approximately once every three months. ICWC operates through 4 executive bodies: BVO Syr Darya along with BVO Amu Darya, ICWC secretariat and Scientific Information Centre (SIC). Another high level agency founded in 1997 is International Fund to Save the Aral Sea (IFAS). IFAS is headed by one of the presidents of five states by rotation. The executive committee of IFAS is comprised of the Prime Ministers of the five states. These organisations work at regional level under two different aspects. While one set of organisations (IFAS and ICWC) deals with the macro-level water resources, environmental management, funding decisions and political decisions, the other set (BVOs) deal with technical aspects of water regulation among the states. However, most of the regional/interstate arrangements suffer from lack of financial commitment from the member states (IWMI, 2000) and therefore cannot perform optimally.

At the country level, ministries in charge of water resources are responsible for management of the water resources within the country boundaries. These ministries focus on planning and policies and delegate most of the allocation, regulation and distribution tasks to the respective provinces. At the provincial level, provincial water managing organisations, *Oblvodkhozes*, distribute and deliver water to major irrigation schemes. These control main and distributory canals, and their area of control typically ranges from 300,000 to 600,000 ha. Likewise, district water management organisations, *Rayvodkhozes*, are responsible for water distribution to various sets of farms. They operate and maintain inter-farm canals up to the gates of the collective farms or water users associations (WUA). A typical area of responsibility for a Rayvodkhoz is around 20,000 to 25,000 ha.

The farm structure within each state varies, depending on the level of progress in land privatisation. A collective/cooperative farm (*Kolkhoz*) may be an aggregation of several WUAs or private or or subsistence farmers. Each of the WUA is a composition of several private/peasant farms. The WUAs and *kolkhozes* are responsible for water distribution and operation and maintenance of the infrastructure within the boundaries of their farm.

5. Projections for the Future

5.1 Climate

5.1.1 Climate Change Scenarios

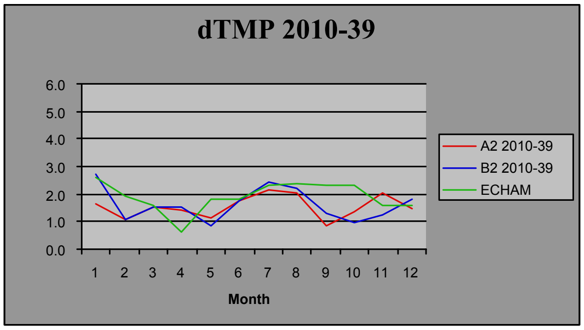
Regional climate change scenarios with integrated A2 and B2 SRES scenarios were constructed based on the outputs of Had3 and ECHAM4 GCMs. The time slices considered are 2010-39 and 2070-99. For the ADAPT project, the scenarios were constructed by ITC team and normalised using a standard approach for all the basins of the project. Since the original resolution of the GSMs is quite coarse (Had-3: 2,5^{o}lat x 3.75^{o}long and ECHAM: 2,8125 x 2,8125^{o}), and taking into account the requirements for higher resolution by the applied models, the downscaling procedure was considered necessary. The spatial downscaling was done by applying interpolated and normalised GCM grid values to the GIS database of baseline (1961-90) climatology, with a resolution of 1x1 km^2.

Table 5.1. Summary of the mean annual changes of the main climate parameters over two time slices, 2010-39 and 2070-99, according to various climate scenarios, in the Syr Darya Basin.

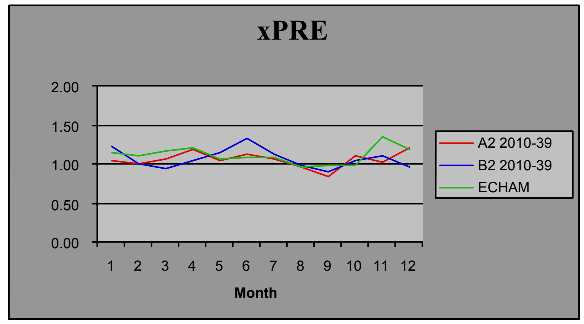
Time slice	Model	dTMP	xPRE
2010-39	ECHAM	2.1	1.13
	A2	1.5	1.08
	B2	1.6	1.07
2070-99	ECHAM	5.4	1.10
	A2	5.1	1.07
	B2	3.7	1.16

Note: dTMP – annual temperature deviation (^{o}C) from baseline (1961-90) value; xPRE – annual precipitation increase related to baseline value (1961-90). Colours for each GCM model correspond to those in the plots below.

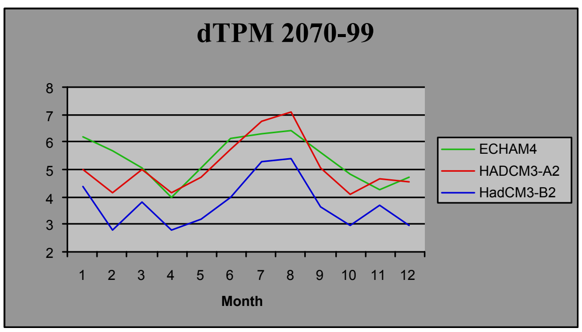
The analysis of the scenarios (Fig. 5.1) shows a good deal of similarity between outputs from Had3 and ECHAM4 GSMs in terms of monthly changes. Thus, for the Syr Darya Basin only two scenarios may be applied, representing the extremes (min and max deviations from present) of the range of future climate variables. Both scenarios were based on the outputs from Had3: A2 SRES based scenario, hereafter A2, has the highest temperatures. B2 SRES based scenario, hereafter B2, represents a future with a moderate temperature increase (3,7^{o}C) H modelled average temperature deviation from baseline (1961-90) value in the Syr Darya Basin ranges from 3 to 5^{o}C, according to all CC scenarios, winter precipitation is expected to increase, and summer precipitation to decrease as related to its present amount. Thus according to all scenarios, the warm period is expected to grow more arid, despite an overall increase of annual precipitation in the range of 1,07 to 1,17 times to its present value at average.



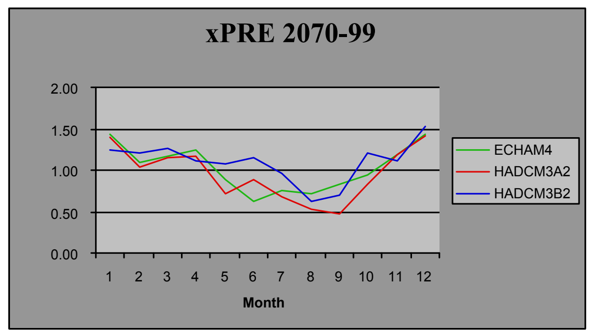
a



b

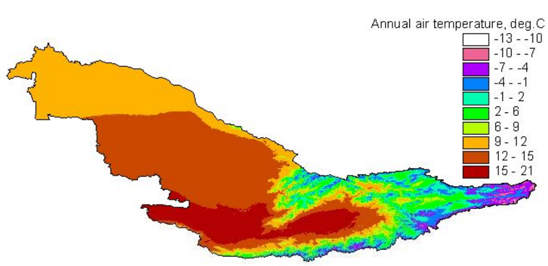


c

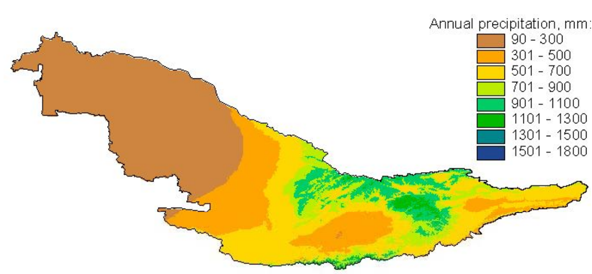


d

Figure 5.1. a - Temperature deviation (dTMP) for the time slice 2010-39 from baseline (1961-90) value; b - Precipitation increase/ decrease (xPRE) for the time slice 2010-39 relative to baseline value (1961-90); c - Temperature deviation (dTMP) for the time slice 2070-99 from baseline (1961-90) value; d - Precipitation increase/ decrease (xPRE) for the time slice 2070-99 relative to baseline value (1961-90). Note: for each time slice, 30-year mean monthly values of the variables are presented in the plot.



a

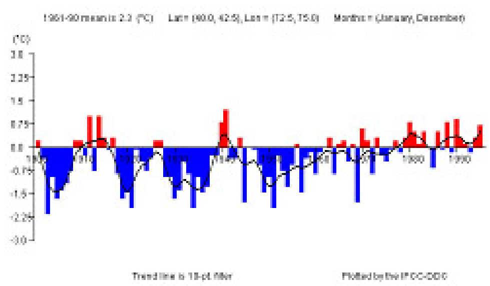


b

Figure 5.2. Downscaled regional climate scenario, based on Had3 outputs for B2 SRES scenario for the time slice 2070-99. This scenario gives moderate mean annual temperature increase of 3.7^{o}C and significant precipitation increase of 1.16 as related to baseline period (1961-90). a – Temperature (^{o}C); b - Precipitation (mm). Compare with climatology for the baseline (1961-90) period (Fig. 2.3)

5.1.2. Climate variability: historic, baseline, modelled

Fig. 5.3. shows data for temperature and precipitation variation in the Syr Darya basin, according to CRU database over period 1900-95. Based on the analyses of long-term climate parameter variations, several conclusions may be drawn. There is an apparent trend over the observed period, for temperature increase in a range of 0.7-1.0^{o}C over the Syr Darya basin. Over the baseline interval (1961-90), the temperature variability is smallest while precipitation variability increases, as compared to the 95 yea record. The warming correlates with an increase of annual precipitation. The historic data validate the climate scenarios used in our study: both A2 and B2 scenarios suppose the same tendency for the Central Asian region: overall increase of precipitation as a consequence of global warming. Data of meteorological observations in the region (Savoskul et al., 2000) suggest also that variability of climate parameters correlates with climate humidity: the more arid the climate, the less variation show extremes in the long-term series. For Syr Darya basin it means less climate variability in the upper reaches of the basin, which is an important note taking into consideration that this is where runoff is formed.



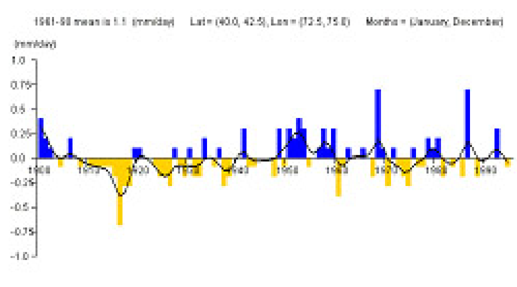


Figure 5.3. Historic Data: time-series anomalies of annual temperature and precipitation (deviation from 1961-90 mean) over 1900-95 in the middle part of the Syr Darya basin, for the grid cell with coordinates 40.00- 42.5 ^{o}N x 72.5 – 75 ^{o}E (source IPCC-DDC). The grid cell is representative for the Syr Darya Basin, since it has the climate parameters most close to the average in the basin.

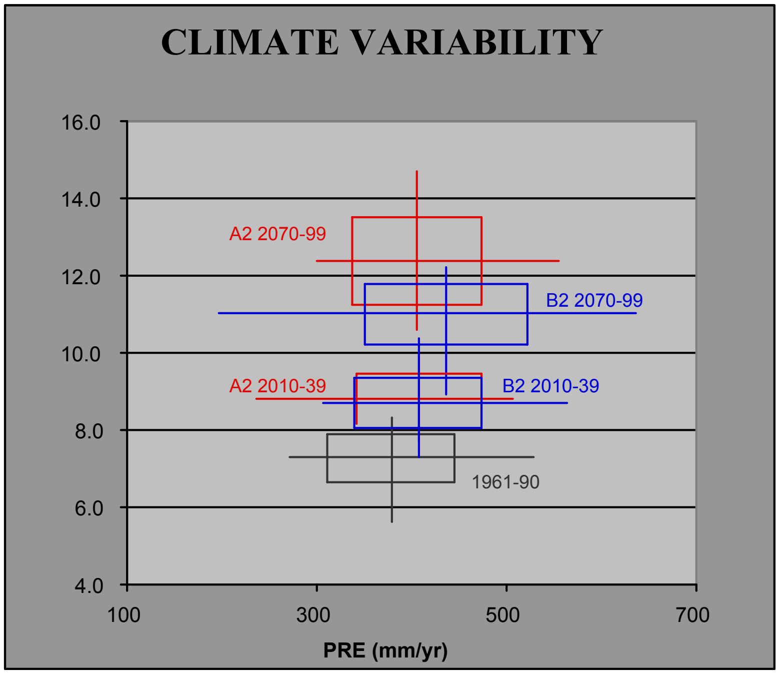


Figure 5.4. Climate variability, current state and under climate change scenarios. The cross in the centre of each box corresponds to the mean annual values of temperature and precipitation, box length and height equals to two standard deviations, whiskers outermost point is absolute maximum/minimum of the corresponding variable.

Under CC scenarios used in this study, the following changes are expected for climate parameters' variability. Absolute changes of temperature over the period of 2010-39 will be compared to the ranges of its baseline period variability (Fig. 5.4.). For the time slice 2070-99, the absolute changes of annual means will be far beyond the range of baseline period extremes. At the same time, the temperature variability is expected to increase: e.g. the standard deviation of temperature fluctuations might increase nearly double fold. On the contrary, the absolute increase of precipitation is expected to remain within the range of its current variability. Precipitation variability is not expected to significantly increase: there are no significant changes of standard deviation, apart from under scenario B2 over the period 2070-99 which also suggests a significant increase of the extremes.

5.2. Population

The population of the countries of the Syr Darya Basin is expected to grow significantly, mostly because large rural population in the region (making 73% of total basin population at present) with extended and strong families with traditionally very high birth rates. Table 5.2 represents the UN data, while in Table 5.3. the data of basin team estimates are shown, specified to the *oblast* level of Syr Darya basin countries for the periods 2010-39 and 2070-99. In our opinion, the UN population growth rates negative at average for Kazakhstan, cannot be applied for the estimation of the population growth in Kazakhstan's *oblasts* in Syr Darya basin, since here only a small fraction of the entire country population is settled and this has a very traditional rural way of life with high birth rates. Apart from this, our estimates concord with the regional trends. Uzbek and Kyrgyz population increase would be especially remarkable, and particularly so in rural Fergana and Golodnaya Step areas, where the highest population density in the basin is. In total, by the end of the century, the population in the basin is expected nearly double compared to present (Table 5.2.)

Table 5.2. Expected population growth (pers.x1000) in the countries of Syr Darya Basin (source UN expertise)

Country	2000	2030	2050
Kyrgyzstan	4,921	6,722	7,538
Tajikistan	6,087	8,475	9,763
Kazakhstan	16,172	16,047	15,302
Uzbekistan	24,881	35,712	40,513

Basin team expertise judgement is reflected in Table 5.3 and Fig. 5.4. For the 2070-2100 time slice the significant growth of population and change of its structure (urban and rural shares) in all countries is expected. By the 2100 the population in basin will be doubled, and also the share of urban population (Fig. 5.4, Table 5.3) will increase. The most significant growth of population is expected in republic of Uzbekistan, in the Tashkent and Fergana region.

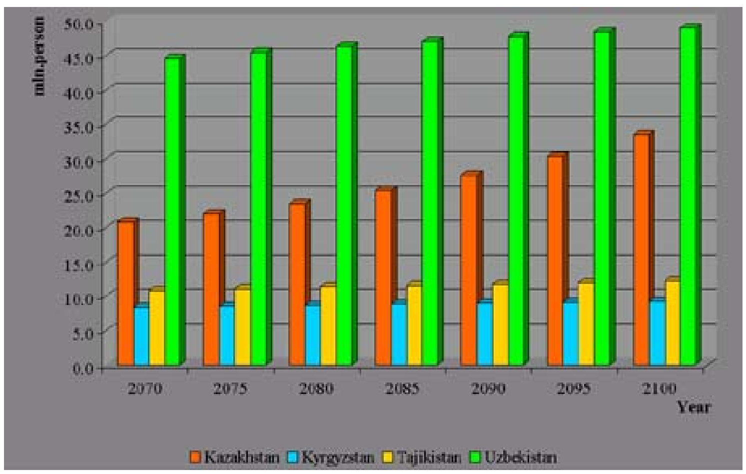


Figure 5.4 The population growth in Syr Darya basin during 2070-2100 (mnl. person).

