Climate Change Impact and Adaptation on the Water Resources in the Amu Darya and Syr Darya River Basins

May 2012

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Report FutureWater: 110

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PREFACE

This report contributes to the Asian Development Bank study TA 7532 “Water and Adaptation Interventions in Central and West Asia” carried out by the Finnish Consulting Group (FCG) in collaboration with FutureWater (Netherlands) and the Finnish Meteorological Institute (FMI).

The relevance of the study is that the regional policy can only be implemented if there is a strong scientific background for investment plans and commitment to international agreements and conventions.

The study focuses on Kyrgyz Republic, Tajikistan, Kazakhstan, Turkmenistan, and Uzbekistan. The approach of the study is to develop hydrological models for the Amu Darya and Syr Darya and include various climate change impact scenarios. Results will be used to develop national capacity in each of the participating countries to use these models to prepare climate change impact scenarios and develop adaptation strategies.

The Request for Proposal for this study was distributed amongst five consortiums on 1-Dec-2010. Based on a Quality- and Cost-Based Selection (QCBS) the consortium of Finnish Consulting Group (FCG) in collaboration with FutureWater (Netherlands) and the Finnish Meteorological Institute (FMI) was granted to undertake the study (Contract number: 100039-S41593). The study started in Mar-2011 and will be completed in Jun-2012.

Since the start of the study in March 2011, the following documents have been published:

- Inception report, June 2011
- Interim report, November 2011
- Climate Change Impacts on the Upstream Water Resources of the Amu and Syr Darya River Basins, March 2012
- Climate Change Impact and Adaptation on the Water Resources in the Amu Darya and Syr Darya River Basins, May 2012 (this report)
- Final report, June 2012 (forthcoming)

This report describes the impact of climate change based on climate change projections produced by FMI using a water allocation model developed in the Water Evaluation and Planning system (WEAP). A model is developed, calibrated and validated for the downstream parts of the Amu Darya and Syr Darya river basins. Results from a preceding climate change impact assessment for upstream runoff generation, also part of this project are used for this downstream assessment [*Immerzeel et al.*, 2012]. This report forms the second and final part of this two-way modeling study. Both reports will be incorporated in the study’s Final Report, to be delivered in June 2012.

Executive Summary

Water resources management in the Central Asia region faces big challenges. The hydrological regimes of the two major rivers in the region, the Syr Darya and the Amu Darya, are complex and vulnerable to climate change. Water diversions to agricultural, industrial and domestic users have reduced flows in downstream regions, resulting in severe ecological damages. The administrative-institutional system is fragmented, with six independent countries sharing control, often with contradicting objectives.

In the Central Asian region, water related issues have been prominent since the break-up of the USSR. Major trans-boundary river basins and management agreements in the Aral Sea Basin include 1) 1992 Aral Sea Basin Water Allocation and Management; 2) 1993 Aral Sea Basin Program and 3) 1994 Nukus Declaration on Aral Sea Basin Management; 4) 1998 Framework Agreement on Rational Water and Energy Use; 5) 1999 Revised Mandate of the International Fund for Saving the Aral Sea; and 6) 2003- Revised Aral Sea Basin Program, Phase-2. One of the regional environmental initiatives in Central Asia Countries (CACs) is the International Fund for Saving the Aral Sea (IFAS), established in 1994. IFAS, together with its two commissions, the Interstate Commission on Sustainable Development (ICSD) and the Interstate Commission for Water Coordination (ICWC), is charged with mobilizing funds to implement interstate activities on water resources and land degradation and other social-economic issues, with financing joint scientific and technical projects, and with participating in international programs and projects directed at the Aral Sea crisis.

UNDP and the Global Water Partnership (2004) have drafted the Integrated Water Resource Management (IWRM) plan that proposed an integrated approach to water management, in which the river basin would be managed holistically, with the participation of water user stakeholders and ensuring environmental sustainability. The regional policy can only be implemented if there is a strong scientific background for investment plans and commitment to international agreements and conventions. It is therefore essential to gain knowledge on the future availability and demand of water resources under of climate change.

The current study applied state-of-the-art and scientifically established approaches to assess the current and future water demand, supply and shortage in the Central Asian region and to explore options, and associated costs, to overcome water shortage. The Amu Darya and Syr Darya rivers are largely fed by ice and snow melt in the Pamir and Tien Shan mountains. A fully distributed cryospheric-hydrological model was developed to estimate future glacier changes and the impact on generated runoff in the upstream mountains until 2050. This upstream model was coupled to a downstream water allocation model to assess demand and unmet demand at the province level for the downstream areas.

The study results show there are large differences in the role that melt water plays in runoff generation in the Amu Darya and Syr Darya river basins. Melt water has a higher contribution to runoff in the Amu Darya basin compared to the Syr Darya river basin. It is very likely that glacier extent in the Pamir and Tien Shan mountain ranges will decrease 45 to 60% by the year 2050. The composition of the four components of stream flow (rainfall-runoff, snow melt, glacier melt, base flow) is very likely to change in the future. This will have major impacts on total runoff, but especially on seasonal shifts in runoff. The runoff peak will shift from summer to spring and decrease in magnitude.

Model output when forced with climate projections generated with five Global Circulation Models shows decreasing runoff generation in the upstream parts of the two basins in 2050. The changes differ strongly spatially. The runoff generation decreases most significantly in upstream areas of glacier retreat. Total annual runoff into the downstream areas is expected to decrease by 22-28% for the Syr Darya and 26-35% for the Amu Darya by 2050. Strongest decreases in stream flow are expected for the late summer months (August, September, October), where inflow into downstream areas decreases around 45% for both river basins.

Due to increasing temperatures, water demand in the Syr Darya basin increases 3.0 - 3.9% in 2041-2050. Due to decreasing runoff generation unmet demand increases from 8.8% in 2001-2010 to 31.6 - 39.7% in 2041-2050. Annual demand in the Amu Darya basin increases 3.8 - 5.0% in 2041-2050. Annual unmet demand increases from 24.8% in 2001-2010 to 45.8 -54.5% in 2041-2050.

To overcome current and future water shortage countries have a range of options at their disposal to respond and adapt. These options can be summarized into three broad categories: (i) expanding supply, (ii) increasing productivity, and (iii) reducing demand. For each of these three categories typical options were explored in the study resulting in the following framework:

Expanding supply:	A: Increased reservoir capacity
Increasing the productivity:	B: Improved agricultural practice
	C: Increased reuse of water in irrigated agriculture
	D: Increased reuse of water for domestic use
Reducing demand:	E: Reduction of irrigated areas
	F: Reduction of domestic demand
	G: Deficit irrigation

Obviously, each of these options is associated with certain marginal unit costs, ranging from US$ 0.02 per m^3 for improving agricultural practices to US$ 2.00 per m^3 in case of reducing supply to domestic demand. It is clear that in general the cheapest options will be introduced first, but at the same time might not be sufficient to overcome water shortage completely and more expensive options are required to bridge the water gap. By ranking the adaptation options by their unit costs country specific water marginal costs curves are constructed. The water availability cost curve's use is limited to comparing measures' financial costs to close the gap. It is important to note that these might be different from the economic costs for society as a whole. The cost curve should be therefore considered as a guide for comparing the financial costs of measures for decision-making.

Most cost-effective adaptation measures are improving agricultural practice, deficit irrigation, increasing the reuse of water in agriculture and the reduction of irrigated areas. Besides, the measures applied to agriculture are much more effective in terms of unmet demand reduction because the domestic water use in the basins is negligible compared to the water use for agriculture. Applying the most cost-effective adaptation measures will close the water gap and cost US$ 1,730 million per year in 2050 (net present value). Closing the water gap caused by climate change only will cost US$ 550 million per year in 2050.

The study concludes that water shortage in the Amu Darya and Syr Darya basins will increase strongly in the next decades due to climate change. Multiple adaptation measures need to be taken to decrease or close the water gap.

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1 Introduction

Water resources management in the Central Asia region faces big challenges. The hydrological regimes of the two major rivers in the region, the Syr Darya and the Amu Darya, are complex and vulnerable to climate change. Water diversions to agricultural, industrial and domestic users have reduced flows in downstream regions, resulting in severe ecological damages. The administrative-institutional system is fragmented, with six independent countries sharing control, often with contradicting objectives.

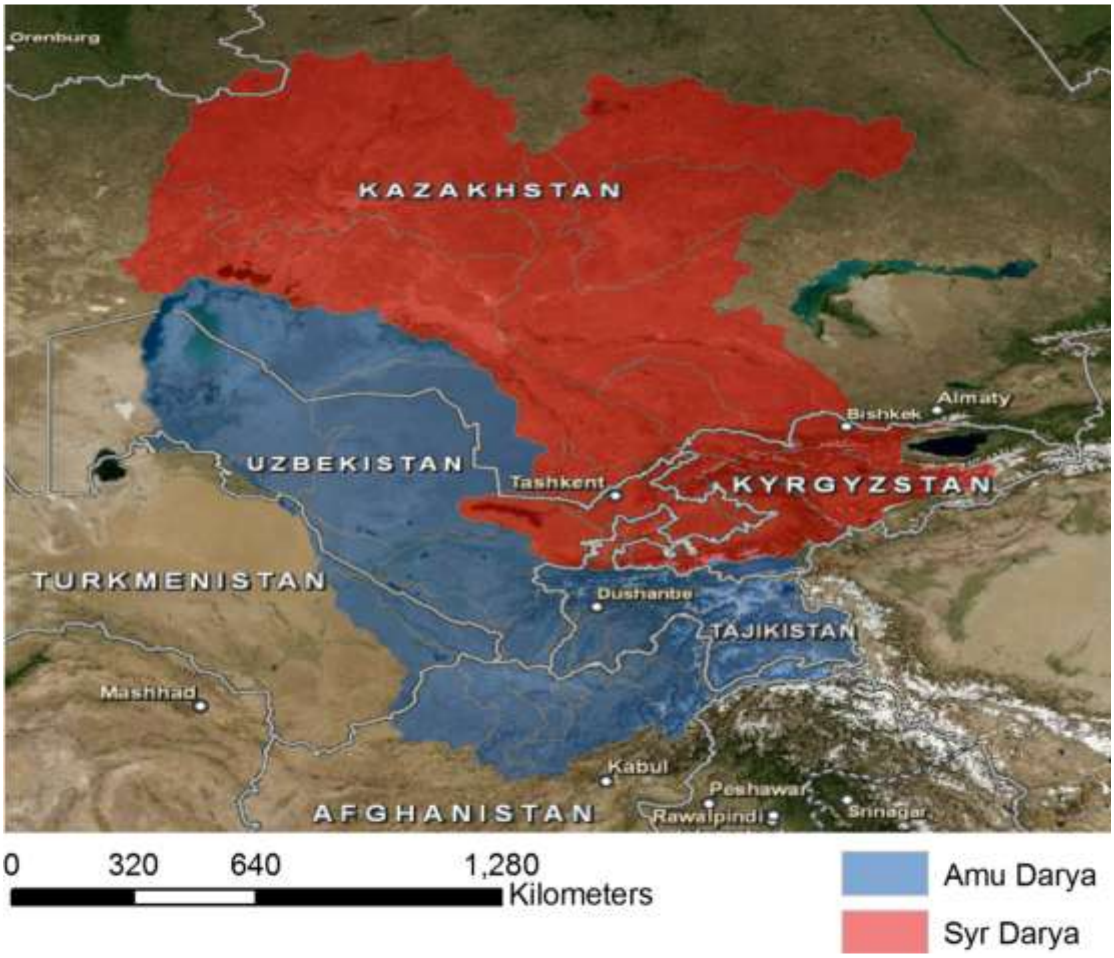

Figure 1-1: Amu Darya and Syr Darya river basins.

In the Central Asian region, water related issues have been prominent since the break-up of the USSR. Major trans-boundary river basins and management agreements in the Aral Sea Basin include: 1) 1992 Aral Sea Basin Water Allocation and Management; 2) 1993 Aral Sea Basin Program and 3) 1994 Nukus Declaration on Aral Sea Basin Management; 4) 1998 Framework Agreement on Rational Water and Energy Use; 5) 1999 Revised Mandate of the International Fund for Saving the Aral Sea; and 6) 2003- Revised Aral Sea Basin Program, Phase-2. One of the regional environmental initiatives in Central Asia Countries (CACs) is the International Fund for Saving the Aral Sea (IFAS), established in 1994. IFAS, together with its two commissions, the Interstate Commission on Sustainable Development (ICSD) and the Interstate Commission for Water Coordination (ICWC), is charged with mobilizing funds to implement interstate activities on water resources and land degradation and other social-economic issues, with financing joint scientific and technical projects, and with participating in international programs and projects directed at the Aral Sea crisis.

UNDP and the Global Water Partnership (2004) have drafted the Integrated Water Resource Management (IWRM) plan that proposed an integrated approach to water management, in which the river basin would be managed holistically, with the participation of water user stakeholders and ensuring environmental sustainability. The regional policy can only be implemented if there is a strong scientific background for investment plans and commitment to international agreements and conventions. It is therefore essential to gain knowledge on the future availability and demand of water resources under of climate change.

The following description of the situation in Central Asia is based on the article 'Water and Energy Conflict in Central Asia' by Tobias Siegfried published in Earth Institute's 'state of the planet' blog.

What once was a basin-wide management approach during the Soviet times has become an uncoordinated management situation with conflicting interests for the upstream countries (Kyrgyzstan, Tajikistan and Afghanistan) and the downstream countries (Uzbekistan, Turkmenistan and Kazakhstan). The hydraulic infrastructure is distributed over various independent countries. As a result, the water resources system is not managed collectively and cooperatively. A mixture of regional, national, and interstate institutions now handles allocation decisions, which used to be centrally administered during Soviet times. As a result, water and energy allocation among the various sectors and users is not efficient. Future water resources development in northern Afghanistan will further add fuel to the water and energy conflict in the region.

In short, the upstream / downstream conflict consists of opposed demand patterns for energy and water resources, in space and in time. Kyrgyzstan and Tajikistan need to release water from a number of large reservoirs during the cold months to generate hydropower for heating. There, hydropower provides the cheapest source of energy with generating costs as low as 0.1 cent/kWh. The winter releases frequently cause flooding in the downstream areas. At the same time and in order to have enough hydropower generating capacity during the cold months, these upstream states spend the warmer summer months saving water in those reservoirs.

That is precisely when the downstream countries have the most pressing need for irrigation water where the degradation of agricultural soils and insufficient flows for ecosystems are issues of growing concern. In the region, cotton is an important cash crop, and, at the same time, wheat is considered essential in order to meet national food security goals. Especially for Uzbekistan, considerations of self-sufficiency have become more important in recent times where food grain prices have increased considerably on the world market.

The original idea in Soviet times was to operate the hydro-infrastructure in irrigation mode. The water resources of Central Asia were managed with the aim to maximize crop production. Part of the hydropower produced during irrigation water-releases in spring and summer was conveniently utilized in the downstream for driving lift irrigation and vertical drainage pumps along the 30,000 kilometers of irrigation channels. In return, the upstream areas received energy supplies in the form of gas and coal to cover winter energy demands.

Future climate change poses additional challenges. The discharge in both the Syr Darya and the Amu Darya rivers is driven mainly by snow and glacial melt. The impact of a warming climate on these key hydrological processes is not sufficiently understood and no mitigation and adaptation strategies are in place. Whereas changes in precipitation levels are hard to predict for the future, there is a solid consensus that average global temperatures are rising. As a result, more precipitation will fall as rain in the upstream and the ice volume in the Tien Shan and Pamir mountain ranges will likely shrink. The former will impact the seasonality of the runoff whereas the latter will at least temporarily increase average annual flows. Furthermore, changes in sediment loads may pose additional problems. At this point in time, the impacts are not sufficiently quantified and adaptation and mitigation strategies not in place.

The ongoing construction of new dams in Kyrgyzstan and Tajikistan is adding tension to the existing situation. The soviet-era designed hydropower projects Kambarata I and II in Kyrgyzstan and the Rogun dam in Tajikistan are on the table again as a result of an increased access to international donor money with Russia and China investing in these projects. For the downstream countries, these developments have raised concern because this can mean that the upstream states can decouple themselves the necessity to receive energy deliveries in the winter from Kazakhstan, Uzbekistan and Turkmenistan. The upstream countries could lose their will to abide to summer operation rules with severe impacts to irrigated agriculture and the overall economy. From this perspective, it is not surprising that certain tensions between the countries exist. Although the new infrastructure will be effective at damming river flow and in adding management options that are direly needed, measures need to be taken so that further flow impediment does not equal impediment to regional integration.

The unfavorable developments in this geopolitically important and fragile region call for urgent attention of the international community. Interdisciplinary research can critically inform decision making in the region for better risk management and the design of mitigation and adaptation strategies[1].

This report presents the second part of a two-way modeling study assessing the impact of climate change for future water availability in the Amu Darya and Syr Darya river basins. The first part focused on the impact of climate change for future runoff generation in the mountainous upstream parts of the basins [*Immerzeel et al.*, 2012]. The projected inflow from the upstream parts into the downstream areas serves as input for a water allocation model developed in the Water Evaluation and Planning system (WEAP) to simulate water demands and resources in the downstream areas. This second part of the modeling study is reported in this document. The effects of future changes in temperature and precipitation for the future water availability and demand are simulated and the effects of possible adaptation measures are explored.

[1] These sections are partly based on http://blogs.ei.columbia.edu/2009/08/18/water-and-energy-conflict-in-central-asia/

2 Methodology

2.1 Water Evaluation And Planning system

WEAP ("Water Evaluation And Planning" system) is a well-known software tool that takes an integrated approach to water resources planning. Allocation of limited water resources between agricultural, municipal and environmental uses now requires the full integration of supply, demand, water quality and ecological considerations. WEAP aims to incorporate these issues into a practical yet robust tool for integrated water resources planning. WEAP is developed by the Stockholm Environment Institute's U.S. Center. WEAP was originally developed for simulating water balances and evaluating water management strategies in the Aral Sea region [*Raskin et al.*, 1992].

A database maintains water demand and supply information to drive a mass balance model on link-node architecture. Simulations calculate water demand, supply, runoff, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge and instream water quality under varying hydrologic and policy scenarios. Policy scenarios evaluate a full range of water development and management options, and takes account of multiple and competing uses of water systems.

WEAP has a user-friendly GIS-based interface with flexible model output as maps, charts and tables. WEAP is available in also Russian and Farsi languages and it is already at use in the Aral Sea Basin. WEAP license is free of charge to non-profit, governmental or academic organization based in a country receiving development bank support (as all the Central Asian countries).[1]

2.2 Model concepts

The first part of the two way modeling study focused on modeling the impact of climate change for the mountainous upstream parts of the basins (Figure 2-1). This was done using a fully distributed cryospheric-hydrological model simulating all major hydrological and cryospheric processes at 1 km spatial scale with a daily time step. The model was forced with climate change scenarios for five Global Circulation Models (GCMs) to project future runoff generation until 2050. The projected inflow from the upstream parts into the downstream areas serves as input for a water allocation model developed in WEAP simulating water demands and resources in the downstream areas.

In WEAP a database maintains water demand and supply information to drive a water balance model on link-node architecture. Simulations calculate water demand, supply, runoff, infiltration, crop requirements, evapotranspiration, flows, reservoir storage under varying hydrologic and adaptation scenarios. Adaptation scenarios evaluate a full range of water development and management options, and take account of multiple and competing uses of water systems.

A water allocation model is developed in WEAP incorporating the agricultural and domestic demand sites, catchments, inflow points from upstream, reservoirs and the connections between them. The effects of future changes in temperature and precipitation for the future

[1] www.weap21.org

water availability and demand are simulated until 2050 and the effects of possible adaptation measures are explored.

The downstream model runs at a monthly time step for three time intervals: for the reference situation (2001-2010) and for two future time interval (2021-2030 and 2041-2050). For each of these time intervals one average year is calculated by averaging the ten years within the interval, to get one representative year. Input from the upstream model is also averaged to the same representative year. The model is calibrated for the reference situation (2001-2010).

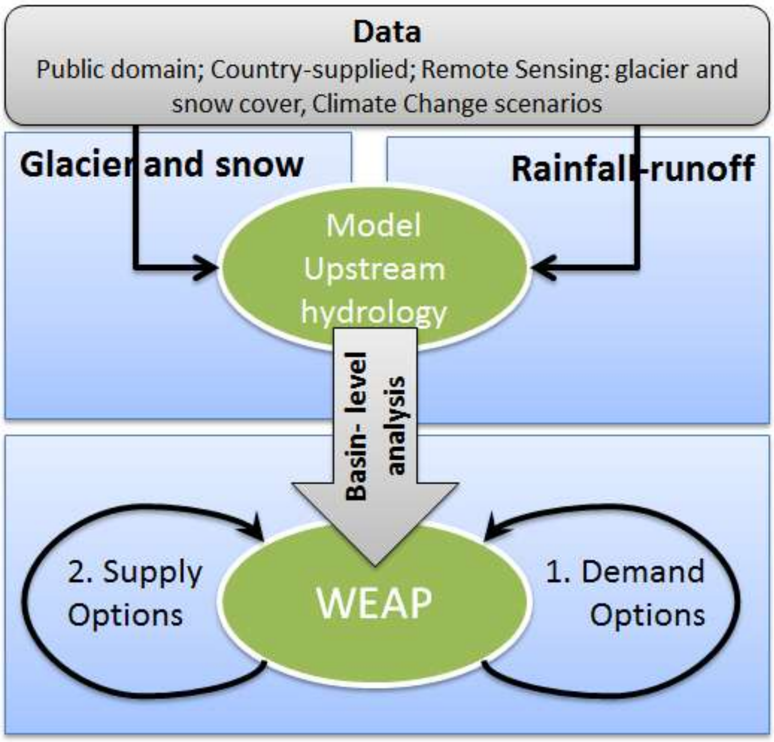

Figure 2-1: Two-way modeling approach

2.3 Model setup and data sources

The model is set up for the Amu Darya and Syr Darya river basins. As mentioned, the basin is divided in an upstream part and a downstream part (Figure 2-2). For the upstream part, the AralMountain model, a combined cryospheric-hydrological model, was developed for this study [*Immerzeel et al.*, 2012]. For the upstream part, the hydrological situation can be described as a natural situation, where human interference can be neglected. The downstream parts are modeled using the ARAL-WEAP model which is designed in the WEAP-tool. The downstream part includes regions where human interference is significant and comprises all major agricultural areas as well as areas where water is extracted for domestic use in highly populated areas. Figure 2-3 and Figure 2-4 show schematic representations of the model setup.

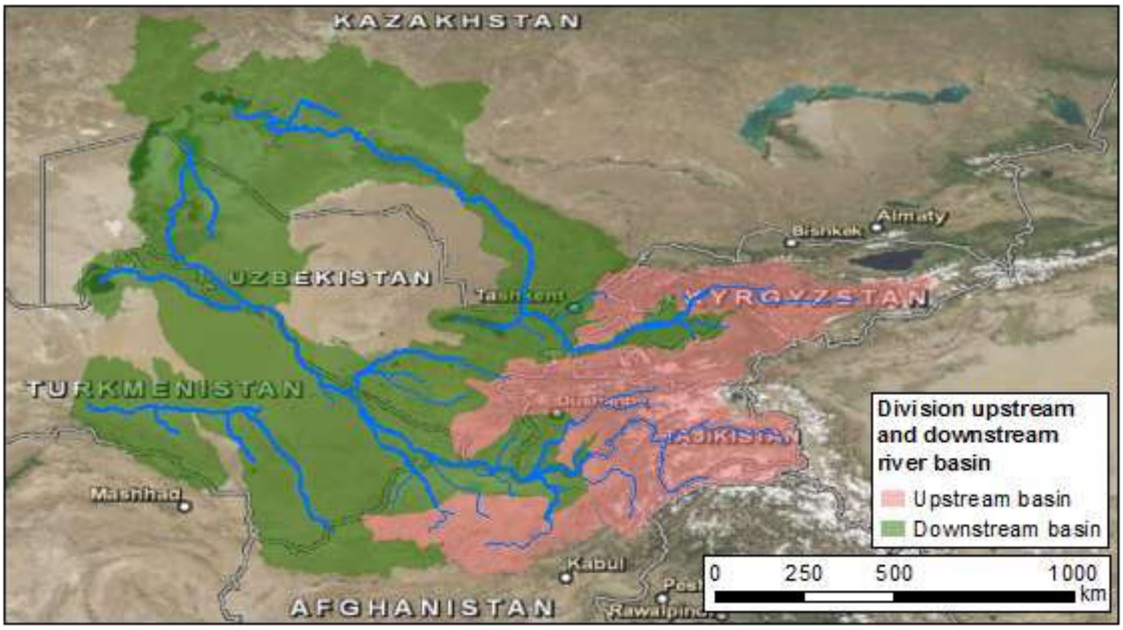

Figure 2-2: Division in upstream and downstream basin

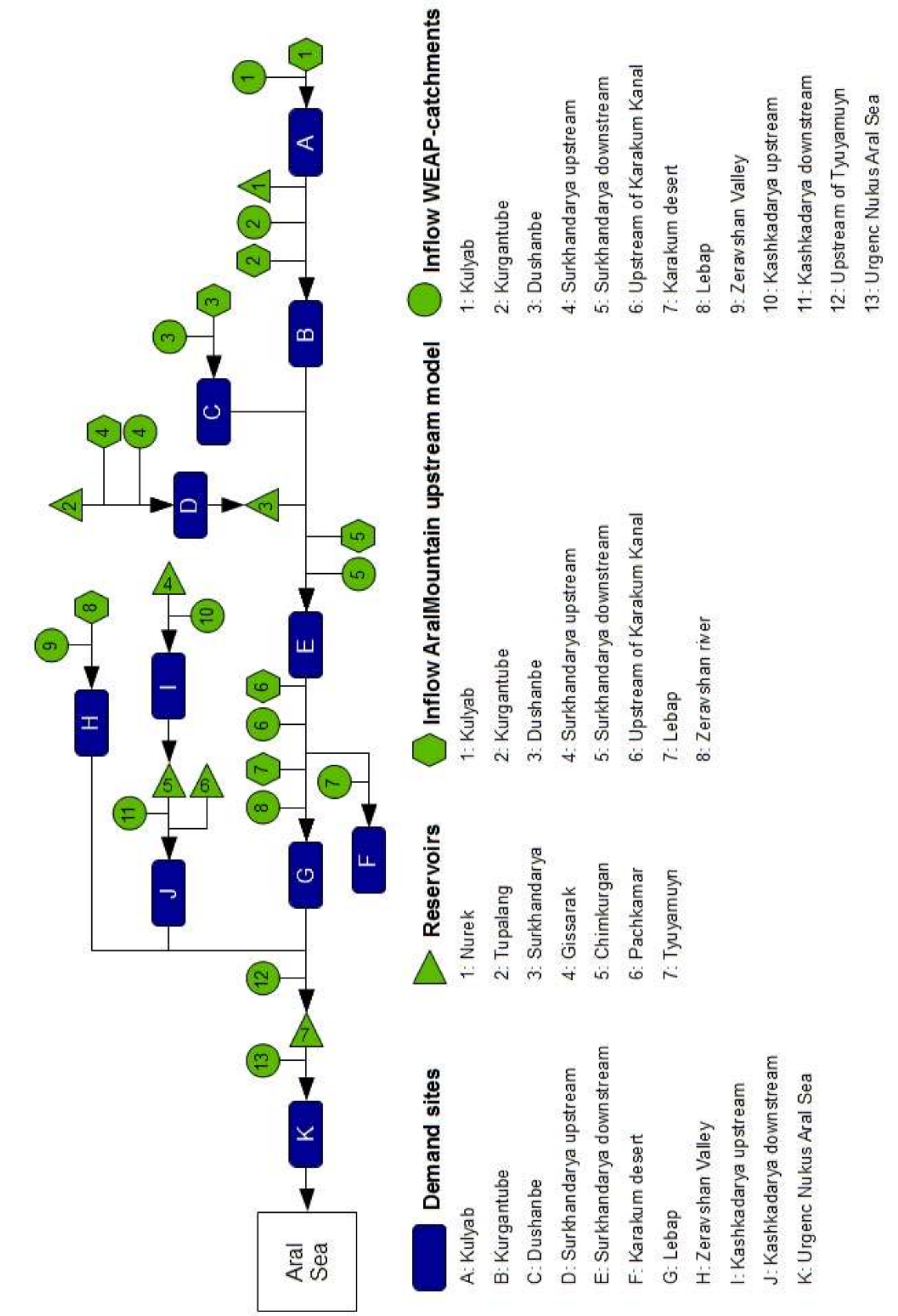

Figure 2-3: Schematic representation Amu Darya river basin in ARAL-WEAP model.

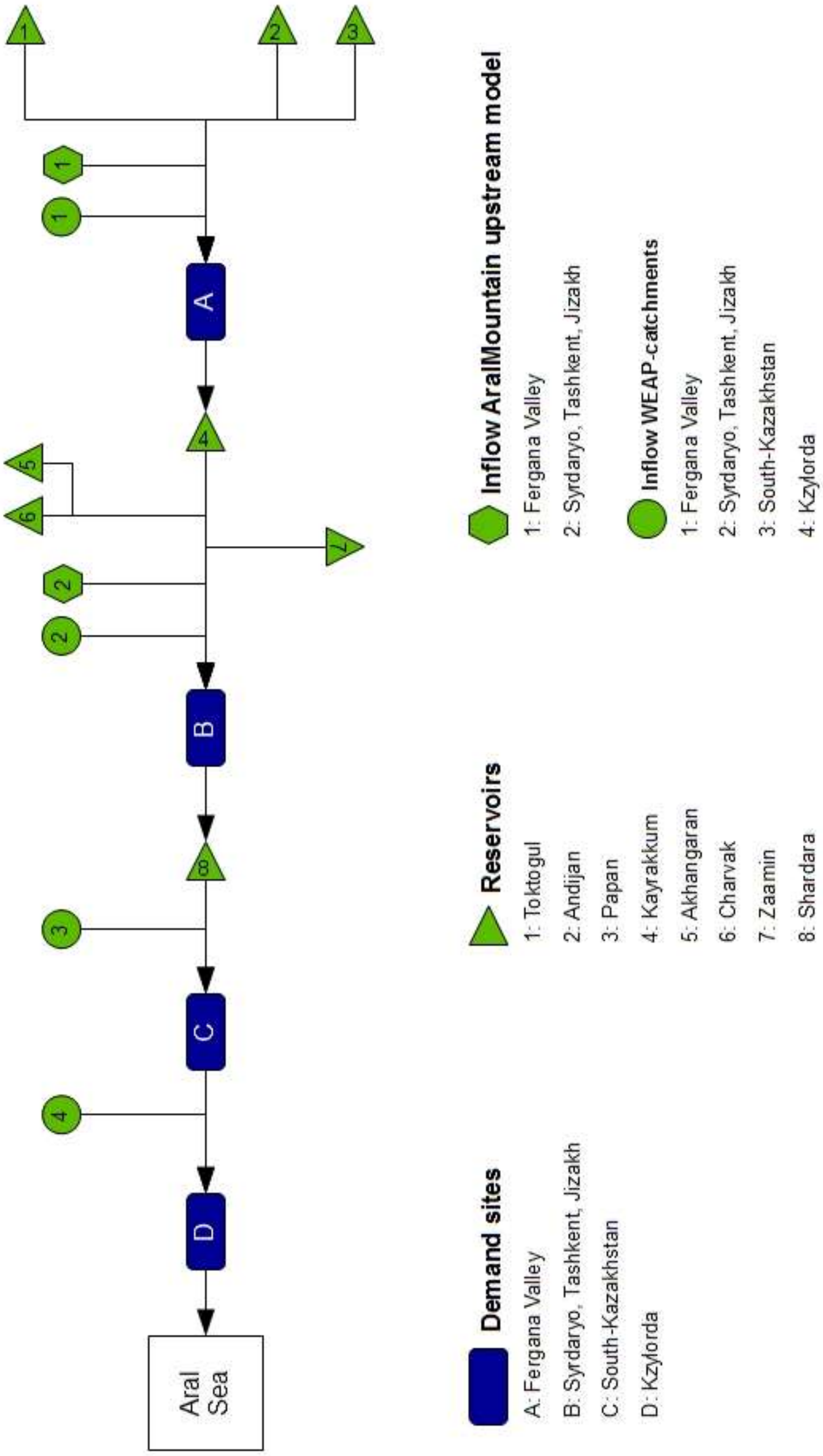

Figure 2-4: Schematic representation Syr Darya river basin in ARAL-WEAP model.

The division of the upstream and the downstream part approximates the division in areas without significant human interference and areas with significant human interference. Partly, this division is well defined where major reservoirs are located in the mountain ranges. Downstream of these locations, the stream flow is human-regulated. In other regions the division in upstream basin and downstream basin is less well defined. For those regions the division is made based on optical analysis of satellite imagery. This boundary approximates the division between the mountain environment and the lower land, extensively used by the human population.

As mentioned before the hydrology in the upstream basin is modeled in the AralMountain model. This is done for the current situation (2001-2010) as well as for future decades (2010-2050). For 2001-2010 the inflow from upstream is daily averaged over the ten years.
The generated model output (stream flow) is subsequently used in the ARAL-WEAP model as model input. To obtain stream flow data to be used as input in ARAL-WEAP, the daily generated runoff in the upstream basin is modeled for multiple subcatchments in the upstream basin corresponding to the demand sites and reservoirs used in ARAL-WEAP (Figure 2-5). In the schematic representations of the basins in ARAL-WEAP (Figure 2-3 and Figure 2-4) these inflows from the upstream model are indicated as 'Inflow AralMountain upstream model' and 'Reservoirs'. The figures also indicate in which order these inflows are added to the system. The geographical visualization of the ARAL-WEAP model (Figure 2-6) shows the geographical positioning of the rivers, demand sites, inflows, catchments, transmission links and return flows as represented schematically in Figure 2-3 and Figure 2-4.

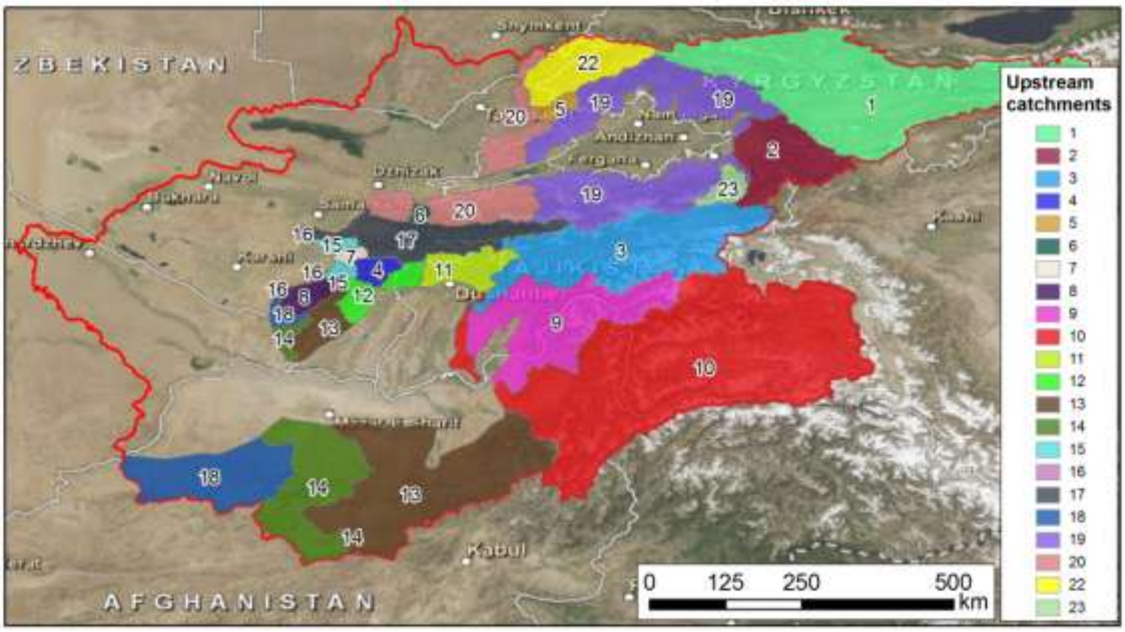

Figure 2-5: Subcatchments used in upstream model for input in downstream WEAP-model. See Table 1 for names of the subcatchments, which are also used in Figure 2-3 an Figure 2-4.

Table 1: Subcatchments upstream parts of the basin (Figure 2-5).

Catchment no.	Catchment name
1	Toktogul reservoir
2	Andijan reservoir
3	Nurek reservoir
4	Tupalangskoe reservoir
5	Akhangaran reservoir
6	Zaamin reservoir
7	Gissarak reservoir
8	Pachkamar reservoir
9	Kulyab catchment
10	Kurgantube catchment
11	Dushanbe catchment
12	Surkhandarya upstream catchment
13	Surkhandarya downstream catchment
14	Karukum kanal catchment
15	Kashkadarya upstream catchment
16	Kashkadarya downstream catchment
17	Zeravshan Valley catchment
18	Lebap upstream catchment
19	Fergana Valley catchment
20	Syrdaryo, Tashkent, Jizakh catchment
21	South Kazakhstan upstream catchment
22	Charvak reservoir
23	Papan reservoir

Based on geographical position and data availability, different demand sites were assigned. Each demand site has two components: agricultural demand and domestic demand. Data on reservoir properties, agricultural land use, and demography are taken from the online Central Asian Waterinfo portal.[1] Data on land use and populations in this database are arranged at province level for five countries in the Amu Darya and Syr Darya river basins (Uzbekistan, Kazakhstan, Tadzhikistan, Kyrgyzstan and Turkmenistan). No data is available in the database for Afghanistan, although a significant part of the Amu Darya river basin is situated in this country. The used data in the database is updated until the year 2000, which is assumed to be representative for the reference situation (2001-2010).

Since data on agriculture and population numbers are arranged at the province level, the division of demand sites was chosen in a way with close resemblance to the province boundaries. In some cases data of different provinces were combined to form one demand site and in other cases data of one province was divided over multiple demand sites.