6. Set Up and Description of Models

6.1 Stream Flow Model (SFM)

Changes in surface runoff were modelled using stream flow model (hereafter SFM) designed for the Syr Darya Basin by the basin team using general approach of Denisov et al. (2002). SFM is a physically based model that simulates surface runoff as function of topography and air temperature, based on simple runoff balance equation. The water income (Q) to the basin area in SFM model is comprised by three main items:

Qr –rainwater
Qs – snowmelt water
Qg – glacial runoff (is used as a direct input into stream flow)

Three major steps comprise the modelling procedure :

- snow cover modelling, to account for the contribution of snow accumulation and snow melt;

- glacial runoff modelling, to account for the contribution of glacial runoff;
- the simulation of the stream flow

Snow Cover Modelling

As was shown above (Section 2.5.1), for the Syr Darya Basin, the consideration of snow cover spatial distribution and correct accounting for the onset of snow melt, is crucial for the correct estimation of surface runoff distribution within a year, since snow cover retains a part of precipitation during cold season; and snowmelt provides extra water for surface runoff in spring. Therefore, the first step of surface runoff modelling was snow cover modelling, i.e. modelling the pattern of snow accumulation and snow melt

The data on long-term mean snow water equivalent dated month's end have been analysed. Information on 75 stations (170 stations-months) located mainly in Uzbekistan at elevation from 66 to 3840 m was collected. The 44 of them are within the watershed of Syr Darya River.

The next model has been applied for each grid cell:

a) snow share (portion of solid precipitation) in monthly precipitation total:

$$\eta = \frac{XS_i}{XT_i} = \frac{1 - \tanh\left(\dfrac{\vartheta_i - \vartheta_{50}}{\sigma_\vartheta}\right)}{2},$$

where: *XS* is so called solid precipitation or snow (mm); *XT* is total precipitation (mm), i.e. snow plus rain; *i* is month number, starting from October; ϑ is mean monthly air temperature (^{O}C); ϑ_{50} is monthly air temperature, at which 50% of precipitation consists of snow (^{O}C), parameter; □$_\vartheta$ - parameter (^{O}C), the smaller it is, the more narrow is air temperature interval near ϑ_{50}, when mixed snow-rain precipitation occurs.

b) monthly snowmelt (M, mm):

$$M_i = \max\left[30 \cdot K \frac{S_i}{388}(\vartheta_i - \vartheta_0), 0\right],$$

where: *K* is snowmelt factor (mm /^{O}C), parameter; *S* is monthly sunshine duration (hours) to capture seasonal pattern of *K*; 388 is maximum sunshine duration for all the stations (hours); ϑ_0 is air temperature threshold (^{O}C), parameter. The snowmelt occurs under the temperature higher than threshold. Under the same air temperature the snowmelt depth is smallest in December and highest in June, which accounts difference in solar radiation;

c) monthly change in snow water equivalent (□*W*, mm):

$$\Delta W_i = \eta \cdot XT_i - M_i,$$

d) snow water equivalent at the end of month (*W*, mm):

$$W_i = \max(W_{i-1} + \Delta W_i, 0),$$

The end of September was assumed the beginning of water year, i.e. there is no snow in any place. It is evident that at the end of the hydrological year the algorithm can result in non-zero water equivalent of the snow for some cells; this is a case of so called firm, but seasonal snow.

This is 4-parameteric model. The parameters were adjusted to minimise standard error of water equivalent estimations. Their final values are as follows:

$$\vartheta_{50} = -2.01^O C, \sigma_\vartheta = 1.53^O C, \vartheta_0 = 1.77^O C, K = 4.55\ mm/^O C.$$

In respect to the model assumptions the total of rain and snowmelt (L) for any *calendar* month (m) can be calculated as follows:

Equation	Month number

$L_{10} = P_{10} - W_{10}$	10
$L_1 = P_1 - (W_1 - W_{12})$	1
$L_m = P_m - (W_m - W_{m-1})$	2-9

As one can see from Fig. 2.6, distribution of monthly moisture availability (total of rain and snowmelt) over the watershed surface is of fundament difference from spatial and respectively seasonal pattern of precipitation.

Glacial runoff modelling

Second step of the surface runoff modelling, was related with the estimation of the glacial runoff contribution. For this purpose, the following model was applied (Glazyrin, 1997)
The model allows to describe changes in the area of glaciation (hereafter Sg) for the glacier systems belonging to a river catchment, based on two input parameters: summer temperature deviation from its baseline value (dTMPs) and a ratio of modelled precipitation to its baseline value (xPRE). The model is based on the calculation of an equilibrium line altitude (hereafter, ELA) For the fine-tuning of the model, knowledge of the local pattern of precipitation distribution according to altitude, and the baseline glaciation parameters listed below, are needed. The model is described by two equations:

$$Sg=5,55\ (H_B\text{-}ELA)^{0,51}\ S_{>ELA} \qquad (A)$$

where
H_B – the altitude of highest point of the glacier system (m)
$S_{>ELA}$ – the area of river catchment located above ELA (km^2)
dTMPs – departure of summer temperature from baseline value

$$dELA=-1/E\ [xPRE\ ab(TMPs(ELA))-ab(TMP\ (ELA)+dTMPs)] \qquad (B)$$

where
E – energy of glaciation or vertical mass-balance gradient at the ELA
ab(TMPs(ELA)) – annual ablation at the ELA, that depends on the summer temperature as described in (Krenke, 1982)

$$ab(TMPs)=1,33\ (9,66+Ts)^{2,85} \qquad (B\text{-supplement})$$

The loss of area of glaciation was recalculated into the ice volume loss, which is the glacial runoff contribution into the balance and was applied in SFM as an adjustment factor.

Model Calibration

Long-term streamflow records at 5 representative sub-basins have validated the model estimations:

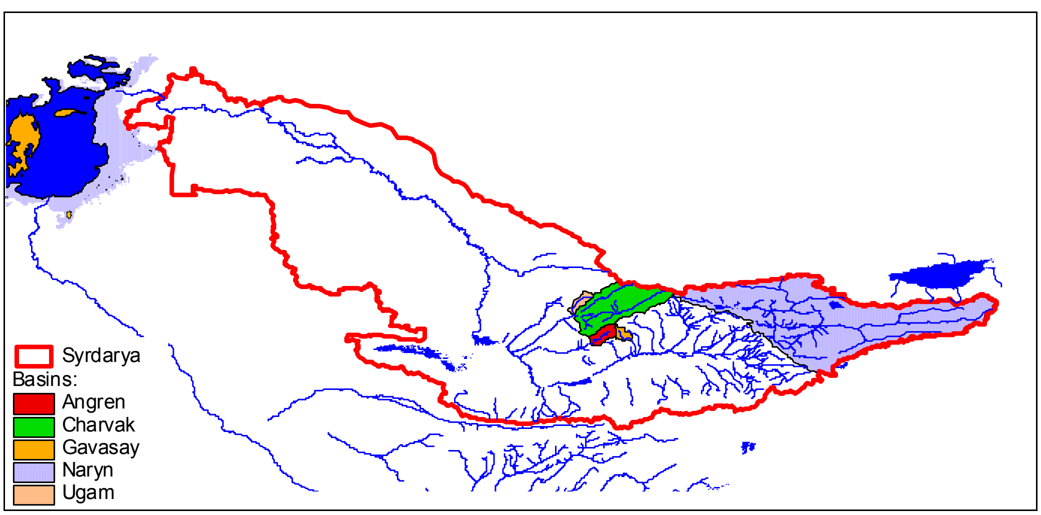


Fig. 6.1. Syr Darya sub-basins.

The summary of this validation is given in Table 6.1.

Table 6.1.

Basin	P, mm	Q, mm	Q/P	R_1	R_2
1	2	3	4	5	6
Charvak	621	629	1.01	0.17	0.90
Ugam	661	835	1.26	0.18	073
Angren	500	518	1.04	0.76	0.98
Naryn	477	224	0.47	0.82	0.86
Gavasay	502	272	0.54	0.63	0.94

Note: P is annual precipitation (modelled), Q is annual mean specific streamflow (measured), R_1 is monthly precipitation-streamflow correlation coefficient, R_2 - is monthly (rain plus snowmelt)-streamflow correlation coefficient.

As one can see from the analysis of runoff coefficients (column 4), our precipitation maps most likely, overestimate precipitation in the upstream of the Syr Darya basin (Naryn) and, certainly, underestimate it in a middle part (Charvak). The correlation coefficients of modelled monthly rain plus snowmelt and streamflow (column 5) are much higher for all the sub-basins, except of Naryn, than ones between precipitation and streamflow (column 4). It means the developed model of snow cover is capable to correct the seasonal pattern of moisture availability in a proper way, which is of great importance for both hydrological and plant life cycles. There is an example of this pattern in Fig. 2.7. Naryn river case is very particular. The hydrograph is highly influenced by the size of the basin and a great number of the glaciers and lakes. For example a relative area covered by glaciers and lakes is much higher here than in the other sub-basin. Still the accounting of snow cover presence improves the correlation between seasonal moisture availability and streamflow.

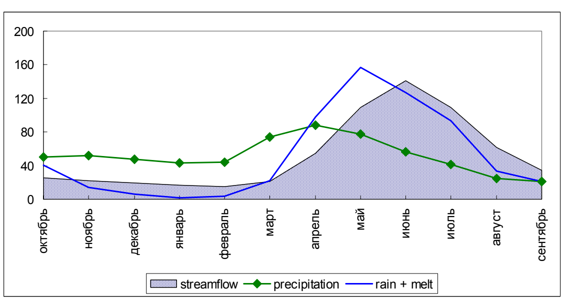


Fig. 6.2. Seasonal variations of precipitation, runoff (rain+melt) and streamflow (mm) in the basin of Charvak water reservoir

In addition to hydrological control the model has been validated by remote sensing information. The comparison of snow cover estimates at the end of March based on the model and on processing of NOAA image (Kobilov et.al., 2000) is presented in Fig. 6.3. Image has been acquired at the end of March, 1996. The weather conditions of 1995-1996 water year were very close to the long-term averages. As one can see the model well simulates snow cover extent very reliable.

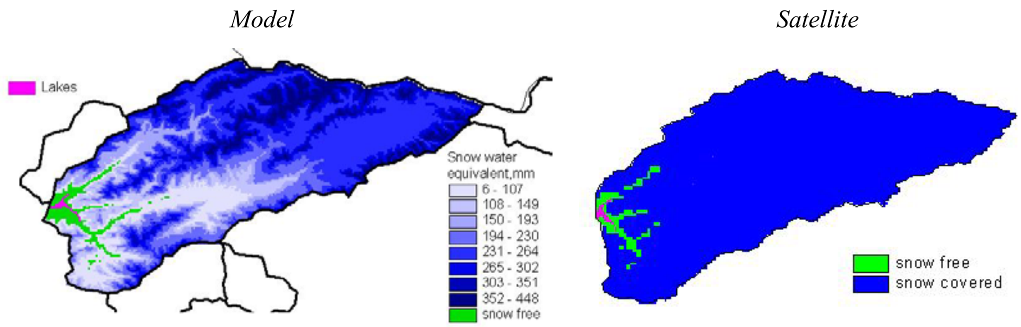


Fig. 6.3. Snow cover extents in Charvak sub-basin: comparison of model and satellite estimates

Simulation of the stream flow

Transformation of income into the streamflow is done on a daily basis using runoff coefficients varying with altitude and taking into account seasonal changes in the vertical temperature gradients. Each simulation was done in 500 runs. Because of extremely intensive water use in irrigation schemes, model calibration is impossible for the mid and lower course of Syr Darya river, where the main agriculture land is located. Therefore the streamflow modelling in the Syr Darya Basin is possible in representative upper stream sub-basins only, which are considered as surface runoff formation zone of the basin. The sum of those sub-basin runoff is estimated in expert judgements as the surface runoff water resources of the entire basin.

6.2. Length Growing Period Model (LGPM)

In modelling LGP pattern, the air temperature and precipitation were treated as the major factors controlling snow accumulation and melting. The maps of snow water equivalent have been developed following the approach described as a component of SFM (Section 6.1.) and used to estimate LGP for compared periods of 1961-1990, 2010-2039 and 2070-2099 (under both A2 and B2 scenarios).

The database used in the LGPM model contains following 30 years averages of monthly values for:

- Maximum air temperature on 379 stations;
- Average air temperature on 396 stations;
- Minimum air temperature on 374 stations;
- Precipitation total on 378 stations;
- Sunshine duration on 66 stations;
- Average relative humidity of the air on 222 stations;
- Average wind speed on 346 stations;
- Snow water equivalent on 170 station-months.

Any information was extracted from “Data Reference Books on Climate”; the summary of national meteorological service observations for the period 1950– late 1980-s. These publications were produced for each of the Soviet Union Republics (e.g. Data reference book on climate, Uzbek SSR, 1989).
The database itself is just a spreadsheet with properly formatted separate sheet for each variable. An extension named “clim_map.xla”, designed for mapping purposes, includes 5 modules to produce the maps of above climatic variables, sunshine duration, potential evapotranspiration, biomass productivity indices and climatic similarity.

The first module is not more than an enhanced user interface between database and Anusplin software package (Hutchinson, 1999), devoted for spline fitting surfaces (particularly climatic) from noisy data as functions of one or more independent variables. The station's longitude, latitude and elevation are used as variables. User can submit an input to Anusplin in a point and grid format. The Spatial extent and the resolution of the output grid depend upon the resolution of the digital elevation model (DEM). The GTOPO30 is a source of the DEM, thus nearly 1 km^2 resolution maps are an outputs, because the cell size for this latitudes is approximately 960·960 m^2. The module was used to map monthly values of mean air temperature, precipitation, relative humidity and wind speed (1961-1990 climate).

The potential evapotranspiration module of Clim_Map is based on Penman-Monteih equation modified by E. de Pauw. It uses air temperature, relative humidity, sunshine duration, wind speed and altitude surfaces as input. For modelling purposes, an assumption was done that apart from air temperature, those variables did not change in future.

The biomass productivity module processes air temperature, precipitation, potential evapotranspiration and snow water equivalent surfaces as input to derive the length of the growing period (LGP) grid. Two major improvements have been made to the traditional way of LGP estimations in low latitude areas. They are the modelling-accounting of snow cover regime and the adjustment of moisture and temperature thresholds for the growing period.

The outputs from snow cover model (see section 6.1) were used in the LGPM. Snow cover retains a part of precipitation during cold season; snowmelt provides extra moisture in spring. It is believed the resulting changes in seasonal pattern of moisture availability are of crucial importance for correct estimations of growing period attributes under Central Asian climate conditions.

Adjustment of moisture and temperature thresholds

The values of moisture and temperature thresholds recommended by FAO for estimations of LGP are valid for low latitude climatic conditions. They don't count on draught and cold tolerance of local vegetation. This chapter deals with procedure applied for adjustment of the above thresholds.

The monthly maximum global vegetation index, available at the National Geophysic Data Center (Ryutaro Tateishi and Koji Kajiwara) as worldwide 10-minute grids, has been used. The 12 grids for 1987 were downloaded and processed. First, for each cell the minimum of 12 values was defined to find out the one during the year with the highest vegetation index (NVI). The minimum was searched actually because the authors have used the next equation to compute 1-byte value stored in a set (SNVI) from normalised vegetation index (NVI):

$$SNVI = \begin{cases} 255, NVI < -0.05 \\ 0, NVI > 0.6 \\ 240 - 350(NVI + 0.05), -0.06 < NVI \le 0.6 \end{cases},$$

The Syr Darya basin with very diverse climate and topography was used. A subset of NVIs was extracted from the global set. The grid was converted to a point theme; the point represents cell's centre. To avoid the influence of irrigation and groundwater near the rivers the points inside a 1-km buffer were excluded from the analysis. Fig. 6.4 illustrates the steps of this filtering.

By this way we tried to outline areas with vegetation influenced by climatic conditions only.

For the remaining 1105 points the input needed for computation of attributes of LGP was extracted from corresponding monthly 30" resolution grids of air temperatures, precipitation, potential evapotranspiration and snow water equivalent. The 100 mm was applied as the soil water holding capacity for the whole area.

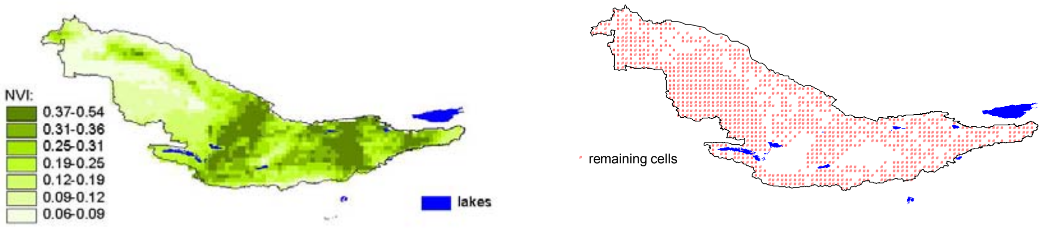


Fig. 6.4 Normalised vegetation index (maximum in 1987), and cells accepted for the analysis

At each point the NVI pattern features "instant" situation with vegetation. The occurrence of the best might differ in time from cell to cell. Moreover there are two growing periods in this area. This is why the maximum (LGP_{max}) of estimated duration of first and second growing period was selected for compare with NVI values. The different combinations of air temperature and moisture thresholds were tested to reach a best NVI(LGP_{max}) correlation. The code described in Bunday (1988) has been used as a search engine. The FAO recommended values namely 50% for moisture (percentage of actual to potential evapotranspiration) and 6.5^{O}C for temperature were used as initial estimates. The final values of the parameters turned to be equal to 34% and 2.7^{O}C. The use of modified values increases correlation coefficient NVI(LGP_{max}) from 0.74 to 0.80.
There are some issues that proves the significance of this increase:

- The climatic data were extracted from the finer resolution maps while NVI values represent an average vegetation health over 400 times bigger area unit - cell;
- One year data on NVI were used while weather conditions of 1987 are very likely different from climatic averages and have some anomalies in a spatial pattern;
- There is a big chance that irrigated areas were not masked completely.

The newer numbers are reasonably lower the FAO's ones. This is in a good agreement with relatively high draught and cold tolerance of vegetation in Central Asia.
The selected thresholds have been used to compute the maximum (from 2) length of the growing period for the whole region. It is shown in Fig. 6.6. There is an NVI pattern at the bottom of same Figure. One can see a lot of similarities in both patterns. The places with a bigger misfit are the well-known areas of intensive irrigation like Fergana valley, Amudarya river mouth and Zeravshan river valley.

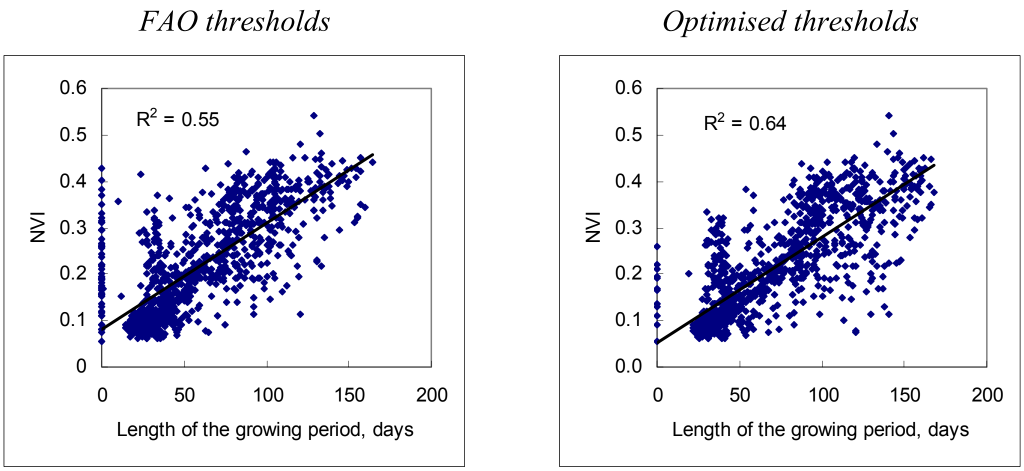


Fig. 6.5 The correlation between computed length of the growing period and vegetation index

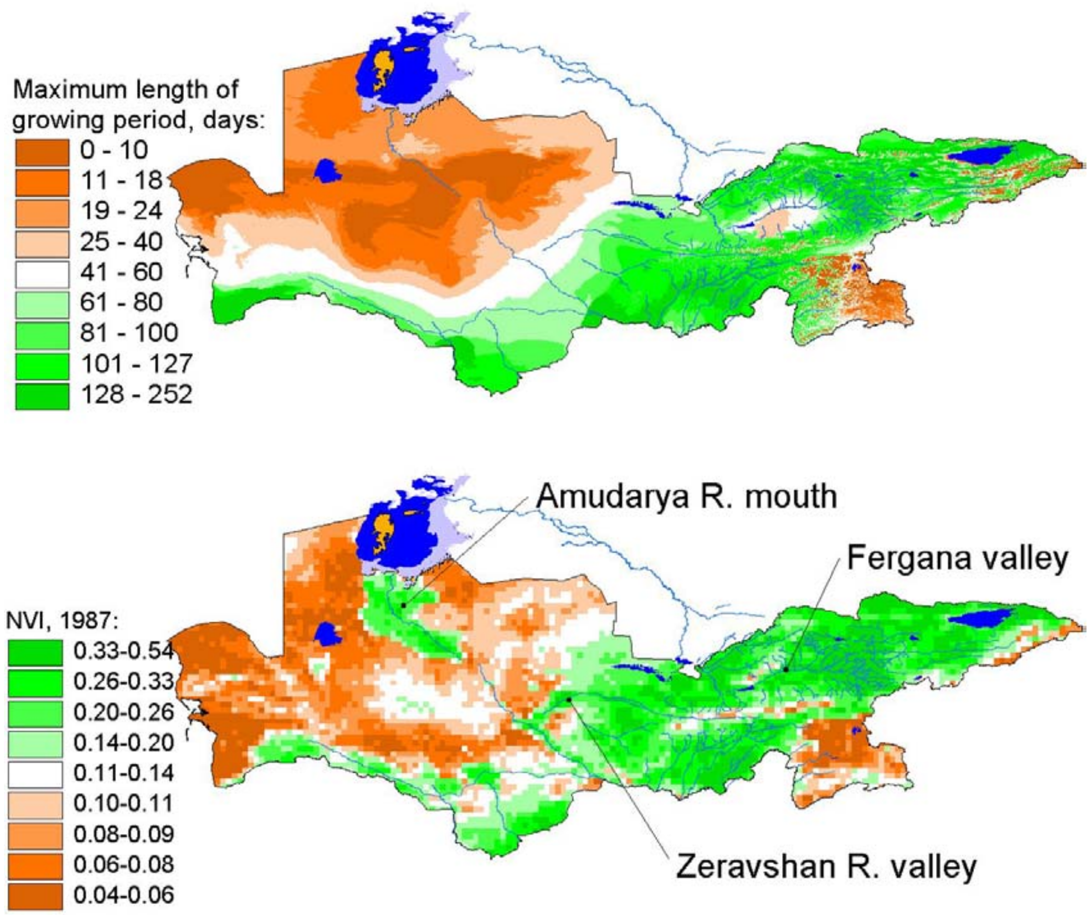


Fig. 6.6. Maximum length of the growing period (top) and vegetation index (1987) over Central Asia

6.3. Water Evaluation and Planning System (WEAP)

Basin scale models can be grouped in different ways depending on the spatial scale they cover or the amount of physics built in. The WEAP model (Water Evaluation and Planning System) is a water allocation model at river basin scale with limited physical processes included, but a very strong focus on scenario analyses. WEAP has been developed by the Boston Center of the Stockholm Environment Institute in the USA. The following sections are excerpted from the WEAP21 manual (WEAP, 2002 (http://www.seib.org/weap)).

"The Water Evaluation and Planning System (WEAP) is distinguished by its integrated approach to simulating water systems and by its policy orientation. WEAP places the demand side of the equation – water use patterns, equipment efficiencies, re-use, prices and allocation – on an equal footing with the supply side – streamflow, groundwater, reservoirs and water transfers. WEAP is a laboratory for examining alternative water development and management strategies.
"WEAP is comprehensive, straightforward and easy-to-use, and attempts to assist rather than substitute for the skilled planner. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, and storage, and pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.
"Operating on the basic principle of water balance accounting, WEAP is applicable to municipal and agricultural systems, single sub-basins or complex river systems. Moreover, WEAP can address a wide range of issues, e.g., sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and streamflow simulations, reservoir operations, hydropower generation, pollution tracking, ecosystem requirements, and project benefit-cost analyses.
'The analyst represents the system in terms of its various supply sources (e.g., rivers, creeks, groundwater, reservoirs); withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. The data structure and level of detail may be customised to meet the requirements of a particular analysis, and to reflect the limits imposed by restricted data."
"WEAP applications generally include several steps. The study definition sets up the time frame, spatial boundary, system components and configuration of the problem. The Current Accounts portion of the model provides a snapshot of actual water demand, pollution loads, resources and supplies for the system. Alternative sets of future assumptions are based on policies, costs, technological development and other factors that affect demand, pollution, supply and hydrology. Scenarios are constructed consisting of alternative sets of assumptions or policies. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.
"The design of WEAP is guided by a number of methodological considerations within an integrated and comprehensive planning framework [this first consideration actually isn't discussed in turn below]: use of scenario analyses in understanding the effects of different development choices; demand-management capability; environmental assessment capability; and ease-of-use. These considerations are discussed in turn below:
"Within WEAP, the so-called Current Accounts of the water system under study should be created first. Then, based on a variety of economic, demographic, hydrological, and technological trends, a "reference" or "business-as-usual" scenario projection is established. One can then develop any number of policy scenarios with alternative assumptions about future developments.
"An intuitive graphical interface provides a simple yet powerful means for constructing, viewing and modifying the system and its data. The main functions--loading data, calculating and reviewing results--are handled through an interactive screen structure that prompts the user, catches errors and

provides on-screen guidance. The expandable and adaptable data structures of WEAP accommodate the evolving needs of water analysts as better information becomes available and planning issues change. In addition, WEAP allows users to develop their own set of variables and equations to further refine and/or adapt the analysis to local constraints and conditions.
'The scenarios can address a broad range of "what if" questions, such as: What if population growth and economic development patterns change? What if reservoir operating rules are altered? What if groundwater is more fully exploited? What if water conservation is introduced? What if ecosystem requirements are tightened? What if new sources of water pollution are added? What if a water-recycling program is implemented? What if a more efficient irrigation technique is implemented? What if the mix of agricultural crops changes? What if climate change alters the hydrology? These scenarios may be viewed simultaneously in the results for easy comparison of their effects on the water system.
"In the current version of WEAP, the hydrologic system is mainly based on flows in rivers and canals (blue water), while water used to sustain crop growth (or forests etc.) is ignored and is defined as one single demand term. In order to account for this green water WEAP has been modified to do simplified groundwater and surface water hydrology. A description of these modifications can be obtained from the authors."

Syr Darya basin in WEAP

The Water Evolution And Planning System (WEAP) simulation model has been applied for imitation of the water management system in Syr Darya basin. WEAP by Stockholm Environment Institute-Boston Tellus Institute is one of three models (REALM, RIBASIM and WEAP), which were tested by GEF IFAS experts for possibility to use for simulation of water system operation in Aral region (GEF ICWC Agency Report, 2002). According to this assessments, WEAP can be used for simulation of water consumption scheme in Syr Darya Basin.

WEAP is based on the balance calculation algorithms and describes the changes of water availability. The interface of the model includes four blocks: schematic, data, results and overview. Within the schematic block there are tools, which support the creation of the linear scheme of the river basin: River, Diversion, Reservoirs, Groundwater, Other water supply and consumption infrastructure: Demand side, Wastewater treatment plants, Hydropower station, Transmission Links, Flow Requirement points, ets. The river network, basin boundary, lake and reservoirs, administrative boundaries GIS-layers are used as base for Syr Darya scheme.

Scheme construction

The hydrological linear scheme of the Syr Darya Basin (Fig. 6.7) includes Syr Darya River (starting at the point of merge of Naryn and Karadarya rivers), the main tributaries: Chirchik, Ahangaran, Keles and Arys and the seasonal and multiseasonal storage reservoirs: Toktogul, Andijan, Kayrakkum, Charvak and Chardara. The additional local supplies are the Ground water of Tashkent and Fergana areas and Return water from agriculture and industrial demand side in the upper part, which can bee used downstream again. These are the natural water resources of the basin. The Demand side are Industry, Domestic and Agriculture. The scheme consists of six sub-regions according to administrative subdivision of the basin (Fergana, Sogd, Syr Darya, Tashkent, South Kazakh and Ksyl-Orda). Kyrgyz part of the basin is considered the runoff formation zone and it was not included into demand side.

The water distribution between the Demand Sides (DS) has determined according to Allocation Order. It means that there are two systems of priorities: the DS preference is higher for more important water users (for example, Domestic), and the Supply Priority (SP) is attached to the demand site or flow requirement. Priorities can range from 1 to 99, with 1 being the highest priority and 99 the lowest.

Many DS can share the same priority. These priorities are useful in representing a system of water rights, and are also important during a water shortage, in which case higher priorities are satisfied as fully as possible before lower priorities are considered. If priorities are the same, shortages will be equally shared. For example, the water for Domestic Fergana taking from Syr Darya River reach (SP = 2) and from Ground Water Fergana (SP = 1).

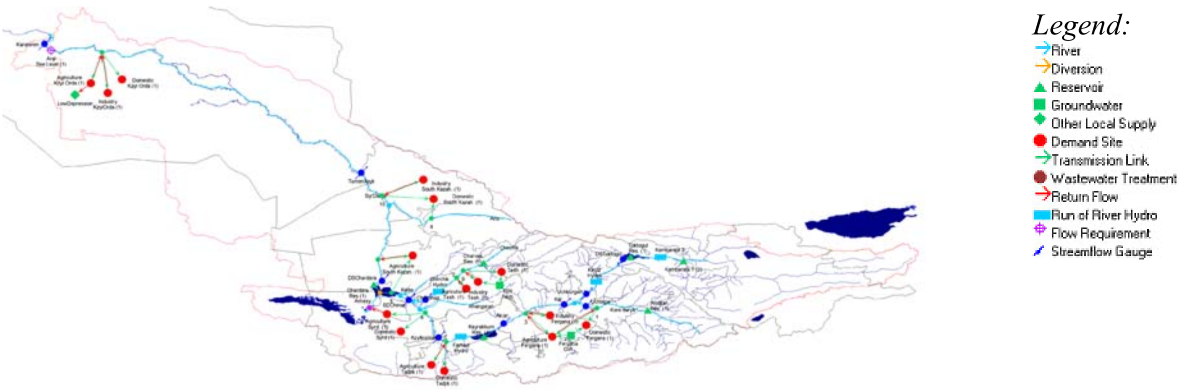


Fig.6.7. WEAP scheme of Syr Darya Basin.