[1] www.cawater-info.net

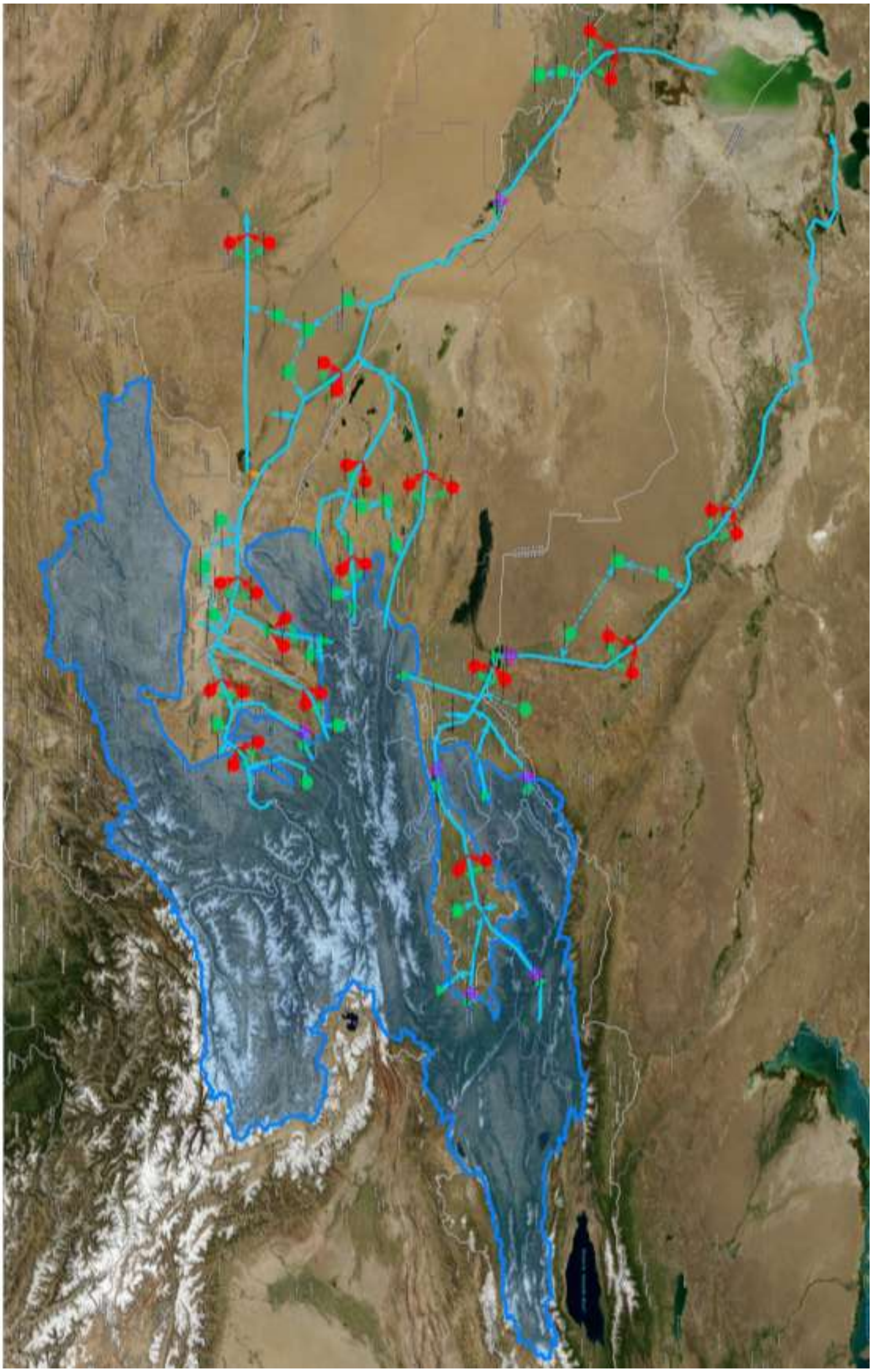

Figure 2-6: Geographical visualization of ARAL-WEAP model. AralMountain upstream model area is indicated with blue color. Demand sites are indicated with red dots, catchments are indicated with green dots.

For example, the demand site labeled ‘Fergana Valley’ is based on all provinces comprising the Fergana Valley. This means, data for the provinces Andijan, Namangan and Fergana provinces in Uzbekistan and data for the Jalalabad and Osh provinces in Kyrgyzstan are combined.
An example of a case where data of one province is divided over multiple demand sites is the Kashkhadarya province in Uzbekistan. This province was divided into an upstream demand site and a downstream demand site at the location of the Surkhandarya reservoir, since this is an important feature with high influence on water budgets and therefore needs to be incorporated in the ARAL-WEAP model. The division of population numbers and agricultural surface area over the demand sites is estimated based on satellite imagery. Table 2 shows the translation of provinces to demand sites as used in the model.

Table 2: Division of provinces over WEAP demand sites.

<table>
<tr><th>Demand site in WEAP</th><th colspan="2">Provinces</th></tr>
<tr><td>Dushanbe</td><td colspan="2">Rayons of republican subordination (TJK)</td></tr>
<tr><td rowspan="3">Fergana Valley</td><td>Andijan (UZB)</td><td>Jalalabad (KGZ)</td></tr>
<tr><td>Namangan (UZB)</td><td>Osh (KGZ)</td></tr>
<tr><td colspan="2">Fergana (UZB)</td></tr>
<tr><td rowspan="2">Karakum desert</td><td colspan="2">Mary (TKM)</td></tr>
<tr><td colspan="2">Akhal (TKM)</td></tr>
<tr><td>Kashkhadarya upstream</td><td colspan="2">20% of Kashkhadarya (UZB)</td></tr>
<tr><td>Kashkhadarya downstream</td><td colspan="2">80% of Kashkhadarya (UZB)</td></tr>
<tr><td>Kurgantube</td><td colspan="2">80% of Khatlon (TJK)</td></tr>
<tr><td>Kulyab</td><td colspan="2">20% of Khatlon (TJK)</td></tr>
<tr><td>Kzylorda</td><td colspan="2">Kzylorda (KAZ)</td></tr>
<tr><td>Lebap</td><td colspan="2">Lebap (TKM)</td></tr>
<tr><td>South Kazakhstan</td><td colspan="2">South Kazakhstan (KAZ)</td></tr>
<tr><td>Surkhandarya upstream</td><td colspan="2">40% of Surkhandarya</td></tr>
<tr><td>Surkhandaraya downstream</td><td colspan="2">60% of Surkhandarya</td></tr>
<tr><td rowspan="2">Syrdarya, Tashkent, Jizakh</td><td>Jizakh (UZB)</td><td>Tashkent (UZB)</td></tr>
<tr><td>Syrdarya (UZB)</td><td>20% of Sughd (TJK)</td></tr>
<tr><td rowspan="3">Urgenc, Nukus, Aral Sea</td><td colspan="2">Khorezm (UZB)</td></tr>
<tr><td colspan="2">Karakalpakistan (UZB)</td></tr>
<tr><td colspan="2">Dashoguz (TKM)</td></tr>
<tr><td rowspan="3">Zeravshan Valley</td><td colspan="2">Bukhara (UZB)</td></tr>
<tr><td colspan="2">Navoiy (UZB)</td></tr>
<tr><td colspan="2">Samarkand (UZB)</td></tr>
</table>

Water inflow is also generated in the downstream parts. This is incorporated in the WEAP-model. Catchments are assigned which coincide with the demand sites. For these catchments monthly mean, maximum and minimum temperature and total monthly precipitation are extracted from the 2001-2010 climate data set prepared by FMI. With this data the monthly incoming water (from precipitation) and the water lost by evapotranspiration is calulated. For this purpose the monthly reference evapotranspiration (ET_{ref}) is calculated using the Modified Hargreaves method [*Droogers and Allen*, 2002]. According to the Modiefied Hargreaves method, the reference evapotranspiration is defined as:

$$ET_{ref} = 0.0013 \cdot 0.408RA \cdot (Tavg + 17.0) \cdot (TD - 0.0123P)^{0.76}$$

Where RA is the incoming extraterrestrial radiation in $MJm^{-2}d^{-1}$, Tavg is the average temperature, TD is the temperature range (Tmax – Tmin) and P is the incoming precipitation. All of these parameters are calculated on a monthly basis from the climate data set. The agricultural area is not taken into account in the calculation of the catchment's evapotranspiration, since this is modeled for the agricultural demand sites in WEAP separately. Precipitation is calculated for the entire catchment, including the agricultural area. Rainfall-runoff is modelled according to the FAO rainfall-runoff model, which is incorporated in WEAP.

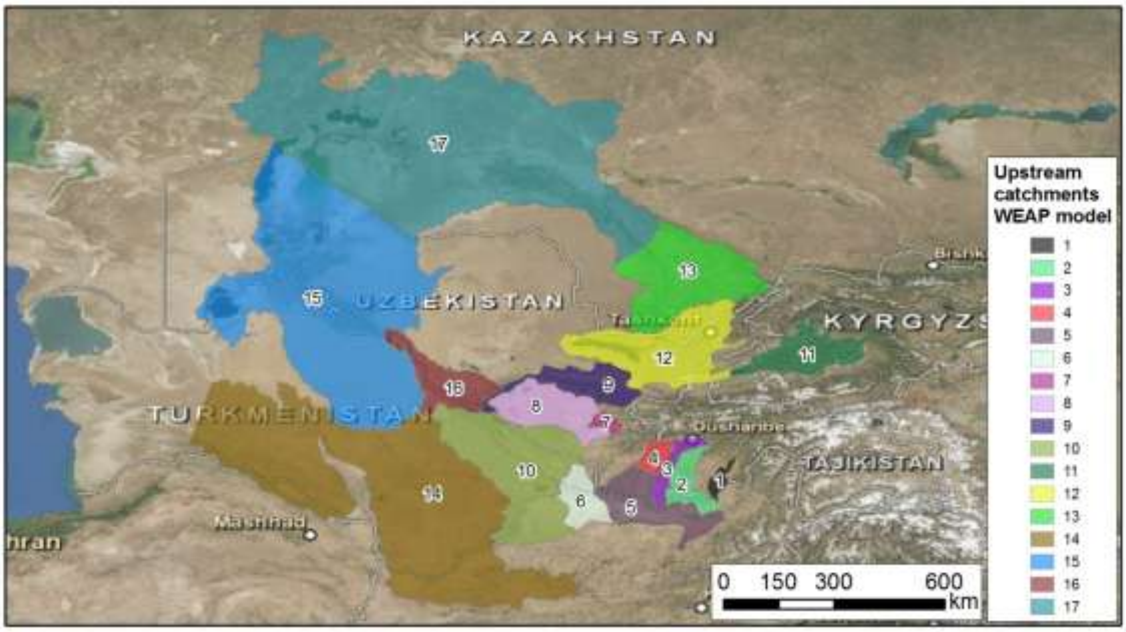

Figure 2-7: Downstream catchments used in WEAP model. See Table 3 for names of the subcatchments, which are also used in Figure 2-3 and Figure 2-4.

Table 3: Catchments used in the downstream model (Figure 2-7)

ID	Catchment name
1	Kulyab
2	KurganTube
3	Dushanbe
4	Surkhandarya upstream
5	Surkhandarya downstream
6	Karakum kanal
7	Kashkadarya upstream
8	Kashkadarya downstream
9	Zeravshan Valley
10	Lebap
11	Fergana Valley
12	Syrdaryo, Tashkent, Jizakh
13	South Kazakhstan
14	Karakum desert
15	Urgenc, Nukus, AralSea
16	Tyuyamuyn
17	Kzylorda

3 Reference Situation 2001-2010

3.1 Population

For the reference situation, population figures for the year 2000 are assumed to be representative. The population figures per demand site are presented in Figure 3-1.

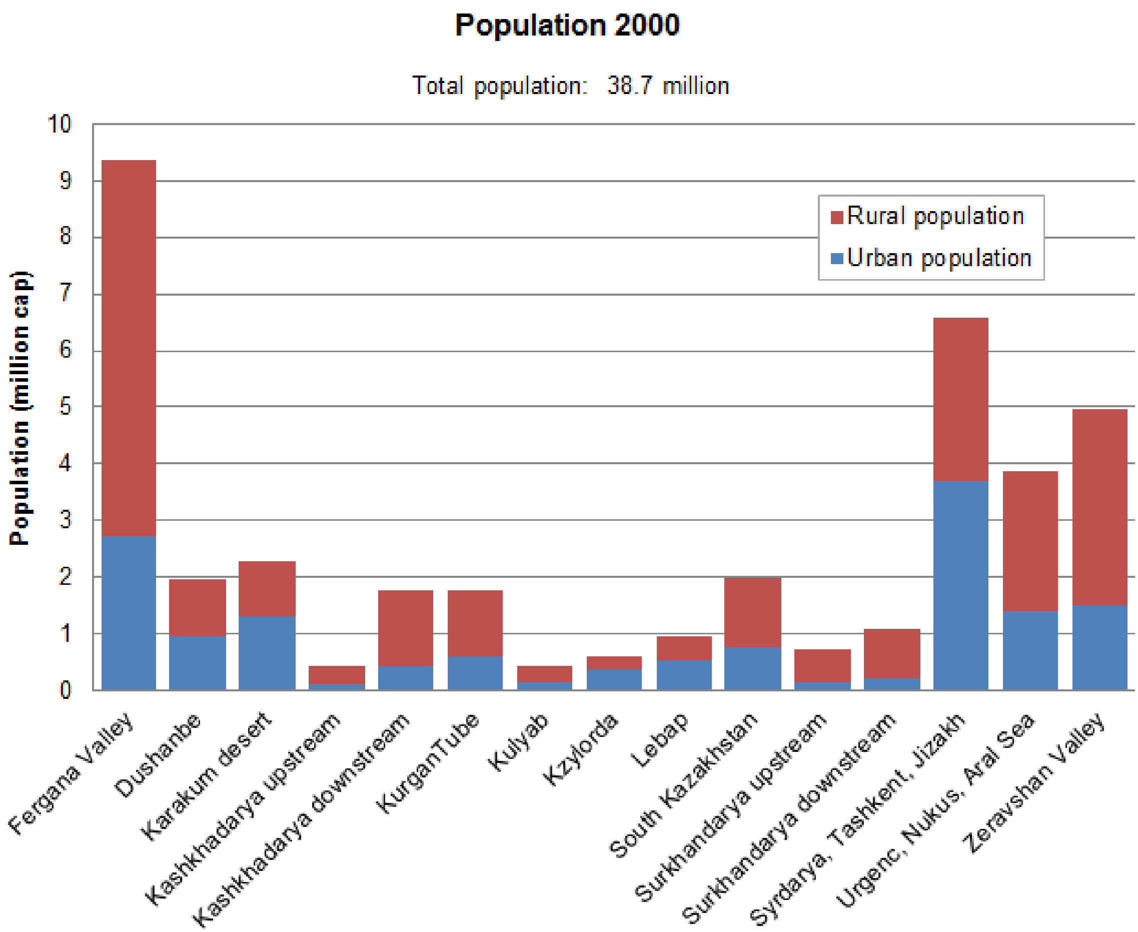

Figure 3-1: Population per demand site in 2000. Source: Central Asian Water Info database

Table 4: Domestic water allocation [*Aldaya et al.*, 2010]

Country	**Annual domestic water use (m^3/cap)**	**Monthly domestic water use (m^3/cap)**
Kazakhstan	39	3.25
Kyrgyzstan	63	5.25
Tajikistan	69	5.75
Turkmenistan	74	6.17
Uzbekistan	109	9.08
Average	*70.8*	*5.9*

These population numbers are used in ARAL-WEAP to calculate monthly domestic water demand. The annual water use rate per capita in this study is assumed to be 70.8 m^3 per capita. This is the average rate for the five countries in the basin (Table 4). The effective domestic consumption is estimated to be 10%, which means 90% of the water allocated for domestic purposes is returned to the system and is available downstream.

3.2 Agriculture

For the reference situation, data on agriculture for the year 2000 are assumed to be representative. Figure 3-2 shows the surface area used for agriculture for each demand site in 2000. Agricultural surface area is sub-categorized for eight crop or land use types (Cotton, forage crops, corn, orchards, cucurbits, grain crops, potatoes). The most important crop in both river basins is cotton. Other important crops are grain crops like wheat. There are large differences between the provinces regarding the types of crops that are grown.

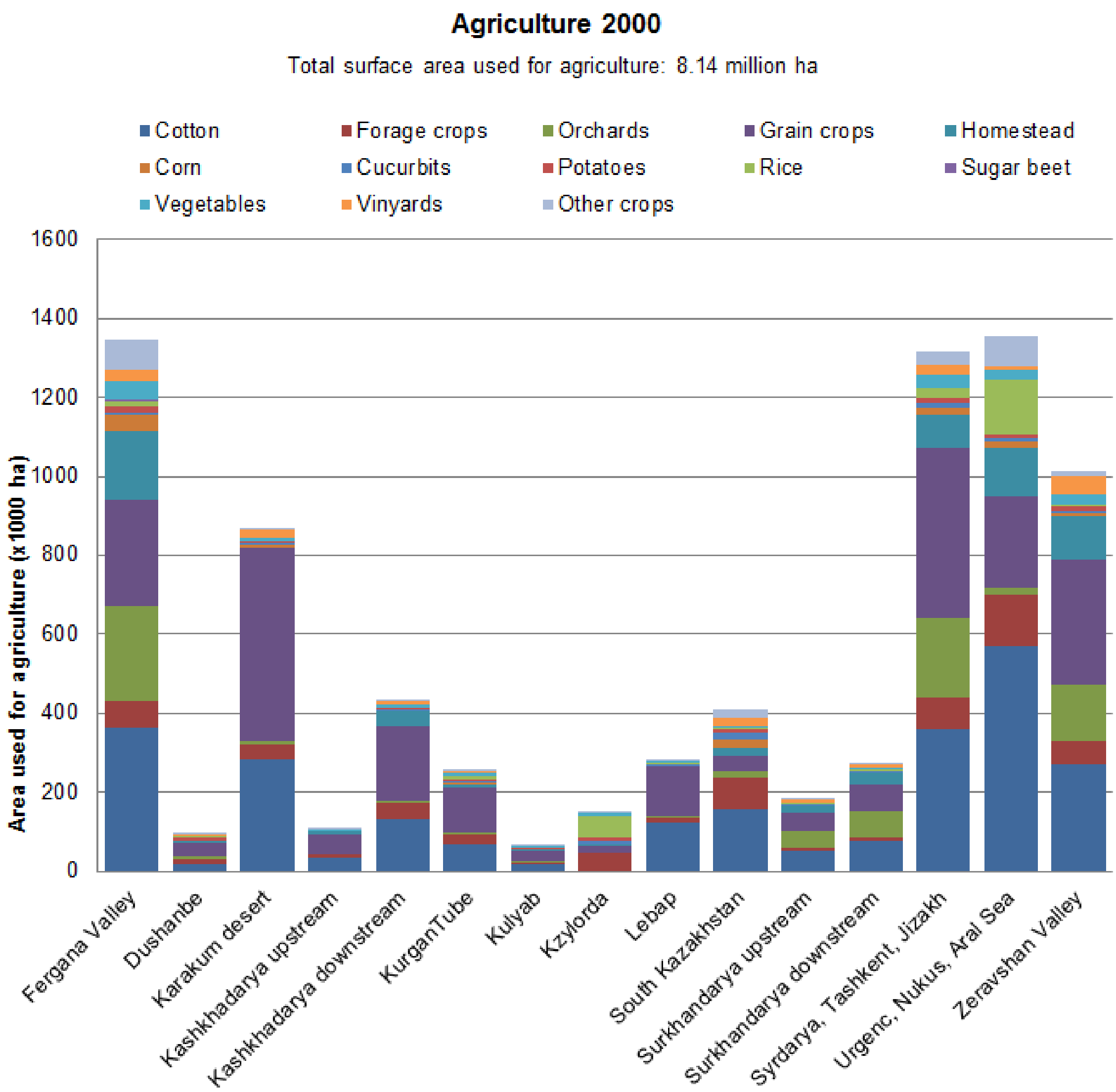

Figure 3-2: Agricultural area per demand site in 2000. Source: Central Asian Water Info database.

To assess the water demand for the agricultural areas it is essential to have a good estimate for the water demand of the different crop types and to have good insights in the crop calendar for the different crops. The crop calendar we use in this study is based on literature, whereas in the most ideal case, data on crop calendar comes from the region directly.

The potential evapotranspiration (ET_{pot}) is calculated using the reference evapotranspiration (ET_{ref}) and the crop coefficient (K_c):

$$ET_{pot} = Kc * ET_{ref}$$

Based on the availability of water, the actual evapotranspiration is calculated by WEAP.

The appropriate values for the crop coefficients and crop calendar are mainly based on the FAO guidelines for computing crop water requirements [*Allen et al.*, 1998] and information from FAO's crop water information website[1]. The crop coefficient differs for the different growth stages of a crop (Figure 3-3). These different crop coefficients are multiplied by the length of each growth stage and then averaged. Because the crops in the available data are often generalized (e.g. Grain crops, Vegetables, Orchards), a most representative crop is chosen.

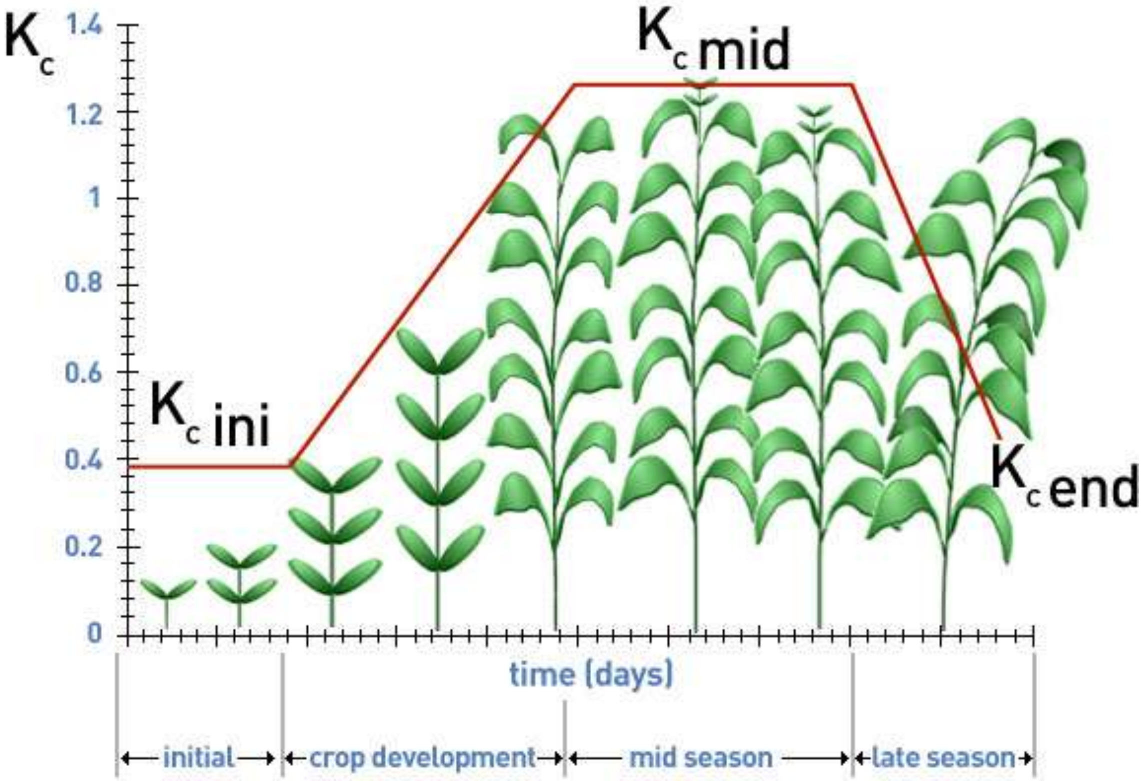

Figure 3-3: Example showing different values for the crop coefficient during the different growing stages of the crop. Source: FAO

[1] http://www.fao.org/nr/water/cropinfo.html

Table 5: Average crop coefficients for crops in the study area. Based on [*Allen et al.*, 1998]

	Average crop coefficient (Kc)
Cotton	0.78
Forage crops	0.76
Orchards	0.78
Grain crops	0.76
Homestead	0.78
Corn	0.81
Cucurbits	0.75
Potatoes	0.75
Rice	1.00
Sugar beet	0.83
Vegetables	0.88
Vinyards	0.49
Other crops	0.78

Table 6: Crop calendar. Numbers represent fraction of month that the crop is growing in the field. Data based on [*Allen et al.*, 1998] **and FAO website.**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cotton	0	0	0	0.5	1	1	1	1	1	0.5	0	0
Forage crops	0	0	1	1	1	1	1	1	1	1	0	0
Orchards	0	0	0	1	1	1	1	1	1	0	0	0
Grain crops	0	0	0.5	1	1	1	1	0	0	0	0	0
Homestead	0	0	0	0.5	1	1	1	1	0.5	0	0	0
Corn	1	1	1	1	0.33	0	0	0	0	0	0	0.5
Cucurbits	0	0	0	0	0	1	1	1	1	0	0	0
Potatoes	0	0	0	0	1	1	1	1	0	0	0	0
Rice	0	0	0	0	1	1	1	1	1	1	0	0
Sugar beet	1	1	1	1	1	0	0	0	0	0	1	1
Vegetables	0	0	0	1	1	1	1	0.5	0	0	0	0
Vinyards	0	0	0	1	1	1	1	1	1	1	0	0
Other crops	0	0	0	0.5	1	1	1	1	0.5	0	0	0

The efficiency of irrigation for the current situation is estimated to be 90% for upstream agricultural demand sites and 95% for downstream agricultural demand sites. These relatively high efficiencies are the total system ones. So reuse of water is included. Obviously, field efficiencies are much lower.

3.3 Reservoirs

Reservoirs are very important features for water management in the Amu Darya and Syr Darya river basins. The major reservoirs in the two river basins are incorporated in the ARAL-WEAP model (Figure 3-4 and Figure 3-5). The inflow for the reservoirs at the boundary between the upstream model and downstream model is calculated using the upstream AralMountain model. The daily inflow averaged over 2001-2010 is calculated and translated to monthly time steps for use in ARAL-WEAP. For the Syr Darya river basin these reservoirs are Toktogul, Andijan, Charvak, Papan, Akhangaran and Zaamin. For the Amu Darya river basin these reservoirs are

Nurek, Tupalangsku, Pachkamar and Gissarak. The inflows in downstream reservoirs, located in between demand sites are calculated within the ARAL-WEAP model.

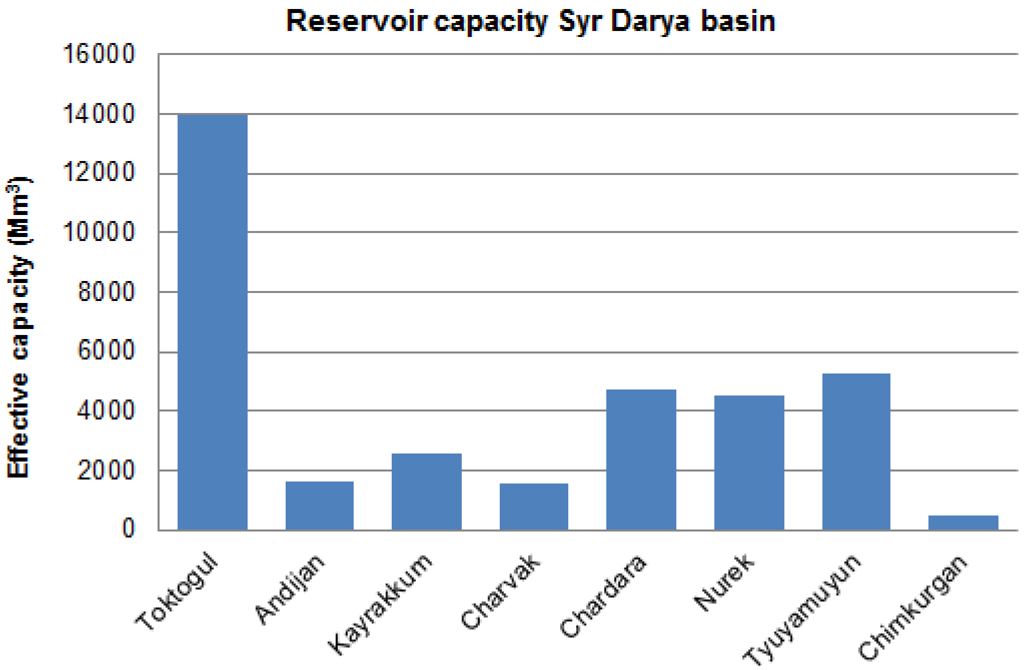

Figure 3-4: Effective storage capacity for major reservoirs in the Syr Darya river basin. Source: Central Asian Water Info database.

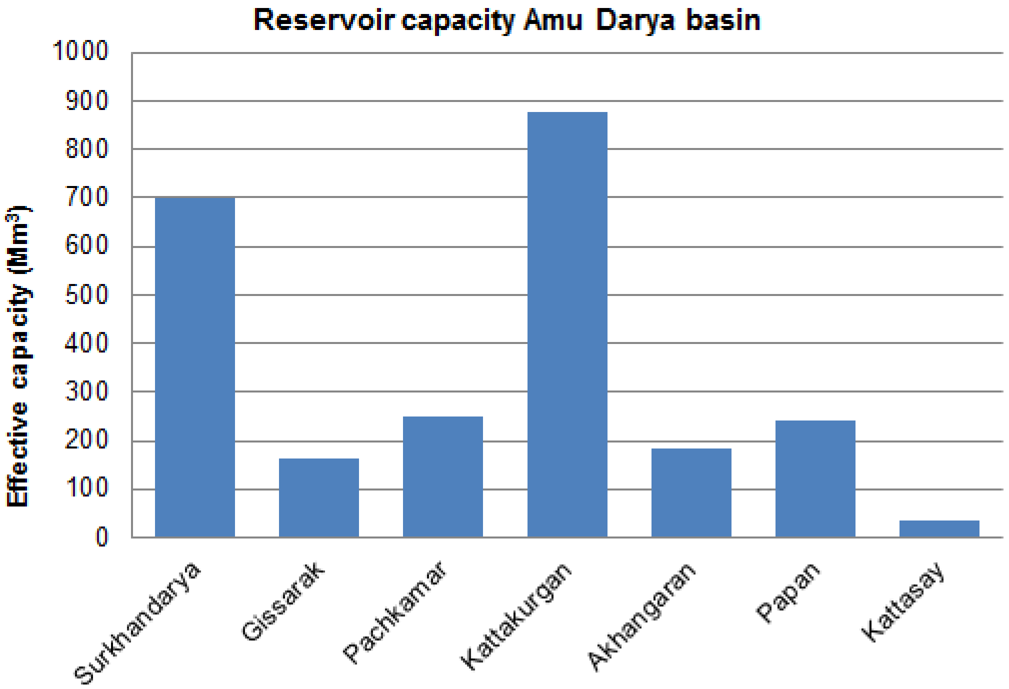

Figure 3-5: Effective storage capacity for major reservoirs in the Amu Darya river basin. Source: Central Asian Water Info database.

3.4 Calibration

The ARAL-WEAP model is calibrated for the reference situation using available data for seven major reservoirs in the basins as well as available data on inflows into the Aral Sea as provided by Central Asian Waterinfo Database. A first estimate on the reliability of these data has been made. In the database, three measurements per month for reservoir inflow, release and storage volume are published. The given observed volumes however, differ significantly from values for volumes which are calculated by adding the observed inflow and subtracting the observed outflow from the initial volume. These differences are shown in Figure 3-6 to Figure 3-10. The cause for this bias between the observed volumes and volumes calculated from the observed in- and outflows is uncertain. Volume losses could be explained to some extent by high evaporation and/or seepage losses and increases in volume could be explained to some extent by inflow of groundwater. Total losses from reservoirs due to evaporation and infiltration in the Amu Darya are estimated to be 14,000 Mm^3 per year[1].

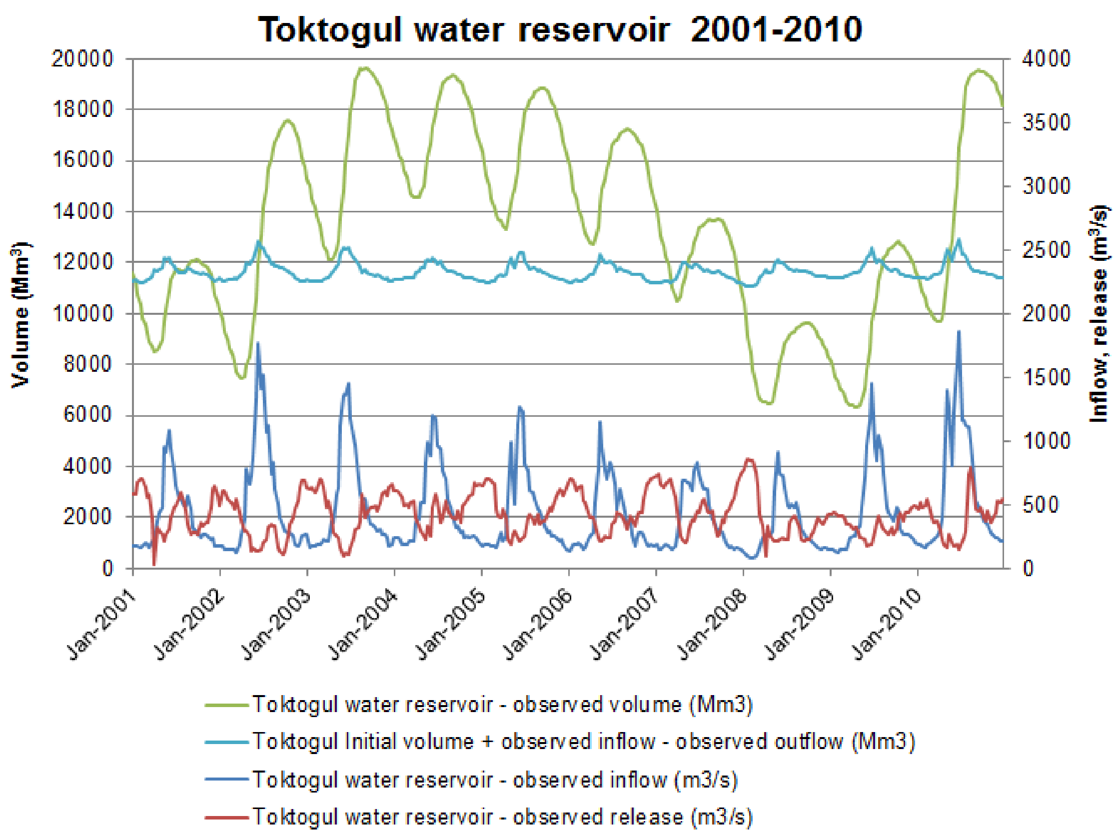

Figure 3-6: Observed inflow, outflow and volume data for Toktogul reservoir 2001-2010. Source: Central Asian Waterinfo Database.

[1] http://www.cawater-info.net/amudarya/losses_e.htm

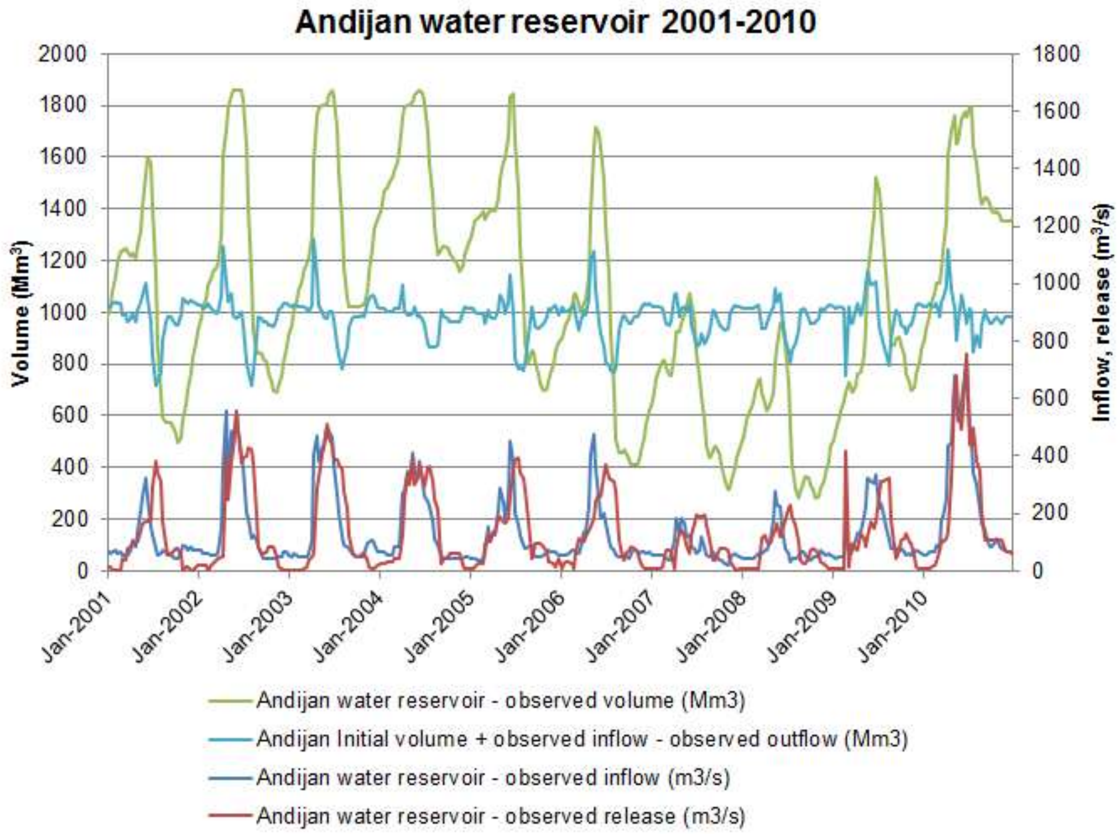

Figure 3-7: Observed inflow, outflow and volume data for Andijan reservoir 2001-2010. Source: Central Asian Waterinfo Database.

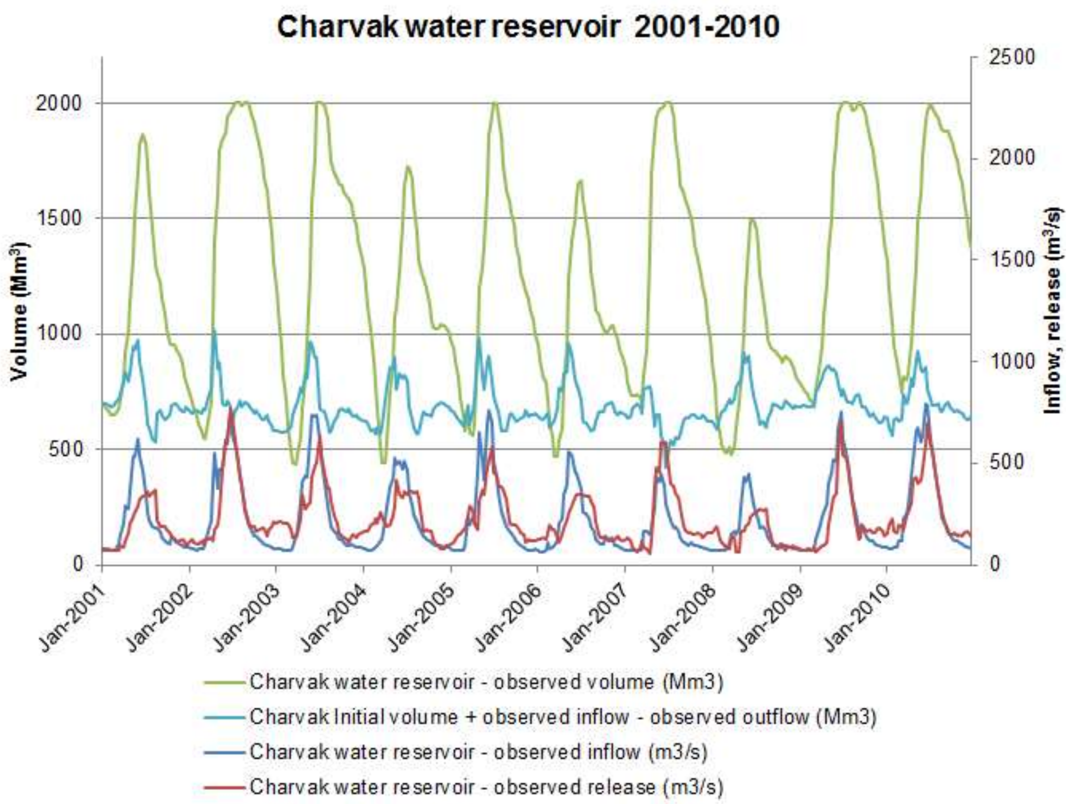

Figure 3-8: Observed inflow, outflow and volume data for Charvak reservoir 2001-2010. Source: Central Asian Waterinfo Database.