Data inputs

First of all, the basic parameters were defined: the Current Account Year and Forecast intervals. The Current Account set corresponds to 2000. There are two time intervals for forecast according to climate and water resources forecasts (2010-39 and 2070-99). Two different WEAP sets of water resources changes for Syr Darya were developed according to CC scenarios A2 and B2.

The data about monthly distribution of water inflow from the major hydrological stations were used to characterise Syr Darya water resources. These are the Toktogul, Andijan and Charvak Reservoirs inflows, and stations Soldatskoe (Ahangaran river) and Keles-Chinaz (Keles river), Shauldel (Arys river). The outflow from area was defined as diversion to Arnasay depression.

Kazakhstan, Uzbekistan and Kyrgyzstan hydrological point's observation data were used for Current Account set of WEAP model. The Ground water sources are additional water supply for Fergana and Tashkent regions, the data were taken from Annual National reports (Information report…, 2001). The reservoirs characteristics are given in Table 2.7.

The following socio-economical characteristics have been used for the description of water demand in the basin:

1. Population in the sub-region: the numbers (mln. person) and structure (percentage for urban and rural), the specific water consumption per capita (for city – 450 liter/per person and for the rural area – 250 liter/per person), the monthly variation of the domestic water consumption.
2. Irrigated area: Total area (thousand ha) and structure (percentage for cotton, grain and other), specific irrigation water consumption (m^3 per thousand ha) for cotton, grain and other, the monthly variation of water consumption (according to specific scheme of irrigation).
3. Industry production: Total activity level of industry (mln. US$), specific industry consumption (m^3 per $). The water consumption in industry sector is stable during the year. Water demands for hydropower production, monthly variation.

The projections of future changes in population, agriculture and industry sectors were included into the WEAP, as discussed in detail in Chapters 5, 7. The future projections of the basin water resources for both CC scenarios A2 and B2 are taken as results from Stream Flow Model (Section 6.1.).

The additional data are Transmission and Return Links Losses in agriculture sector were defined as 25 % for Uzbekistan (GEF ICWC Agency Report, 2002) and 40-60% for Kazakhstan and Tadjikistan (Karlyhanov, 2002). According to the expert estimations (GEF ICWC Agency Report, 2002, Kipshakaev, et al. 2002), the volume of return waters from various water-consumers in WEAP is taken as varying from 53 up to 88 % for agriculture, and up to 12 - 16 % for industry. Downstream, in the Kazakh Kzyl-Orda sub-regions, the part of return flow from agricultural fields comes to deserted depressions (Low Depression in system WEAP). The losses of water on the field are taken as 20 % for the Kazakh and Tadjik *oblasts* and as 25 % for Uzbek *oblasts.*

Because of the absence of the data on the character of hydraulic connection between surface and ground waters, this component was not taken into account in the model. It was accepted, that inflow and outflow to ground waters from surface does not occur. This approach is acceptable in the given task (Raskin et al., 1992). However, due underestimation of this factor, there are possible some infringement monthly distributions of the stream flow on the reaches. Therefore, the basic criterion for model calibration was reception of the minimal divergence in annual runoff volume, with the maximal conformity of monthly distributions.

For the case of the reservoirs storage decreasing, in particular Toktogul, a “Supply priority for filling reservoir” is set into action with the factor varying. At factor equal to 1 the scheme is favourable to the downstream water consumers as much as possible, and at 99 - the least favourable. The evaporation from reservoirs and water basin surface was taken following previous WEAP expertise (Raskin et al., 1992)

Model calibration

The calibration points (hydrological stations), where the balance calculations were tested, are listed in Table 6.2. Comparison of the WEAP calculations and the real data on stream flow, from h/st. Karateren (inflow to Aral sea) has shown the good convergence of model calculations (Fig. 6.8), both in annual and monthly distribution scales. The maximal error of stream flow calculation on given reach is 14 %, on the average it makes 5-7 %.

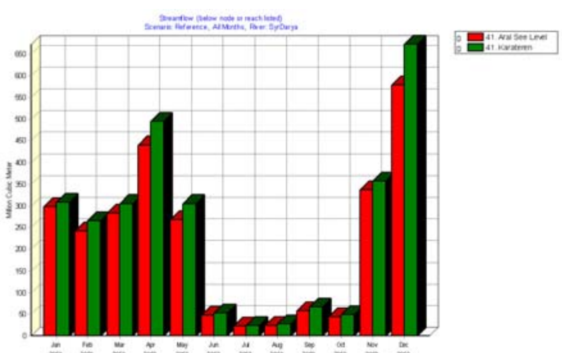


Fig. 6.8. Modelled (red) and observed (green) monthly inflow to Aral in 2000.

Table 6.2. List of hydrological points used for the calibration WEAP model.

Hydrological point
Uchkurgan, Uchtepe
Kal’, Akjar
Kzyl Kishlak
Syr Darya Chinaz, Inflow to Chardara
Tumen’ kishlak
Karateren’

WEAP Scenarios

WEAP «Manager Scenarios» is a tool for designing the future projections and introduction of the adaptable measures. While creating the forecasts block in the model changes of water-supply under CC, and socio-economic changes, such as population and industrial growth were taken into account. The scenarios, according to the Adaptation Strategies (Chapter 8) are divided into Reference (Business us Usual), Industrial Preference, Food Preference Environmental Preference, and Mixed. Those will be discussed in detail in Chapter 8.

7. Impacts

7.1. Hydrology

The CC impacts on general basin hydrology can be outlined with the help of SFM modelling (Fig. 7.1.) Since the modelled changes in temperature and precipitation for the time slice 2010-39 are virtually the same under both A2 and B2 scenarios, there is nearly no difference between SFM outputs under A2 and B2 scenarios. For 2010-39, SFM runs do not give any significant change for the inter-annual runoff distribution (Fig. 4.1.). However, there is a pronounced tendency that is much more apparent in the modelled changes of runoff distribution for the time slice 2070-99, for an earlier onset of spring high waters (shifting it by 5-7 days compared to the baseline period (1961-90), sharpening the annual runoff peak in spring and increasing its height, while a slight lowering of streamflow (approximately by 10% as compared to the baseline period) is expected to occur from late June till August. Despite an overall increase of annual precipitation (in the range of 1.07-1.08 of the baseline value) and very insignificant increase of annual runoff (in the range of 1.03-1.04 of the baseline value), on average less water will be available in the period of highest demands for irrigation. However, this is not expected to impose any significant impact on agriculture, since currently existing water management mechanisms in transboundary water allocation allow effective adjustments for much broader range of year-to-year variations in the availability of water resources.
Over the period 2070-99, there are remarkable differences in the SFM outputs for the scenarios A2 and B2 (Fig. 4.2). The most drastic changes as compared to current situation are expected to occur under scenario A2. Onset of spring high waters is expected to start 3 to 4 weeks earlier than over the baseline period (1961-90), the duration of annual peak is expected to shorten considerably (See Tables 4.1 and Fig. 4.2), the maximum specific runoff is expected to be 25% higher, and starting from mid June the runoff is expected to significantly decrease , down to 30% of the baseline period values (Table 4.3). The changes of hydrological cycle under B2 scenarios are similar, but less pronounced, the onset of spring high water period would be 2-3 weeks earlier than at present, it peak approximately 30% higher, but the duration of the high water period will decrease less dramatically than under A2 scenario.

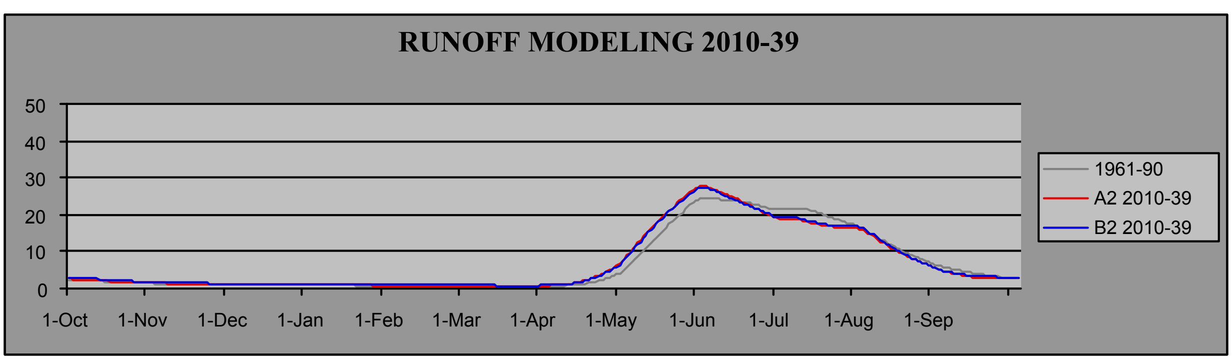


Figure 7.1. Streamflow (m^3/sec) modelling for the Charvak sub-basin for the time slice 2010-39.

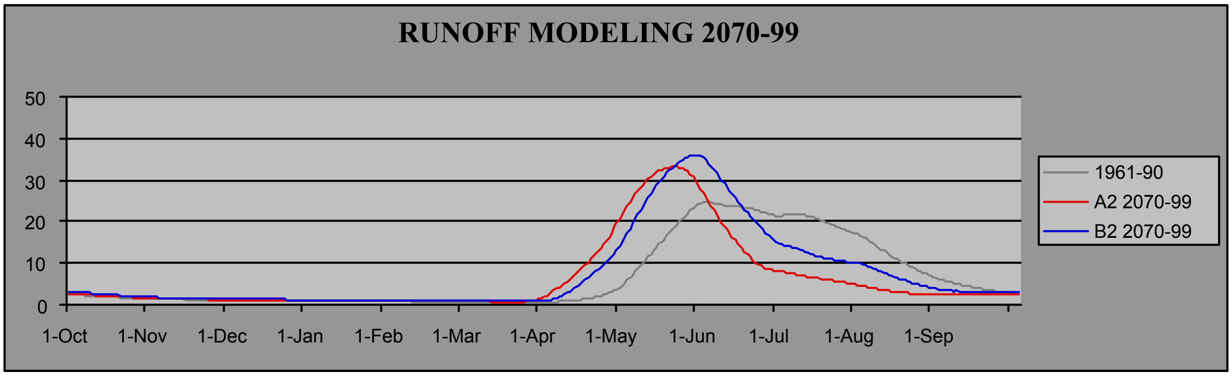


Figure 7.2. Streamflow (m^3/sec) modelling for the Charvak sub-basin for the time slice 2070-99.

SFM runs give for A2 period slight reduction (-4%) of annual flow as compared to baseline period, and slight increase (+7%) for B2 scenario. However, though the annual water availability would be slightly affected, the changes of the inter-annual runoff distribution pattern would lead to serious water shortages over summer period, when the water is mostly needed for irrigation. While at present, 68% of annual flow occurs during three summer months (June, July, August), under A2 scenario this figure would be nearly twice as less (35%), and under B2 scenario it would be only 50% (Table 4.4.). For the time interval 2070-99, both A2 and B2 scenarios impose a very serious negative impact on the agriculture, which would require an application of very balanced adaptation strategy to mitigate the risks for food production in the Syr Darya Basin. The impacts on industry and environment are also negative for the risks of spring floods might significantly increase, causing danger for dam security and over-flooding in the lower basin.

Table 7.1. Duration and dates of the period when 50% of annual streamflow occurs, according to SFM runs under A2 and B2 scenarios for the time slice 2070-99 and over the baseline period (1961-90).

Scenario	Duration, days	from	to
A2	39	30.04	9.06
B2	45	7.05	22.06
1961-90	54	4.06	18.07

Table 4.2. Duration and dates of the period when 66,7% of annual streamflow occurs, according to SFM runs under A2 and B2 scenarios for the time slice 2070-99 and over the baseline period (1961-90).

Scenario	Duration, days	from	to
A2 2070-99	65	17.04	21.06
B2 2070-99	74	27.04	10.07
1961-90	77	16.05	1.08

Table 7.3. Changes of monthly streamflow values as compared to baseline value (1961-90) shown as percentage of baseline value, according to SFM runs under A2 and B2 scenarios for the time slice 2070-99.

	April	May	June	July	August
A2 2070-99	572	250	68	32	30
B2 2070-99	330	216	108	60	59

Water resources

According to SFM and WEAP outputs, the future total water resources (surface and ground water) could increase up to 46.0 km^3/year (average) under A2 CC scenario and up to 50,1 km^3/year under B2 scenario. The modelled monthly inflow from the main tributaries (as summed up for Naryn, Karadarya, Ahangaran, Keles and Arys) to area under CC change Scenario A2 is compared to Current account inflow in Fig. 7.3. Table 7.4 shows the annual volume surface water inflow to area in dry, wet and normal years for 2070-99 period under both CC scenarios A2 and B2.

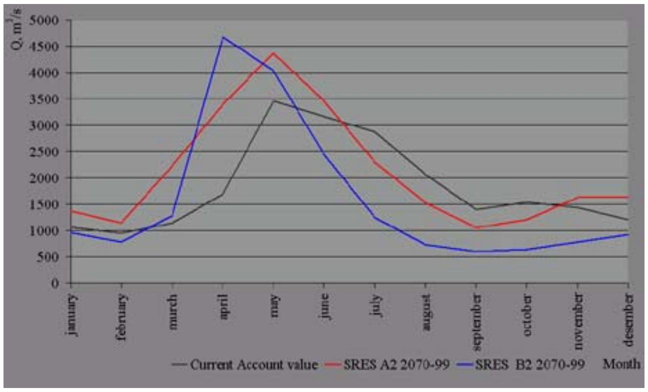


Fig. 7.3 WEAP modelled monthly average inflow to area (m^3/s) 2070-99 under A2 CC scenario (red), B2 cc scenario (blue) compared with Current account value (grey)

Table 7.4. WEAP modelling: annual main tributaries inflow to area 2070-99, km^3.

Inflow point	SRES A2			SRES B2		
	Dry	Wet	Normal	Dry	Wet	Normal
Below Ahangaran Headflow	0.37	0.99	0.60	0.38	1.54	1.22
Below Chirchik Headflow	5.77	9.98	5.23	6.11	9.21	6.58
Below Aris Headflow	0.25	0.47	0.72	0.34	0.56	0.98
Below Keles Headflow	0.23	0.32	0.40	0.33	0.75	0.32
Below Kara darya Headflow	1.84	3.56	4.56	2.18	9.65	6.80
Below SyrDarya Headflow	12.52	14.93	13.03	12.94	14.36	12.99
Sum	20.98	29.85	24.93	22.29	36.07	28.89

7.2 Environment

Recent pattern of LGP and resulting changes under different climate scenarios are shown in Fig. 7.4 (note different intervals in legend). Tables 7.5 and 7.6 summarise LGP changes over the entire basin.

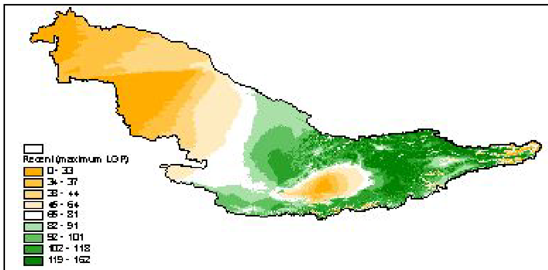
Numbers in Tables 7.5 and 7.6 provide the averages for the basin, more specific conclusions may be drawn based on the analysis of spatial pattern of modelled LGP changes (Fig. 7.4). Under all scenarios, one can expect the positive LGP changes particularly in a middle stream part of the basin in Fergana valley and Golodnaya Steppe especially remarkable (deep green) under A2 scenario for the period 2070-99), where the main cropland is located (Fig. 7.4.). That CC impact on LGP could be potentially favourable for the cropping agriculture. However, since the crop agriculture in those areas is highly dependent on irrigation (90% of the cropland is irrigated, while agriculture in total consumes 86% of water resources in the basin), the projected summer water shortages may overweight the positive effects of LGP changes.