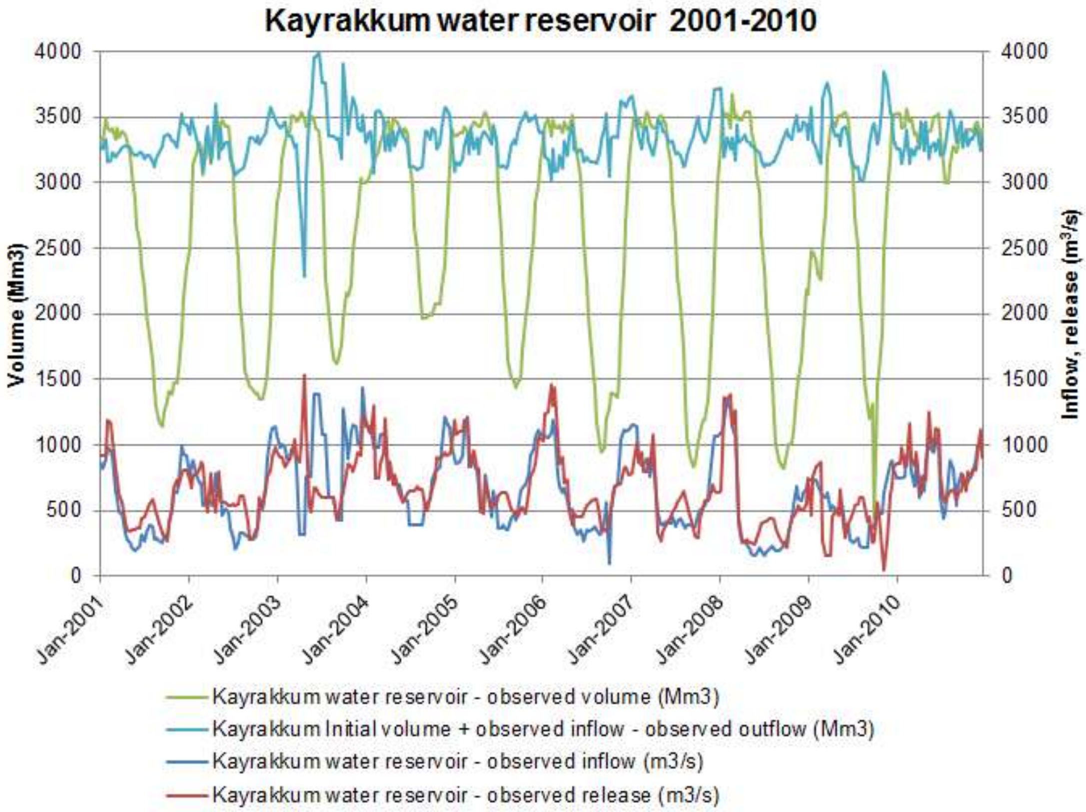

Figure 3-9: Observed inflow, outflow and volume data for Kayrakkum reservoir 2001-2010. Source: Central Asian Waterinfo Database.

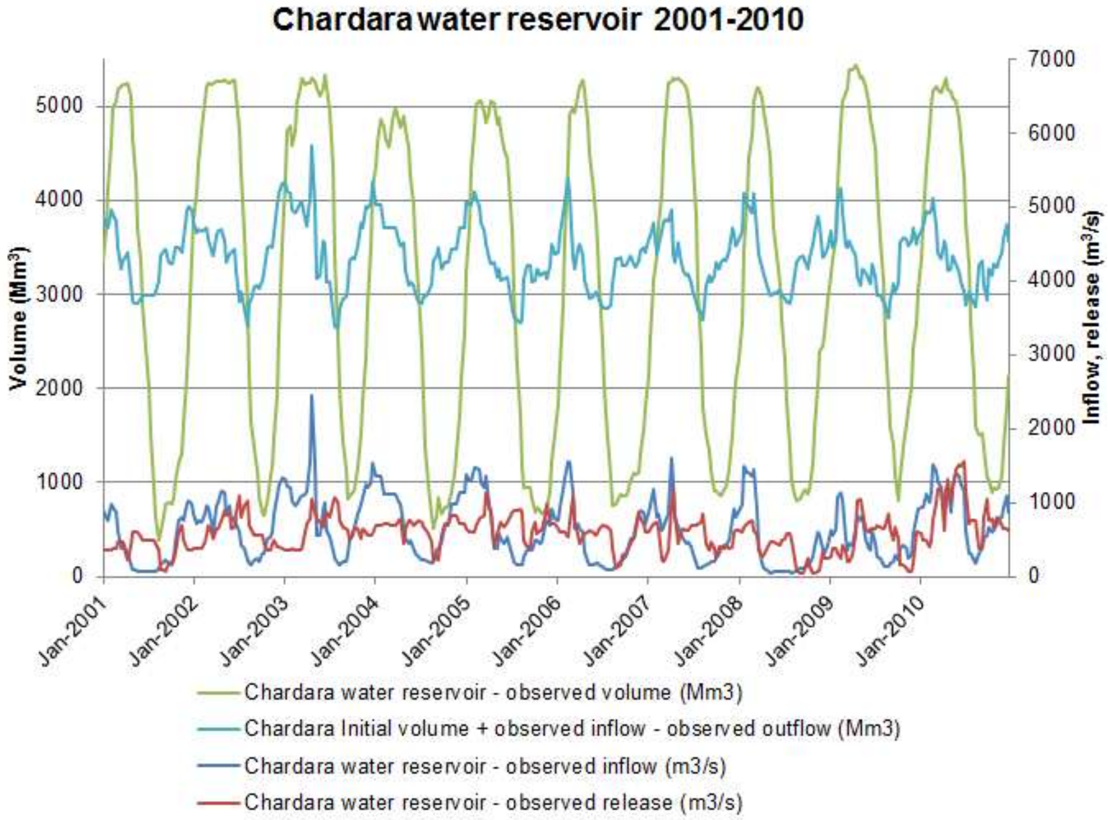

Figure 3-10: Observed inflow, outflow and volume data for Chardara reservoir 2001-2010. Source: Central Asian Waterinfo Database.

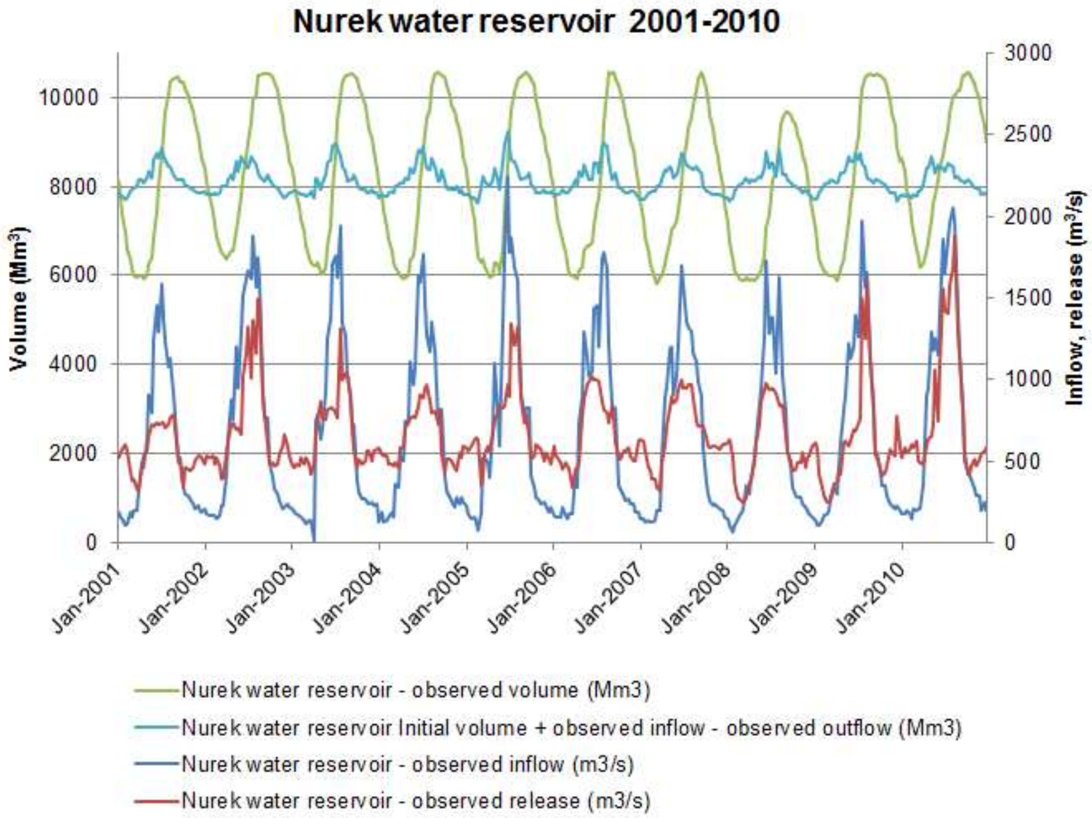

Figure 3-11: Observed inflow, outflow and volume data for Nurek reservoir 2001-2010. Source: Central Asian Waterinfo Database.

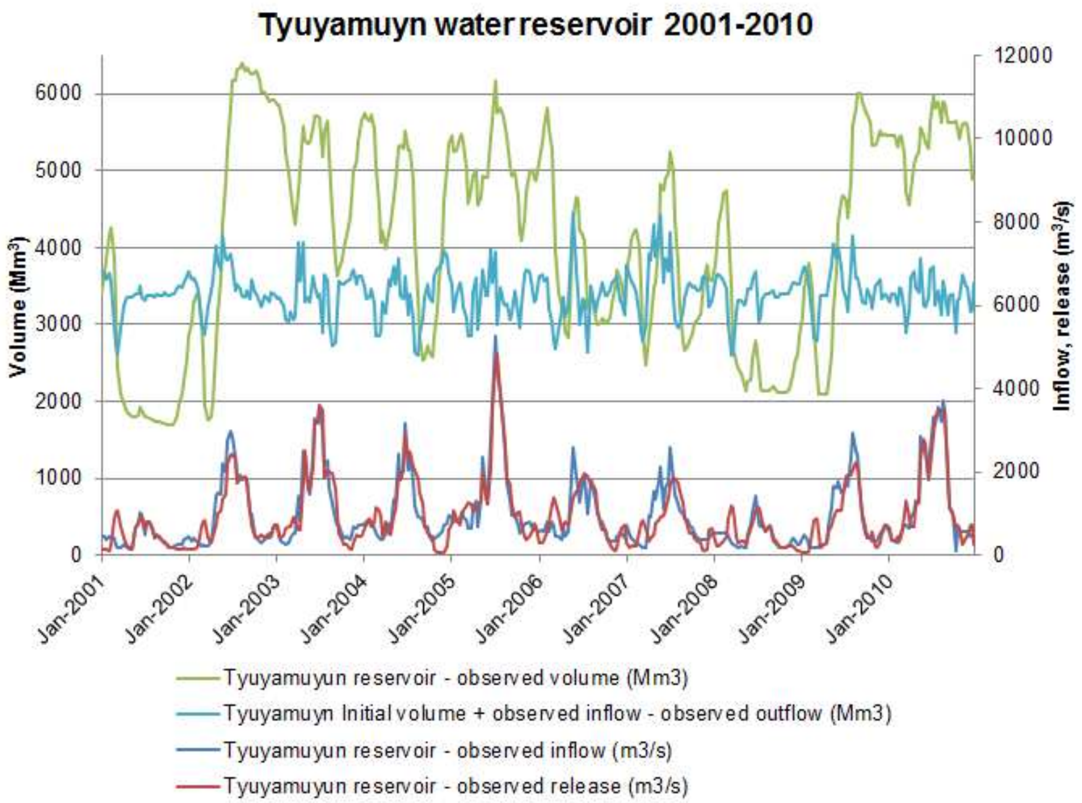

Figure 3-12: Observed inflow, outflow and volume data for Tyuyamuyun reservoir 2001-2010. Source: Central Asian Waterinfo Database.

Despite some questions on the reliability of the observed data as presented in the previous section, these data were used to validate/calibrate the ARAL-WEAP model. Initially, the ARAL-WEAP model performed already satisfactory before any calibration as performed. After some further fine-tuning using the calibration parameters (Table 8, Table 9), the model performed very satisfactory. The parameters are calibrated separately for the Syr Darya basin and the Amu Darya basin.

For each of the two basins the calibration is done for an average year in the reference period (2001-2010). All daily values are averaged for the ten year period to obtain the average year. The model performs very well for the reference period. For the Syr Darya basin, observed reservoir inflow, outflow and volume are available for Toktogul, Andijan, Charvak, Kayrakkum and Chardara reservoirs. For the Amu Darya basin, these data are available for Nurek and Tyuyamuyn reservoirs.

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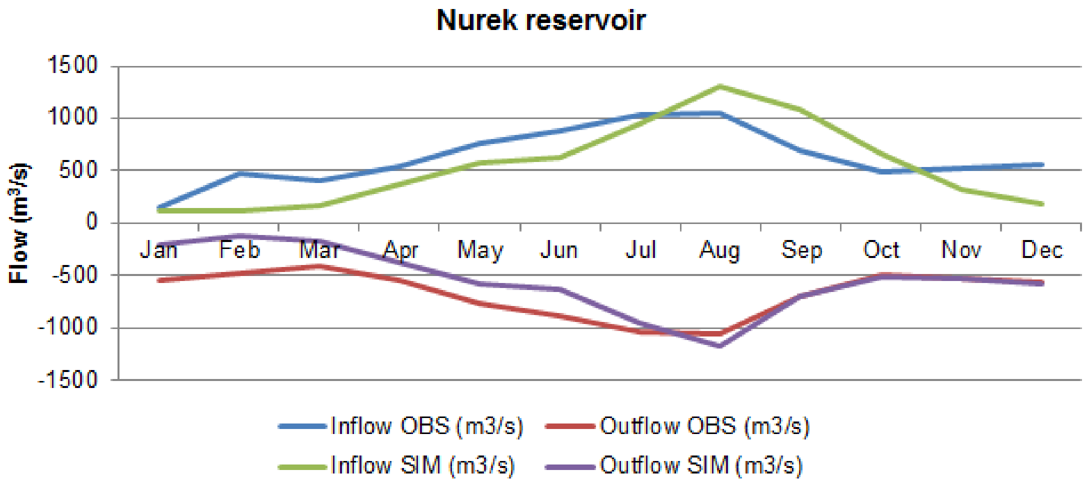


Figure 3-13: Observed and simulated in- and outflows Nurek reservoir reference period.

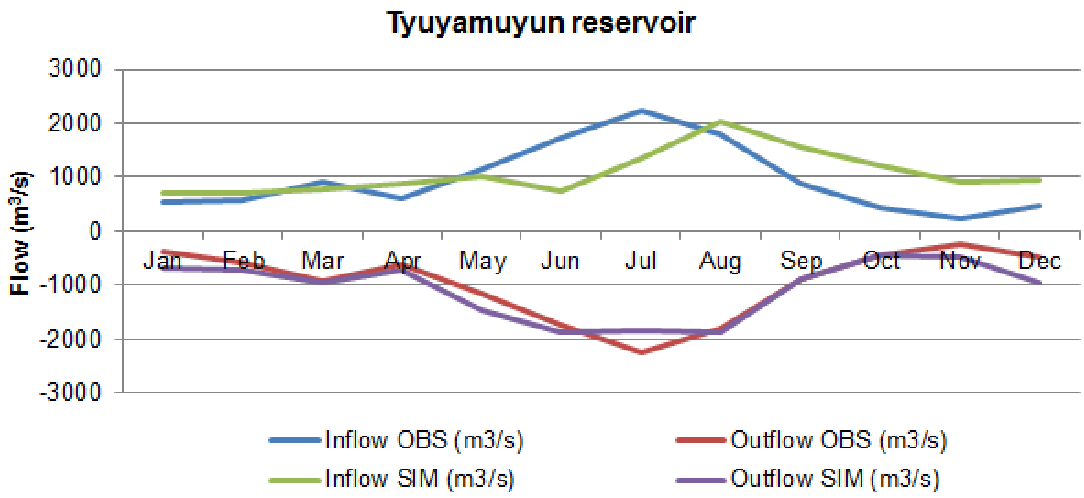


Figure 3-14: Observed and simulated in- and outflows Tyuyamuyun reservoir reference period.

When we let the model regulate the water release from the reservoirs based solely on downstream agricultural and domestic demand, the outflow numbers differ from the observed numbers. In reality, other interests next to agricultural and domestic water use, like for example the generation of hydropower, are considered in the water release regime of reservoirs. Since these other interests are not included in the model, certain rules are applied to the reservoirs to mimic the water release regime that was observed for the reference period. Examples of observed and simulated in- and outflows for reservoirs are shown in Figure 3-13 and Figure 3-14

Besides reservoir data, the model is also calibrated using available data for Aral Sea inflow from the Amu Darya and Syr Darya (Table 7). Total observed average annual inflow during the reference period into the Aral Sea is 7082 Mm^3 for the Syr Darya and 7309 Mm^3 for the Amu Darya. Table 8 and Table 9 list the calibrated parameters used in the ARAL-WEAP model.

Table 7: Observed and simulated average annual inflow into the Aral Sea for the reference period 2001-2010

River	Observed (Mm^3)	Simulated (Mm^3)	Bias
Amu Darya	7309	7419	1.5%
Syr Darya	7082	7440	5.0%

Table 8: Calibrated parameters ARAL-WEAP model Syr Darya basin

Parameter	Value
Double cropping factor	1.30
Return flow upstream	10%
Return flow downstream	5%
Domestic consumed	10%
Downstream runoff factor	0.1
Loss from riverbed South Kazakhstan - Kzylorda	15.5%

Table 9: Calibrated parameters ARAL-WEAP model Amu Darya basin

Parameter	Value
Double cropping factor	1.35
Return flow upstream	10%
Return flow downstream	5%
Domestic consumed	10%
Downstream runoff factor	0.1
Loss from riverbed PyandjVakshKerki	1.97%
Loss from riverbed Kerki-Tyumayun	10.36%
Loss from riverbed downstream Tyumayun	14.23%
Loss from riverbed downstream Urgenc Nukus	13.50%

A double cropping factor was introduced to correctly simulate the use of a plot of land for multiple crops throughout the year. This factor is calibrated for both basins separately. A downstream runoff factor was introduced to produce more realistic runoff generation in the downstream catchments. Since these areas have a very sandy subsoil, the infiltration rates are estimated to be very high. To compensate for this effect, which is not incorporated in the FAO rainfall runoff module in WEAP, we estimate that 90% of generated runoff is lost due to infiltration.

Seepage losses of water into the sandy subsoil is also very important for the actual streams of the Amu Darya and Syr Darya. Besides, water loss due to evaporation is significant given the fact that temperatures get very high in the downstream parts of the basins. Unfortunately, information regarding riverbed losses is very sparse and estimates are not very accurate. Some estimates for riverbed losses for the Amu Darya are reported at the Central Asian Water database[1]. We used these estimates in our model and made assumptions for loss from the riverbed in the Syr Darya basin.

After calibration the model was run and validated by comparing simulated water demand for irrigated farming in the Amu Darya basin to the reported demand for irrigated farming. The model simulates an average annual demand of 56,672 Mm^3 on average for 2001-2010. This correlates excellent to the observed annual demand varying from 56,638 to 58,565 Mm^3 for 1997-2010, with a bias of 0.06% to 3.23%.

The average annual modeled water balance for both basins are illustrated in Figure 3-15 and Figure 3-16, showing the calculations regarding inflows, demands, precipitation, evapotranspiration and runoff generation in catchments.

[1] http://www.cawater-info.net/amudarya/losses_e.htm

Annual water balance WEAP Syr Darya (2001-2010)

Inflow upstream model	(blue)
Demand site	(red)
Catchment	(green)

Parameters:	
Double cropping factor Syr Darya	1.3
Return flow upstream	10%
Return flow downstream	5%
Domestic consumed	10%
Downstream runoff factor	0.1
Loss from riverbed Syr Darya	15.5%

IN				River Flow					OUT	OUT
	Area (ha)	mm	Mm^3	Mm^3		Area (ha)	mm	Mm^3	Return flow	Observed (Mm3)
Inflow Toktogul			17353							14028
Inflow Andijan			3481							4202
Inflow Papan			676							
Inflow AralMountain model other			10212							
				31722						
Pcatchment	2136264	272	5812		ETact catchment	2136264	166	3541		
				33993						
					Fergana Valley					
					Agriculture	1346500	1120	15075	0.1	
					Domestic			662	0.1	
				20360						20708
Inflow Akhangaran			362							
Inflow Charvak			3470							7065
Inflow Zaamin			119							
Inflow AralMountain model other			4952							
				29263						
Pcatchment	4744339	228	10828		ETact catchment	4744339	199	9431		
				30660						
					Syrdaryo, Tashkent, Jizakh					
					Agriculture	1316000	1193	15698	0.1	
					Domestic			466	0.1	
				16485						20040
					Loss from riverbed				15.5%	
				13930						
Pcatchment	5052690	256	12929		ETact catchment	5052690	209	10567		
				14166						
					South Kazakhstan					
					Agriculture	409420	1157	4739	0.05	
					Domestic			140	0.1	
				9651						
					Loss from riverbed				15.5%	
				8155						
Pcatchment	24342716	237	57618		ETact catchment	24342716	202	49281		
				8988						
					Kzylorda					
					Agriculture	152410	1155	1760	0.05	
					Domestic			42	0.1	
				7312						
					Loss from riverbed				15.5%	
				6179						7082
				ARAL SEA						

Figure 3-15: Average annual water balance Syr Darya ARAL-WEAP reference period (2001-2010). P catchment is rainfall in the cathment; ETact catchment is the actual evapotranspiration from the natrual landscape and the rainfed crops.

Annual water balance WEAP Amu Darya (2001-2010)

Inflow upstream model	(blue)
Demand site	(red)
Catchment	(green)

Double cropping factor Amu Darya	1.35
Return flow upstream	10%
Return flow downstream	5%
Domestic consumed	10%
Downstream runoff factor	0.1
Loss from riverbed per reach 1	1.97%
Loss from riverbed per reach 2	10.36%
Loss from riverbed per reach 3	14.23%
Loss from riverbed per reach 4	13.50%

Amu Darya 2001-2010	IN	Area (ha)	mm	Mm3	River Flow Mm3	OUT	Area (ha)	mm	Mm3	Return flow	
	Inflow Amu Darya			10960							
					10960						
					10960						
Kulyab	Pcatchment	270284	250	675		ETact catchment	270284	220	595		
					11039						
					11039						
						Kulyab					
						Agriculture	63340	1053	667	0.1	
						Domestic			31	0.1	
					10435						
	Inflow Kurgantube			39500							
					49936						
Kurgantube	Pcatchment	1029211	330	3392		ETact catchment	1029211	233	2398		
					50930						
	Inflow Nurek			16772							
					67702						
					66368	1.97%					
						Kurgantube					
						Agriculture	253360	1141	2892	0.1	
						Domestic			125	0.1	
					63753						
					62497	1.97%					
	From Dushanbe inflow			1806							1
					64303						
					63036	1.97%					
	Inflow Surkhandarya downstream			8718							
					71754						
					70340	1.97%					
Surkhandarya downstream	Pcatchment	2506984	152	3821		ETact catchment	2506984	131	3280		
					70394						
	From Surkhandarya inflow			2266							2
					72661						
					71229	1.97%					
						Surkhandarya downstream					
						Agriculture	272700	1096	2989	5%	
						Domestic			76	10%	
					68382						
					67035	1.97%					
	Karakum kanal PCRaster inflow			3308.9							
					70344						
					68958	1.97%					
Karakum kanal	Pcatchment	1198385	293	3512		ETact catchment	1198385	249	2990		
					69011						
					67651	1.97%					
						To Karakum desert			11783		3
					55868						
					50080	10.36%					
Lebap	Pcatchment	6623242	234	15477		ETact catchment	6623242	205	13556		
					50272						

To be continued on next page

					45064	10.36%				
						Lebap				
						Agriculture	279130	1075	3000	5%
						Domestic			67	10%
					42208					
					37835	10.36%				
	From Kashkadarya inflow			0						4
					37835					
					33915	10.36%				
	Zeravshan Valley inflow			0						5
					33915					
					30402	10.36%				
	Lebap PCRaster inflow			4337						
					34739					
					31140	10.36%				
Tyuyamuyn	Pcatchment	1992814	110	2192		ETact catchment	1992814	110	2192	
					31140					
					27914	10.36%				
					23942	14.23%				
Urgenc_Nukus_AralSea	Pcatchment	19419441	193	37569		ETact catchment	19419441	183	35502	
					24148					
					20888	13.50%				
						Urgenc Nukus AralSea				
						Agriculture	1354900	1246	16885	5%
						Domestic			274	10%
					4820					
					4170	13.50%				
					ARAL SEA					

	IN				River Flow				OUT	
		Area (ha)	mm	Mm3	Mm3		Area (ha)	mm	Mm3	Return flow
	Inflow Dushanbe			3203						
					3203					
Dushanbe	Pcatchment	585388	169	992		ETact catchment	585388	159	928	
					3267					
						Dushanbe				
						Agriculture	92810	1732	1608	10%
						Domestic			138	10%
1					1806					

	IN				River Flow				OUT	
		Area (ha)	mm	Mm3	Mm3		Area (ha)	mm	Mm3	Return flow
	Inflow Tupalang			2107						
	Inflow Surkhandarya upstream			2322						
					4430					
Surkhandarya upst	Pcatchment	458271	182	832		ETact catchment	458271	156	714	
					4548					
						Surkhandarya upstream				
						Agriculture	181800	1391	2530	10%
						Domestic			50	10%
2					2266					

3

	IN	Area (ha)	mm	Mm3	River Flow Mm3		Area (ha)	mm	OUT Mm3	Return flow
Karakum desert	Pcatchment	21518520	197	42328		ETact catchment	21518520	187	40195	
					213					
						Karakum desert				
						Agriculture	865180	1368	11834	
						Domestic			162	
					-11783					

4

	IN	Area (ha)	mm	Mm3	River Flow Mm3		Area (ha)	mm	OUT Mm3	Return flow
	Gissarak inflow			353						
					353					
Kashkadarya upstream	Pcatchment	251075	319	801		ETact catchment	251075	231	581	
					573					
						Kashkadarya upstream				
						Agriculture	107760	1292	1392	10%
						Domestic			31	10%
					0					
	Pachkamar inflow			551.9						
					552					
Kashkadarya downstream	Pcatchment	2346324	152	3576		ETact catchment	2346324	143	3345	
					575					
						Kashkadarya downstream				
						Agriculture	431050	1301	5607	5%
						Domestic			126	10%
					-4764					

5

	IN	Area (ha)	mm	Mm3	River Flow Mm3		Area (ha)	mm	OUT Mm3	Return flow
	Zeravshan PCRaster inflow			6855						
					6855					
Zeravshan Valley	Pcatchment	1787672	171	3055		ETact catchment	1787672	122	2181	
					6942					
						Zeravshan Valley				
						Agriculture	1012100	1433	14503	10%
						Domestic			350	10%
					-6145					

Figure 3-16: Average annual water balance Amu Darya ARAL-WEAP reference period (2001-2010).

3.5 Water availability and unmet demand

This paragraph list the modeling results for the reference situation. As described in the previous paragraphs, the model runs for the average year of the ten year interval 2001-2010. Modeling output therefore is also representative for the average situation. In years where climate/hydrology/agricultural activity differs from the average year, demand and unmet demand will be different. The model runs at a monthly time-step, providing monthly output. Here we report the agricultural and domestic demand and unmet demand differentiated for the Syr Darya basin and the Amu Darya basin.

3.5.1 Demand and unmet demand Syr Darya basin

In the Syr Darya basin the agricultural demand is about 35 times larger than the domestic demand averaged over the year. During summer months, the agricultural demand can be 95 times larger than the domestic demand. Agricultural demand varies from nearly 0 Mm^3 per month in winter to 8600 Mm^3 per month in July (Figure 3-17). The largest amounts of water are used in the Fergana Valley and the areas directly downstream of the Fergana Valley.

Unmet agricultural demands occur in the summer months (July, August and September) for all demand sites, when the demand is at its maximum and inflow from the mountains gets lower (Figure 3-18). The water storage in reservoirs is largely depleted by July.

The domestic demand remains constant throughout the year (Figure 3-19). Variations in the diagrams are due to a different number of days in a month. For the Syr Darya basin, the domestic demand is around 110 Mm^3 per month.

Although the domestic demand is very small compared to the agricultural demand, unmet demands do occur (Figure 3-20). In the summer months (July, August, September), unmet demands occur simultaneously to the period of unmet agricultural demands. But also in winter (January, February, December) demands are unmet because of the stagnating flow from the upstream mountains.

The unmet demand for the entire Syr Darya basin is around 8.8% on an annual basis.

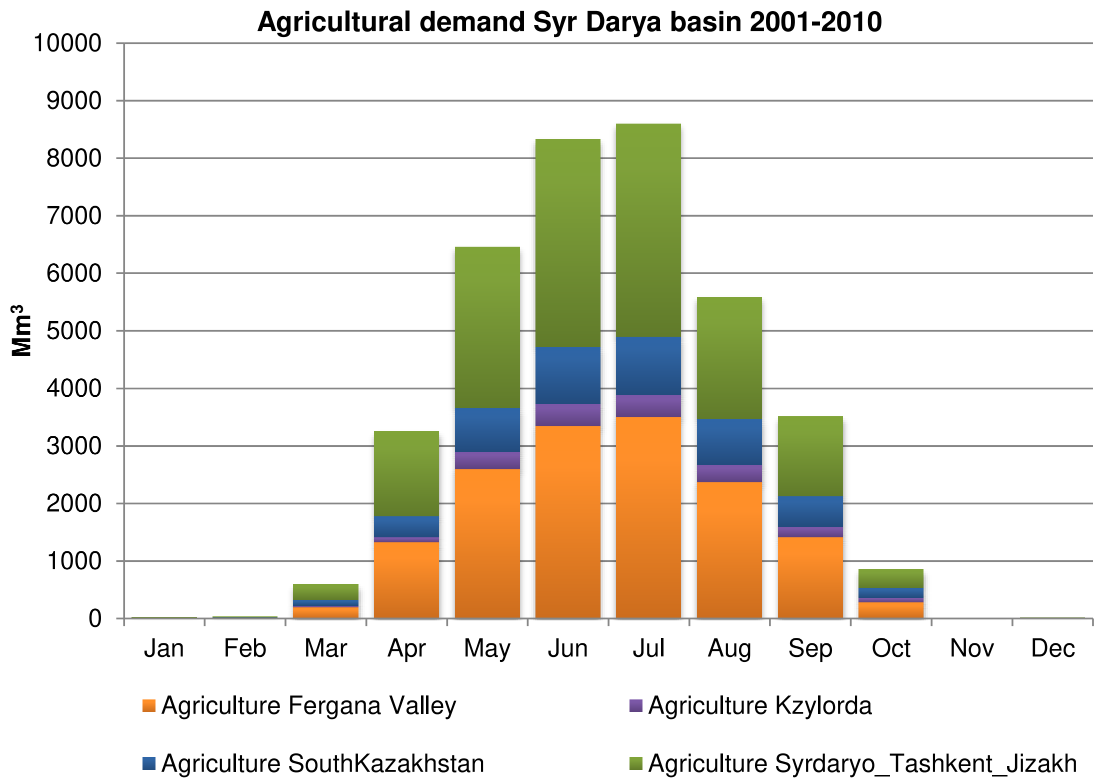


Figure 3-17: Monthly average agricultural demand Syr Darya basin 2001-2010.

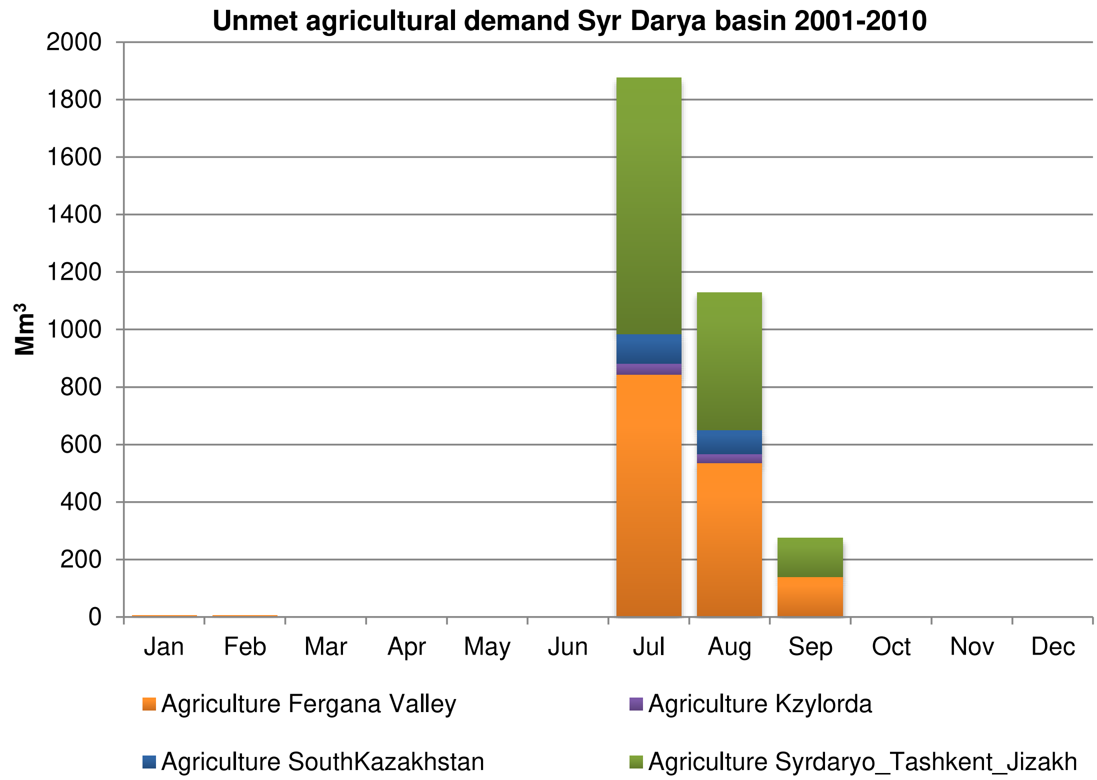


Figure 3-18: Monthly average unmet agricultural demand Syr Darya basin 2001-2010.

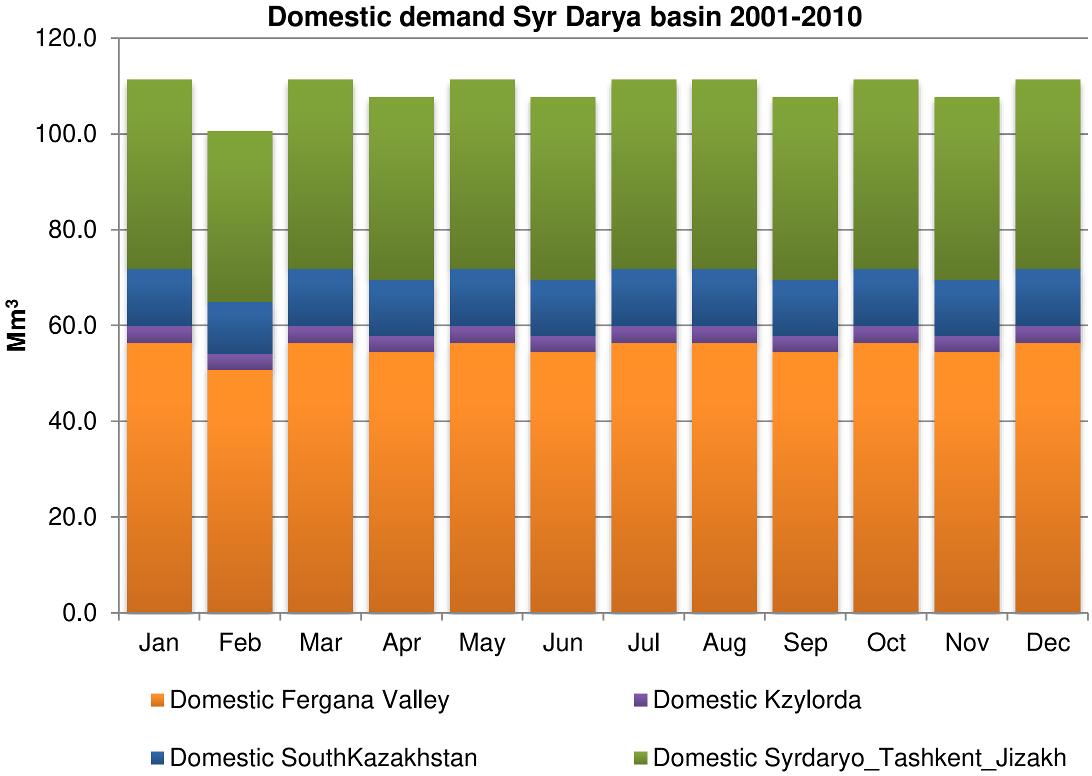


Figure 3-19: Monthly average domestic demand Syr Darya basin 2001-2010.

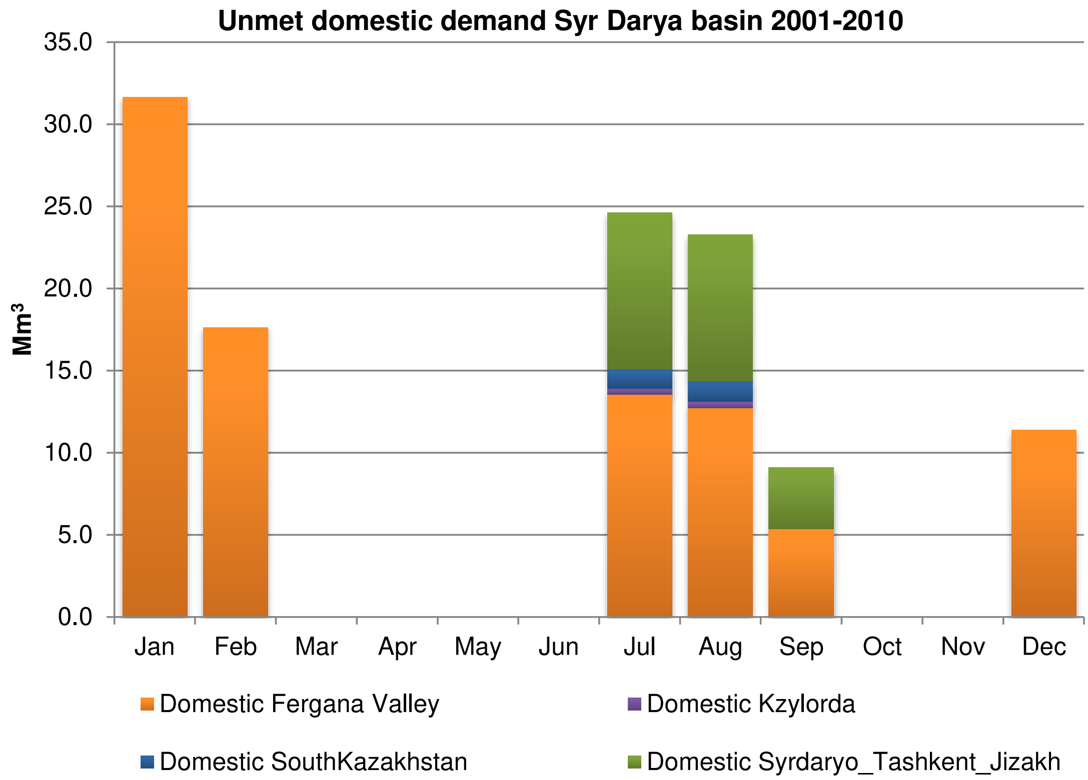


Figure 3-20: Monthly average unmet domestic demand Syr Darya basin 2001-2010.

3.5.2 Demand and unmet demand Amu Darya basin

The agricultural demand in the Amu Darya basin also has its peak during summer, when the growing season is at its maximum (Figure 3-21). The peak in monthly demand is in June, when agricultural demand is 13200 Mm^3. Demands are low during the winter months. Areas consuming the largest amounts of water are the Zeravshan Valley, Karakum desert and the areas close to the Aral Sea.

Unlike the Syr Darya basin, unmet agricultural demands are already occurring in April for the Amu Darya basin, whereas the agricultural unmet demands begin to occur in June in the Syr Darya basin (Figure 3-22). These unmet demands in the early growing season are especially large for the valleys of Amu Darya's tributaries (Zeravshan Valley, Kashkhadarya Valley). Unmet demands increase until July, when the other demand sites also experience unmet demands. In August, September and October, unmet demands occur again only for the tributary valleys (Zeravshan Valley, Kashkhadarya Valley). From November to March, no unmet agricultural demands are experienced in the Amu Darya basin.

Domestic demand in the Amu Darya basin is about 120 Mm^3 per month (Figure 3-23**)**. Largest domestic demands occur in the Zeravshan Valley, in the area near Urgenc and Nukus near the Aral Sea, Karakum desert and around Dushanbe.

The unmet domestic demand shows roughly the same pattern as the unmet agricultural demand (Figure 3-24). Unmet demands occur from April to October and peak in July. Zeravshan Valley and Kashkhadarya experience unmet demands during all of these month, whereas other demand sites only have unmet domestic demands during July. Unmet monthly domestic demand for the entire Amu Darya basin is almost 45 Mm^3 at its maximum in July.

The unmet demand in the Amu Darya river basin is 24.8% on annual basis.

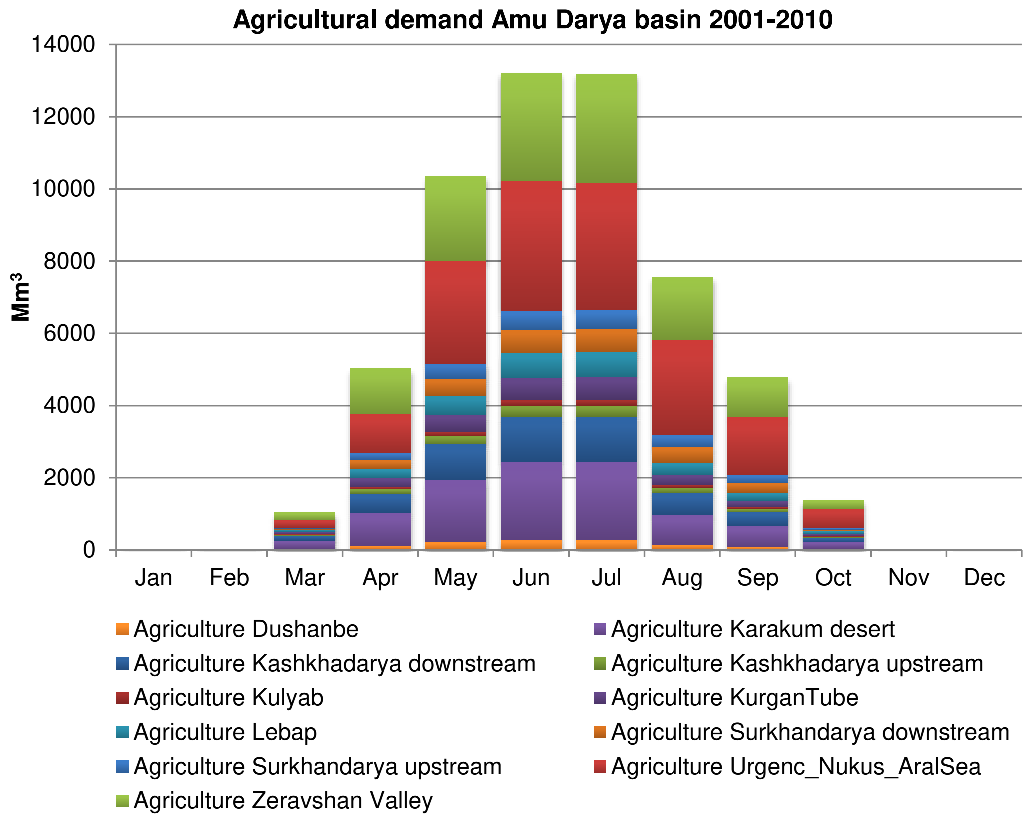


Figure 3-21: Monthly average agricultural demand Amu Darya basin 2001-2010.

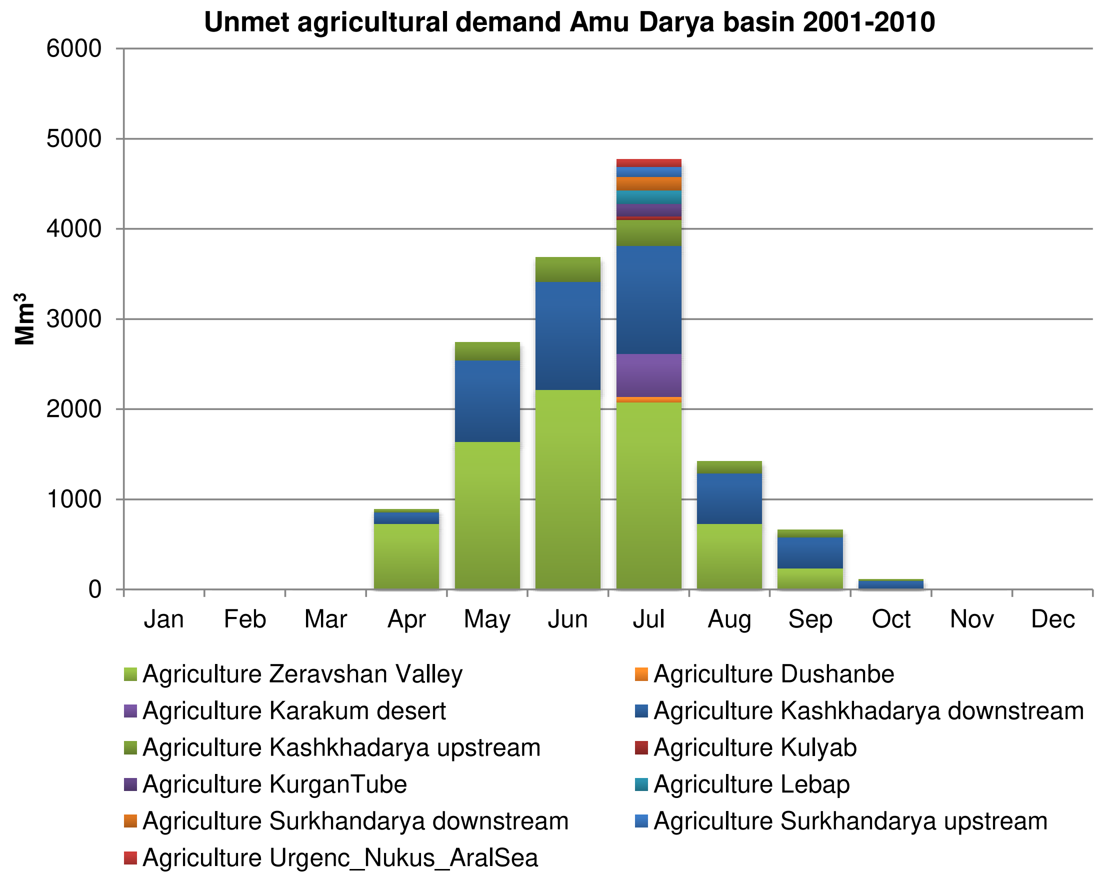


Figure 3-22: Monthly average unmet agricultural demand Amu Darya basin 2001-2010.

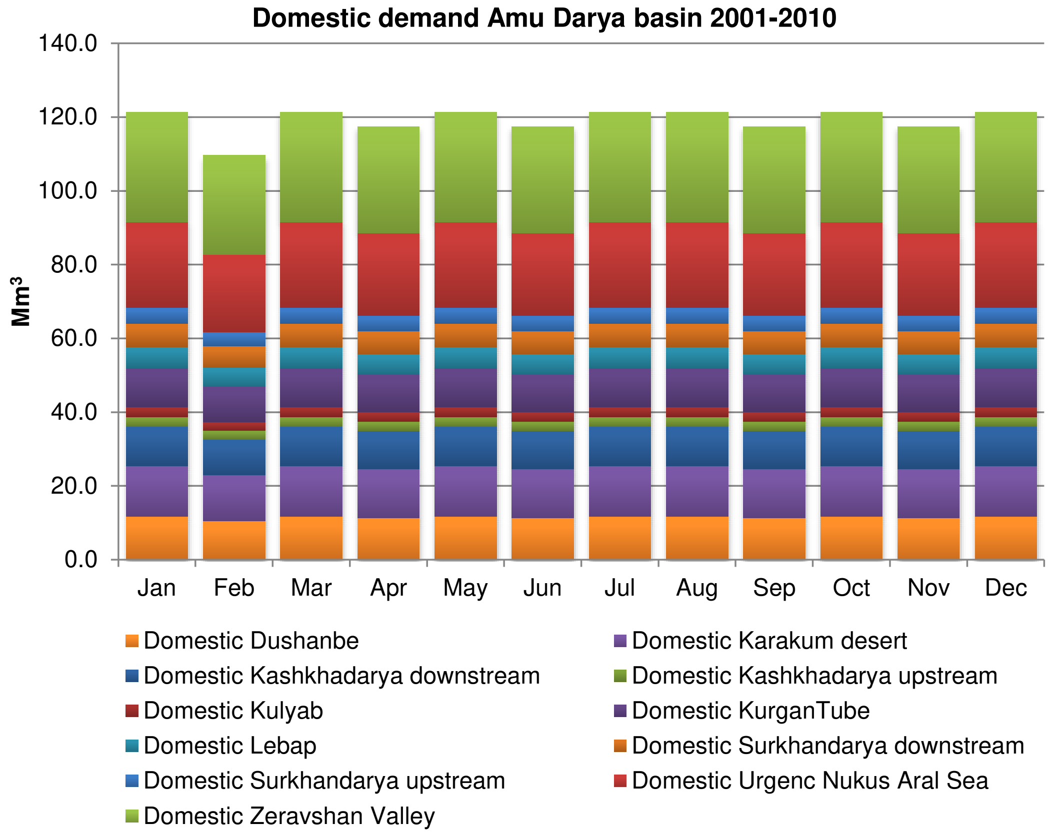


Figure 3-23: Monthly average domestic demand Amu Darya basin 2001-2010.

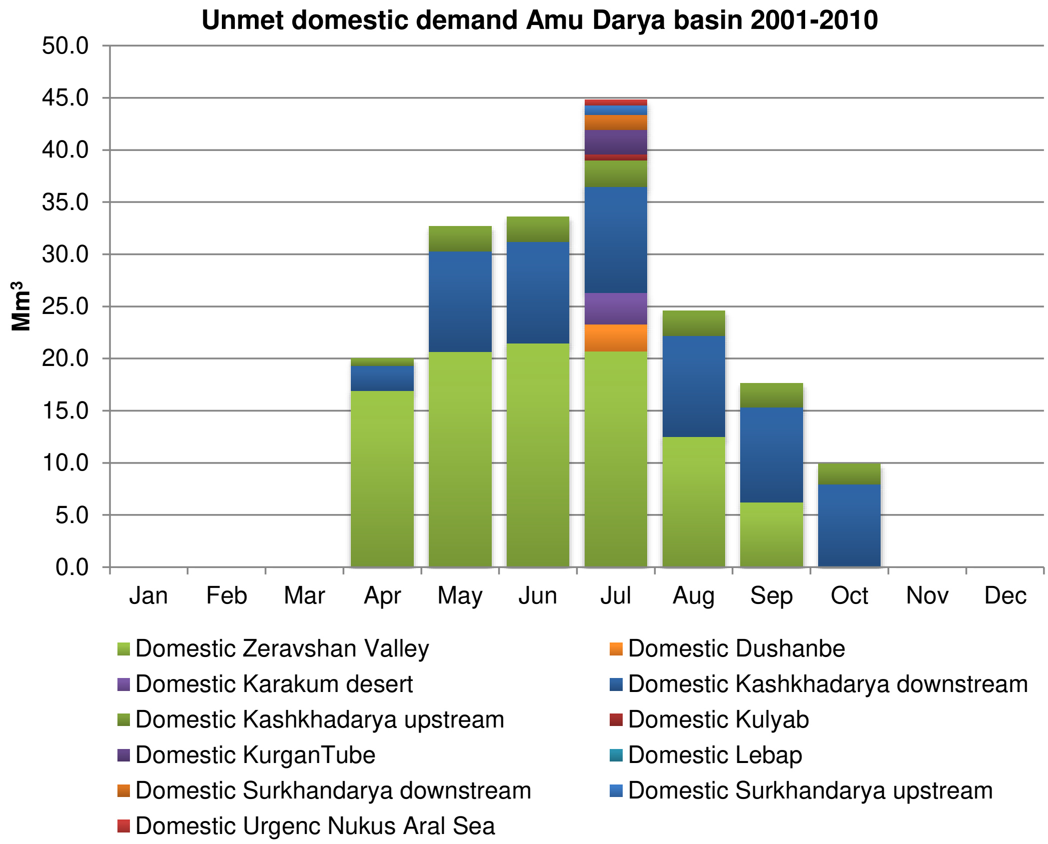


Figure 3-24: Monthly average unmet domestic demand Amu Darya basin 2001-2010.

3.5.3 *Aral Sea inflow*

The total annual inflow into the Aral Sea is 14,859 Mm^3 average per year (Figure 3-25). The numbers for the Amu Darya and Syr Darya are both about the same (± 7,400 Mm^3). This correlates very well to the observed values for annual Aral Sea inflow (See paragraph 3.4 and Table 7).

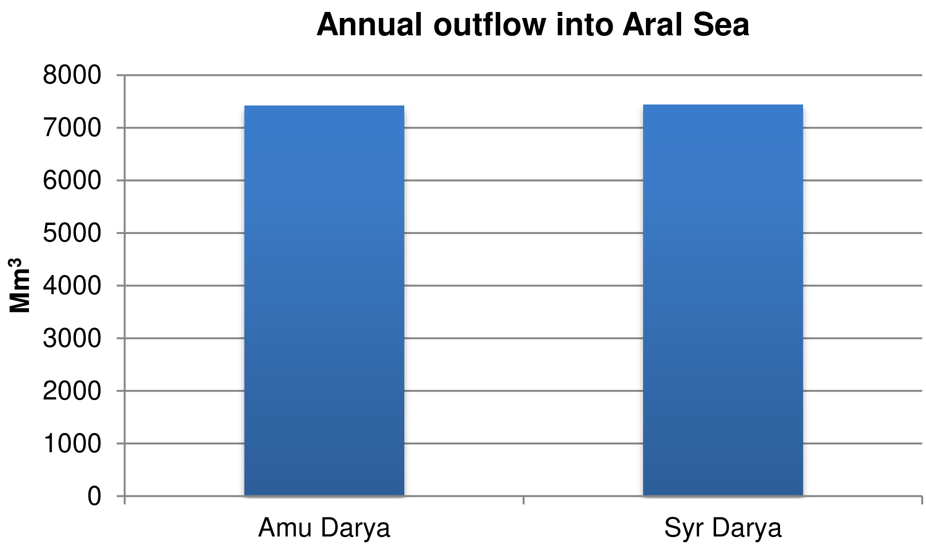


Figure 3-25: Average annual outflow into the Aral Sea 2001-2010.

4 Projections 2030 and 2050

The situation in the future in terms of the availability of water resources and demand is assessed for two time intervals. The first future interval is the timeframe from 2021 to 2030 and the second future interval is the timeframe from 2041 to 2050. This is done for five different climate change scenarios. For five Global Circulation Models (GCM's) the daily changes in temperature and precipitation are projected for both the upstream parts of the river basins and the downstream parts of the river basins. The impact of climate change in the upstream parts of the river basins is described in the separate report on upstream impacts [*Immerzeel et al.*, 2012].

Table 10: Global Circulation Models used to force ARAL-WEAP model.

GCM name	Developing institute	Abbreviation used in report
CGCM3(T63)	Canadian Centre for Climate Modelling and Analysis, Canada	CCCMA
Community Climate System Model 3.0 (NCAR-CCSM3)	Community Earth System Model	CCSM3
CNRM-CM3	Centre National de Recherches Météorologiques, France	CNRM
ECHAM5/MPI-OM	Max Planck Institute for Meteorology, Germany	ECHAM
Model for Interdisciplinary Research On Climate (MIROC3.2 HIRES)	Atmosphere and Ocean Research Institute, University of Tokyo	MIROC

For the inflow points where output from the upstream model serves as input for the downstream models (Paragraph 2.3) the inflow for an average year within the considered period is used. For the reference situation all daily inflow values for January 1st of 2001-2010 are averaged and this is done for every day in a year to obtain one averaged year for the reference period. The same is done with model output for 2021-2030 and 2041-2050. In this chapter, the impact of climate change for the downstream parts of the Amu and Syr Darya river basins is discussed.

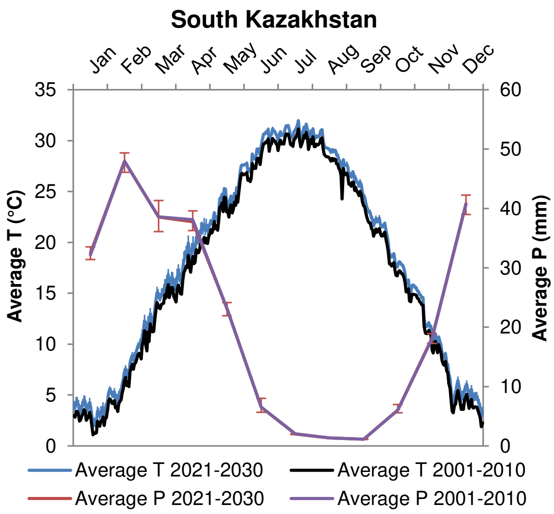
Analyses are performed under the following assumptions:

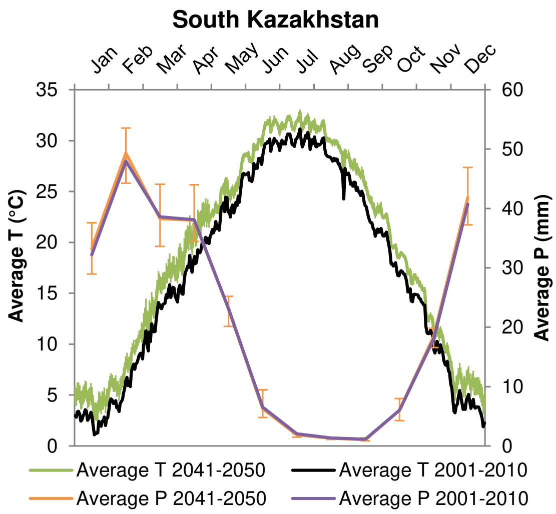
- First, we assume the population to remain constant at the level observed in the year 2000.
- Second, we assume the agricultural area to remain constant at the level observed in the year 2000. This is done to be able to separate effects of climate change from other causes that change the future water demand and unmet demand.
- Third, we assume the regime applied to reservoir water release to stay the same as the average during the reference period (2001-2010). In the model, water is sometimes forced to be released from reservoirs, although the water demand downstream is already fulfilled. This is done to mimic the current water release regime. In reality this might be due to other interests than agriculture and domestic use, for example for hydropower generation.

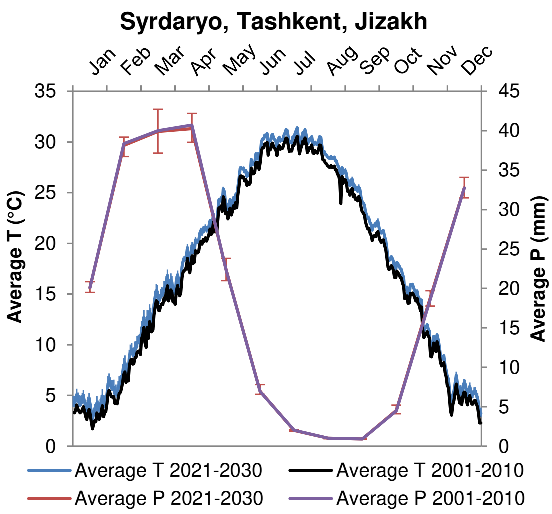
4.1 Changes in temperature and precipitation

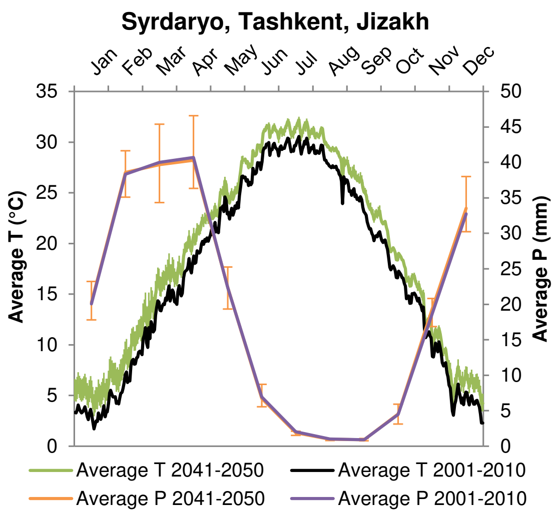
For each downstream subcatchment as defined in paragraph 2.3 the average change in temperature and precipitation is extracted from the climate projection dataset at a monthly time scale. The daily temperature and precipitation series for 2011-2050 are constructed by repeating the conditions for the ten year reference period four times and adding or subtracting the projected temperature and precipitation changes. The following range of figures shows how the average daily temperature and average monthly precipitation (summed from daily values) change for 2021-2030 and 2041-2050 for each of the subcatchments. The figures show the range of projections from the five GCMs for 2021-2030 and 2041-2050. Temperature rises by multiple degrees for all subcatchments according to the projection from all the GCMs. The range of projections is quite small. This increase in temperature will have a substantial impact on the water demand by crops (potential evapotranspiration) and might lead therefore to increasing water shortages and reduced river flows.

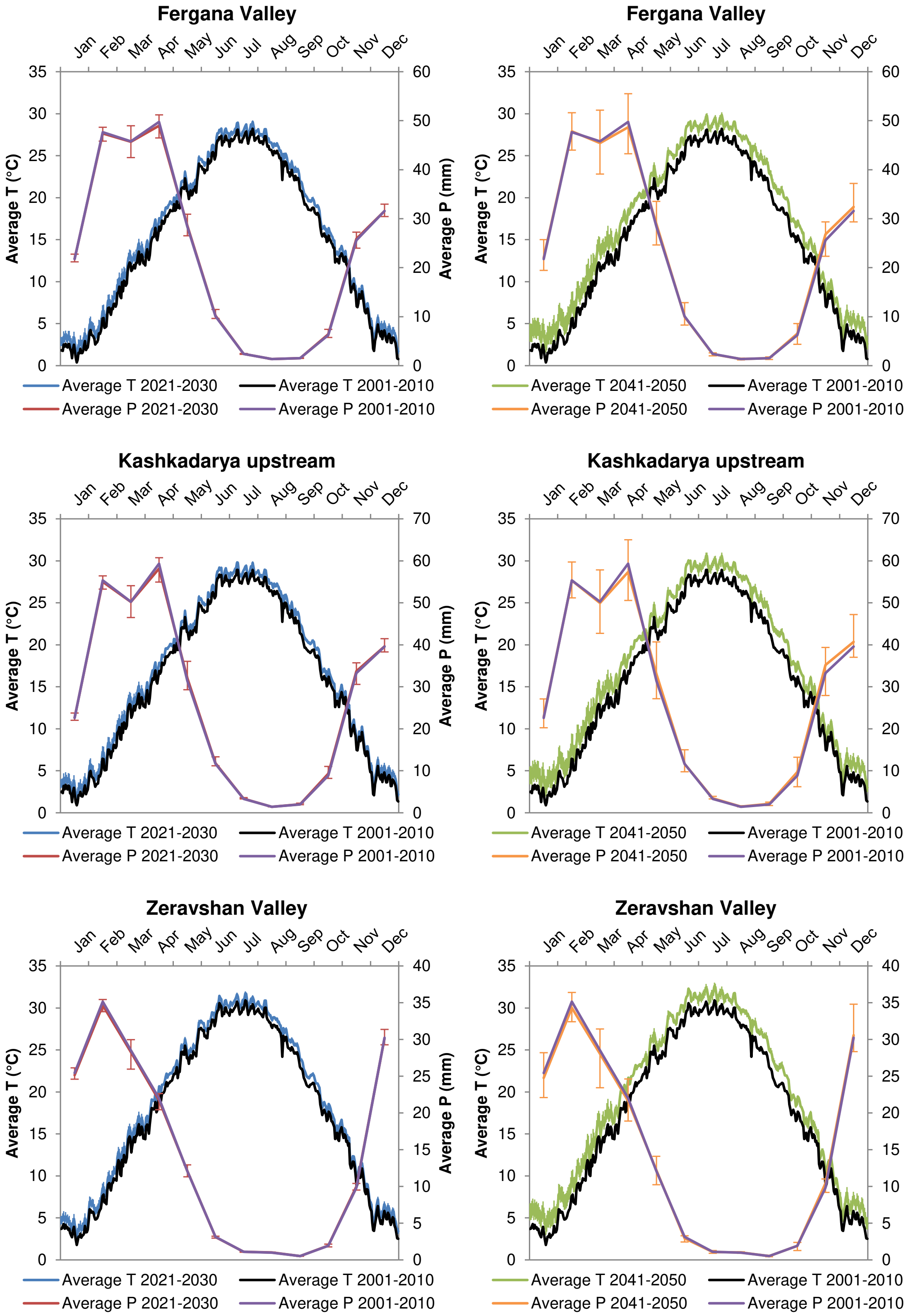
The precipitation is likely to decrease by a few millimeters or remain unchanged. However, the range of projections for precipitation changes are quite large as can be seen in the figures. Detailed information can be obtained from the report of the Finnish Meteorological Institute on downscaled climate change scenarios in Central Asia.

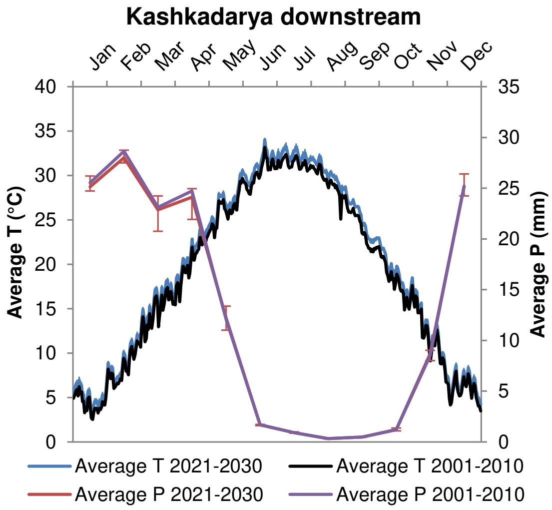


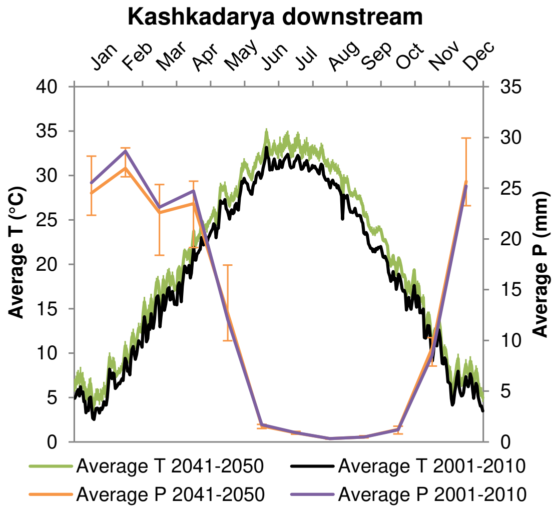


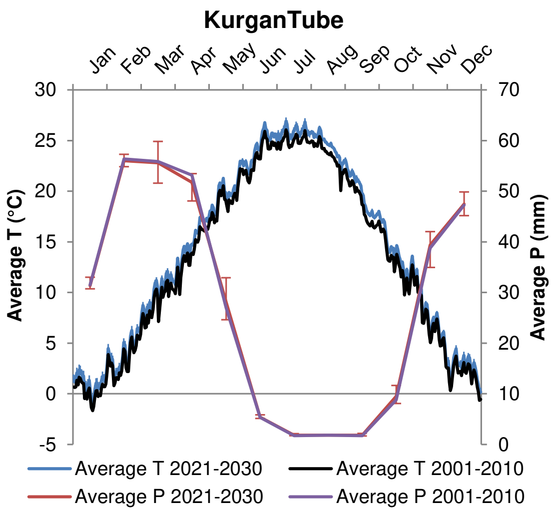


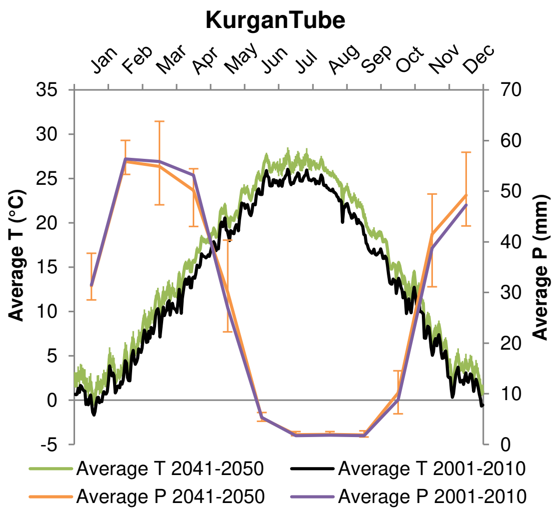


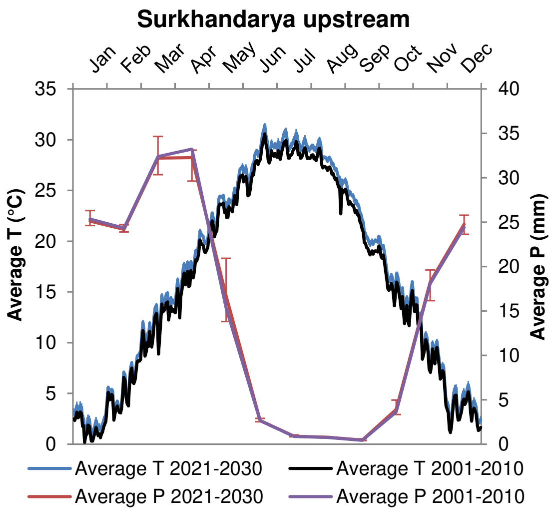

Fergana Valley
Average T (°C)
Average P (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T 2021-2030
Average T 2001-2010
Average P 2021-2030
Average P 2001-2010
Fergana Valley
Average T 2041-2050
Average T 2001-2010
Average P 2041-2050
Average P 2001-2010
Kashkadarya upstream
Average T 2021-2030
Average T 2001-2010
Average P 2021-2030
Average P 2001-2010
Kashkadarya upstream
Average T 2041-2050
Average T 2001-2010
Average P 2041-2050
Average P 2001-2010
Zeravshan Valley
Average T 2021-2030
Average T 2001-2010
Average P 2021-2030
Average P 2001-2010
Zeravshan Valley
Average T 2041-2050
Average T 2001-2010
Average P 2041-2050
Average P 2001-2010

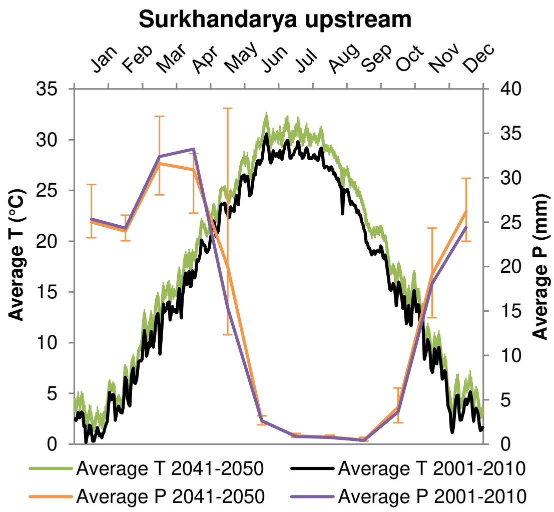

Kashkadarya downstream
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2021-2030
Average T 2001-2010
Average P 2021-2030
Average P 2001-2010

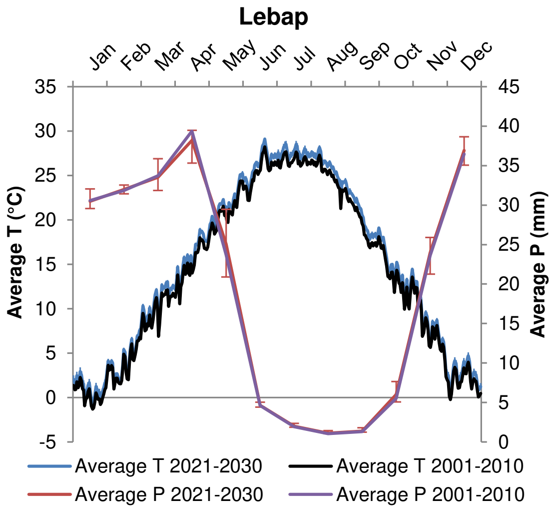

Kashkadarya downstream
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2041-2050
Average T 2001-2010
Average P 2041-2050
Average P 2001-2010

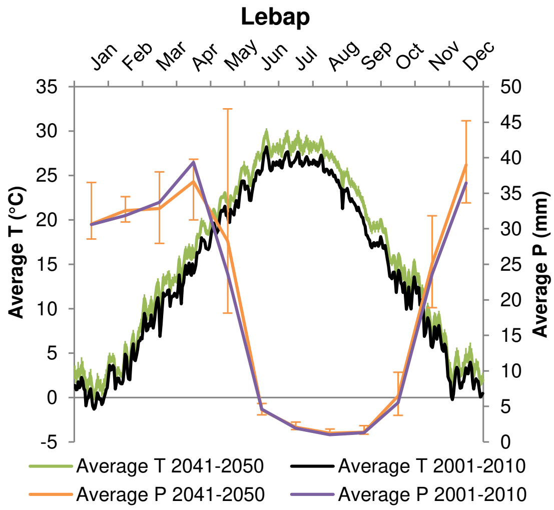

KurganTube
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2021-2030
Average T 2001-2010
Average P 2021-2030
Average P 2001-2010

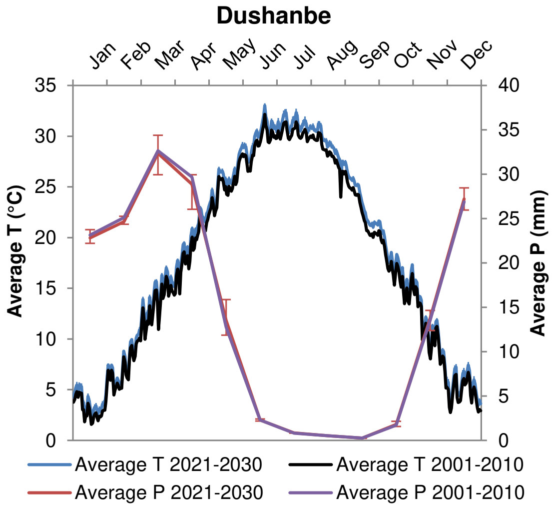

KurganTube
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2041-2050
Average T 2001-2010
Average P 2041-2050
Average P 2001-2010

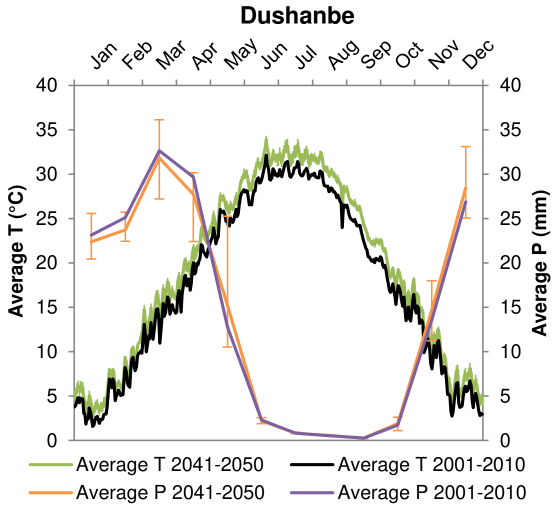

Surkhandarya upstream
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2021-2030
Average T 2001-2010
Average P 2021-2030
Average P 2001-2010

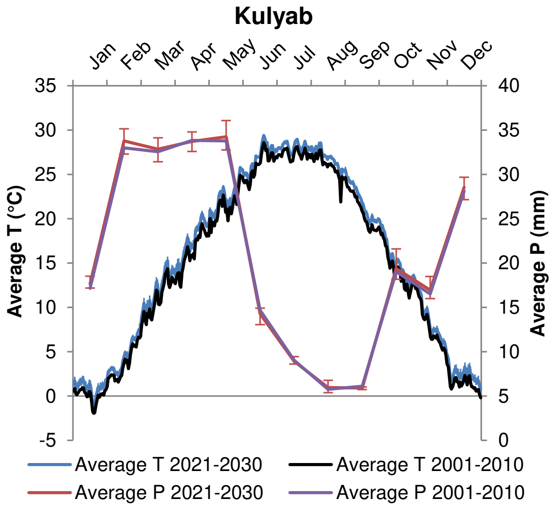

Surkhandarya upstream
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2041-2050
Average T 2001-2010
Average P 2041-2050
Average P 2001-2010