Table 7.5. Changes in LGP (days)

SRES scenario	Period	
	2010-2039	2070-2099
A2	+6	+29
B2	-3	+16

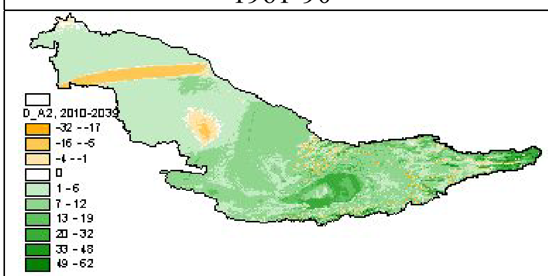
Table 7.6. Percentage of the basin with positive changes of LGP

SRES scenario	Period	
	2010-2039	2070-2099
A2	90	66
B2	58	59

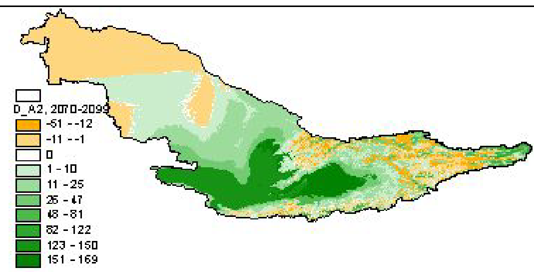


1961-90

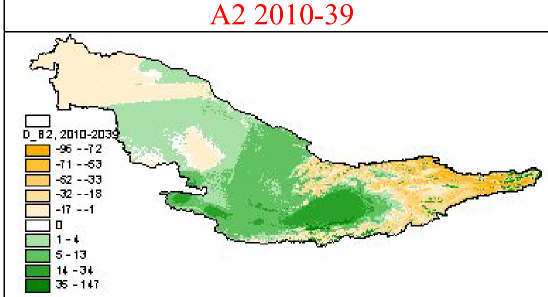
Figure 7.4: Recent pattern of LGP and expected changes (days/year) under different climate scenarios in 2010-2039 and 2070-2099



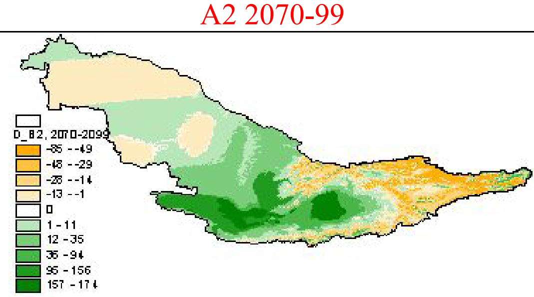
A2 2010-39



A2 2070-99



B2 2010-39



B2 2070-99

In terms of changes of rangeland productivity, the LGPM outputs are less optimistic. Semi-deserts in the downstream part of the Syr Darya Basin (Kazakhstan) and alpine meadows upstream (Kyrgyzstan)are very vulnerable to CC-induced changes. Apart from the LGPM runs under the A2 scenario for the time period 2010-39, they are expected to suffer overall negative changes for the LGP. Those areas are traditionally used as pastures for semi-nomad sheep, cattle and horse breeding in

Central Asia. Table 7.7. shows the correlation between LGP and average annual productivity of natural pastures, namely consumable part of the crops, in some desert and semi-desert locations in Uzbekistan. Any negative changes in already low LGP in those rangeland areas would potentially result in a less productive or almost vegetation free landscape and reduction of rangelands area in the basin.

Table 7.7: Length of the growing period (LGP) and pastures productivity (C)

Location	LGP, days	C, kg x 10^2/ha
Karakalpakistan	18	0.7
Bukhara viloyat	34	1.1
Navoi viloyat	28	1.5

CV changes as outlined in section 5.1.2, would have mostly negative impacts on food security through increasing probability of drought years. As shown above, the productivity of ecosystems upstream and downstream may prove rather vulnerable to the extremely dry conditions. The increased risks of spring floods in extremely wet years may have negative impacts on industry and environment due to the risks imposed on dams' safety. The areas in the lower basin, particularly in Ksyl-Orda oblast of Kazakhstan are potentially prone to the winter-spring flood risks. Of especial importance for the environment is the issue of radioactive tailings in Mailu-Suu in Kyrgyzstan. In case of extremely high spring floods, the radioactive pollutants may leak into the streams and contaminate the main flow of Syr Darya.

7.3. Food production

Growing population is expected to produce and consume more food. The estimates for the main crop production and yield changes according to FAO data, are shown in Table 7.8. Those are done assuming very substantial increase of cropland area and yield increase. However, expert judgement, according to basin team interviews shows that there is very limited potential in the Syr Darya Basin for increasing cropland area. Our assumption reflected in Table 7.9., is that under business as usual (i.e. without application of adaptation strategies) there would not be any substantial increase in the cropland area in the basin. We consider this rather as a measure of adaptation, than as a self-adjusting response of the system.

SWAP modelling for the Syr Darya Basin (Droogers and Dam, 2003) suggests significant increase of yields under A2 CC scenario due to higher levels of CO_2 concentrations as compared to B2 scenario (Fig. 7.5.) However, since water availability remains the main factor restricting crop production, we assume that «moderate and humid» B2 scenario would be more favourable in terms of yield increase as well as overall crop production, compared to «hot and dry» A2 scenario. The assumed changes of production for the main crops in the basin according to basin team judgement, are related rather with change of cropping pattern, i.e. reduction of cotton production as the most water demanding crop in the basin and switching to less water dependent wheat, potato and fodder (Table 7.10). This tendency became quite apparent in the last decade, when due to the political changes (disintegration of Soviet Union) a new water management and allocation relationship has developed in the newly independent countries of Syr Darya basin that resulted in drastic water shortages for agriculture first years (see Chapter 4). Thus, the last decade's farmers' adaptation for that change in water availability can be used as a model of a response for the future changes.

Table 7.8. Expected changes of the crop area, production and yield for the main crops in Syr Darya Basin (FAO expertise)

Crop		1998	2030	2050

Cotton	area (ha)	812,000	882,000	1,030,000
	production (ton)	1,786,400	2,116,800	2,472,000
	yield (ton/ha)	2.2	2.4	2.4
Wheat	area (ha)	1,079,000	1,373,000	1,473,000
	production (ton)	2,457,900	4,033,000	4,882,300
	yield (ton/ha)	2.3	2.9	3.3
Potato	area (ha)	84,000	66,000	60,000
	production (ton)	1,106,400	1,828,200	2,117,600
	yield (ton/ha)	13.2	27.7	35.3
Fodder	area (ha)	1,350,000	1,544,000	1,634,000
	production (ton)	1,350,000	2,161,600	2,614,400
	yield (ton/ha)	1.0	1.4	1.6
Total cropland (ha)		4,088,000	4,978,000	5,327,000
of this irrigated (per cent)		88	88	88

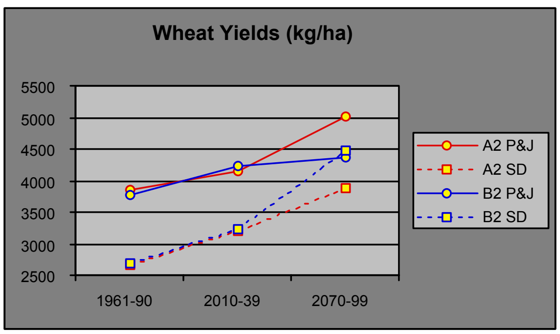


Fig. 7.5-a Wheat yields according to SWAP outputs (non-dashed line) and Basin team assumptions (dashed line), for CC scenarios A2 (red) and B2 (blue)

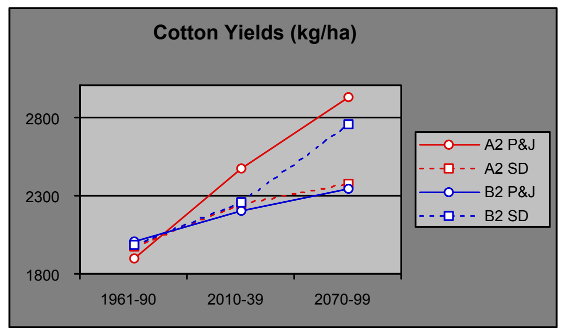


Fig. 7.5-b Cotton yields according to SWAP outputs (non-dashed line) and Basin team assumptions (dashed line), for CC scenarios A2 (red) and B2 (blue)

Another assumption is that there would be an increase in the animal raising in the region, for there was an apparent decline in sheep and cattle stock in the early 1990s, following economic hardship after the disintegration of the Soviet Union, which however would not continue, and in the late 1990s the stock numbers became gradually increasing. Compared to Soviet times, the rangelands in the area were significantly underused in the last decade. Thus, our estimates for the production of meat and milk are giving positive changes. Small scale animal husbandry in subsidiary farms is also a traditional measure for family self-subsistence in the Central Asian region.

Table7.9. Assumed changes of the cropland and rangeland area for the scenarios A2 and B2 in 2070-99.

	1961-90	2070-99 A2	2070-99 B2
Cropland (ha)	4,141,500	4,100,000	4,500,000
Rangeland (ha)	26,273,800	22,500,000	21,500,000

Table 7.10. Expected changes of the production for the main crops, meat and milk and in Syr Darya Basin (Basin team expertise). Production is given in ($x10^6$ ton).

Crop	1961-90	2010-39 A2,B2	2070-99 A2	2070-99 B2
Cotton	2.240	1.971	2.368	2.756
Wheat	2.660	3.207	3.890	4.470
Potato	1.964	4.422	5.896	6.287
Meat	0.517	0.891	1.180	1.196
Milk	1.676	2.295	2.535	2.727

Water-related industry in Syr Darya Basin is confined to the hydropower generation only. Since 1970s Syr Darya river formerly navigable up to the mountain foothills is no longer used for transport purposes. This is related with both drastic decrease of river stream flow due to the overexploitation of water for irrigation purposes and construction of numerous dams. Population growth in the basin would certainly be related with higher demands for hydropower production. Currently there are several new hydropower plants under construction in upstream Kyrgyzstan territories.

The population growth and increase of food production in the basin would certainly impose more pressure on the environment first of all due to increased use of pollutants, organic contamination and water salinity increase.

Summary for the time interval 2010-30:

Under A2 and B2 scenarios, the CC-impact on the Syr Darya Basin hydrology are virtually coinciding. CC is not expected to lead to serious changes of basin hydrology, neither in terms of annual water availability nor in terms of inter-annual runoff distribution pattern, as compared to baseline 1961-90 period. However, CC-induced changes are not expected to overweight the effects of present and modelled CV. Modelled changes in hydrological cycle would not impose any additional serious negative impact on environment, food and industry. Under business as usual, the transboundary water management and allocation institutions in the basin would allow to cope with the CV-impacts more or less effectively to meet the food producers demands for water for irrigation. The LGP model outputs suggest significant increase of LGP in the main cropland areas under both scenarios. LGP changes under A2 scenario are also favourable for both cropland and pasture land productivity. Under B2 scenario, the changes in rangeland and natural ecosystems productivity are expected to decrease insignificantly.

Summary for the time interval 2070-99:
Under both A2 and B2 scenarios, the CC-induced impact on hydrological cycle in the Syr Darya Basin significantly overweighs the CV-induced changes. CC would seriously affect the pattern on inter-annual runoff distribution by causing

- earlier onset of spring high waters,
- shortening the duration of high water period
- increasing height of annual maximum
- significant decreased streamflow in summer

Those changes could be amplified either in the extremely dry or extremely wet years, increasing probability and intensity for both floods and droughts, which is the main negative impact of modelled increase in CV. LGP is expected to increase considerably in the main cropland areas in the middle part of the basin, but it would have a positive impact on crop production only provided that agriculture water demands for irrigation are met, which is unlikely under modelled changes in hydrology. Under B2, negative impacts are somewhat more moderate than under A2. The natural rangeland productivity under both scenarios, is expected to decrease due to the negative changes of LGP in semi-desert and alpine areas. The combined effect of CC and CV-induced changes might impose a very serious treat to the food security, which would require an application of very balanced adaptation strategy to mitigate the risks of harvest failure in the Syr Darya Basin. The CV-impacts on industry and environment are negative for the risks of spring floods might threaten dam and water quality safety.

8. Development and assessment of adaptation strategies

Since CC and CV-induced impacts for the period 2010-39 as outlined in Chapter 7, under both A2 and B2 scenarios do not impose any serious treat to food security, industry or environment, development of adaptation strategies for the Syr Darya Basin is essential only for the period 2070-99.

8.1. Outline of possible adaptation measures to the CC/CV and SE impacts

The development of future adaptation measures in Syr Darya Basin is to some degree enhanced by the analyses of the pattern of adaptation and adjustments of riparian countries economies to the last decade's changes in availability of water resources (Dukhovniy, 2001, Sarsembekov, 1999, Tuzova, 2001). Adaptation measures (Table 8.1.) are divided into three categories (E, F, I) according to a water user that is supposed to get most benefits from introducing a measure. E stands for environment, F – for food production, I – for industry.
To estimate the efficiency and relative costs of various adaptation measures (Table 8.1), expert and farmer's interviews were used. In order to compare relative costs of the adaptation strategies, we introduced five cost categories. Category 0 was assigned to the measures that involve virtually no costs and are related just to the policies, e.g. open reservoir in winter or change crop pattern. Cost categories 1 and 2 were assigned to relatively inexpensive measures, i.e., introduce water pricing, employ desalinisation techniques, increase water productivity, prevent desertification. Categories 3 and 4 were assigned to engineering measures which are money, time and labour-consuming and request major investments, like for the construction of dikes and reconstruction of irrigation network. Dam and hydropower plant construction for large water reservoirs was placed under category 4. Estimate of relative costs of an adaptation strategy was made as a sum of the cost categories for each measure, whereas construction of each dam was considered as a separate measure, i.e. relative costs of the construction of 3 new dams were estimated as 12 (3x4).

Table 8.1. Set of adaptation measures for the proposed CC/CV and socio-economic changes for the Syr Darya Basin.

MEASURES	Comments	Cost category*
E: Environmental measures		
1. Develop dikes and protection	Is important in Kyrgyzstan and Kazakhstan, i.e. in upper and low basin mostly. Requires capital investment.	3
2. Prevent desertification	Very important measure in arid climate, essential elsewhere, but particularly in upper and low basin, is based on sustainable land use policies	1-2
3. Develop sewage treatment plants	Very needed measure for the middle part of the basin	2-3
F: Food security measures		
1. Increase water use efficiency and productivity	This is actually a set of relatively low costing measures like educating farmers, introducing water saving techniques, searching for the most effective water use practices at the field scale	0-1
2. Improve water management	Proved to be an effective measure in transboundary water allocation. The measure includes also water pricing, which at field scale, proves effective and in transboundary relationships, depends on political stability and countries willingness and readiness to implement it	0-1
3. Change cropping pattern and introduce new crops	Effective and low costing measure	0-1
4. Increase water storage capacity and decrease losses in the network	Measure may involve construction of small local water reservoirs as well as constructing of one major Kambarata dam upstream to create a reservoir with storage capacity of 4.6 km3 mainly for the irrigation purposes. The most costly and needed measure is to reduce leakage in irrigation network, what involves maintenance & operation costs as well as major investments into network reconstruction.	4-8
5. Increase crop area	There are limited land resources in Syr Darya basin. Requires a regulation of land rights.	2-3
6. Salinity control/ desalinization	Not very realistic at large scale. Feasible together with I2 measure, for in downstream areas the water used for the generation of hydropower may be utilised for this purpose	2-3
7. Revive cattle-raising	Very needed measure, provides security for the local food produces	1-2
F: Industrial measures		
1. Build new reservoirs & hydropower plants	The most costly measure	4 x #dams
2. Generate hydropower in winter	This measure is the main reason for the conflict of interests between industry and agriculture on one hand, and upstream and downstream countries on another hand. Without a balanced transboundary water allocation policy, may lead to political instability in the region.	0-1

*) cost estimates are divided into five categories: 0 - virtually no costs; 1 - very low, 2 – medium; 3 – very costly; 4 – extremely costly. For more details see the relevant text.