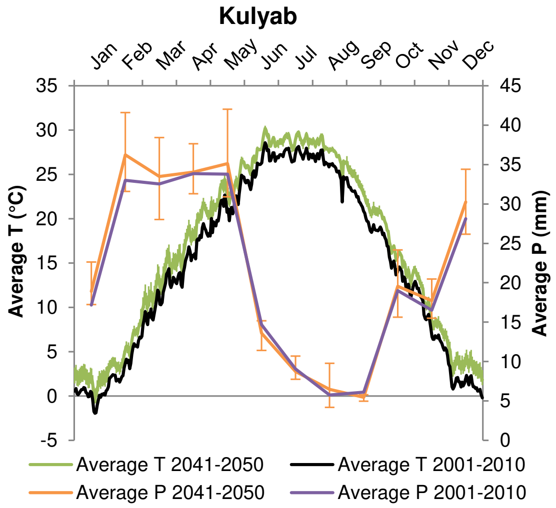

Lebap
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2021-2030
Average T 2001-2010
Average P 2021-2030
Average P 2001-2010

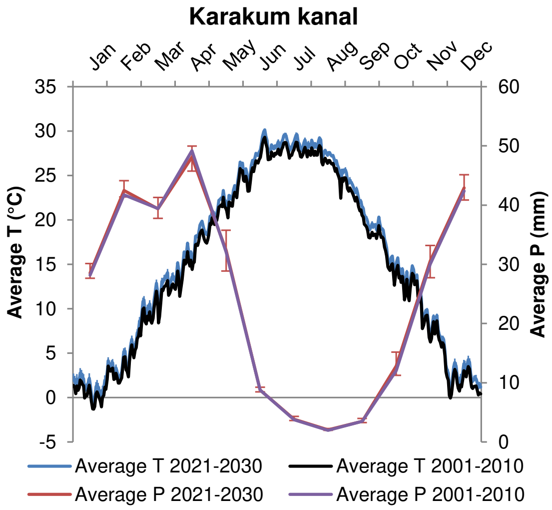

Lebap
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2041-2050
Average T 2001-2010
Average P 2041-2050
Average P 2001-2010

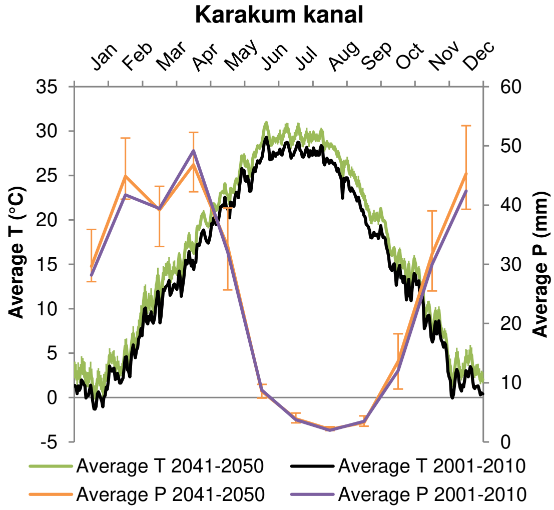

Dushanbe
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2021-2030
Average T 2001-2010
Average P 2021-2030
Average P 2001-2010

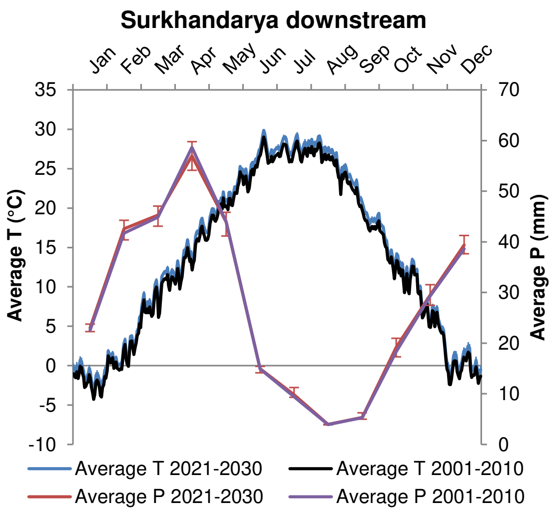

Dushanbe
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2041-2050
Average T 2001-2010
Average P 2041-2050
Average P 2001-2010

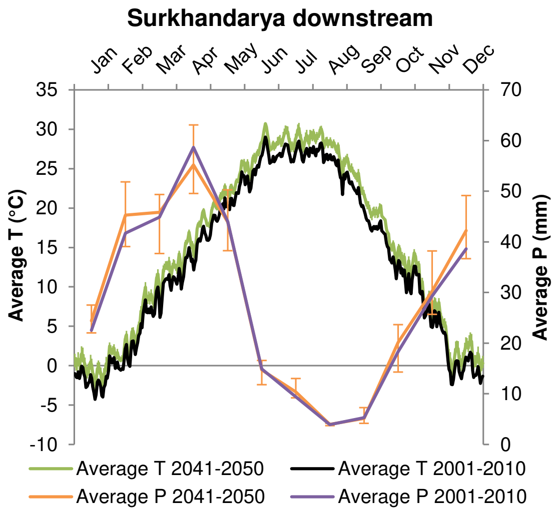

Kulyab
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2021-2030
Average T 2001-2010
Average P 2021-2030
Average P 2001-2010

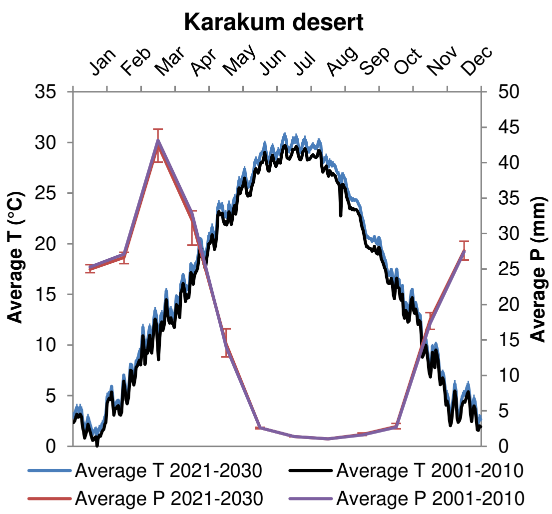

Kulyab
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2041-2050
Average T 2001-2010
Average P 2041-2050
Average P 2001-2010

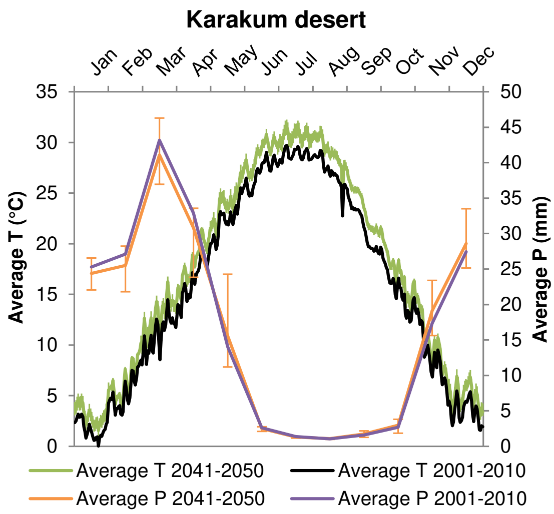

Karakum kanal
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2021-2030
Average T 2001-2010
Average P 2021-2030
Average P 2001-2010


Karakum kanal
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2041-2050
Average T 2001-2010
Average P 2041-2050
Average P 2001-2010


Surkhandarya downstream
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2021-2030
Average T 2001-2010
Average P 2021-2030
Average P 2001-2010


Surkhandarya downstream
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2041-2050
Average T 2001-2010
Average P 2041-2050
Average P 2001-2010


Karakum desert
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2021-2030
Average T 2001-2010
Average P 2021-2030
Average P 2001-2010


Karakum desert
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Average T (°C)
Average P (mm)
Average T 2041-2050
Average T 2001-2010
Average P 2041-2050
Average P 2001-2010

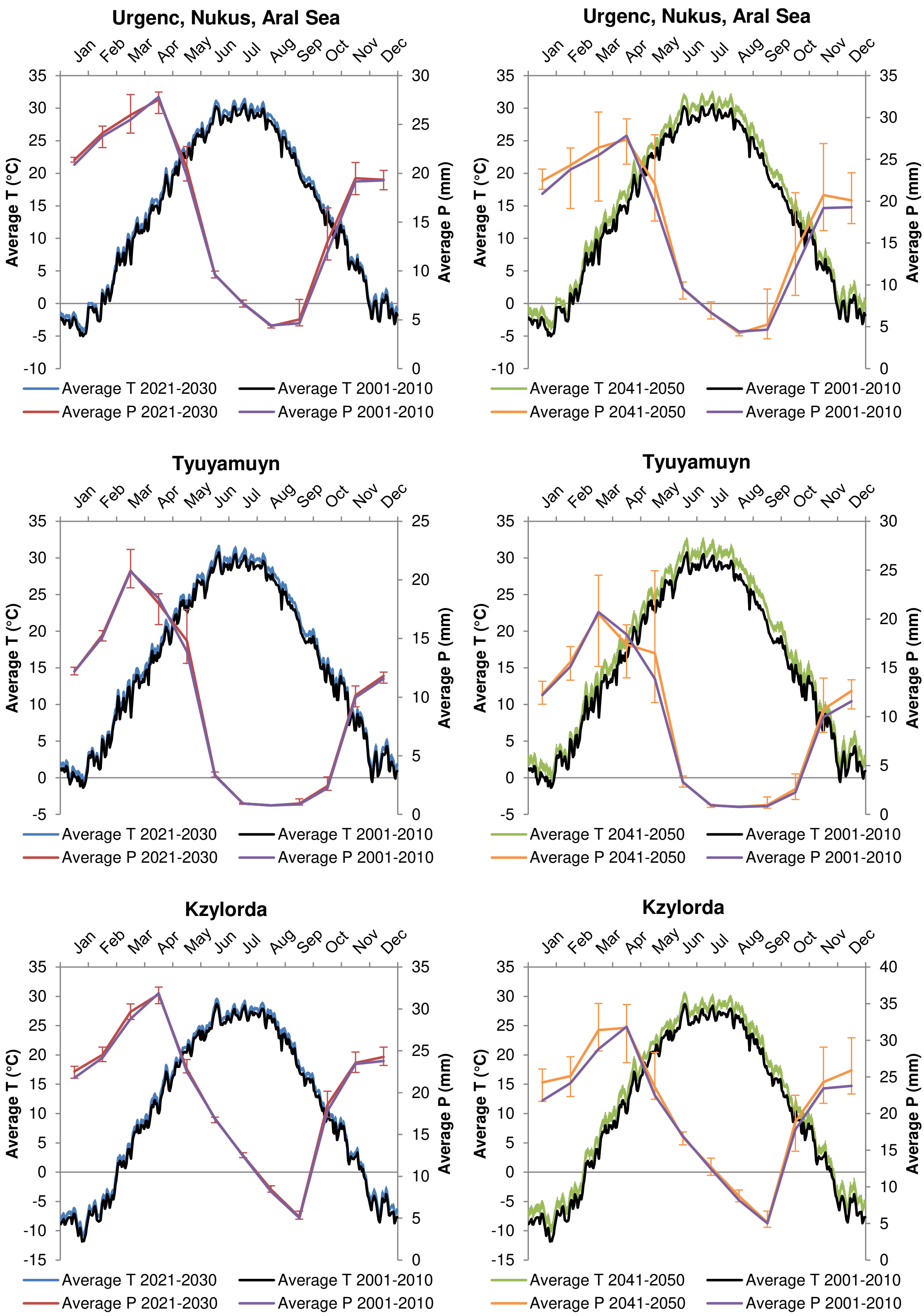


Figure 4-1: Projected changes in temperature and precipitation for the demand sites in ARAL-WEAP model. Projections show the average and range of 5 GCMs. Projections are for 2021-2030 and 2041-2050.

4.2 Changes in demand and unmet demand Syr Darya basin

Changes in demand and unmet demand for 2021-2030 and 2041-2050 are modeled for each of the five GCMs using the upstream PCRaster model and the downstream ARAL-WEAP model. In this paragraph the changes in average annual demand and unmet demand in the Syr Darya basin are presented and compared to the reference situation. Detailed information on changing demand and unmet demand per month and per demand site can be found in Appendix A.

4.2.1 Mean of five projections

The changes in demand and unmet demand are modeled for each of the five GCMs. A mean is calculated from this output. As can be seen in Figure 4-2 the annual demand increases by 3.7% until 2041-2050. The annual unmet demand however increases from 8.8% in 2001-2010 to 34.3% in 2041-2050 for the mean of the five projections. The increasing demand can be explained by the increase in temperature, leading to higher evapotranspiration rates and thus to higher unmet demands. Moreover, since precipitation change is somewhat limited in the downstream areas, the significant increase in unmet demand is caused by the decrease in runoff generation in the upstream mountains (see report on impact of climate change on the upstream part of the Aral Sea).

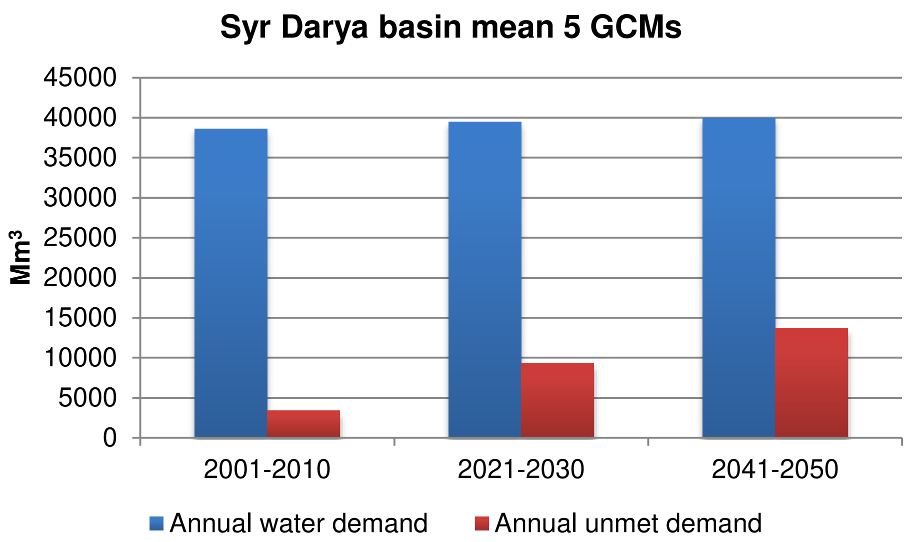


Figure 4-2: Changes in annual demand and unmet demand Syr Darya basin.

4.2.2 CCSM3

The CCSM3 scenario projects unmet demand above the average of the five GCMs. Changes in annual demand increase by 4.7 % until 2041-2050. Unmet demand increases from 8.8% in 2001-2010 to 39.7% in 2041-2050 (Figure 4-3). This GCM projects high temperature rises, especially in the upstream mountains, leading to less runoff generation. In the downstream regions, higher temperatures increase the evaporation rates of agricultural crops, leading to an increase in water demand.

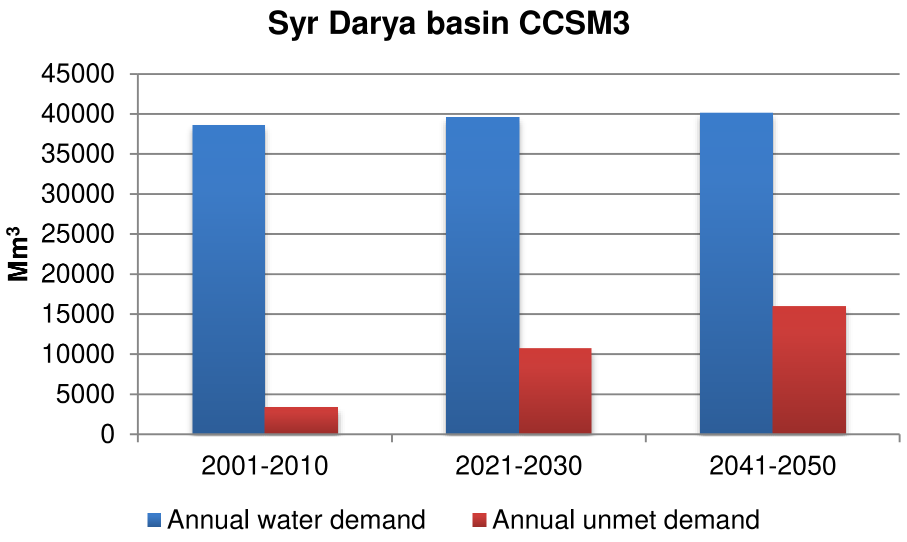


Figure 4-3: Changes in annual demand and unmet demand Syr Darya basin CCSM3 GCM.

4.2.3 CNRM

Changes in unmet demand are just below average for the CNRM GCM. Projected unmet demand increases from 8.8% in 2001-2010 to 32.2% in 2041-2050 (Figure 4-4). The annual water demand increases by 3.1% for the same period.

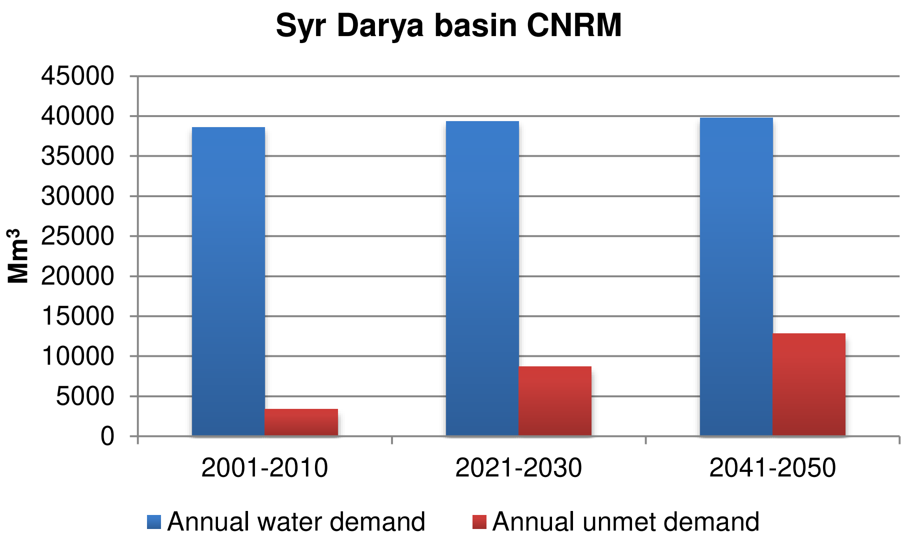


Figure 4-4: Changes in annual demand and unmet demand Syr Darya basin CNRM GCM.

4.2.4 MIROC

The MIROC GCM projects changes in demand and unmet demand close to the average of the five GCMs. The model forced by this GCM projects a 3.8% increase in water demand until 2041-2050. The annual unmet demand increases from 8.8% in 2001-2010 to 34.6% in 2041-2050 (Figure 4-5). Because the projection for the MIROC GCM is closest to the average of the five GCMs it is used as representative GCM in the adaptation measures analysis (Chapter 5).

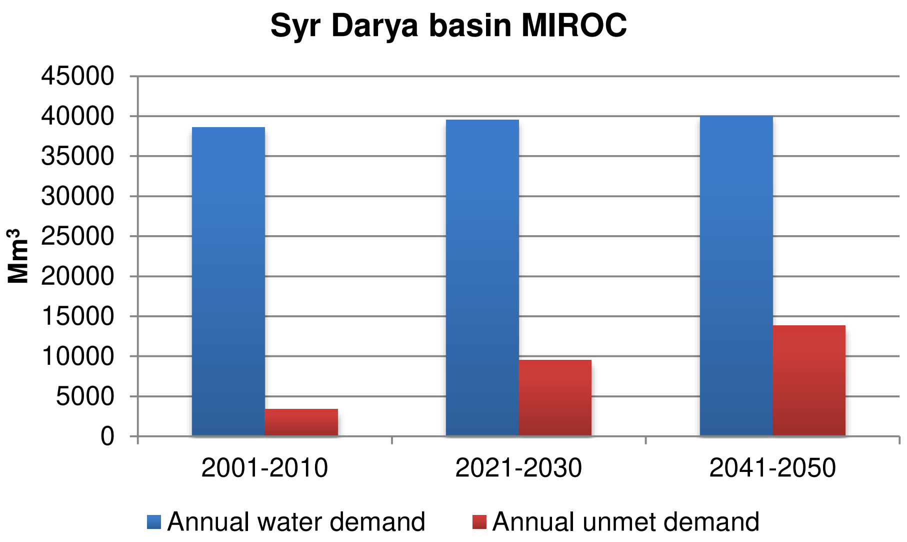


Figure 4-5: Changes in annual demand and unmet demand Syr Darya basin MIROC GCM.

4.2.5 ECHAM

The ECHAM GCM also projects changes in demand and unmet demand which are close to the average of the five GCMs. A 3.6% increase in water demand is projected until 2041-2050. The annual unmet demand increases from 8.8% in the current situation to 33.4% in 2041-2050 (Figure 4-6).

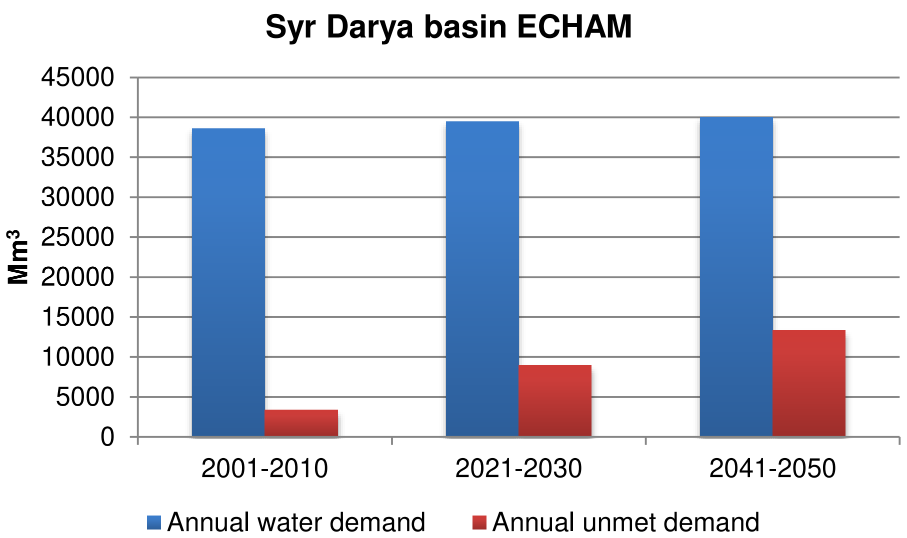


Figure 4-6: Changes in annual demand and unmet demand Syr Darya basin ECHAM GCM.

4.2.6 CCCMA

The CCCMA GCM projects changes in annual demand and unmet demand lower than the average for the five GCMs (Figure 4-7). Annual demand increases by 3.6% until 2041-2050. The annual unmet demand increases from 8.8% in 2001-2010 to 31.6% in 2041-2050.

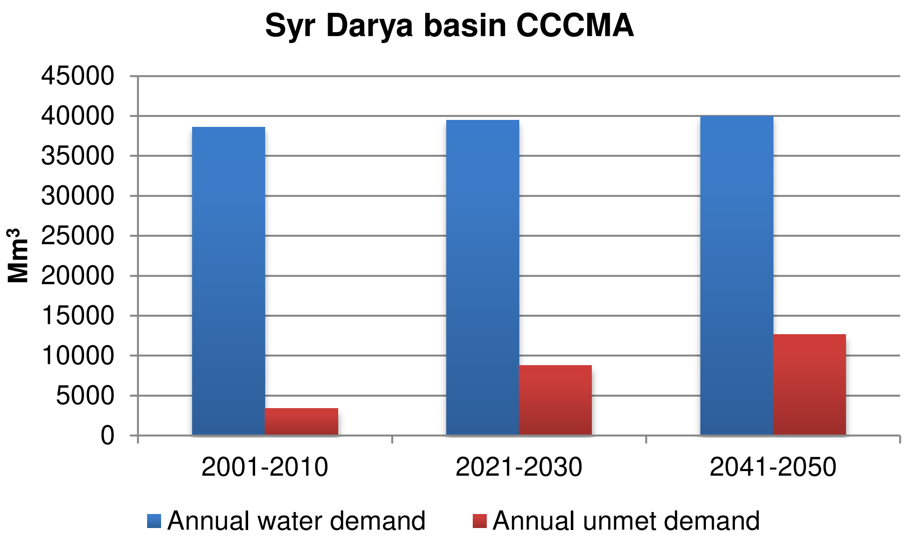


Figure 4-7: Changes in annual demand and unmet demand Syr Darya basin CCCMA GCM.

4.3 Changes in demand and unmet demand Amu Darya basin

Changes in demand and unmet demand for 2021-2030 and 2041-2050 are modeled for each of the five GCMs. In this paragraph the changes in average annual demand and unmet demand in the Amu Darya basin are presented and compared to the reference situation. Detailed information on changing demand and unmet demand per month and per demand site can be found in Appendix A.

4.3.1 Mean of five projections

The changes in demand and unmet demand are modeled for each of the five GCMs. A mean is calculated from this output. Figure 4-8 shows how the annual demand increases by 4.4% until 2041-2050. The annual unmet demand however increases from 24.8% in 2001-2010 to 48.6% in 2041-2050 for the mean of the five projections. Like in the Syr Darya basin, the increasing demand can be explained by the projected increase in temperature, leading to higher evapotranspiration rates for agricultural crops and thus to higher unmet demands. The stronger increase in demand for the Amu Darya basin (4.4%) in comparison to the demand increase for the Syr Darya basin (3.8%) is due to the slightly stronger projected increase in temperature in the Amu Darya basin compared to the Syr Darya basin. Moreover, since precipitation does not change much in the downstream areas, the large increase in unmet demand is also caused by the decrease in runoff generation in the upstream mountains.

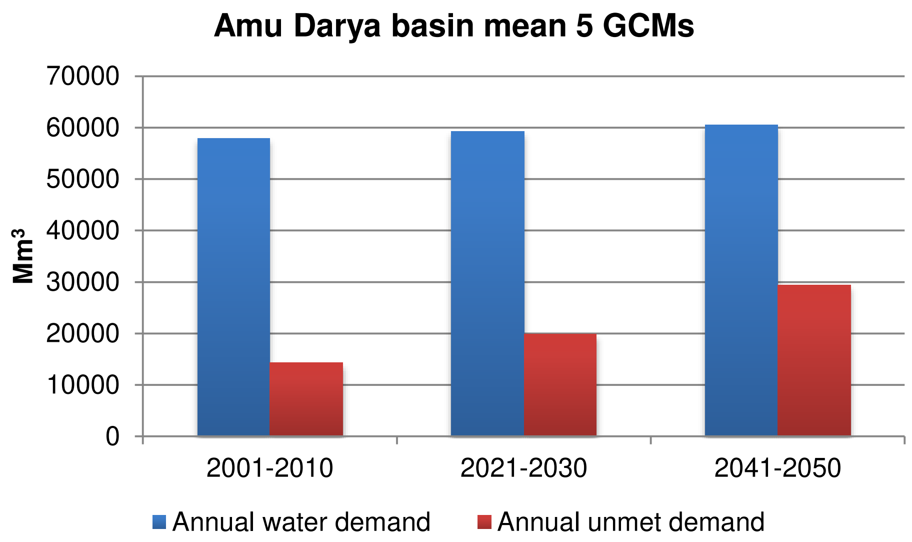


Figure 4-8: Changes in annual demand and unmet demand Amu Darya basin.

4.3.2 CCSM3

The model forced with the CCSM3 GCM projects a higher increase in unmet demand than the average of the five GCMs (Figure 4-9). Unmet demand increases from 24.8% in 2001-2010 to 54.5% in 2041-2050. The increase in demand is 4.7% until 2041-2050.

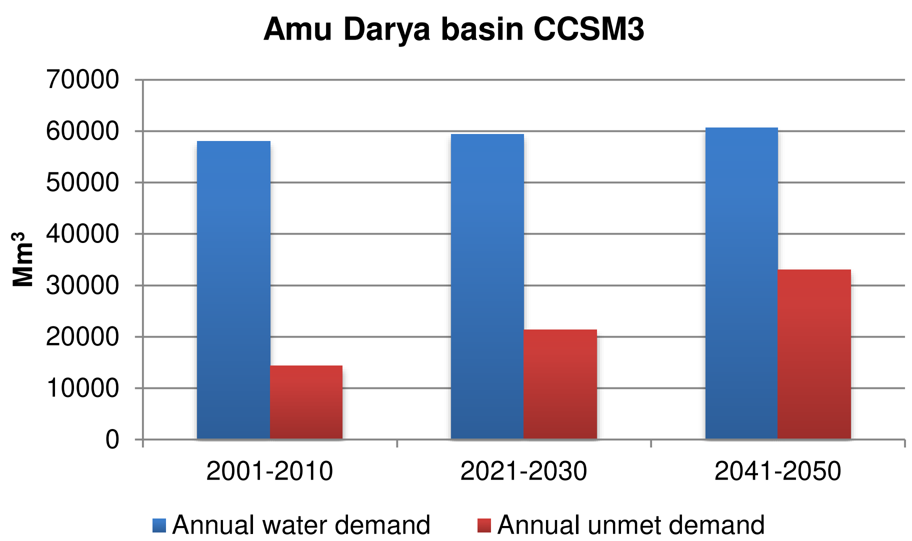


Figure 4-9: Changes in annual demand and unmet demand Amu Darya basin CCSM3 GCM.

4.3.3 CNRM

The increase in demand unmet demand for the model forced with the CNRM GCM is slightly below the average of the five GCMs. The demand increases by 3.8% until 2041-2050. Unmet demand increases from 24.8% in the current situation to 46.5% in 2041-2050 (Figure 4-10).

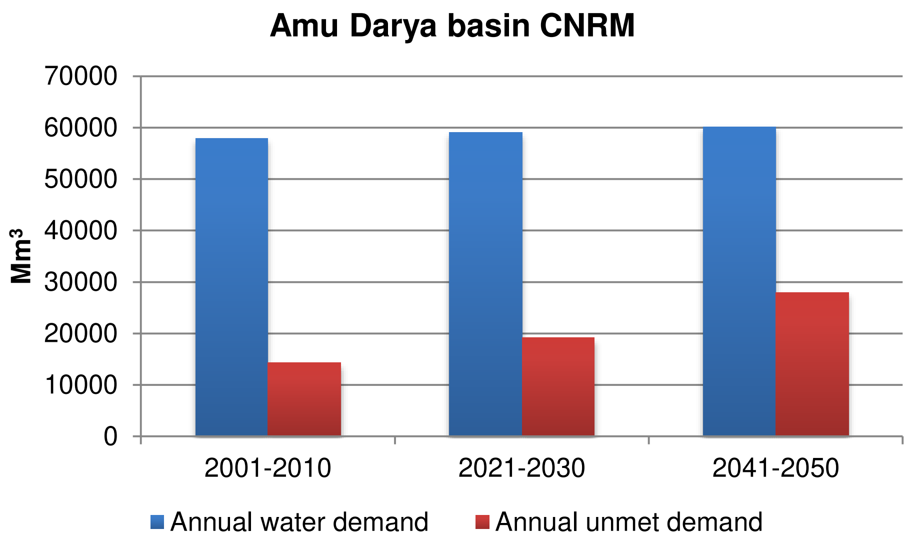


Figure 4-10: Changes in annual demand and unmet demand Amu Darya basin CNRM GCM.

4.3.4 MIROC

For the model forced with the MIROC GCM, a 5.1% increase in demand is projected for 2041-2050. The unmet demand increases from 24.8% in 2001-2010 to 48.1% in 2041-2050 (Figure 4-11).

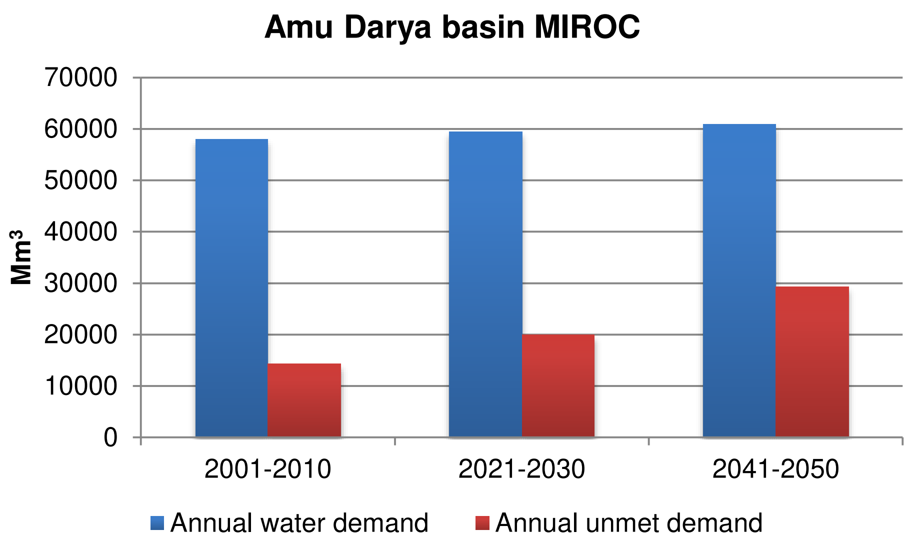


Figure 4-11: Changes in annual demand and unmet demand Amu Darya basin MIROC GCM.

4.3.5 ECHAM

For the model forced with the ECHAM GCM, a 4.1% increase in demand is projected for 2041-2050. The unmet demand increases from 24.8% in 2001-2010 to 48.2% in 2041-2050 (Figure 4-12).

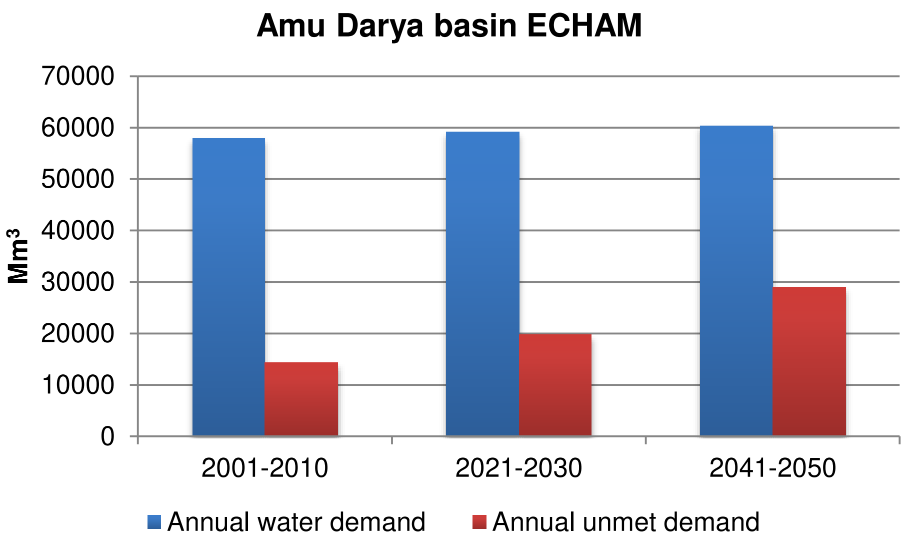


Figure 4-12: Changes in annual demand and unmet demand Amu Darya basin ECHAM GCM.

4.3.6 CCCMA

The CCCMA GCM projects changes in annual demand and unmet demand lower than the average for the five GCMs (Figure 4-7). Annual demand increases by 4.3% until 2041-2050. The annual unmet demand increases from 24.8% in 2001-2010 to 45.8% in 2041-2050.

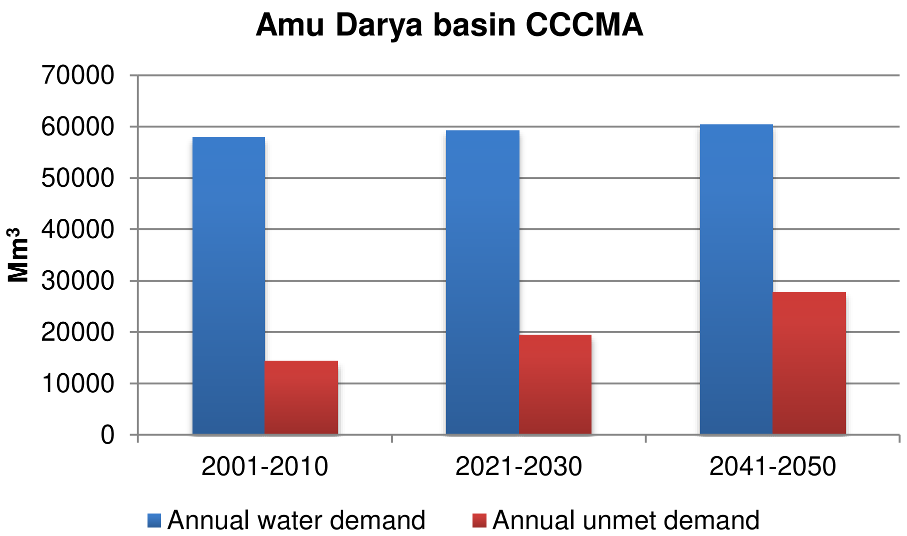


Figure 4-13: Changes in annual demand and unmet demand Amu Darya basin CCCMA GCM.

4.4 Changes in Aral Sea inflow

In response to lower inflow from upstream to the downstream areas and increasing demand, less water will reach the Aral Sea. The average annual inflow for the Amu Darya and Syr Darya into the Aral Sea is calculated by the model when forced by each of the five GCM projections.

4.4.1 Mean of five projections

The outcomes of the model forced by each of the five GCMs are averaged to obtain the mean output. Average annual outflow into the Aral Sea decreases for both rivers (Figure 4-14). The decrease is strongest for the Amu Darya river. Outflow for the Syr Darya river into the Aral Sea decreases 10.8% until 2041-2050. The outflow from the Amu Darya decreases 38.3% for the same time interval.

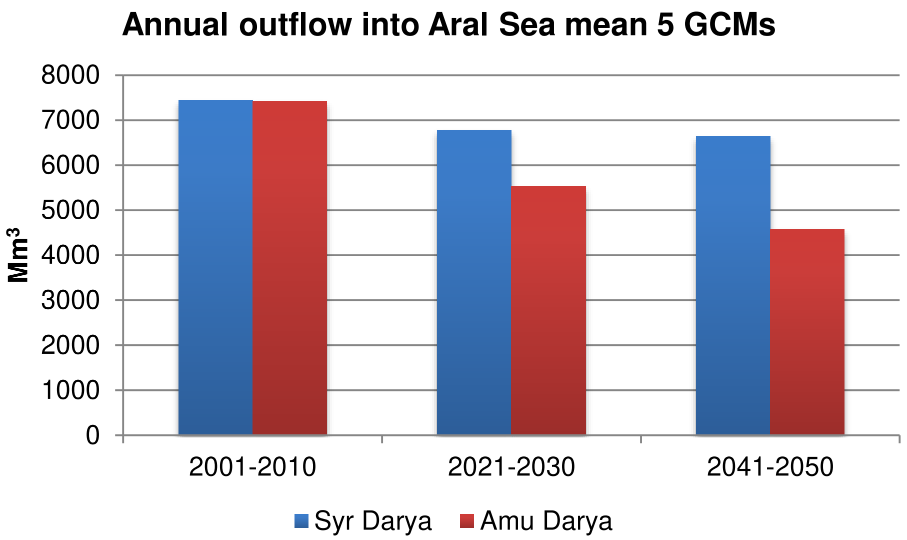


Figure 4-14: Average annual outflow into Aral Sea. Mean output of model forced by five GCMs.

4.4.2 CCSM3

For the model forced with the CCSM3 GCM the average annual inflow into the Aral Sea provided by the Amu Darya decreases by 39.8% until 2041-2050 (Figure 4-15). For the Syr Darya the decrease is 13.1%. The model forced with the CCSM3 GCM projects the largest impact for Aral Sea inflow, compared to the four other GCMs.

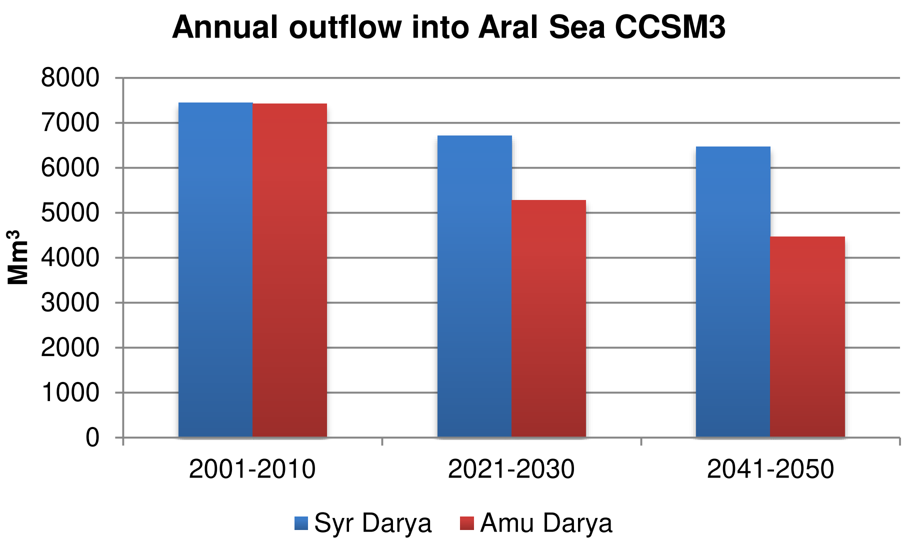


Figure 4-15: Average annual outflow into Aral Sea for model forced with CCSM3 GCM.

4.4.3 CNRM

Average annual inflow into the Aral Sea for the model forced with the CNRM GCM is projected to decrease 38.2% for the Amu Darya in 2041-2050 relative to 2001-2010 (Figure 4-16). For the Syr Darya, the projected decrease is 11.6% for 2041-2050 relative to 2001-2010. Both projections are very close to the average of the projections.

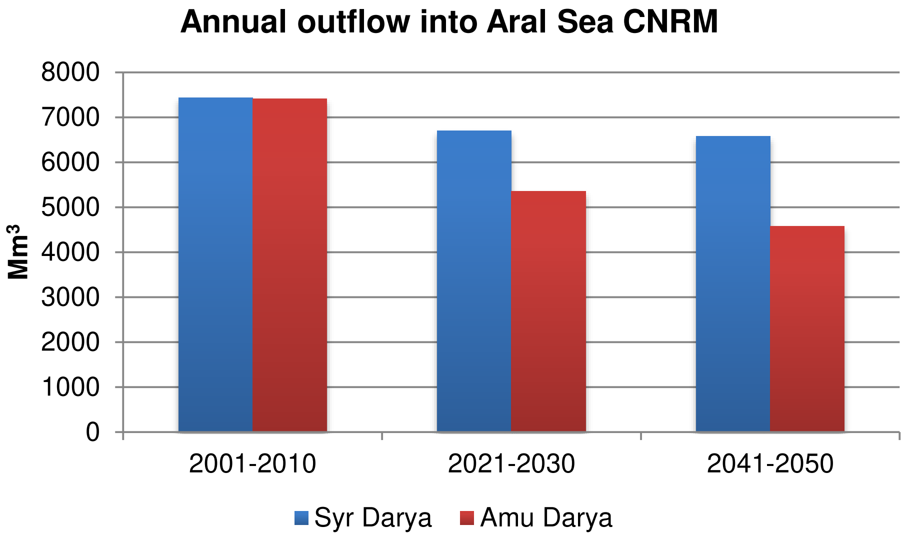


Figure 4-16: Average annual outflow into Aral Sea for model forced with CNRM GCM.

4.4.4 MIROC

The model forced with the MIROC GCM projects the average annual inflow into the Aral Sea from the Amu Darya to decrease by 38.4% until 2041-2050. For the same period, the average annual inflow into the Aral Sea from the Syr Darya decreases by 11.2% (Figure 4-17).

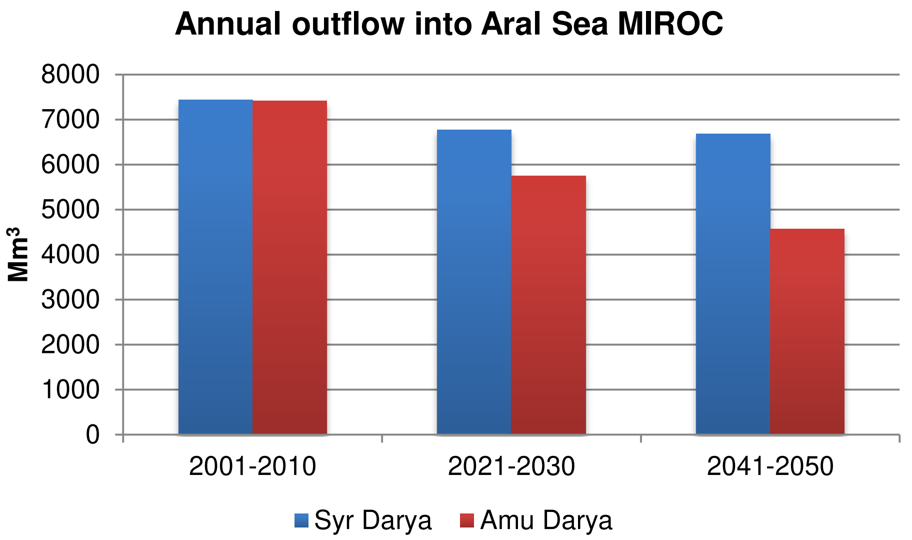


Figure 4-17: Average annual outflow into Aral Sea for model forced with MIROC GCM.

4.4.5 ECHAM

The model forced with the ECHAM GCM projects decreases in Aral Sea inflow which are close to average too. For the Amu Darya, the average annual inflow into the Aral Sea decreases by 38.2%. A decrease of 11.5% is projected for the Syr Darya (Figure 4-18).

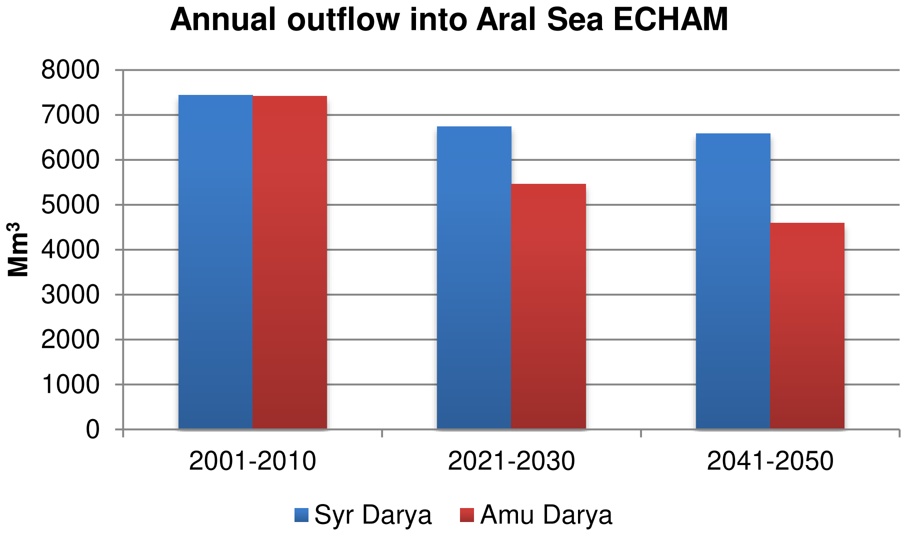


Figure 4-18: Average annual outflow into Aral Sea for model forced with ECHAM GCM.

4.4.6 CCCMA

The model forced with the CCCMA GCM projects the lowest decreases in average annual inflow into the Aral Sea compared to the four other projections. For the Amu Darya the average annual inflow into the Aral Sea decreases 37.0%, whereas a decrease of 7.4% in average annual inflow into the Aral Sea is projected for the Syr Darya (Figure 4-19).

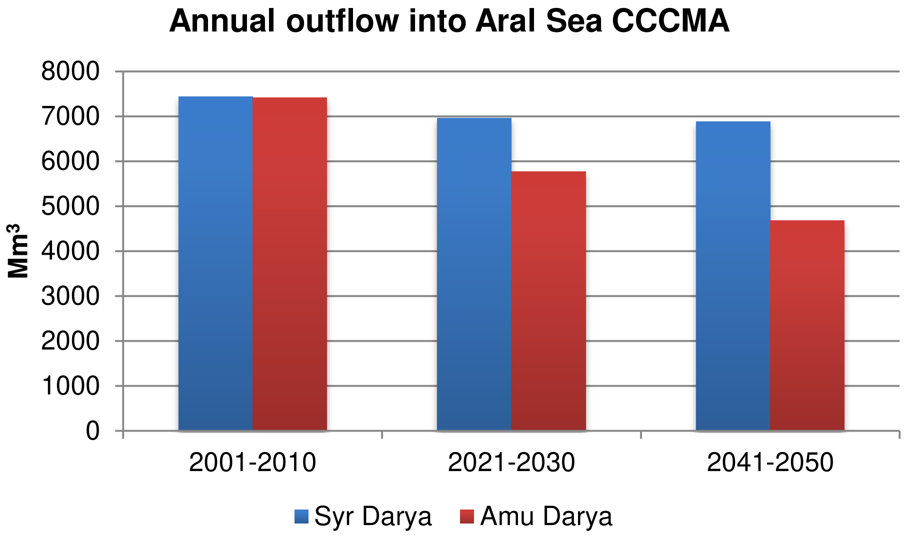
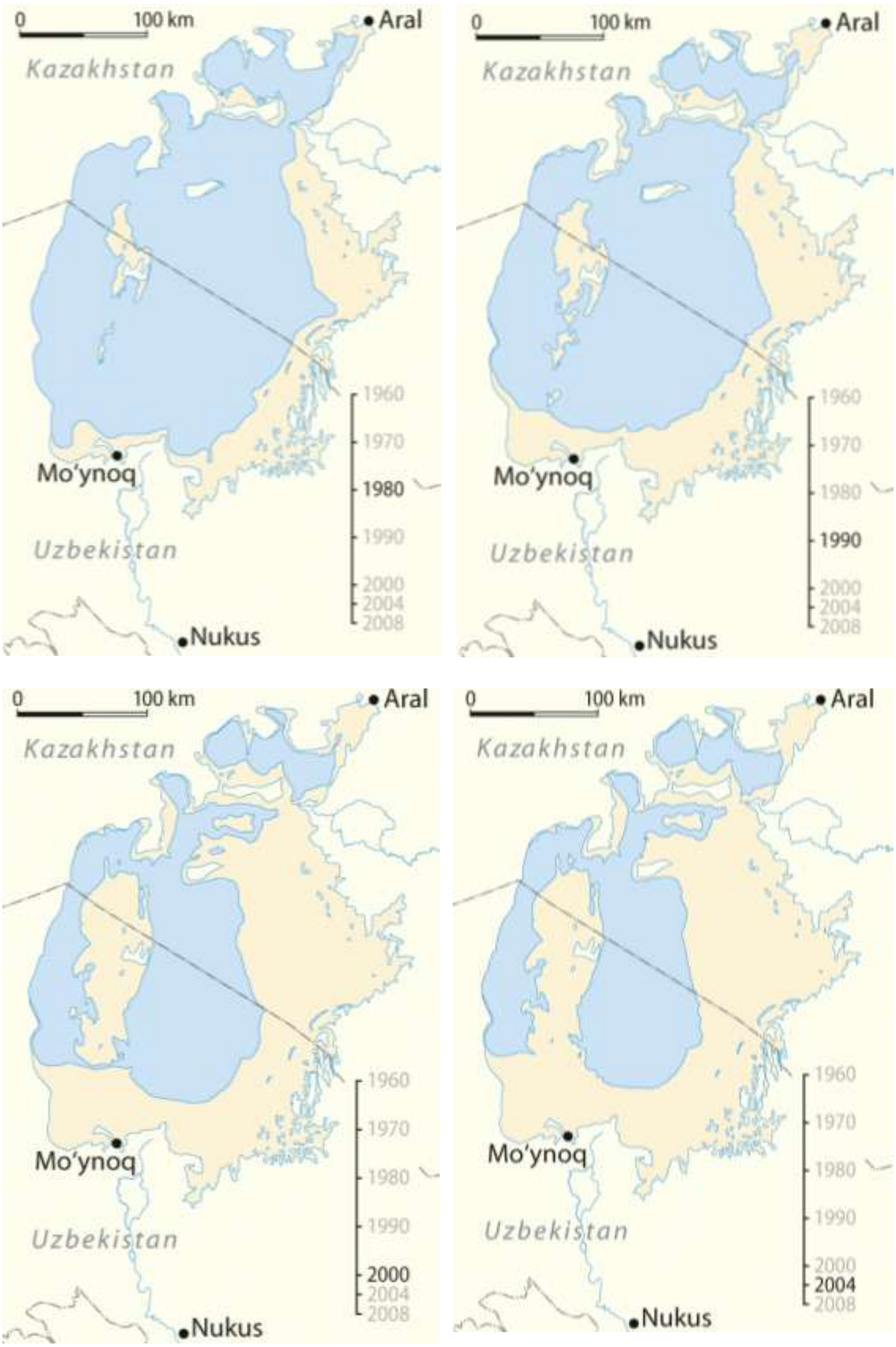


Figure 4-19: Average annual outflow into Aral Sea for model forced with CCCMA GCM.

4.5 Future Aral Sea development

Due to decreasing inflows into the Aral Sea from the Amu Darya and Syr Darya rivers, the Aral Sea has been decreasing in size rapidly. Figure 4-20 shows the development of the Aral Sea shoreline for different time steps from 1960 to 2008. In 2005, the northern part of the Aral Sea was dammed with the Kokaral dike, dividing the sea in a northern sea fed by the Syr Darya and a southern sea fed by the Amu Darya.


0
100 km
Aral
Kazakhstan
Mo'ynoq
Uzbekistan
Nukus
1960
1970
1980
1990
2000
2004
2008
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100 km
Aral
Kazakhstan
Mo'ynoq
Uzbekistan
Nukus
1960
1970
1980
1990
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2004
2008
0
100 km
Aral
Kazakhstan
Mo'ynoq
Uzbekistan
Nukus
1960
1970
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1990
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2004
2008
0
100 km
Aral
Kazakhstan
Mo'ynoq
Uzbekistan
Nukus
1960
1970
1980
1990
2000
2004
2008

Figure 4-20: Aral Sea shoreline development 1960-2008. Source: www.unimaps.com, based on NASA imagery.

A first estimate of Aral Sea dimensions in 2041-2050 was made for the northern and southern Aral Sea. Using the climate data used in the model for 2001-2010 and 2041-2050 it is possible to estimate the annual evaporation from the lake surface and the annual precipitation falling into the lake. The WEAP model calculates the reference evapotranspiration for the area. Multiplying the reference evapotranspiration (ET_{ref}) by an open water coefficient (K_w) gives an estimate of the evaporation from open water:

$$E = K_w * ET_{ref}$$

A K_w value of 1.10 provides a good estimate of the actual evaporation from open water [*Jensen*, 2010]. Besides inflow from Amu Darya and Syr Darya rivers into the Aral Sea, precipitation falls on the lake surface. The annual precipitation is also extracted from the climate data set for 2001-2010 and 2041-2050. Table 11 lists the values for lake surface, open water evaporation, precipitation, required inflow to sustain lake size, observed inflow and projected inflow. The evaporation rate and precipitation in 1960 are assumptions, for 2005-2008 and 2041-2050 model climate data is used. Historical lake surface data and inflow observations are obtained from the Central Asian Waterinfo database. Projected inflows are mean of 5 GCM model runs output.

Observed inflow into the Aral Sea in 1960-1970 is much smaller than the inflow required to sustain the lake, resulting in the observed Aral Sea shrinkage. In 2005-2008, the northern Aral Sea is gaining surface area, because of the completion of the Kokaral dike. At the same time, the southern Aral Sea is still shrinking since inflow requirements to sustain the lake's size are not met.

Projected average annual inflow into the northern Aral Sea is projected to be 6639 Mm^3 in 2041-2050, which would be sufficient to maintain a lake with approximately 5158 km^2 surface area. In theory, the northern lake could grow, although the lake dimensions are currently limited by the Kokaral dike. The projected average annual inflow for 2041-2050 into the southern Aral Sea is 4576 Mm^3, which would be sufficient to maintain a lake with an approximate surface area of 8680 km^2. This implies a significant decrease in lake size compared to the 2005-2008 situation.

Table 11: Estimating Aral Sea size in 2041-2050 based on historic inflow observations and simulated future inflows using PCRaster and ARAL-WEAP.

		Lake surface (km^2)	Evaporation open water (mm/yr)	Precipitation over lake (mm/yr)	Required inflow to sustain lake (Mm^3/yr)	Observed inflow (Mm^3/yr)	Projected inflow (Mm^3/yr)
1960-1970		64470	1320	193	72650	42800	
2005-2008	North lake	3000	1409	193	3648	7197	
	South lake	14000	1409	193	17025	6254	
2041-2050	North lake	*5158*	1486	199			6639
	South lake	*8680*	1486	199			4576

5 Adaptation Strategies

5.1 Water marginal cost curves

5.1.1 Cost curves

The cost-effectiveness of various measures to close the supply-demand gap is be compared in this study by means of the "water-marginal cost curve", similar to the approach used in a World Bank study for the Middle-East and Northern Africa Water Outlook [*Immerzeel et al.*, 2011]. This cost curve shows the cost and potential of a range of different measures- spanning both productivity improvements and supply expansion – to close the gap. Such a water-marginal cost curve is estimated for the region to assess the total costs to close the supply-demand gap projected under the MIROC scenario in 2041-2050. The MIROC scenario is used, because it is closest to the average of the five projections used.

Each of these measures is represented as a block on the curve (Figure 5-1). The width of the block represents the amount of incremental water that becomes available from adoption of the measure. The wider a measure, the larger its net impact on water availability. The height of the block represents its unit cost in US$ per m^3. The vertical axis measures the financial cost –or savings- per unit of water released by each measure. This is the annualized capital cost, plus the net operating cost compared to business as usual. The unit costs are ordered from the lowest costs to the highest on the cost curve.

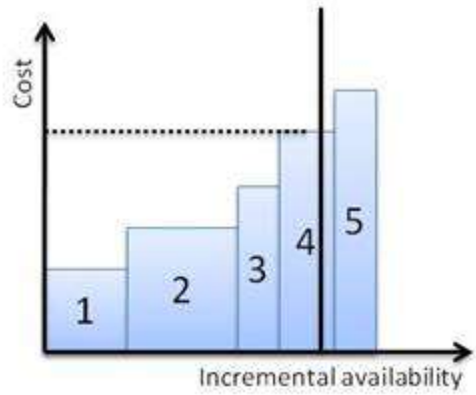

Figure 5-1: Schematic representation of the cost curve.

It is important to note that the cost curve's use is limited to comparing measures' financial cost and technical potential to close the gap. It does not include or evaluate policies that would be used to enable, incentivize, or enforce the adoption of those measures such as pricing, standards, and behavioral changes. Rather, it provides information on what the cost would be of adopting a set of technical measures, which in turn can be used to inform policy design. Of course, cost is not the only basis on which choices are made, but shedding light on the cost and technical potential of measures allows these to be compared and evaluated in a common context. The cost curve, then, is not prescriptive: it does not represent what the plan for closing the supply-demand gap ought to be. Rather, it should be considered as a tool to help decision-makers understand and compare different options for closing the gap under a given demand scenario. It is therefore important to emphasize that the estimates generated by the cost curve are not explicit predictions, but approximate guides to decision-making.

5.1.2 Measures to close the supply-demand gap

To close the gap between projected future water demand and supply, three core ways of matching water supply and demand are distinguished:

- Expanding supply;
- Increasing the productivity of existing water use;
- Reducing demand by shifting the economy towards less water-intensive activities.

The following potential measures are assessed in this study:

Expanding supply:
A: Increased reservoir capacity

Increasing the productivity:
B: Improved agricultural practice
C: Increased reuse of water in irrigated agriculture
D: Increased reuse of water for domestic use

Reducing demand:
E: Reduction of irrigated areas
F: Reduction of domestic demand
G: Deficit irrigation

5.1.3 Costs of these options

The total annual costs for the combined set of measures can be calculated by multiplying the specified deficit by the unit cost of each block required to close the gap. The considered unit cost of each measure is presented below. As there are a large number of measures and a lot of uncertainty about the costs of these measures in the various countries in the future, some crude assumptions have to be made in this study.

A) The costs of expanding reservoir capacity are taken to be 0.04 $\$/m^3$ [*Immerzeel et al.*, 2011]. Obviously these costs can vary per region.

B) For improved agricultural practices that increase the productivity of water a unit cost of 0.02 $\$/m^3$ is considered [*Immerzeel et al.*, 2011]. There are various kinds of improved agricultural practices, such as drip and sprinkler irrigation, no-till farming and improved drainage, utilization of the best available germplasm or other seed development, optimizing fertilizer use, innovative crop protection technologies and extension services. Costs of such measures vary, but are relatively cheap compared to the water supply measures. Some of the productivity measures can even result in a net cost saving, when operating savings of the measures outweigh annualized capital costs. The 2030 Water Resource Group shows that the majority of the costs of such measures are in the range of 0.02 $\$/m^3$ to 0.03 $\$/m^3$ [*2030 Water Resources Group*, 2009]. Converting this to costs per hectare (assuming on average 1000 mm of water consumption per hectare) is US$ 200 to US$ 300 per hectare per year.

C) The unit costs of increased reuse of irrigation water are assumed to be 0.04 $\$/m^3$ [*2030 Water Resources Group*, 2009]. These costs are relatively low as it was assumed that this water is only reused for agricultural purposes so that no additional treatment is necessary. The price of 0.04 $\$/m^3$ is based on

- Reuse of 50 mm = 500 m^3 per ha / year
- Investment costs of $ 1000 /ha
- Annualized capital costs (investment over 10 years) $100 / ha / year; for 500 m^3 = 0.02 $/$m^3$
- Annual operational costs (maintenance, pumping) of 0.02 $/$m^3$

D) The unit cost of increased reuse of domestic water depends on the treatment level. According to the 2030 Water Resources Group the unit cost of municipal and industrial waste water reuse is on average 0.30 $/$m^3$ [*2030 Water Resources Group*, 2009].

E) The unit cost of reduced irrigated areas is assumed to be 0.10 $/$m^3$, as the value of irrigation water ranges usually between 0.05 $/$m^3$ and 0.15 $/$m^3$ [*Immerzeel et al.*, 2011] and foregone benefits can be considered as unit costs. This value is, of course, strongly dependent on the price of agricultural products, which in turn are strongly affected by interventions of governments and trading blocs

F) The unit cost of reduced domestic demand is assumed to be 2.00 $/$m^3$. While drinking water is a necessity of life, its value can be expected to be very high. The other uses of water within households, which make life more comfortable, can be expected to have lower values.

G) The unit cost of deficit irrigation is assumed to be 0.025 $/$m^3$. The average productivity of water in agriculture is around 0.10 $/$m^3$. We assume that reducing the irrigation to 90% of optimum water amounts leads to a reduction in production of 25%. This corresponds to a cost of 0.025 $/$m^3$.

5.2 Effectiveness of adaptation measures

The ARAL-WEAP model for the Amu Darya and Syr Darya basins was used to evaluate the impact of the adaptation measures described in paragraph 5.1.2. The WEAP-model was run for five different climate projections, based on five different Global Circulation Models. The impact of adaptation measures is evaluated for the MIROC GCM, for which the climatic impact for water availability is closest to the mean of the five outputs. No distinction is made between the Amu Darya and Syr Darya basin, the effectiveness of the adaptation measures is evaluated for the total Amu and Syr Darya basin. The effectiveness of the adaptation measures is evaluated for 2041-2050.

Table 12 lists the annual water demand and unmet demand for the entire basin for 2041-2050 with and without adaptation measures.

Table 12: Annual water demand and unmet demand for Amu and Syr Darya river basins for 2041-2050 for the MIROC GCM climate projection. REF reflects scenario without adaptation measures; A to H differences compared to REF (in Mm^3).

	REF	A	B	C	D	E	F	G
DEMAND	100950	0	-14732	-2085	-548	-9821	-274	-19642
Agriculture	98211	0	-14732	-2085	0	-9821	0	-19642
Domestic	2739	0	0	0	-548	0	-274	0
UNMET DEMAND	43133	-3437	-12682	-1871	-203	-8697	-102	-16617
Agriculture	42443	-3388	-12590	-1859	-64	-8636	-32	-16492
Domestic	690	-49	-92	-12	-140	-61	-70	-125

The differences in effectiveness of measures applied to agricultural versus domestic are striking. Since agricultural demands are much higher than domestic demands, adaptation measures applied to agricultural demands are much more effective than adaptation measures applied to domestic demand. Improving for example agricultural practice by 15% reduces the demand by 14732 Mm^3 per year, whereas reducing domestic demand by 10% reduces the demand by 274 Mm^3; about 54 times less effective.

A: Increased reservoir capacity
Increasing the reservoir capacity has limited effect in terms of closing the water gap in the region. Reservoir capacity is large in the region. Increasing the reservoir capacity by 25% will decrease the unmet demand by 3437 Mm^3, corresponding to an 8% reduction in unmet demand.

B: Improved agricultural practice
Improving agricultural practice reduces the agricultural demand by 15%. The unmet agricultural demand is reduced by 30%. Subsequently unmet domestic demand decreases 13%. In 2041-2050 this reduces the total unmet demand by 12682 Mm^3 (29.4% reduction).

C: Increased reuse of water in irrigated agriculture
The overall irrigation efficiency, taking into account reuse, is increased from 95% to 97% in the downstream areas and from 90% to 92% in the upstream areas. Increasing the irrigation efficiency in agriculture reduces the agricultural demand by 2.1%. The unmet agricultural demand is reduced by 4.4%. Subsequently unmet domestic demand decreases 1.7%. In 2041-2050 this reduces the unmet demand by 1871 Mm^3 (4.3% reduction).

D: Increased reuse of water for domestic use
Increasing the reuse of water in domestic use reduces the domestic demand by 20%.The domestic unmet demand is reduced by 20.3%. Subsequently, the agricultural unmet demand decreases by 64 Mm^3. In 2041-2050 the total unmet demand is reduced with 203 Mm^3 (0.5% reduction).

E: Reduction of irrigated areas
Reducing the irrigated areas reduces the agricultural demand by 10%. The agricultural unmet demand decreases by 20.3%. Subsequently unmet domestic demand decreases 8.8%. In 2041-2050 this reduces the unmet demand by 8697 Mm^3 (20.2% reduction).

F: Reduction of domestic demand
Reducing the domestic demand reduces the unmet domestic demand 10.1%. The agricultural unmet demand is reduced by 32 Mm^3. Reducing the domestic demand by 10% reduces the total unmet demand 102 Mm^3 in 2041-2050 (0.2% reduction).

G: Deficit irrigation
Applying deficit irrigation to agricultural areas reduces the agricultural demand with 20%, because evapotranspiration rates decrease strongly. The unmet agricultural demand is reduced by 39%. Subsequently unmet domestic demand decreases 18%. In 2041-2050 this reduces the total unmet demand by 16617 Mm^3 (38.5% reduction).

5.3 Water marginal cost curve

The effectiveness of the seven explored adaptation measures in terms of reduction in water shortage is described in the previous section. Another important question is whether these adaptation measures are cost effective. Combining the costs of these adaptation scenarios (paragraph 5.1.3) with the results of the reductions in unmet demand of the measures (paragraph 5.2) results in the water availability cost curve as seen in Figure 5-2.

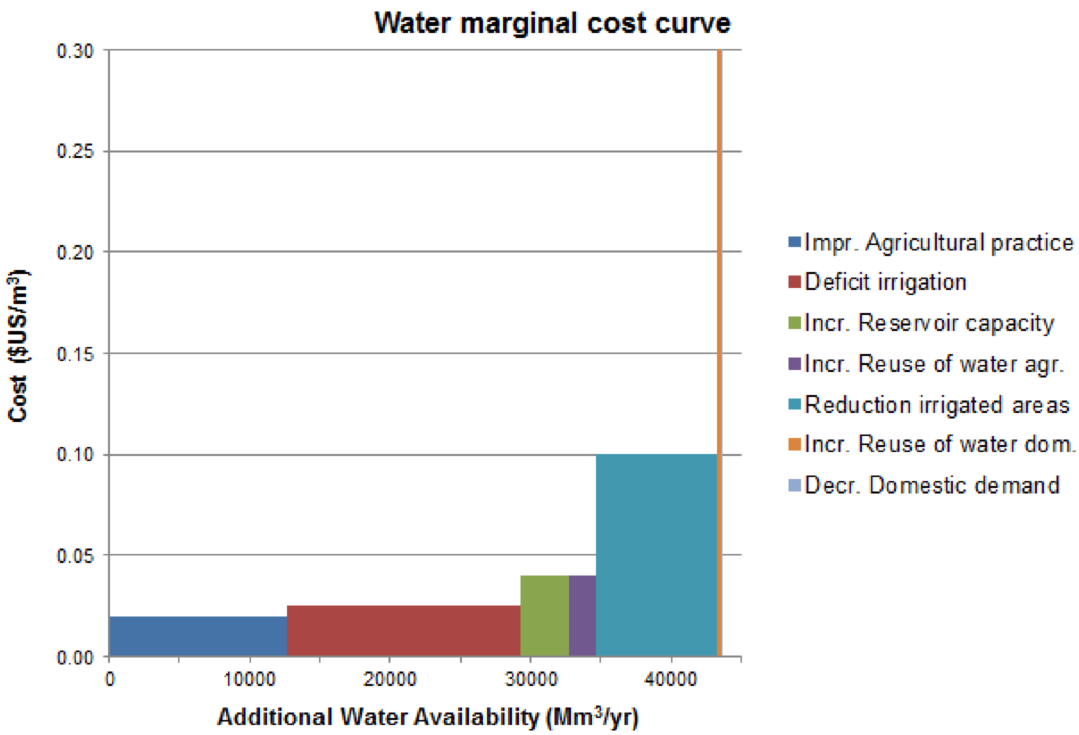

Figure 5-2: Water marginal cost curve Amu and Syr Darya basin. Note: Cost-axis has been cut off at US$ 0.30. Cost for decreasing domestic demand is 2.00 $/m³.

The water marginal cost curve shows the unit costs of the reductions in unmet demand ordered from the lowest unit cost (0.02 $/m³) to the highest unit cost (2.00 $/m³). The ranking of the adaptation measures (B, G, A, C, E, D, F) reflects the cost-effectiveness of the adaptation measures. The cheapest options are concerning demand reductions in agriculture, and these are also most effective in terms of reducing the unmet demand. Reducing the domestic demand is expensive and reduces the unmet demand insignificantly. The most cost-effective option is the improvement of agricultural practice, followed by the application of deficit irrigation. On the third place comes the increased reuse of water in agriculture and fourth is the reduction of irrigated areas. Least cost-effective are the measures affecting the domestic water use, the increased reuse of domestic water and decreasing the domestic demand.

The unmet demand in 2041-2050 caused by climate change only can be derived from the model results. The total unmet demand for the two basins in the reference period (2001-2010) is 17,800 Mm^3/yr (Table 13). This unmet demand rises to 43,133 Mm^3/yr, solely in response to the expected climatic changes in the two basins. This means the unmet demand in 2041-2050 which is caused by climate change equals 25,333 Mm^3/yr.

Table 13: Total unmet demand and unmet demand caused by climate change.

	Syr Darya	Amu Darya	Total
Unmet demand 2001-2010 (Mm^3/yr)	3,410	14,390	17,800
Total unmet demand 2041-2050 (Mm^3/yr)	13,846	29,287	43,133
Unmet demand caused by Climate Change 2041-2050 (Mm^3/yr)	10,436	14,897	25,333

Overlaying the projected supply and demand gap (unmet demand) for the Amu and Syr Darya basin in the 2041-2050 representative projection (43,133 Mm^3/yr) on the cost curve, it becomes clear that the water gap can be closed completely with the explored adaptation measures (Figure 5-3). Closing the water gap completely would cost about 1,730 million US$ annually (present value). The average unit costs to reach this are 0.040 $/m^3$. Closing the water gap that is caused by climate change only (25,333 Mm^3/yr) would cost about 550 million US$ annually. The average unit costs to reach this are 0.022 $/m^3$.

It is important to notice that the water gap is calculated for the average climate change projection (MIROC GCM). The water gap is larger for warmer and/or drier climate projections and smaller for cooler and or wetter climate projections.

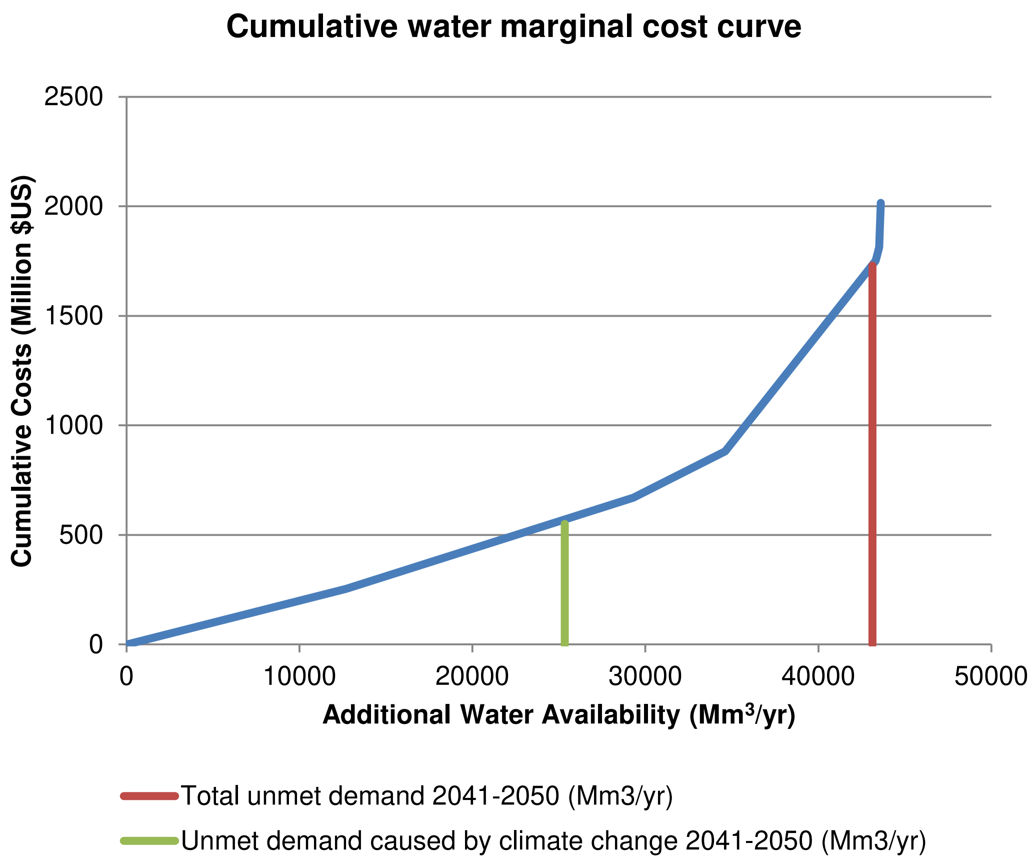

Figure 5-3: Cumulative water marginal cost curve Amu Darya and Syr Darya basin.

6 Conclusions

Climate change might have a big impact on water resources in the Central Asia region, but a rigorous analysis of these impacts is so far missing as the hydrological regimes of the two major rivers in the region (Syr Darya and the Amu Darya) are complex. Only recently, by the advent of advanced computer modeling combined with remotely sensed data and scientific progress, processes can be better understood and impact analysis related to climate change are more accurate.

The work described in this report in combination with a report on climate change impact for the upstream water resources (published in March 2012) contribute to a study initiated by the Asian Development Bank to better understand and to explore adaptation strategies in the Aral Sea Basin. The ultimate objective of this project is to develop national capacity in each of the participating countries (Kyrgyz Republic, Tajikistan, Kazakhstan, Turkmenistan, Uzbekistan) to use the models, tools, data and results to prepare climate impact scenarios and develop adaptation strategies. This will then result in improved national strategies for climate change adaptation.

This report describes the analysis focusing on the downstream parts of the Amu Darya and Syr Darya river basins. Based on local and public domain datasets and hydro-meteorological observations a water allocation model has been developed for the downstream parts of the two rivers. The downstream model is coupled to a cryospheric-hydrological model developed for the mountainous upstream parts of the basins. This is one of the first models that covers the entire upstream parts of these basins and includes all processes related to glacier and snow melt, rain runoff and base flow. The downstream water allocation model is used to quantify the impact of climate change for water resources in the two river basins until 2050 and to explore possible adaptation measures.

The key messages resulting from the two-way modeling study are:

- The developed models are able to mimic observed streamflows and water use rates and can be used to explore the impact of climate change on water resources in the region.
- There are large differences in the role that melt water plays in runoff generation in the Amu Darya and Syr Darya river basins. Melt water has a higher contribution to runoff in the Amu Darya basin compared to the Syr Darya river basin.
- It is very likely that glacier extent in the Pamir and Tien Shan mountain ranges will decrease by 45 to 60% by the year 2050.
- The composition of the four components of stream flow (rainfall-runoff, snow melt, glacier melt, base flow) is very likely to change in the future. This will have major impacts on total runoff, especially on seasonal shifts in runoff. The runoff peak will shift from summer to spring and decrease in magnitude. Model output when forced with climate projections generated with five Global Circulation Models shows decreasing runoff generation in the upstream parts of the two basins in 2050. The changes differ strongly spatially. The runoff generation decreases most significantly in upstream areas of glacier retreat.
- Total annual runoff into the downstream areas is expected to decrease by 22-28% for the Syr Darya and 26-35% for the Amu Darya by 2050.