8.1.1. Environmental measures

Environmental measures are: E1. development of dikes and protection; E3. construction of sewage treatment plants and E2. measures to prevent desertification. Construction of dikes and protection (E1) is considered important in Kyrgyzstan, at Maily Suu and other Syr Darya tributaries in the upper course of the basin to avert a treat of the stream water contamination by radioactive tailings. In the lower part of the basin, particularly so in Ksyl Orda oblast, dikes and protection are important measure to prevent early spring floods. Rapid desertification is one of the hottest environmental issues in the lower and upper basin, that negatively affects quality and availability of pasture land and hence endangers cattle-raising. Therefore, prevention of desertification (E2) is an important measure, with both environment and agriculture benefiting from it. However, it should be noted that the climate in the basin is arid and projected climate change is expected to increase area of deserts considerably (see outputs from LGPM), therefore mitigation of those negative effects by adaptation measures is rather limited. Construction and reconstruction of sewage treatment plants (E3) is especially critical in densely populated middle part of the basin.

8.1.2. Food security measures

Measures to enhance food production in the basin include: F1. Increase water use efficiency and productivity; F2. Improve water management; F3. Change cropping pattern; F4. Increase water storage capacity and reduce losses in the network; F5. Increase crop area; F6. Salinity control/desalinisation; F7. Revive cattle-raising. Increase water use efficiency and productivity (F1) involves a set of relatively low costing measures like educating farmers for introducing advanced water saving techniques and the most effective water use practices at the field scale. This measure would prove favourable for environment as well. Improving water management (F2) in transboundary water allocation in the last decade, proved to be an effective measure, however further development of water management principles is still needed at the *oblast* and field scale. This measure is favourable also for industry and environment. The measure includes also introduction of water pricing, that in the last decade proved effective at the field scale, but in transboundary relationships, depends on political stability and countries willingness and readiness to implement it. Change cropping pattern (F3) is a low costing measure which however may prove very effective, since in some areas under projected climate change a switch to two harvests per year practices is feasible. We include introduction of more productive crops into this measure as well. Increase water storage capacity and reduce losses in the irrigation network (F4) is one of the mostly needed, but expensive measures. The most costly and needed action is to reduce water transportation losses in irrigation network, what involves maintenance and operation costs as well as major investments into network reconstruction. This measure involves also construction of small local water reservoirs and construction of one major Kambarata dam upstream to create a reservoir with storage capacity of 4.6 km^3 , which would allow to use Toktogul reservoir mainly for the irrigation purposes, a project already in development. Increase crop area (F5) requires a regulation of land rights, for there are limited land resources still available in Syr Darya basin, the measure is however considered feasible by experts. To introduce salinity control and implement effective desalinisation techniques (F6) would help to reduce losses in soil productivity and reduce water pollution. The measure is feasible only in case of intensification of hydropower production in winter time, since it provides an excess of water in the middle-basin, which under general water deficiency in the basin, may prove unrealistic for it is causing conflict of interests between middle and low basin countries' demands for irrigation in summer and Kyrgyzstan's needs for hydropower production in winter. Revive cattle-raising (F7) at least up to the level of Soviet times is feasible and effective measure since traditional nomadic agriculture does not impose heavy extra demands on water resources while production of meat and milk products plays and essential role in Syr Darya countries economies for both domestic needs and export.

8.1.3. Industrial measures

To enhance water resources related industry two measures are effective to cope with CC, CV and SE impacts: I1. Built new reservoirs and hydropower plants; I2. Generate hydropower in winter. The first measure is extremely costly, the second measure is the main reason for the conflict of interests between industry and agriculture on one hand, and upstream and downstream countries on another hand. Without a balanced transboundary water allocation policy, may lead to political instability in the region.

8.2. Development of adaptation strategies

Under adaptation strategy we understand a set of adaptation measures. Four adaptation strategies were developed, namely environmental (E), food (F), and industrial (I) strategies, representing the best coping mechanisms for each of three main water users in the basin in minimising the negative impacts of CC/CV and SE stressors. Mixed adaptation strategy (M) was developed in attempt to balance the interest of those users. Table 8.2. presents a set of adaptation measures and outlines four sets of adaptation strategies, proposed for the Syr Darya Basin.
The choice of measures for adaptation strategies was done through expert judgement and fine-tuned with the application of WEAP model. WEAP was used as a tool for estimating an overall feasibility and sustainability of a strategy in terms of meeting demands of different users. An efficiency of adaptation strategies will be assessed through a number of indicators listed in Table 6.2

Table 8.2. Adaptation measures and adaptation strategies, proposed for the Syr Darya Basin

MEASURES	ADAPTATION STRATEGIES
E: Environmental measures	**Environmental AS**
1. Develop dikes and protection	**E1, E2, E3**
2. Prevent desertification	**F1, F2, F6**
3. Develop sewage treatment plants	**I2**
F: Food security measures	**Food AS**
1. Increase water use efficiency and productivity	**E2**
2. Improve water management	**F1, F2, F3, F4, F7**
3. Change cropping pattern, introduce new crops	**Industrial AS**
4. Increase water storage capacity, reduce network losses	**E1**
5. Increase crop area	**F3, F7**
6. Salinity control/desalinisation	**I1, I2**
7. Revive cattle-raising	**Mixed AS**
I: Industrial measures	**E1, E2, E3**
1. Build new reservoirs	**F1, F2, F3, F4, F5, F7**
2. Generate hydropower in winter	**I1**

8.2.1. Environmental AS

Environmental adaptation strategy includes all the measures designed to mitigate negative impacts of discussed pressors, i.e. develop dikes and protection in upper and middle part of the basin (E1) in order to avert contamination of Syr Darya by radioactive waste and avoid risks of flooding in the lower course of the river, measure to prevent desertification (E2) through application of sustainable land use practices would be beneficial for agriculture. Developing sewage treatment plants (E3) will allow to improve water quality in the middle and low basin. The low costing measures designed for enhancing food security, i.e. increasing water use efficiency and productivity (F1), improving water management (F2) are expected to have a positive impact on the environment by increasing outflow to Aral. Industrial measure to generate hydropower in winter (I2) is closely related with salinity control and desalinisation (F6) the measure would contribute to increasing outflow to Aral, and is favourable, though not crucial for agriculture, for it diminishes losses in soil productivity, but utilises water, that could be otherwise utilised for irrigation purposes in summer.

8.2.2. Food AS

Food security adaptation strategy includes following measures. From the set of environmental measures prevent desertification (E2) is considered the most beneficial for agriculture, i.e. cattle-raising. The measure is discussed above. The choice of measures designed to directly enhance food production is done with the purpose of meeting agriculture demands for water in two ways: by reducing the actual demands and by increasing amount of water resources available. Measures F1 (increase water use efficiency and productivity), F3 (change cropping pattern), and F7 (revive cattle-raising) would prove extremely effective under both scenarios by decreasing demands for water. Those measures are favourable for environment too. To improve water management (F2) is actually a universal measure in terms of coping with water deficits and rationalising the principles of water allocation between different users. In transboundary relations it may help to make more water available for irrigation, at the local scale this measure may help to save water resources and is closely linked with increasing water use efficiency. The most costly measure (F4) of food adaptation strategy is related with increasing water storage capacity by constructing major Kambarata reservoir in the headwaters of Syr Darya, and reducing losses in the irrigation network through reconstruction of the irrigation scheme, it requires major investments but would help to raise more water resources for the demands of crop production. Since the industry demands for water and the measures to enhance water-related industry in the basin come into a conflict of interests with agricultural demands, no industrial measures are included in this adaptation strategy.

8.2.3. Industrial AS

Industrial adaptation strategy is composed of the measures for enhancing hydropower generation, i.e. measure I1 (build new reservoirs) for the climate change scenario A2 would be constructing 3 more new dams and hydropower plants, and for the scenario B2 – constructing 4 more plants than under business as usual. Together with measure I2 (generating more hydropower in winter), this would enable significant increase of hydropower production as compared to business as usual. The latter in combination with measure E1 (develop dikes and protection) and less developed crop production would make industrial strategy favourable for environment in terms of improving water quality and decreasing risk of radioactive contamination, however, in terms of increasing outflow to Aral this strategy is the least effective compared to other adaptation strategies. Food security enhancing measures of this strategy involve only measures of low costs such as change cropping pattern (F3) and revive cattle-raising (F7).

8.2.4. Mixed AS

Mixed adaptation strategy is designed in order to provide a compromise between interests of three main water users in the basin. Therefore, it includes all the measures favourable for environment since those are not in conflict with interests of food production and industry, and major part of the measures to enhance food production and industrial development with exception of measure F6 (salinity control and desalinisation) and measure I2 (generate more hydropower in winter), which would be in conflict with water demands for agriculture. Measure I1 for this strategy is meant as to constructing 2 new hydropower plants (A2) or 3 plants (B2) more than under business as usual.

8.3. Assessment of adaptation strategies

An assessment of adaptation strategies is comprised by the following steps

- selecting a set of indicators to demonstrate the efficiency of a strategy
- introducing a reference point, i.e. business as usual when no adaptation measures are taken
- assessment, i.e. cross-comparison of the strategies with the reference point, which would be done in form of an assessment matrix

To illustrate the main assumptions regarding water resources allocation in the Syr Darya under each adaptation strategy and for business as usual, the WEAP model settings for the monthly operation of reservoirs are given in Figs. 8.1 and 8.5-8.8. Relative costs of each adaptation strategies will be evaluated under different cost categories.

8.3.1. Introducing indicators

The first step of an assessment of an adaptation strategy, is to select criteria or indicators, which would allow to give judgement on the overall efficiency of a strategy. Set of the indicators proposed for the Syr Darya basin is given in Table 8.3. We subdivide indicators into three categories: Environmental, Food and Industrial, each one representing the benefits for a corresponding water resources user. For each indicator we give the following details:

- how it is measured, +++/--- means it is a qualitative estimate, otherwise the units are given;
- what factor (climate change, climate variability, socio-economic change) is affecting it mostly;
- how it is estimated, e.g. based on a model output or through an expert judgement;
- comments

Table 8.3. Proposed indicators for the assessment of adaptation strategies for the Syr Darya Basin.

Indicator	measured in	Primary affected by	Estimated	Comment
Environment				
ha desert/badland (x10_6)	+++/---	CC	Expert judgement based on LGPM outputs	It is an important indicator, for rapid desertification is one of the hottest environmental issues in the lower and upper basin, that negatively affects quality and availability of pasture land. Mitigation by adaptation measures rather limited. The negative impacts are given as + (i.e. increase of desert area)
Longitudinal freedom	number	SE	Expert judgement	
Outflow to Aral	10_6xm_3	CC SE	WEAP outputs	This indicator shows if the ecosystem in Syr Darya delta areas and Northern Aral lake can be kept from further deterioration. Is given as 30 year average value, i.e. represents integrated CC impacts. The higher it is the better for environment
PCB, Fertiliser	+++/---	SE	Expert judgement	Indicates level of water pollution

NaCl	+++/---	SE	Expert judgement	Indicates level of water pollution
Food				
tons of cotton	number	CC SE	Expert judgement based on LGPM, SWAP and economic growth model outputs	Though it is not food crop, it is currently one of the two important commercial crops in the basin, common for all farm types
tons of wheat	number	CC SE		This is an important commercial crop, common for large –scale farming
tons of potato	number	CC SE		This is an important crop, for both commercial purposes and for subsistence, very common for small–scale farming
tons of meat	number	CC SE		Those two indicators are important for the Syr Darya basin, for in the upper and lower basin the stock-raising is common among the semi-nomadic Kyrgyz and Kazakh people, meat and milk products play important role in the traditional diet and are important for the subsistence
tons of milk	number	CC SE		
Average farm income	USD/yr	CC, CE		
# years wih unmet demands for agriculture	number	CV	WEAP outputs	Indicates level of food security. Unmet demands are determined as less than 75% coverage for the agriculture demands, with equal priorities for all other users apart from domestic user
Industry				
# of dams	number	SE	Expert judgement	
Hydropower	+++/---	SE, CC, CV	Expert judgement	

8.3.2. Setting reference point: Business as usual, time slice 2070-99

Second step of an assessment is to select a reference point, i.e. to determine a set of conditions to compare the strategies under consideration with. In our study under reference point called Business as usual we understand a hypothetical situation in future, when no adaptation measures to mitigate negative impacts of CC, CV and SE pressors were taken. Business as usual is characterised by the status of indicators showing the expected changes in the period 2070-99 as compared to their status in the baseline period, i.e. 1961-90. Adaptation strategies, i.e. hypothetical situation when adaptation measures were taken, will be cross-compared to Business as usual.

Under business as usual, the negative impacts of CC/CV and socio-economic pressors as compared to the baseline period, can be outlined as follows. For the environment, the major treats are: increase of desert/badland area, more significant under «hot and dry» A2 scenario than under «moderate» B2 scenario, water quality worsens, outflow to Aral drops, also more significantly under A2 (2.1 km^2) than under B2 (2.4 km^2) climate change scenario. For agriculture, we project an overall increase of crop production, because of increasing yields under higher CO_2 levels in atmosphere (Droogers and Dam, 2003) and positive changes in LGP. Though the SWAP model outputs suggest higher crop yields under scenario A2, we assume that B2 scenario is more favourable for the overall crop production, since water availability remains the main constraint in agriculture production. Meat and milk production is also expected to increase due to increased rangeland productivity and projected socio-economic changes. As WEAP model outputs demonstrate, the changes in CV, particularly in precipitation, are expected to impose a serious treat to the food security. Under A2 scenario, the risks of unmet water demands in agriculture increase more significantly than under B2 scenario: WEAP runs indicate 18 years with unmet agriculture demands under A2, and 12 years for B2. Average annual farm income is supposed to be 2950 USD under A2 scenario and 3310 USD under B2 scenario. In industry, number of reservoirs and hydropower plants would increase from 25 to 30 and overall hydropower production will increase.