- Strongest decreases in stream flow are expected for the late summer months (August, September, October), where inflow into downstream areas decreases around 45% for both river basins.
- Annual total water demand in the Syr Darya basin increases by 3.0 - 3.9% in 2050. Annual unmet demand increases from 8.8% currently to 31.6 - 39.7% in 2050.
- Annual total water demand in the Amu Darya basin increases by 3.8 - 5.0% in 2050. Annual unmet demand increases from 24.8% currently to 45.8 - 54.5% in 2050.
- The total extent of the Aral Sea will reduce from about 17,000 km^2 currently to 13,800 km^2 in 2050. Differences between the North and South Lake are striking; the North Lake is expected to expand by about 72%, while the South Lake will shrink by about 38%.
- Most cost-effective adaptation measures are (i) improving agricultural practice, (ii) deficit irrigation, (iii) increasing the reuse of water in agriculture, and (iv) the reduction of irrigated areas.
- Costs for closing the entire water gap (43,000 Mm^3) are estimated at US$ 1,730 million per year in 2050.
- Closing the additional water shortage caused by climate change only (25,000 Mm^3) will cost US$ 550 million per year in 2050.

7 References

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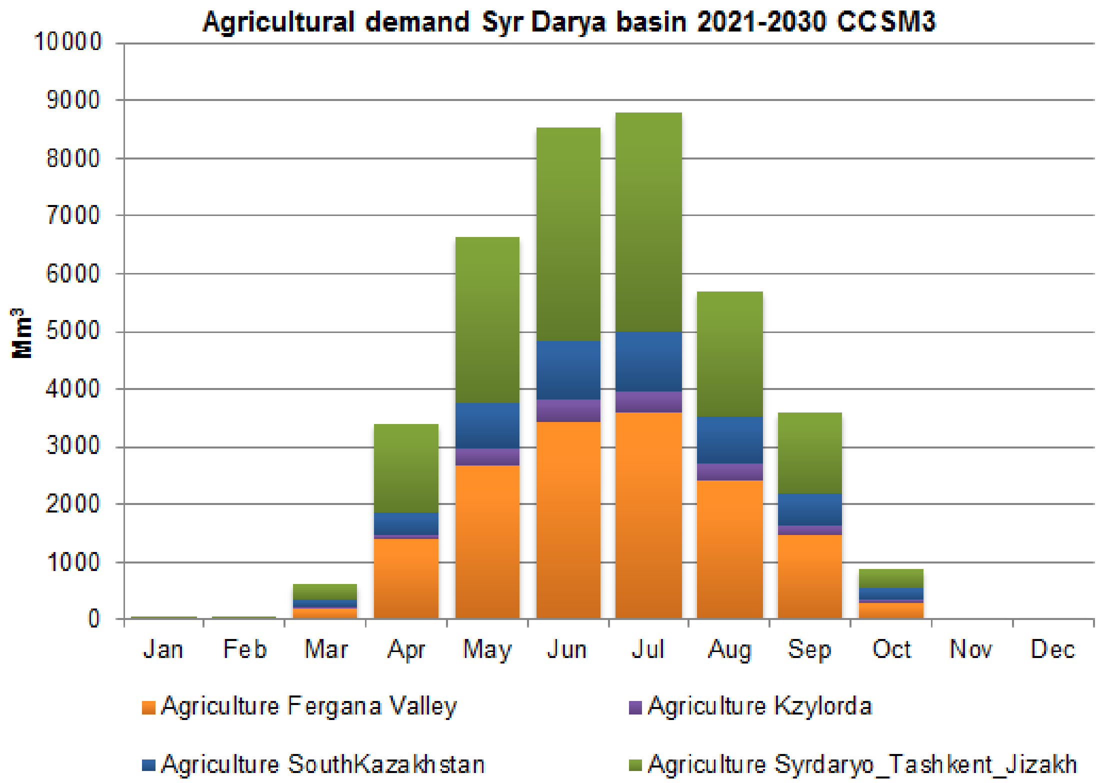
Appendix A

Agricultural and Domestic Demand and Unmet Demand per Region 2021-2030 and 2041-2050 for 5 GCM climate projections specified per region per month