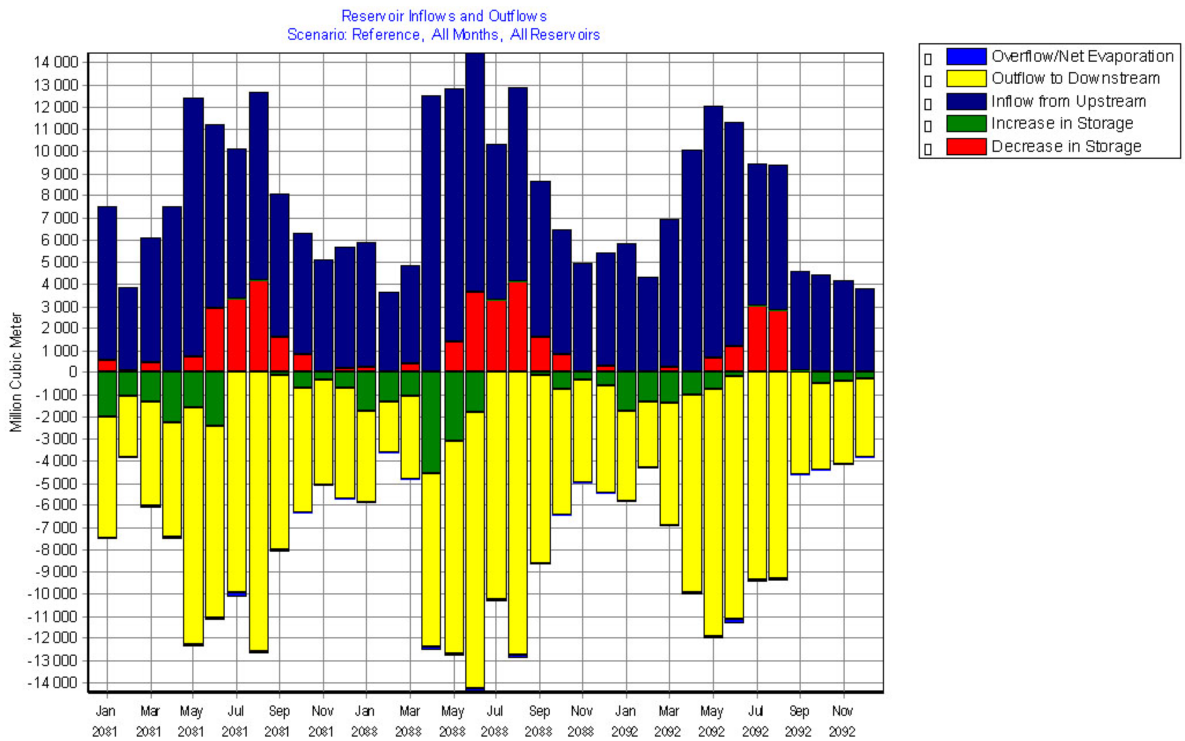


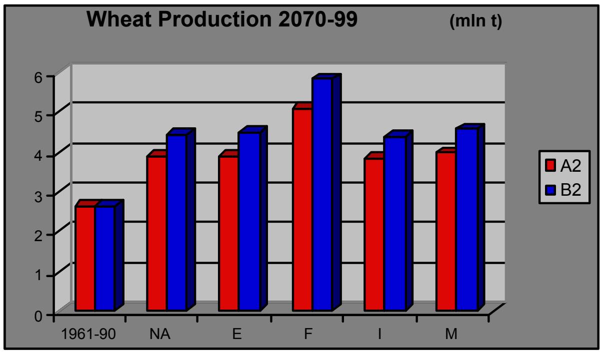
Fig 8.1. WEAP settings for the Business as Usual (Reference scenario): Syr Darya reservoirs monthly operation scheme for normal (2081), wet (2088) and dry (2092) years 2070-99 A2.

Table 8.4. Assessment matrix for the adaptation strategies under CC scenario A2, time slice 2070-99

Indicator		Measured in	1961-90	2070-99 business as usual	Adaptation Strategy			
					2099 E	2099 F	2099 I	2099 M
Environment	ha deserts (x10_6)	+++/---	115,000	+++	++	++	+++	++
	Longitudinal freedom	number	29	34	34	35	37	35
	Fertiliser, PCB, NaCl	+++/---	+	++	+	+++	++	++
	Radioactive pollution	+ or -	-	+	-	+	-	-
	Outflow to Aral	+++/---	5-10	2.1	3.8	3.7	2.4	5.8
	# years with flood risk	number	350	885	--	+/-	+	+/-
Food	tons of cotton (x10_6)	number	2.240	2.370	2.520	2.820	2.430	2.570
	tons of wheat (x10_6)	number	2.660	3.890	3.970	5.100	4.020	4.120
	tons of potato (x10_6)	number	1.960	5.900	6.030	7.600	6.370	6.980
	tons of meat (x10_6	number	0.520	1.180	1.240	1.430	1.300	1.380
	tons of milk(x10_6)	number	1.680	2.540	2.590	3.310	2780	3.030
	Average farm income	USD/yr	1500	2950	3170	4060	3380	3890
	# years with unmet demand	number	7	18	9	5	12	6
Industry	# of dams	number	25	30	30	30	33	32
	Hydropower	(MWatt)	60,950	+	++	+	+++	++
AS relative costs					8-14	9-15	16-19	24-32

Table 8.5. Assessment matrix for the adaptation strategies under CC scenario A2, time slice 2070-99

	Indicator	Measured in	1961-90	2099 business as usual	Adaptation Strategy			
					2099 E	2099 F	2099 I	2099 M
Environment	ha deserts (x10_6)	+++/---	115,000	++	+	++	++	+
	Longitudinal freedom	number	29	34	34	35	38	37
	Fertilizer, PCB	+++/---	+	++	+	+++	++	++
	NA Cl (Kazalinsk station, g/l))	+++/---	28	++	+	++	+	++
	Outflow to Aral	+++/---	5-10	2.6	4.6	4.2	3.0	7.1
Food	tons of cotton (x10_6)	number	2.240	2.760	2.800	3.280	2.620	3.040
	tons of wheat (x10_6)	number	2.660	4.480	4.780	5.860	4.930	5.550
	tons of potato (x10_6)	number	1.960	6.290	6.380	8.100	6.860	7.790
	tons of meat (x10_6	number	0.520	1.190	1.040	1.580	1.280	1.430
	tons of milk(x10_6)	number	1.676	2.730	2.880	3.560	3.150	3.220
	Average farm income	USD/yr	1500	3310	3420	4690	3570	4420
	Variation in farm income	USD/yr	7	12	6	3	9	4
Industry	# of dams	number	25	30	30	30	34	33
	Hydropower	(MWatt)	60,950	+	++	+	+++	+++
AS relative costs					8-14	9-15	20-23	28-36



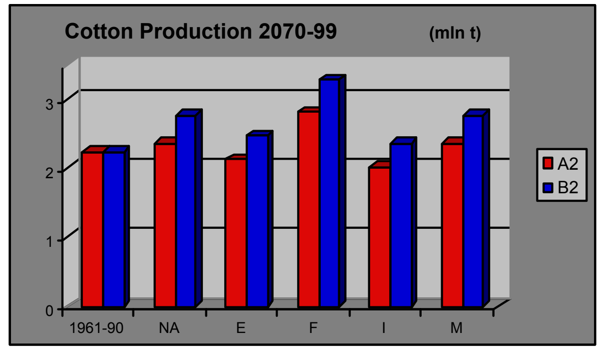


Fig. 8.2.

Fig. 8.3.

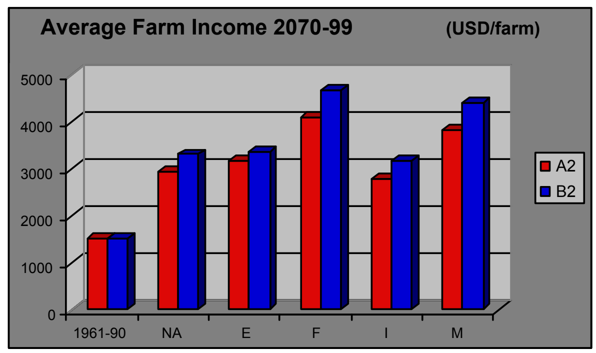


Fig. 8.4

Fig. 8.2. Wheat Production under CC scenarios A2 (red) and B2 (blue)

Fig. 8.3. Cotton Production under CC scenarios A2 (red) and B2 (blue)

Fig. 8.4.Changes in Average Farm Income under CC scenarios A2 (red) and B2 (blue)

Note: 1961-90 – baseline period; W/A – Business as usual 2070-99; E, F, I, M adaptation strategies

8.3.3. Environmental AS

The effects of the environmental AS can be illustrated by the set of indicators as following: water quality would slightly improve as compared to business as usual, not entirely because of still high levels of pollution resulting from agriculture. Area of deserts, i.e. rangeland and crop land turned into badland, would increase less dramatically than under business as usual, average outflow to Aral would increase from 2.1 km^2 to 3.8 km^2 under A2 scenario, and from 2.4 km^2 to 4.6 km^2 under B2 scenario. Crop production would increase due to measures F1 and F2, while meat and milk production would be higher due to the measures preventing desertification (E2). Number of years with unmet agricultural demands will drop from 18 to 9 under A2 scenario and from 12 to 6 under B2. Farmer's income is expected to increase insignificantly compared to business as usual. Hydropower production would be somewhat higher than under business as usual due to high production in winter. All the positive effects will be more remarkable under B2 scenario than under A2. Relative costs of Environmental strategy are 8-14, i.e. the least expensive in relation to other adaptation strategies considered below.

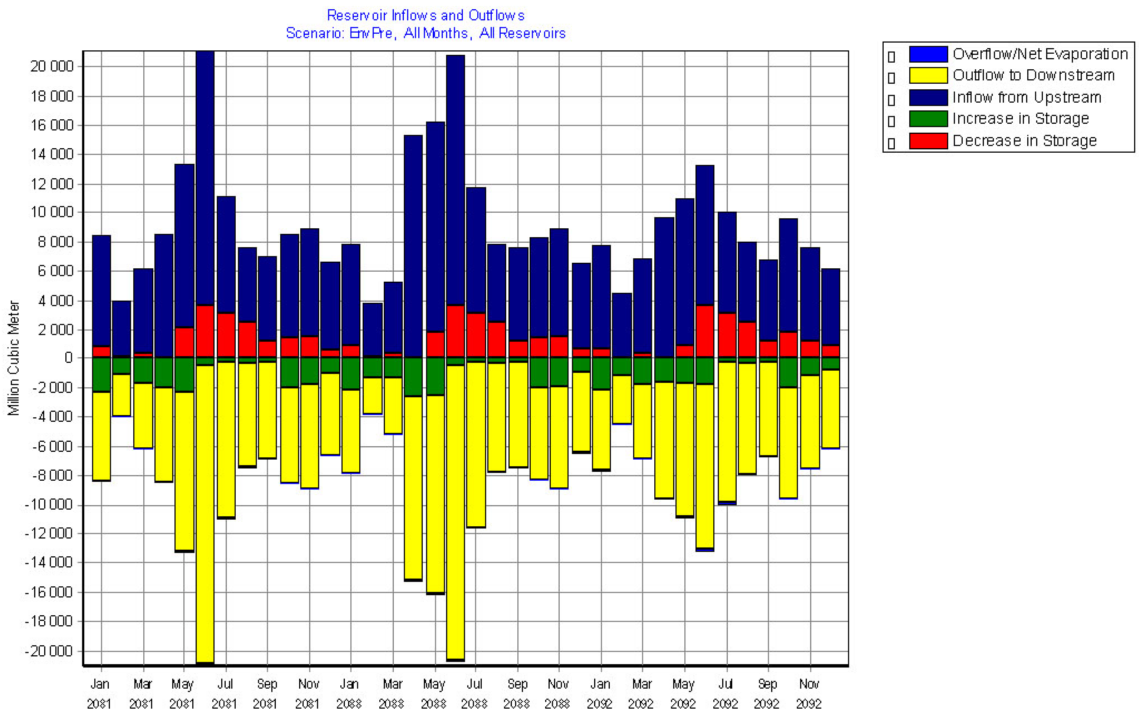


Fig. 8.5. WEAP settings for the Environmental Adaptation Strategy: Syr Darya reservoirs monthly operation scheme for normal (2081), wet (2088) and dry (2092) years 2070-99 2070-99 A2.

8.3.4. Food AS

The food adaptation strategy is not very effective in terms of satisfying environmental needs. The water quality will remain at the same level as under business as usual, though outflow to Aral would increase similarly to that under Environmental AS, i.e. to 3.7 km^2 under A2 scenario and to 4.1 km^2 under B2 scenario. This strategy would allow to make natural ecosystems less vulnerable to desertification. Food adaptation strategy is expected to provide the most essential increase of crop production, particularly so of crops less dependent on irrigation, such as wheat and potato. Meat and milk production would increase, and expected average farm income is the highest under this strategy compared to other strategies: 4060 USD for A2 scenario and 4690 USD for B2 scenario, which is approximately 1,5 higher than under business as usual. The strategy is apparently the most effective in coping with the risks of non-meeting demands for irrigation. WEAP outputs indicate that number of years with unmet agricultural demands would drop from 18 to 5 under A2 scenario, and from 12 to 3 under B2 scenario. Hydropower production under this adaptation strategy would remain at the same level as under business as usual. The food adaptation strategy too would be more effective under B2 climate change scenario, compared to A2 scenario. The relative costs of Food AS are 9-15, i.e. this strategy requires investment comparable to Environmental AS and nearly double less than that for Industrial AS and Mixed AS.

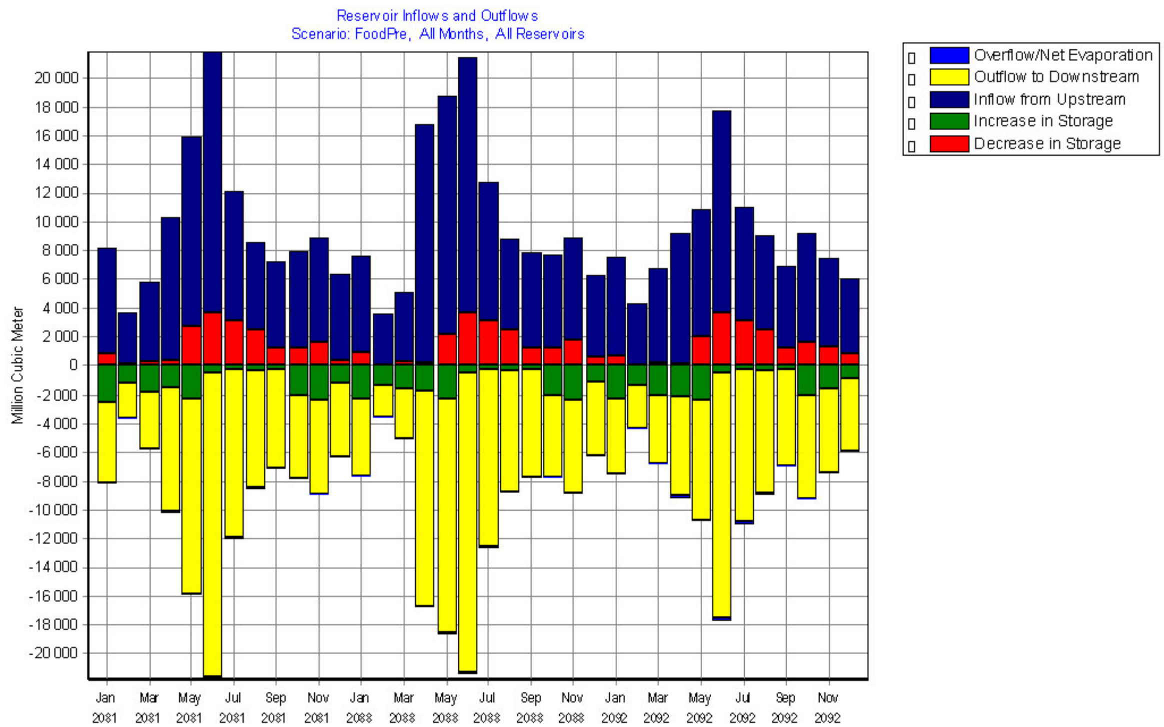


Fig. 8.6. WEAP settings for the Food Adaptation Strategy: Syr Darya reservoirs monthly operation scheme for normal (2081), wet (2088) and dry (2092) years 2070-99 2070-99 A2.

8.3.5. Industrial adaptation strategy

The assessment of the industrial strategy by the proposed indicators a moderate increase of water quality, expected outflow to Aral slightly differs from that under business as usual, reaching meagre amount of 2.4 km^2 under climate change scenario A2 and 3.0 km^2 under scenario B2, and there would be no change in the rates of desertification. This strategy would make crop production, particularly so of wheat and potato, and production of meat and milk products increase and consequently the average farm income would slightly increase compared to business as usual. Level of food insecurity would remain rather high: the number of years with unmet demands for agriculture would not decrease drastically: it would be 12 instead of 18 years for the scenario A2, and 9 instead of 12 years for the scenario B2. It should be kept in mind that this effect would be reached not by increasing amount of water available for agriculture, but by decreasing agricultural demands. Hydropower production would be significantly higher than under business as usual. The costs of Industrial adaptation strategy are high in comparison with Food and Environmental AS, reaching in sum 16-19 points for scenario A2 and 20-23 for the scenario B2.

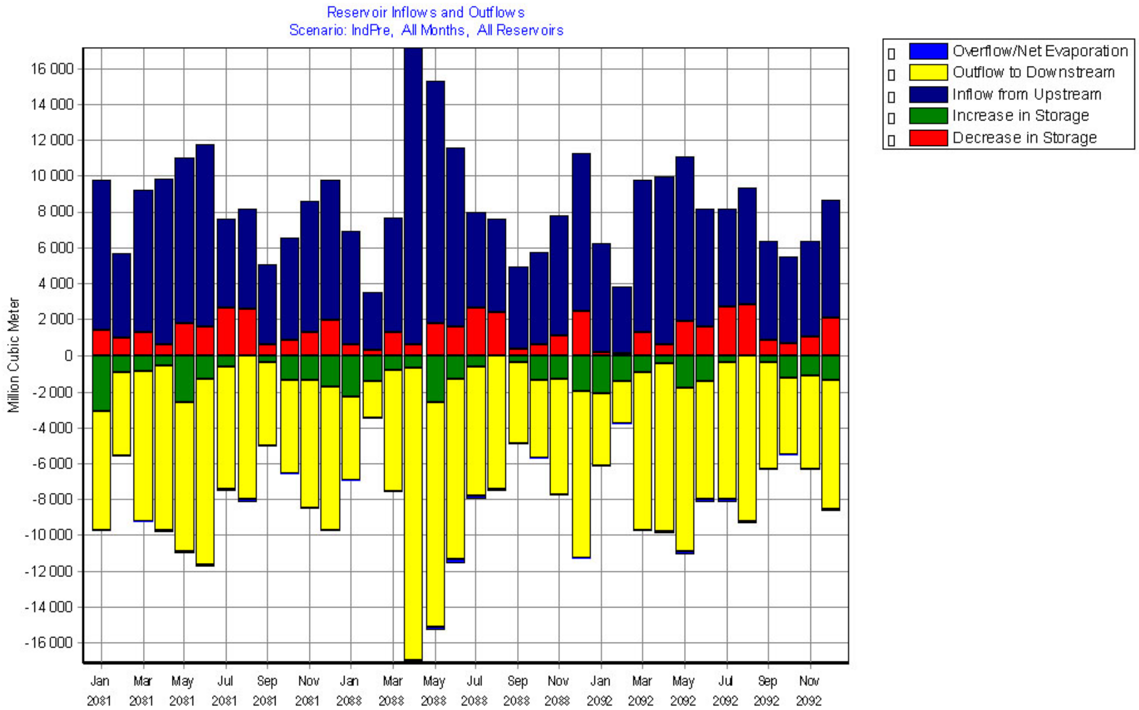


Fig. 8.7. WEAP settings for the Industrial Adaptation Strategy: Syr Darya reservoirs monthly operation scheme for normal (2081), wet (2088) and dry (2092) years 2070-99 2070-99 A2.

8.3.6. Mixed adaptation strategy

Mixed adaptation strategy may be assessed as second to most satisfying in reaching interests of the three main water users in the basin, i.e it would help in improving water quality, though less effective than Environmental strategy, reducing risks of radioactive contamination, preventing desertification, and increasing outflow to Aral most effectively compared to other strategies: to 6.8 km^2 under climate change scenario A2 and 7.1 km^2 under scenario B2. The Mixed strategy would be providing second to maximum, i.e. to that under Food AS, increase in crop, milk and meat production and in average farm income, raise level of food security in terms of meeting water demands for agriculture (6 and 4 years of unmet demands for scenarios A2 and B2 correspondingly) and hydropower production would also be higher under this strategy than under business as usual, second to best, i.e. that under Industrial AS. However, the relative costs of this strategy are the highest among all the adaptation strategies under consideration, since it combines most costly measures of all other strategies: thus, relative cost of Mixed strategy would reach 24-32 under scenario A2 and 28-36 under scenario B2. This strategy too is expected to be more effective under B2 climate change scenario as related to A2.

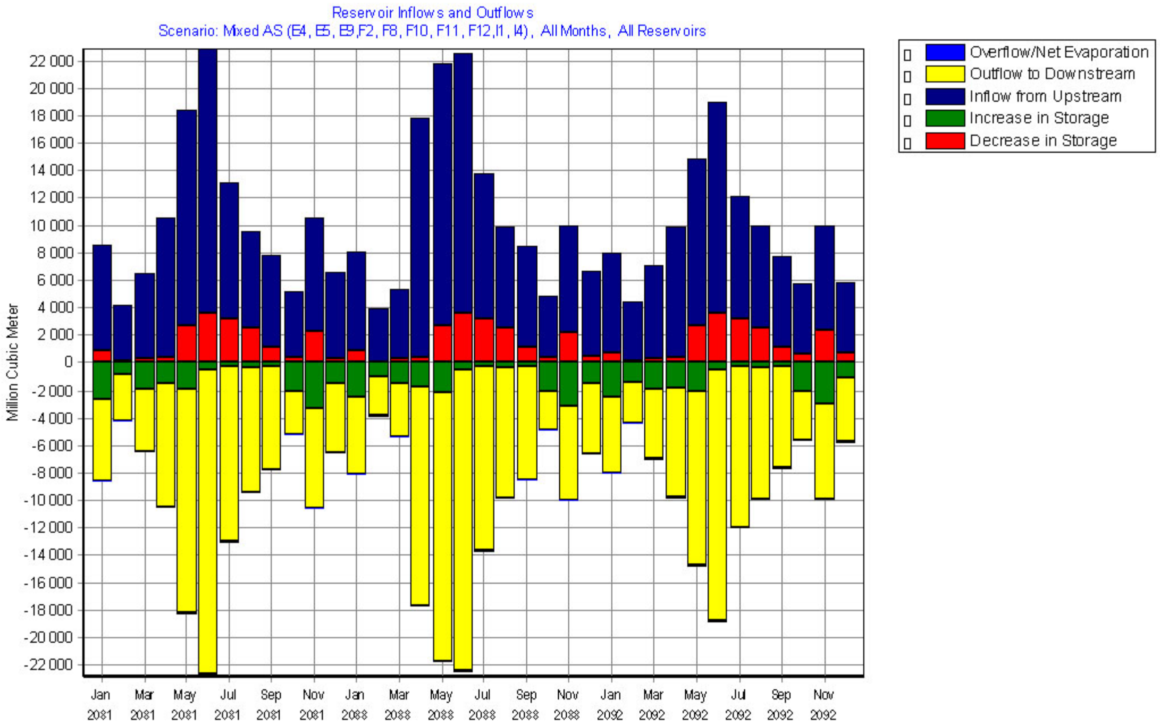


Fig. 8.8. WEAP settings for the Mixed Adaptation Strategy: Syr Darya reservoirs monthly operation scheme for normal (2081), wet (2088) and dry (2092) years 2070-99 A2.

Acknowledgement

The basin team is grateful to the Dutch Ministry of Foreign Affairs (DGIS) for the financial support of the project. International Water Management Institute (IWMI) provided logistical support, and we are particularly thankful to Dr V. Horinkova, Dr I. Abdulaev, L. Gatina and I. Babaev for their invaluable help. We express our sincere gratitude to the Executive Committee of the International Fund for Saving Aral See (EC IFAS), and especially to its chairman Dr S.M. Aslov, Dr A.K. Nogoibaev Dr T.T. Sarsembekov (IFAS), to the World Bank office in Tashkent, and especially to Dr. A.N. Krutov, and to the Swiss Aral Sea Mission, particularly so to Dr A. Shultz for logistical help and valuable consultations. We are thankful to Dr. A. Izmailova, Dr. V.M. Yakimov, S.V. Zaitseva, Dr S. Mustafin, Dr. L.V. Grom, A. Yulchiev, H. Hodzhev, I. Halimov, S. Karimov, K.S. Avazav, R. Usekov, N.T. Sultanov, Z. Saimatov, A. Madaminov, Z. Siddikov and other stakeholders for their valuable comments, consultations and interviews that helped us to outline the adaptation strategies and criteria for their assessment. We would like to acknowledge critical and constructive remarks from Professor V.A. Dukhovniy, the director of Scientific Information Center of the Interstate Commission on Water Coordination (SIC MCWC). We also extend our warmest gratitude to Mr Th. Kouwenaar, Counsellor, Royal Netherlands Embassy in Moscow, Tashkent office, for his personal involvement and support. Future climate and population growth projections for Syr Darya basin were provided by ITC and FAO expertise. We would finally like to say warmest thanks to A.Guliamov for technical assistance.

References

Aerts. J., Droogers, P. 2002. ADAPT, Water, Climate, Food and Environment: Adapting Strategies for River Basins under Changing Environments. Project Proposal v. April 4, 2002.

Baradaragoda, D.J. 1999 Institutional implications of water resources management in Central Asian Republics. Internal Report Water Management Institute. Lahore.

Bunday, B. (1988): Basic optimization methods. Nauka, Moscow (in Russian), 128 pp.

CGIAR. 2003. Collaborative Research Program for Sustainable Agricultural Production in Central Asia and the Caucasus. http://www.icarda.cgiar.org/cac/index.htm.

Data reference book on climate, Uzbek SSR, 1961-89. (in Russian)

De Pauw, E. 2000. Evapotranspiration, Crop Water Requirements And Regional Water Demand

De Pauw, E. Biomass Productivity Modeling Lecture module prepared for the Advanced Course on "Agroecological characterization for resource management in dry areas: use of GIS, remote sensing and modelling", Ankara, Turkey, 12-23 June 2000 organized by CIHEAM/IAMZ and MARA/GDAR/CRIFC

Denisov, Y.M., Agaltseva,.N.A., Pak, A.V. 2000, Automated methods of long-term forecasting of mountain rivers run-off in Central Asia. Tashkent, SARHMI, p. 160 (in Russian)

Droogers, P., J. van Dam, 2003, Adaptation Strategies to Climate Change to Sustain Food Security: a modeling approach across seven contrasting basins, manuscript submitted to IWMI publications

Dukhovniy, V.A., ed. Ways of Water Conservation, 2001, Tashkent, SIC-IWCW, 150 p.

FAO. 2002. Digital soil map of the world and derived soil properties on CD-rom. http://www.fao.org/ag/agl/agll/dsmw.htm.

GEF ICWC Agency, The Program of Aral see region: Water resource and environment management. Subcomponent A1: Water resource and soil management on regional and national levels. Technical report #2 (Phase 3 – regional needs and restrictions. 2002 (in Russian).

Glazyrin, G.E. 1996 The reaction of glaciers in Western Tien Shan to climate change. Zeitschrift fuer Gletscherkunde und Glazialgeologie, 32, p. 33-39

GTOPO30. 2002. Global digital elevation model. http://edcdaac.usgs.gov/gtopo30/gtopo30.html

Heaven, S., Koloskov, G.B. Lock, A.C., Tanton, T.W. 2002 Water Resources Management in the Aral Basin: a River Basin Management Model for the Syr Darya. Irrigation and Drainage, 51, 2, 109-118

Hutchinson, M. (1999): ANUSPLIN Version 4.1. User Guide /The Australian National University. Centre for Resource and Environmental Studies, Canberra, CRES, ISBN 086740 512 0.

HYDRO1k. 2002. Elevation Derivative Database. http://edcdaac.usgs.gov/gtopo30/hydro/

Information bulletin for groundwater resources assessment, pumping and pollution Uzbekistan Republic 2000, # 27, Tashkent, 2001, p. 32 (in Russian)

Initial National Communication of the Republic of Uzbekistan under the UN Framework Convention on Climate Change. Phase 1 1999. Tashkent, 118 pp.

Initial National Communication of the Republic of Uzbekistan under the UN Framework Convention on Climate Change. Phase 2, 2001. Tashkent, 2001, 125 pp.

IPCC-TGCIA, 1999: Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment. Version 1. Prepared by carter, T.r., Hulme, M., and Lal, M., Intergovernmental Panel on Gclimate Change, Task Group on Scenarios, for Climate Impact Assessment, 69 pp.

Karlyhanov A.K. 2002 Water resources management and a water law. Water resources of the Central Asia Abstract of scientific - practical conference devoted to 10-anniversary ICWC February, 20-22. 2002. - pp. 175-180 (in Russian).

Kipshakaev, I.K., Sokolov, V.I. 2002 Water resources of Aral sea basin - formation, distribution, water use. Abstract of scientific - practical conference devoted to 10-anniversary ICWC. February, 20-22. 2002. - pp. 47-55. (in Russian).

Kobilov, T. et.al. 2001 Operational technology for snow cover mapping in the mountains of Central Asia by means of NOAA AVHRR data (3 coauthors). Remote Sensing and Hydrology 2000 (Proceedings of a symposium held at Santa Fe, New Mexico, USA, April 2000). IAHS Publ. no. 267.

Kotlyakov, V.M.. ed., 1963-1978. Inventory of the Glaciers in USSR. Leningrad, Hydromeoizdat. (in Russian)

Main indicators of Social and economic development of the Republic of Uzbekistan. Statistical collection. 2001. Ministry of macroeconomics and Statistics, Tashkent (in Russian)

Ososkova, T.A., Chub, V.E. Eds. An assessment of the vulnerability of thewater resources to the climate change. 1999, Tashkent, GUHKM Uzbek Republik-SAHRMI Bulletin No3, 73 pp. (in Russian)

Pertziger, F. De Pauw, E. and Lebed, L. (2002) Agroecological Characterization of Central Asia. Presented at the Symposium on 'Agricultural Development in Central Asia', American Society of Agronomy Meeting, Indianapolis, 11-14 November 2002, expected in 2003

Raskin, P., Hansen, E., Zhu, Z., Stavisky, D. 1992 Simulation of Water Supply and Demand in the Aral Sea Region. Water International, 17, 55-67

Rust, H.M., Abdulaev, I., Hassan ul, M., Horinkova, V. 2001 Water productivity in the Syr Darya river basin. IWMI technical report

Ryutaro Tateishi, Koji Kajiwara. Monthly Maximum Global Vegetation Index and Land Cover Classifications from NOAA-9 http://www.ngdc.noaa.gov/seg/eco/cdroms/gedii_b/datasets/B05/ JAN 1986 - DEC 1989

Sarsembekov, T.T. 2000. Water and Food Security: a brief review of some world problems of water resources, food production and irrigation. In Integrated Management of Water Resources, Dukhovniy, V.A. ed., Tashkent., 14 p.

Savoskul, O.S. ed. 2000 Modelling future environmental change in continental and maritime Asia, Project Report to the Institute of Open Society under program of Research Support Scheme, 70 p.

Tuzova, T.F. ed., Water and sustainable development in Central Asia, 2001, Bishkek, Soros-Kyrgyzstan Foundation, 177 pp. (in Russian)

Users guide for WEA21 Stockholm Environment Institute, Boston, http://www.seib.org/weap

Van Dam, J.C. 1999 Imacts of climate change and climate variability on hydrological regimes. Cambridge University Press, Cambridge, 140 pp.

WEAP. 2002. Water Evaluation and Planning System. http://www.seib.org/weap