Agricultural demand Syr Darya basin 2021-2030 CCSM3
Mm3
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
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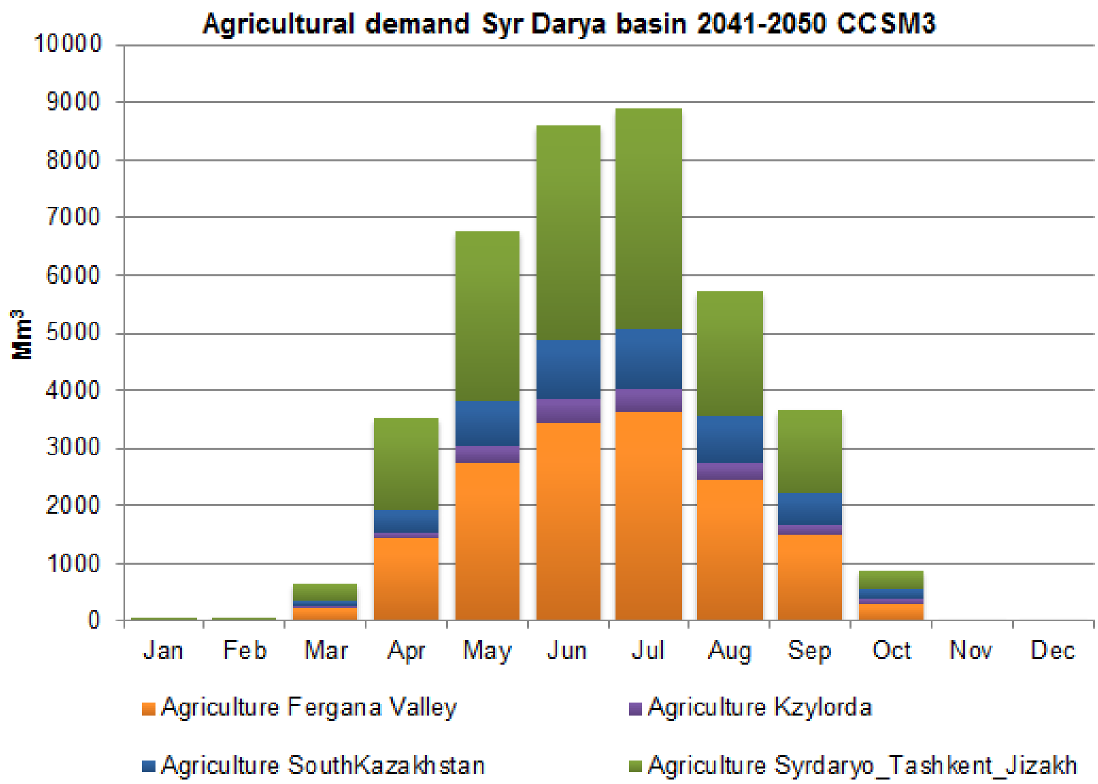
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Agricultural demand Syr Darya basin 2041-2050 CCSM3
Mm3
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Jan
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May
Jun
Jul
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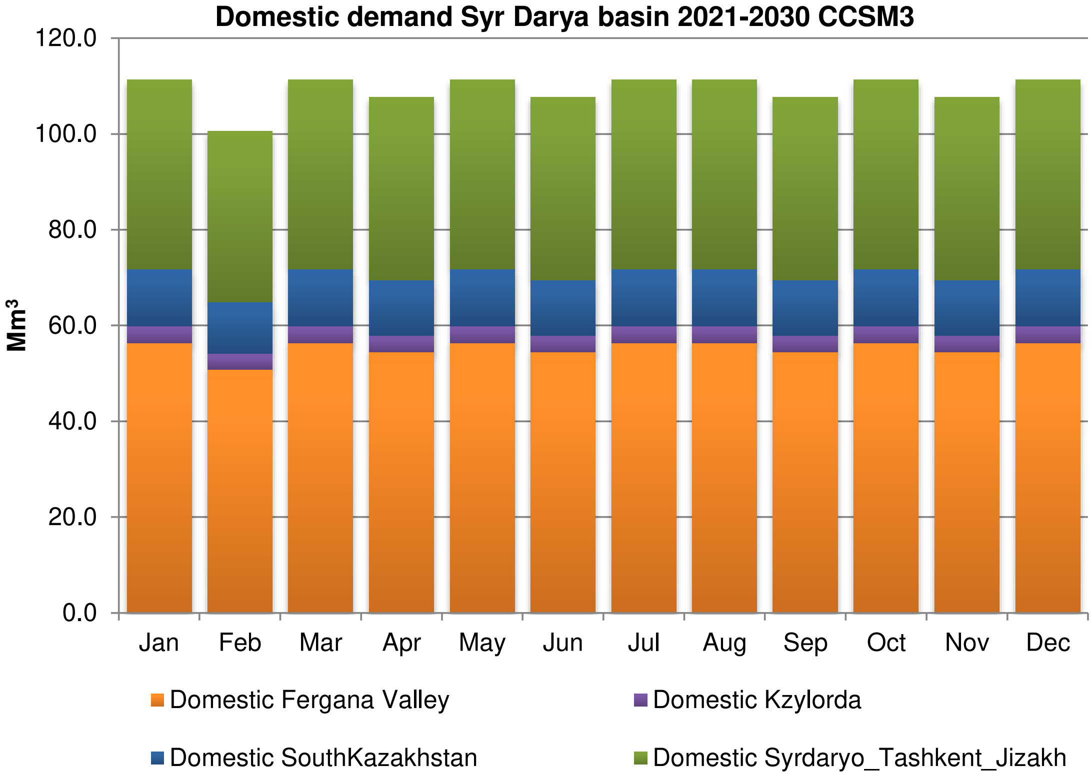
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Domestic demand Syr Darya basin 2021-2030 CCSM3
Mm³
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Jan
Feb
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Apr
May
Jun
Jul
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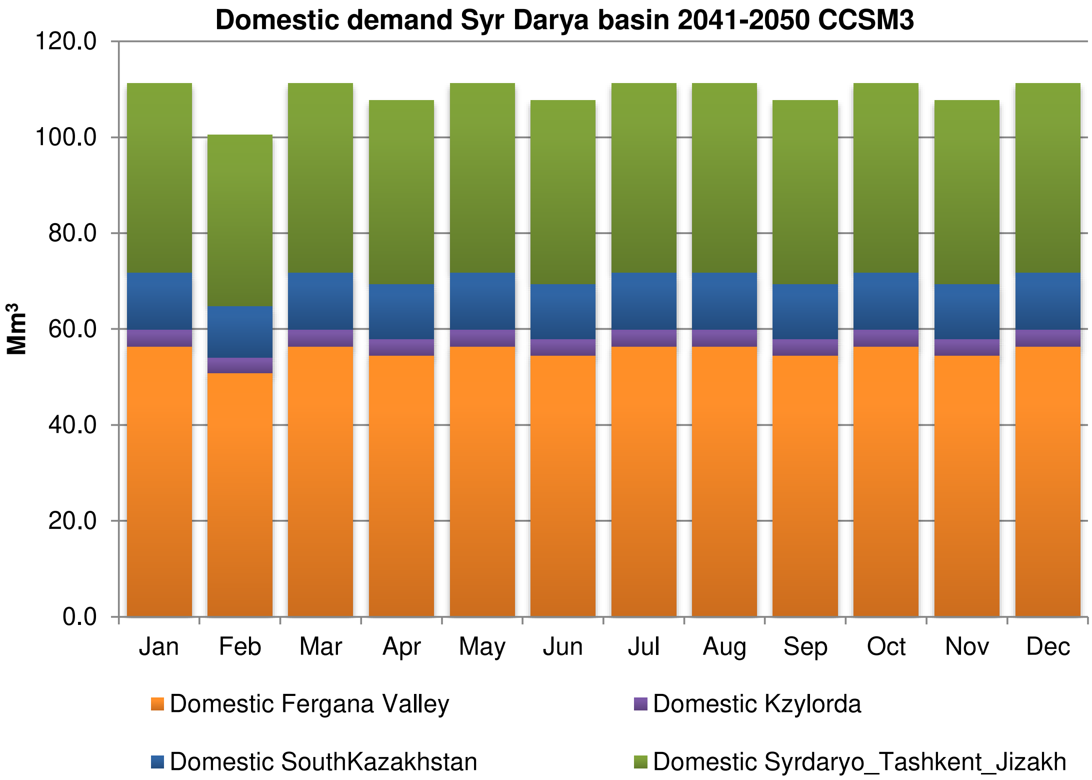
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Domestic demand Syr Darya basin 2041-2050 CCSM3
Mm³
120.0
100.0
80.0
60.0
40.0
20.0
0.0
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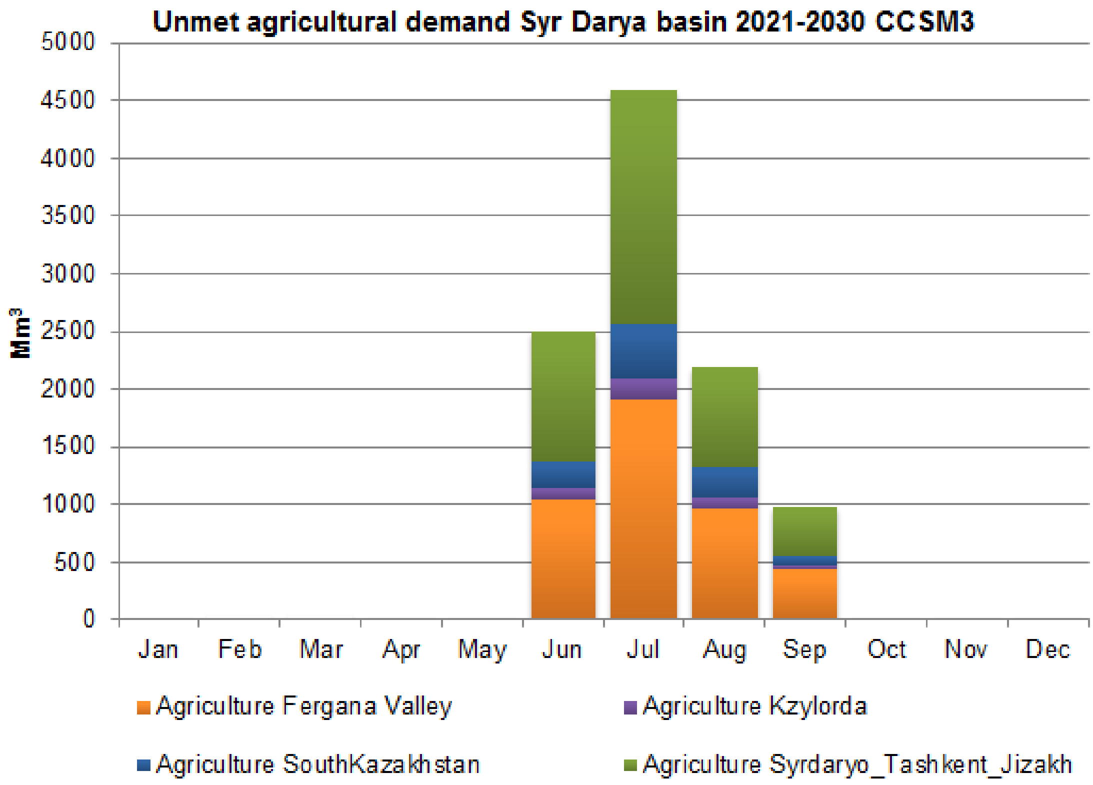
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Unmet agricultural demand Syr Darya basin 2021-2030 CCSM3
Mm3
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Jan
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May
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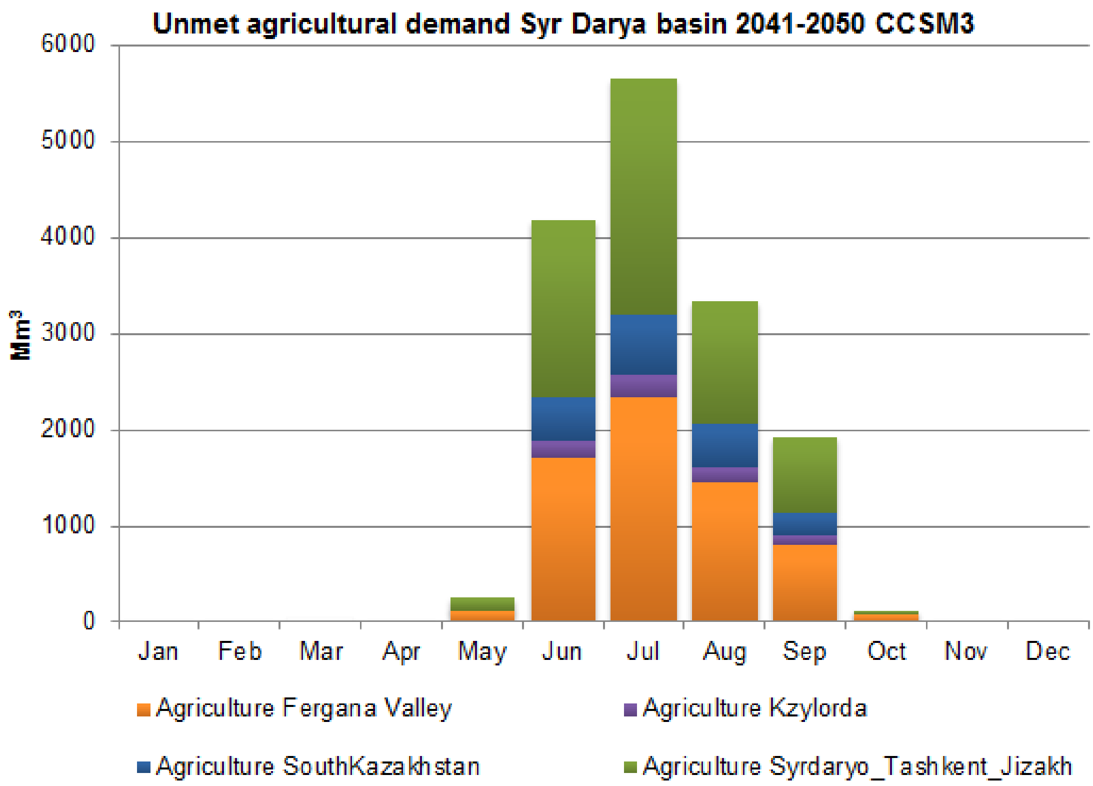
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Unmet agricultural demand Syr Darya basin 2041-2050 CCSM3
Mm3
6000
5000
4000
3000
2000
1000
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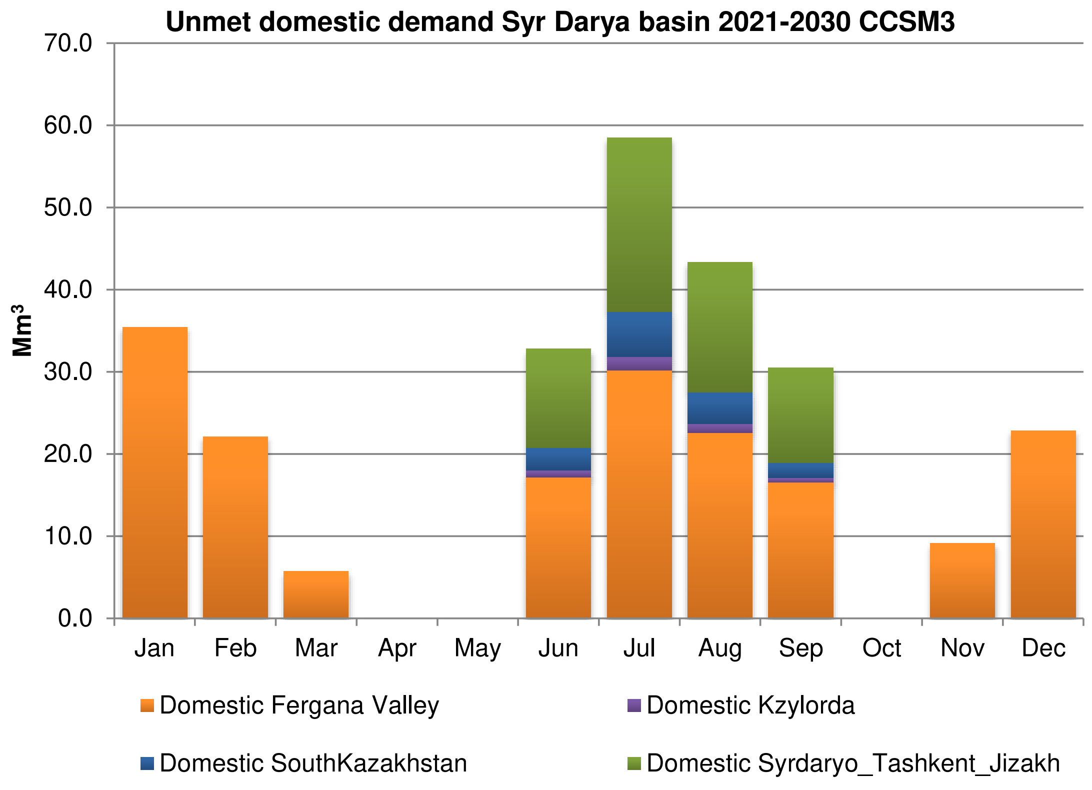
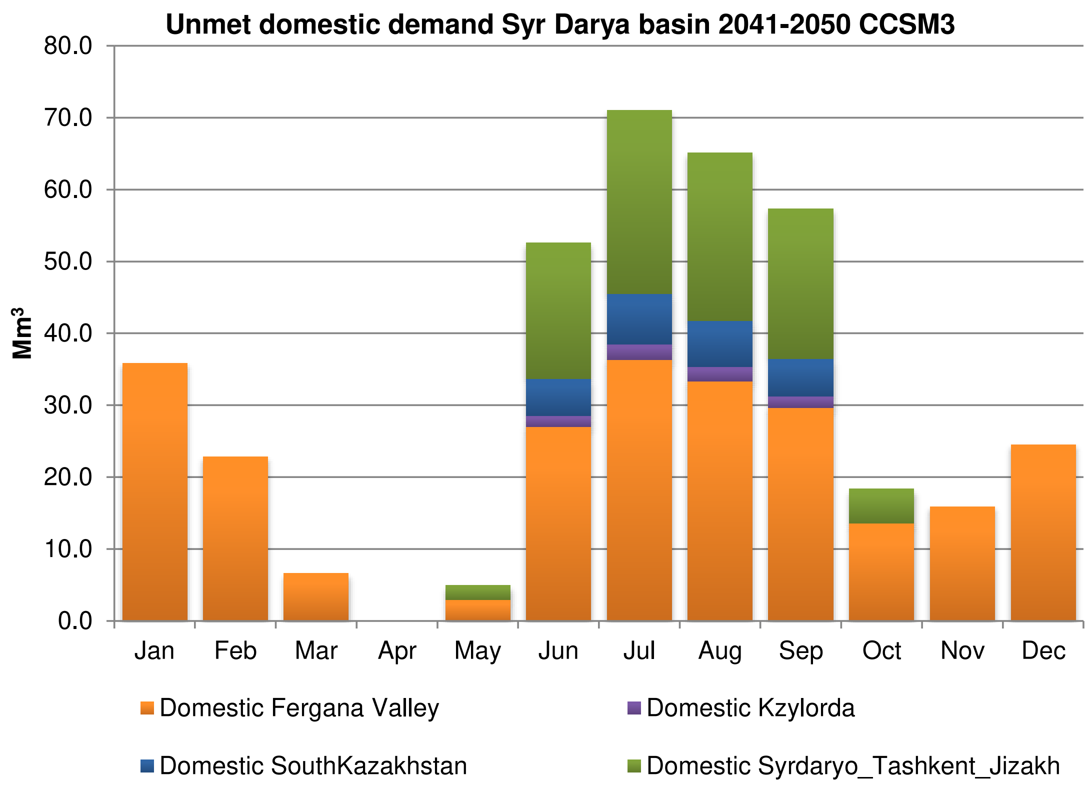
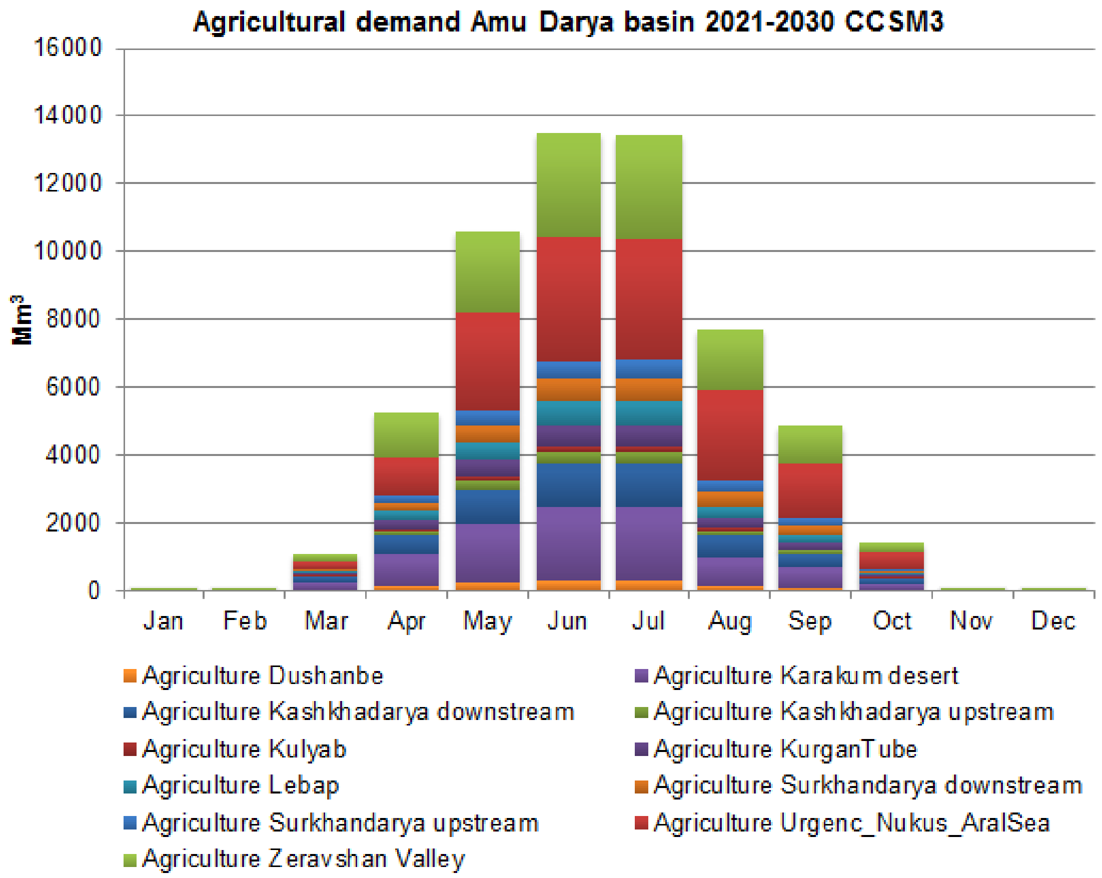
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Unmet domestic demand Syr Darya basin 2021-2030 CCSM3
Mm³
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Unmet domestic demand Syr Darya basin 2041-2050 CCSM3
Mm³
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Agricultural demand Amu Darya basin 2021-2030 CCSM3
Mm3
16000
14000
12000
10000
8000
6000
4000
2000
0
Jan
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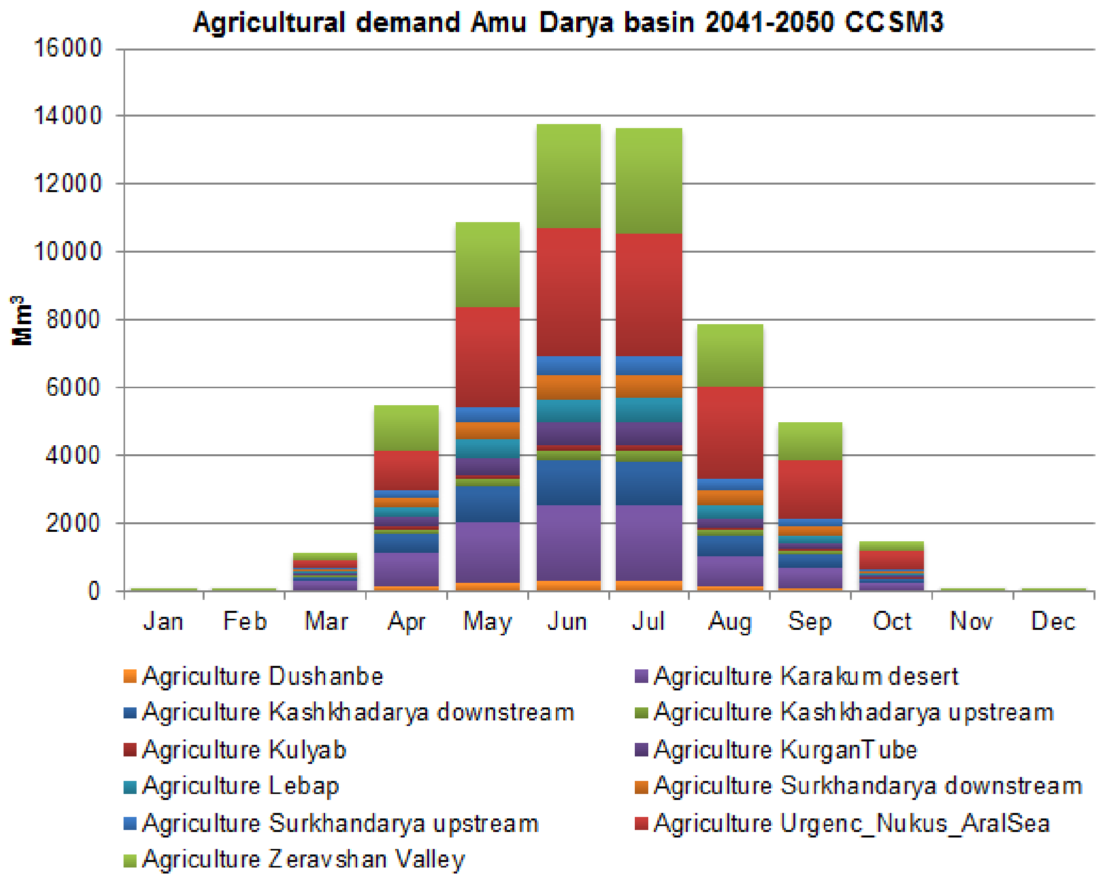
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Agricultural demand Amu Darya basin 2041-2050 CCSM3
Mm3
16000
14000
12000
10000
8000
6000
4000
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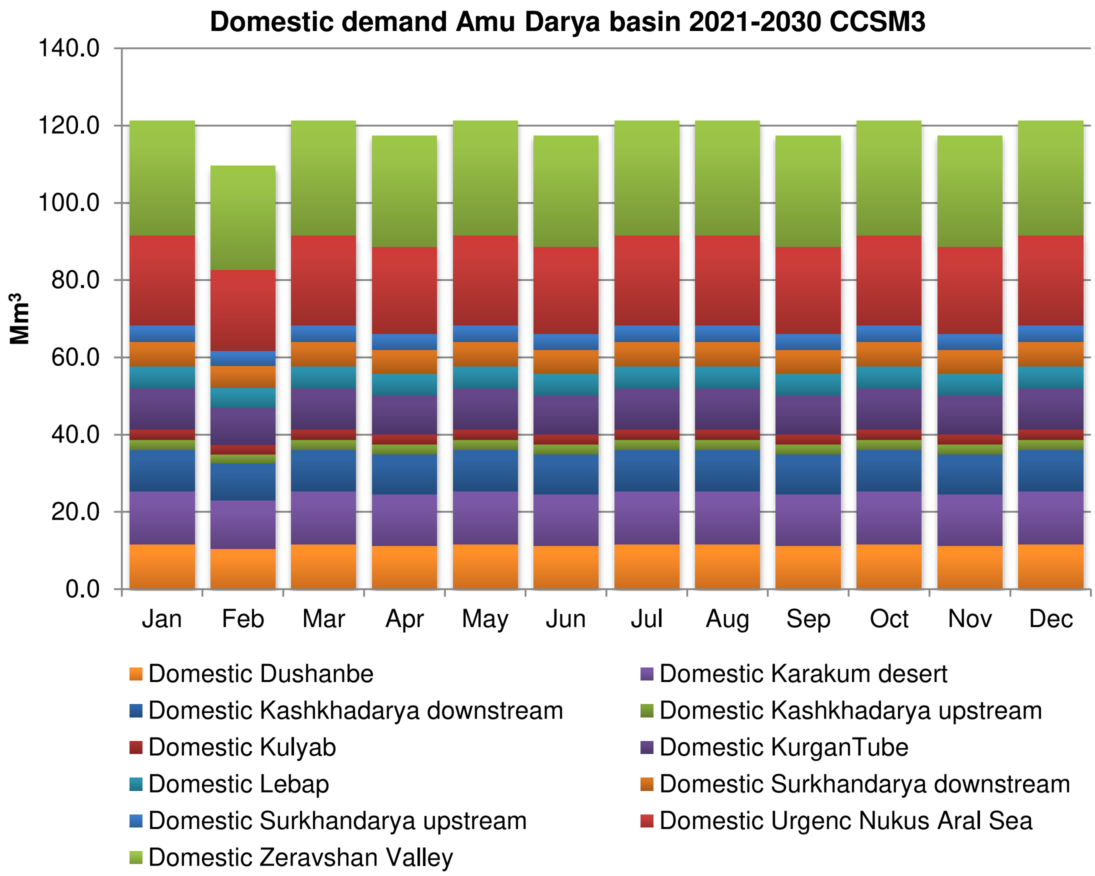
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Domestic demand Amu Darya basin 2021-2030 CCSM3
Mm³
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
Domestic Kulyab
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Domestic Lebap
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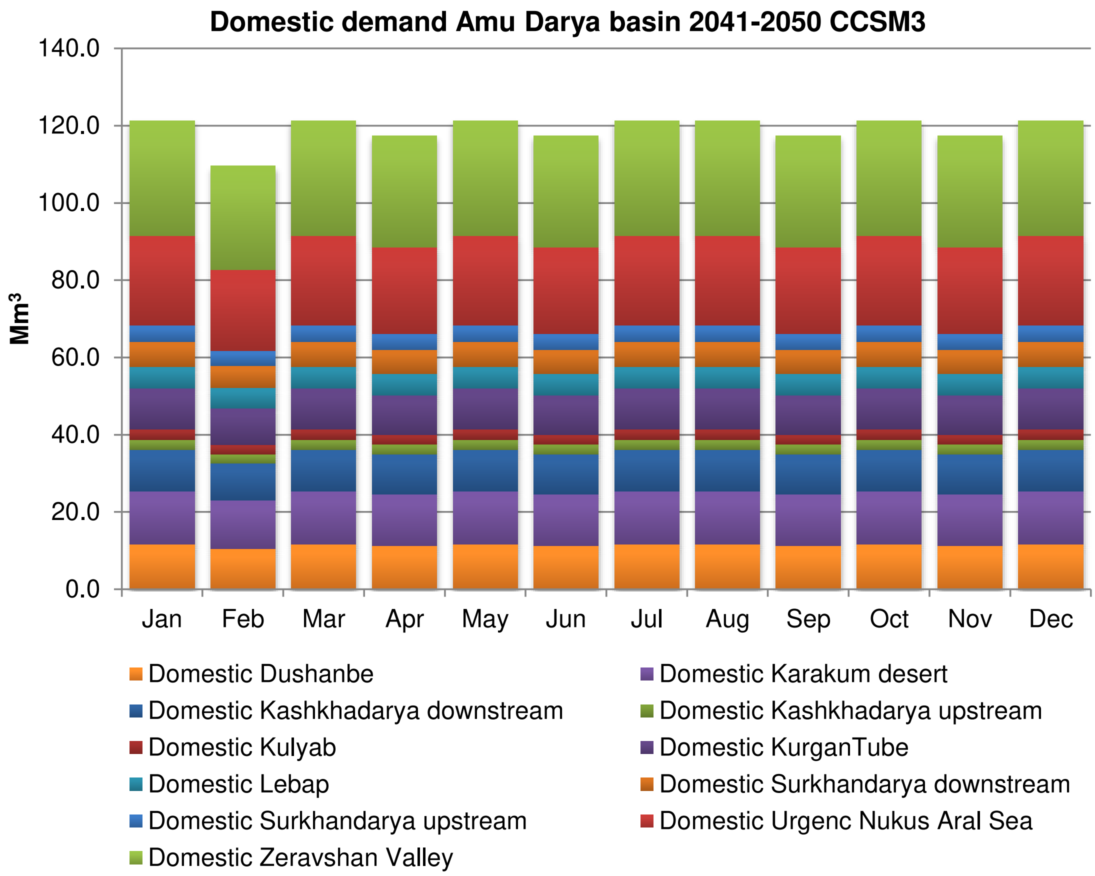
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley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Mm³
140.0
120.0
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Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
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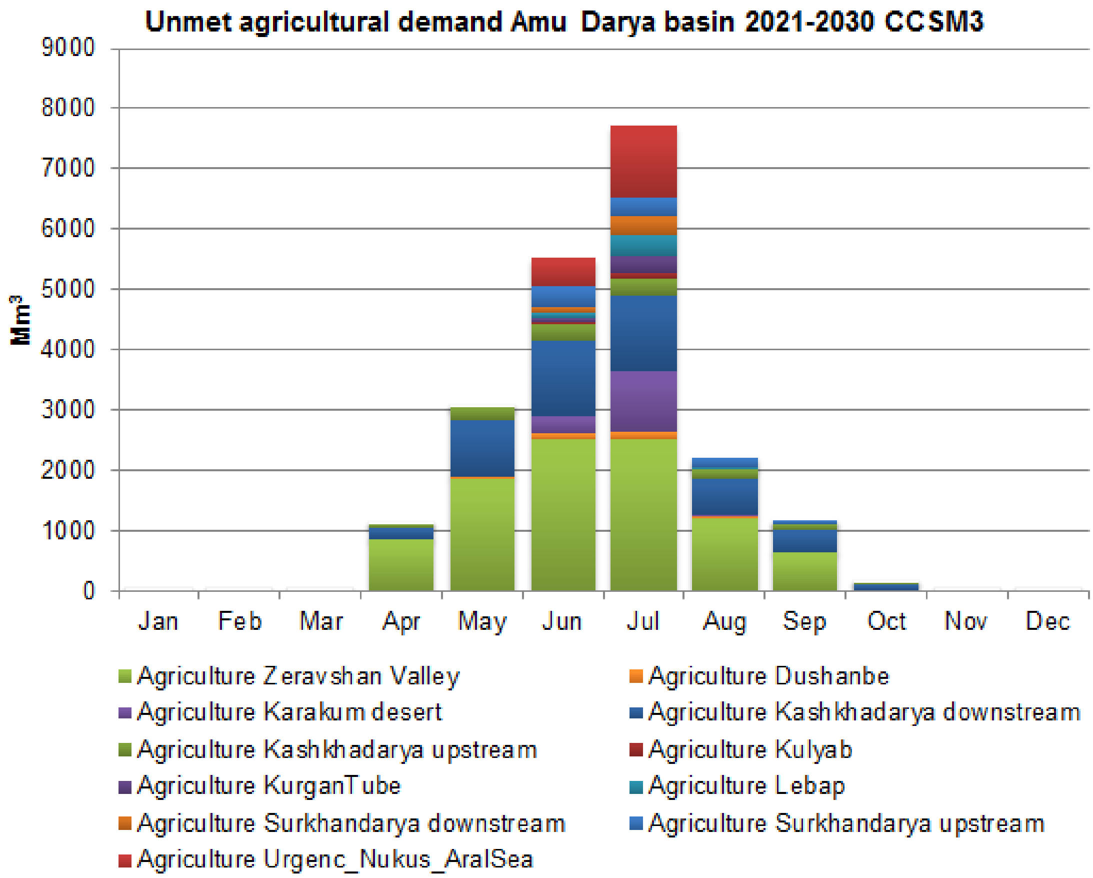
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley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Mm³
9000
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Agriculture Zeravshan Valley
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Agriculture Karakum desert
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Agriculture Kashkhadarya upstream
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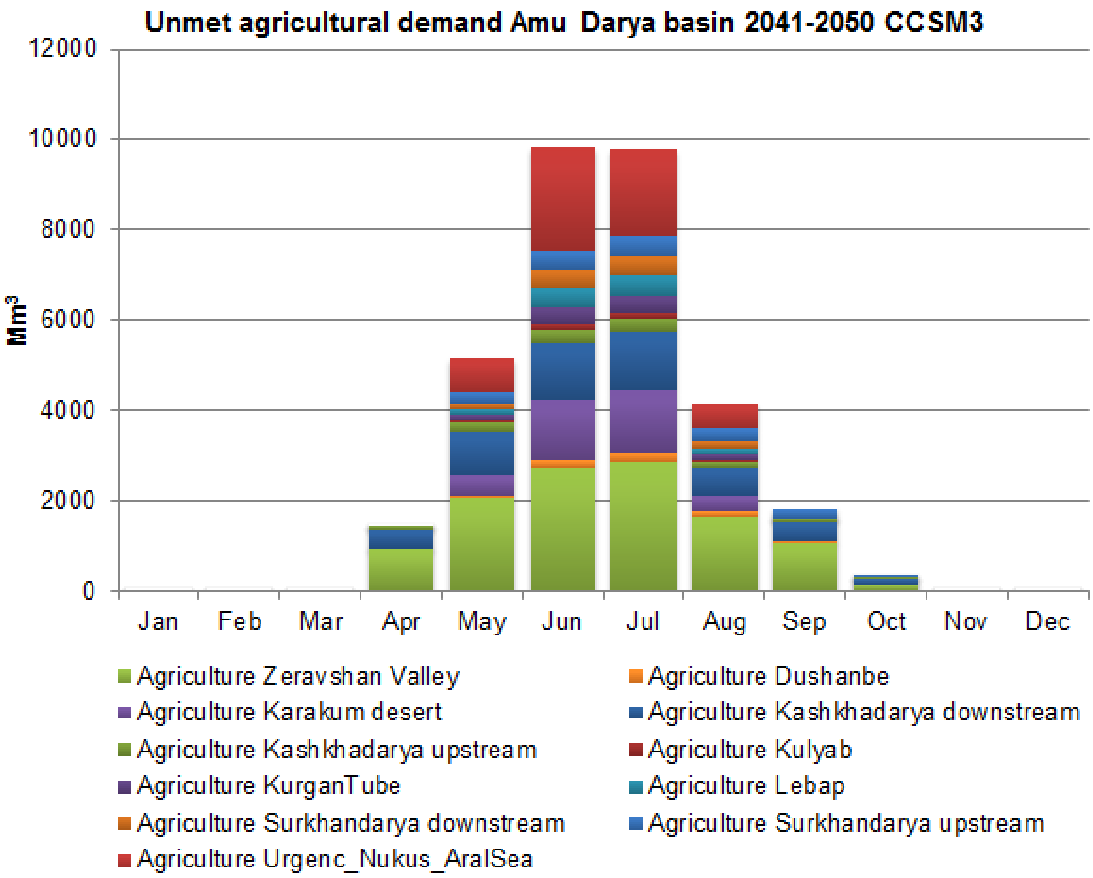
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea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Mm³
12000
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Agriculture Zeravshan Valley
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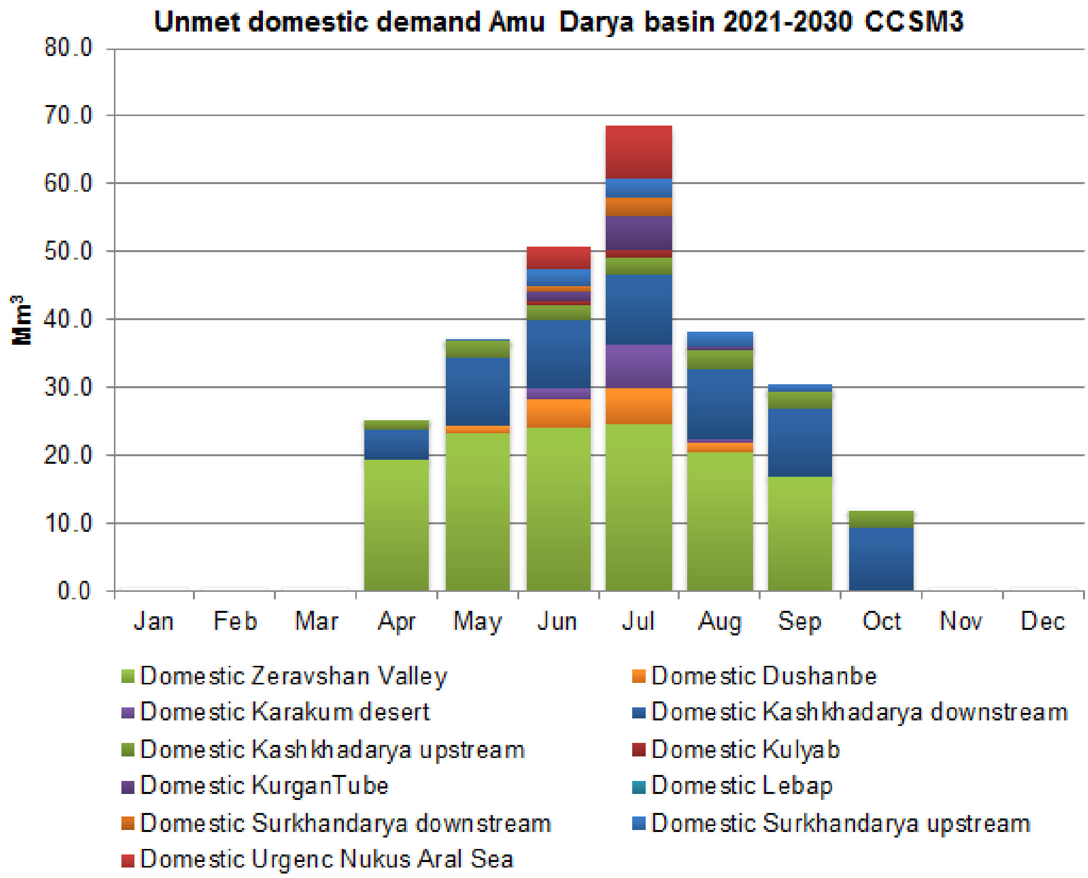
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Mm³
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70.0
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Domestic Zeravshan Valley
Domestic Dushanbe
Domestic Karakum desert
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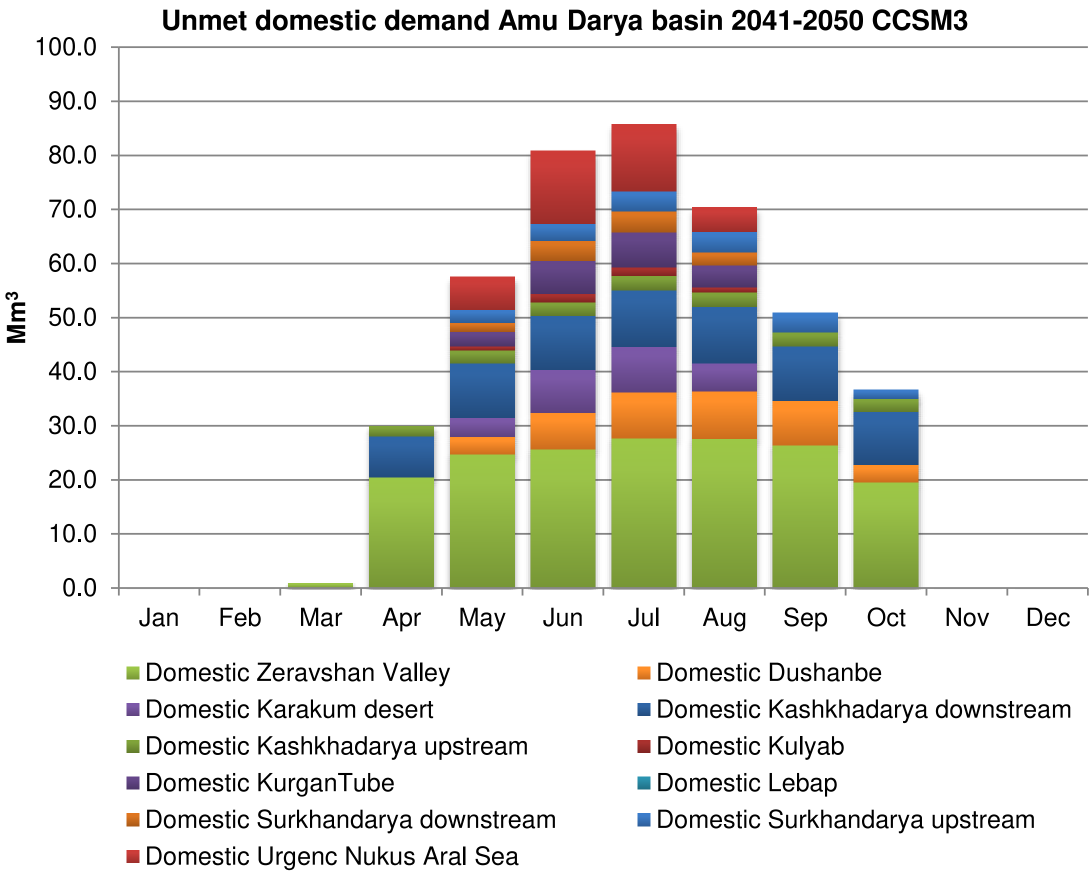
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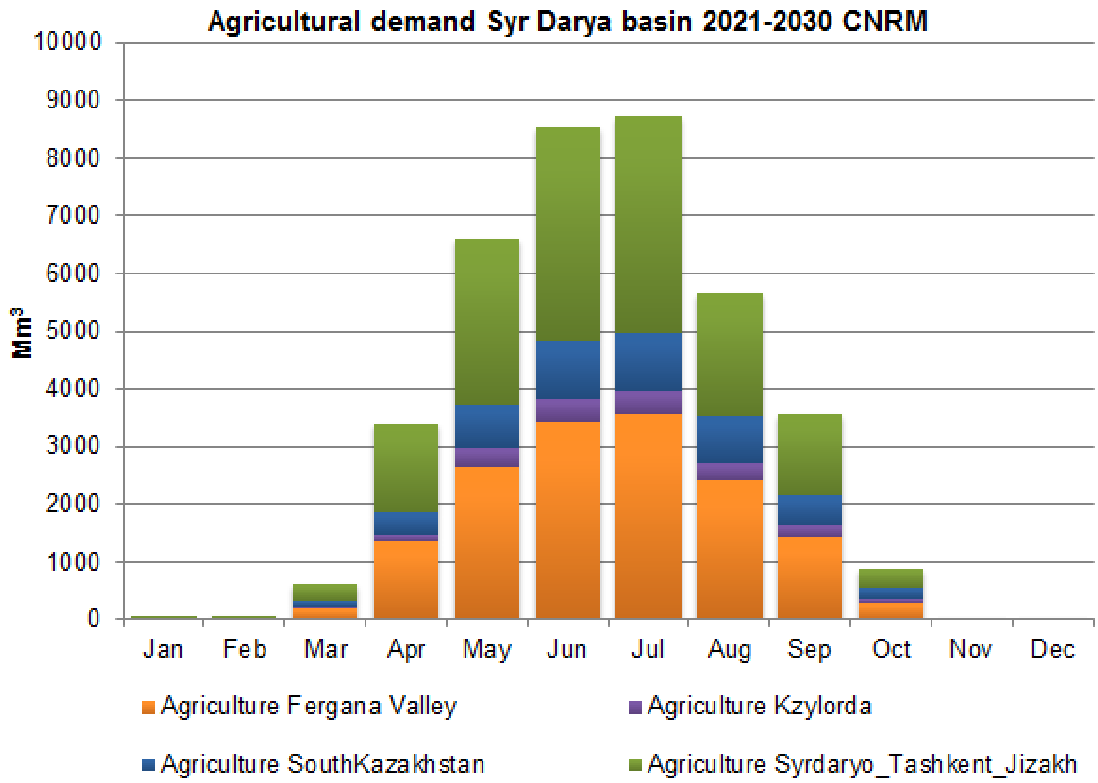
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Mm³
10000
9000
8000
7000
6000
5000
4000
3000
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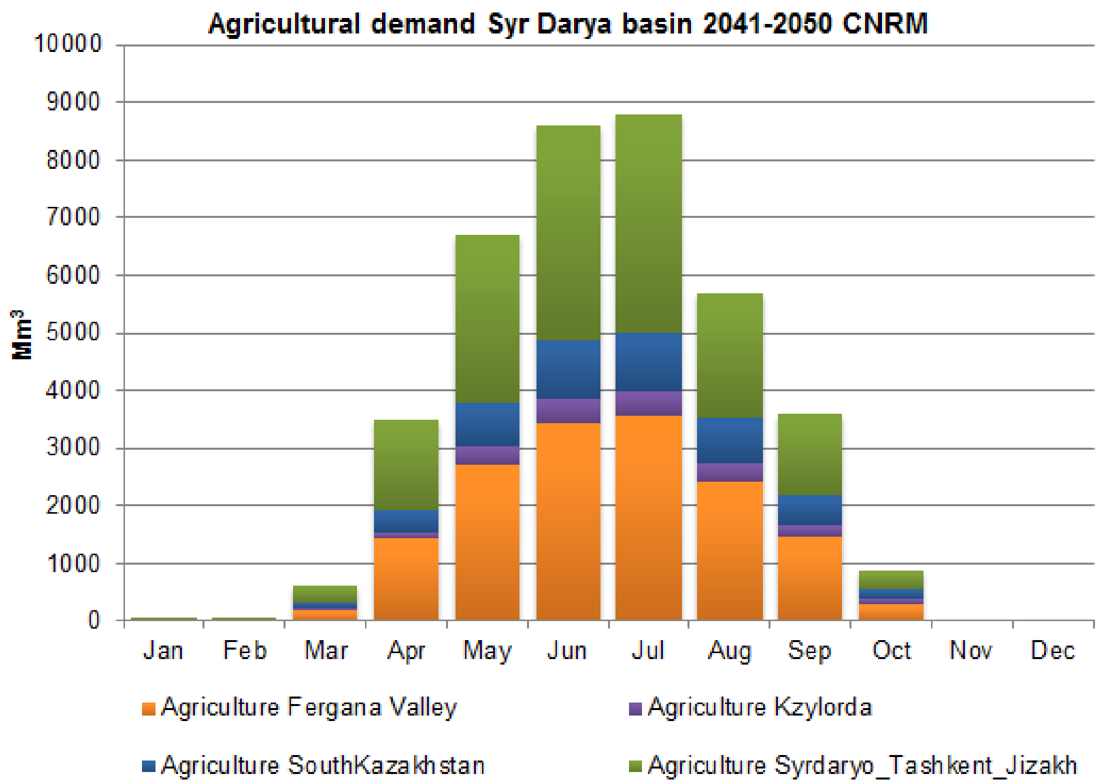
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Agricultural demand Syr Darya basin 2041-2050 CNRM
Mm³
10000
9000
8000
7000
6000
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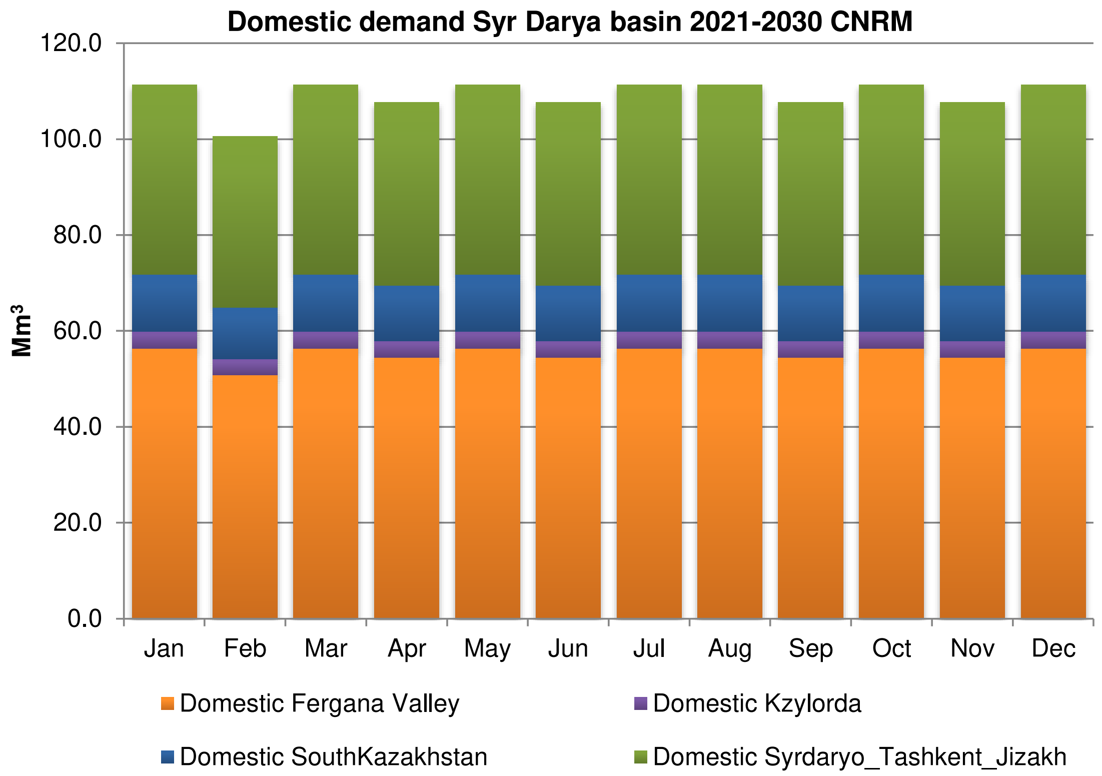
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Domestic demand Syr Darya basin 2021-2030 CNRM
120.0
100.0
80.0
60.0
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Mm³
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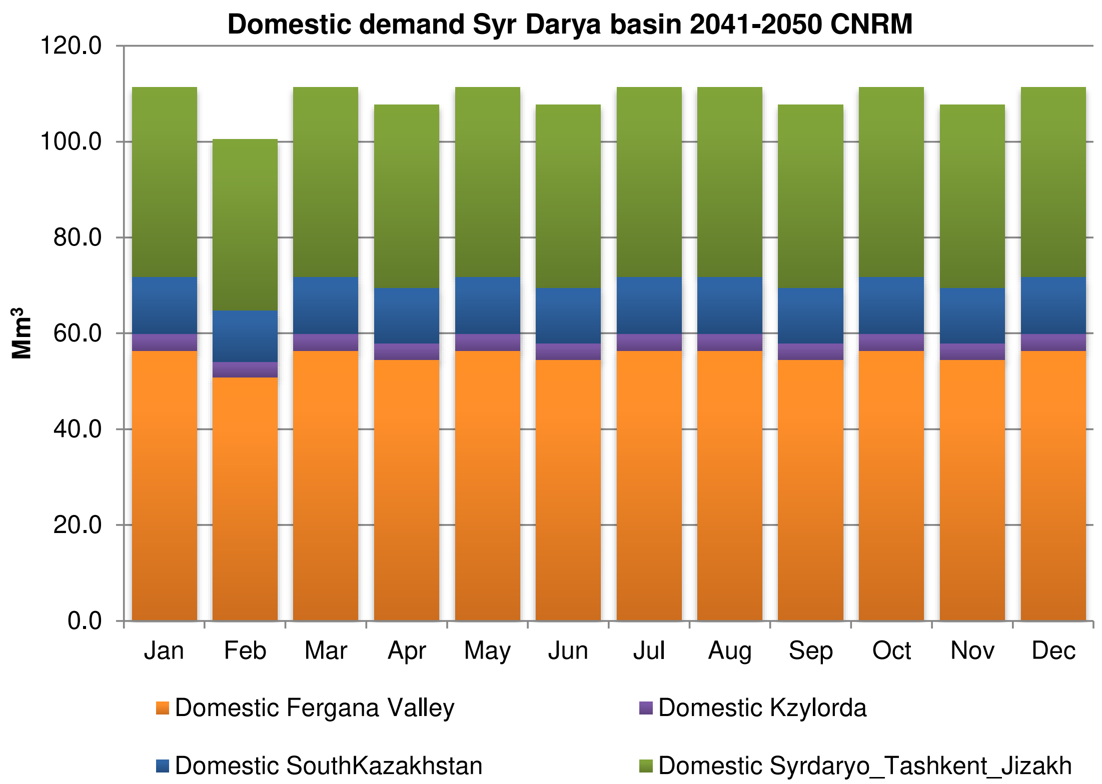
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh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120.0
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Mm³
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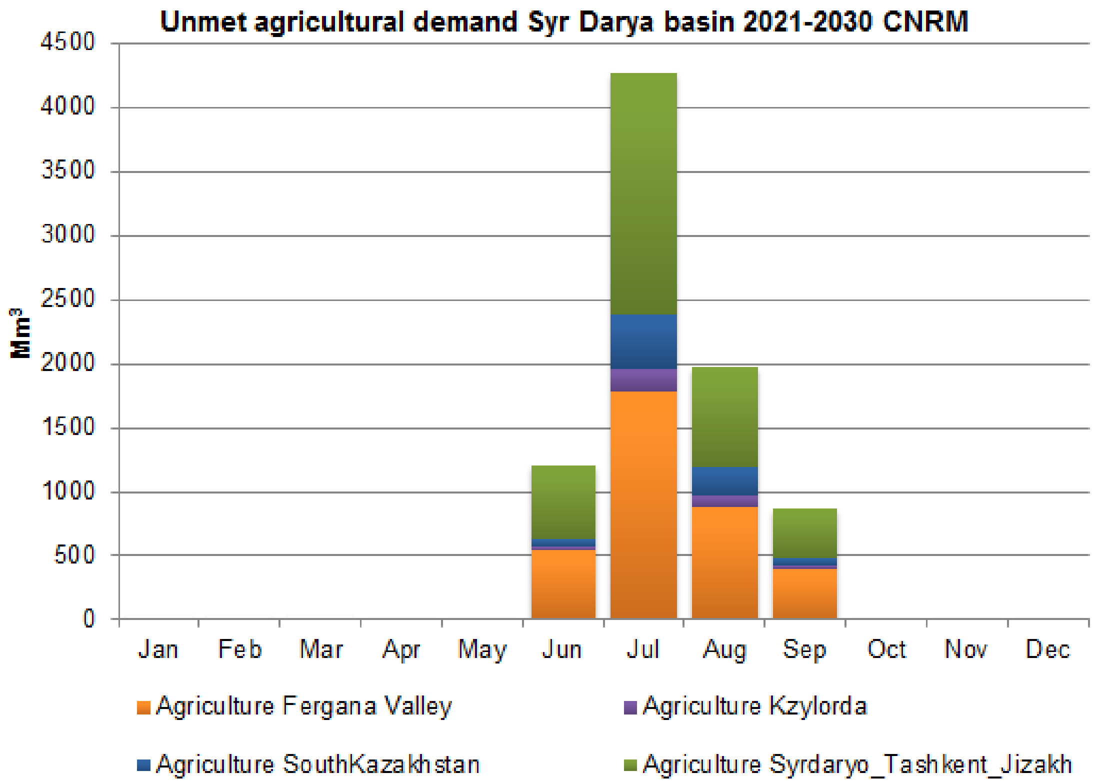
Unmet agricultural demand Syr Darya basin 2021-2030 CNRM
Mm^3
4500
4000
3500
3000
2500
2000
1500
1000
500
0
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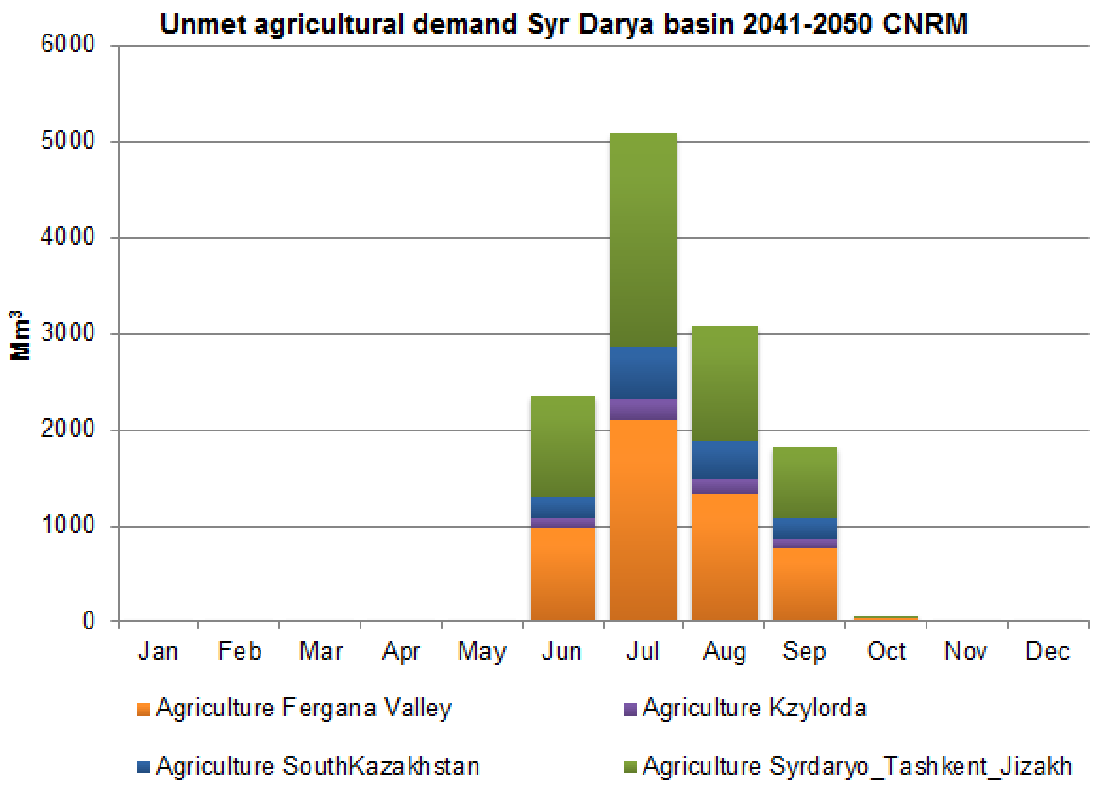
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Unmet agricultural demand Syr Darya basin 2041-2050 CNRM
Mm^3
6000
5000
4000
3000
2000
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0
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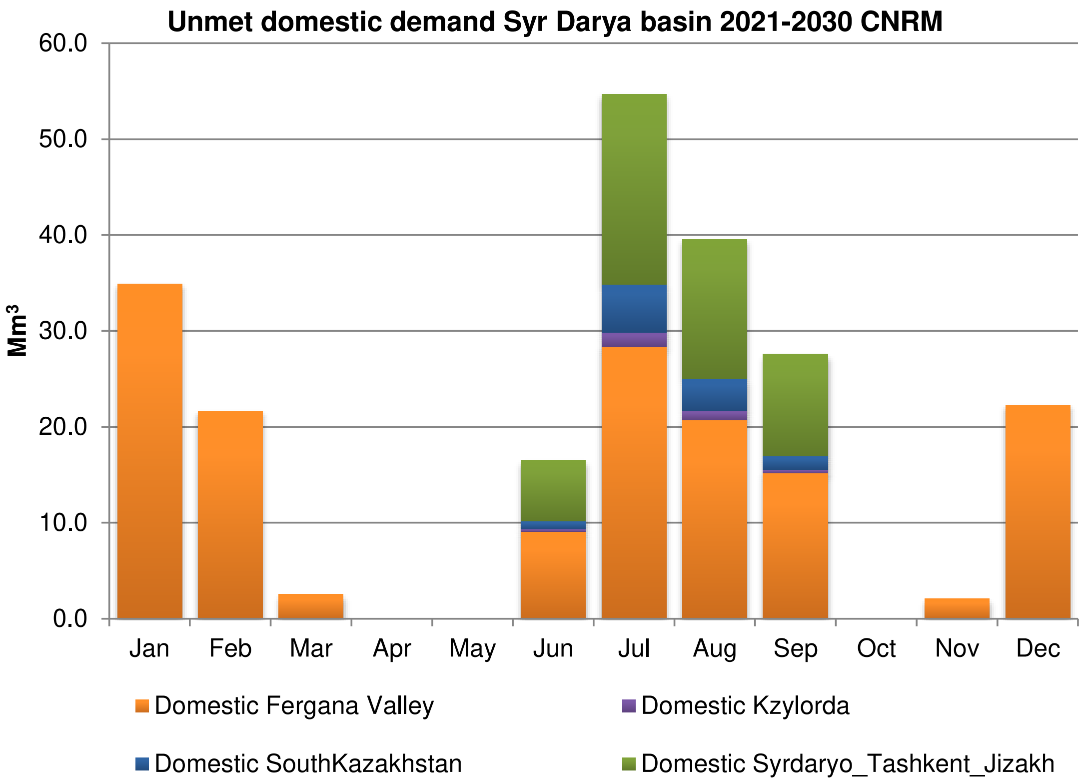
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Unmet domestic demand Syr Darya basin 2021-2030 CNRM
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Mm³
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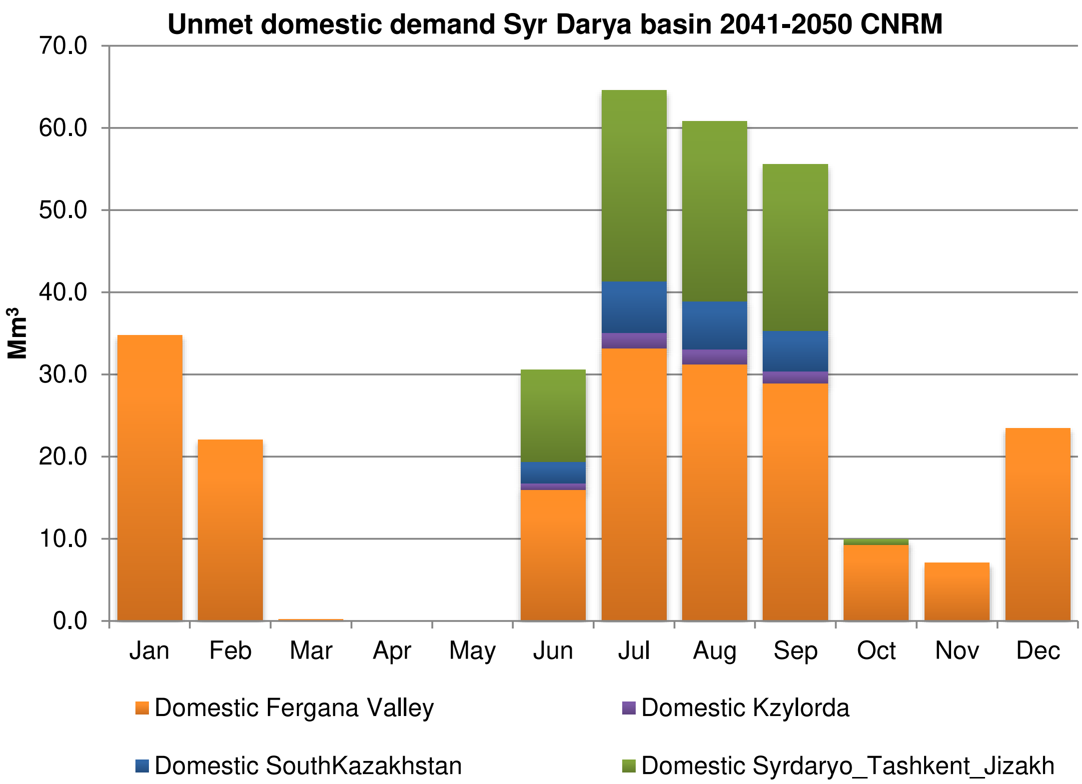
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Unmet domestic demand Syr Darya basin 2041-2050 CNRM
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Mm³
Jan
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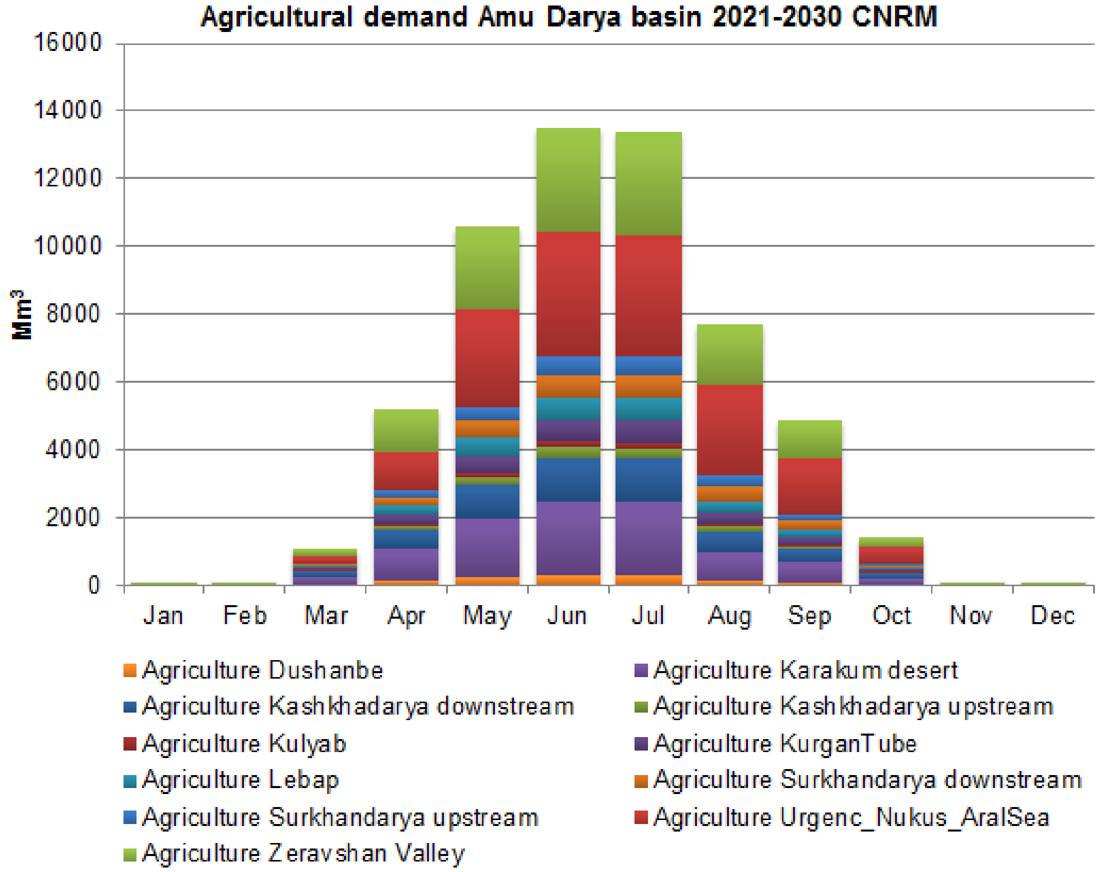
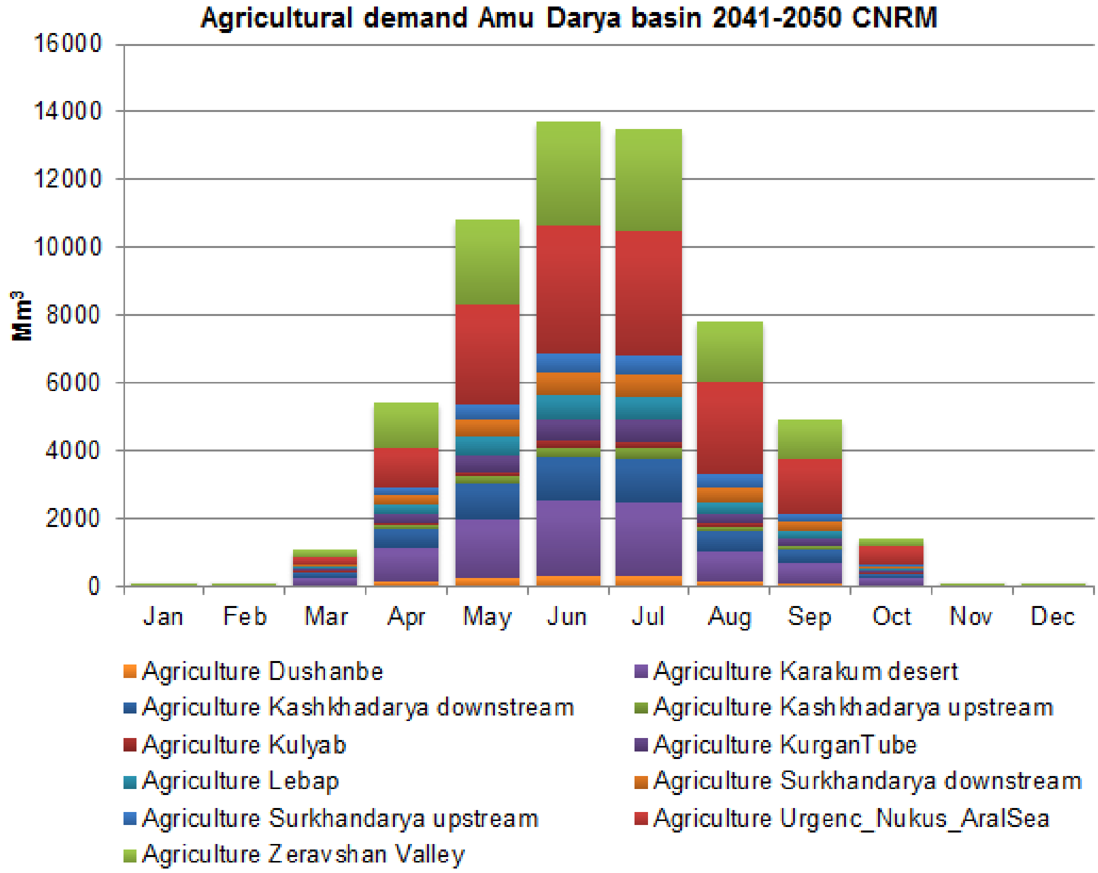
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh



Agricultural demand Amu Darya basin 2021-2030 CNRM
Mm³
16000
14000
12000
10000
8000
6000
4000
2000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley



Agricultural demand Amu Darya basin 2041-2050 CNRM
Mm³
16000
14000
12000
10000
8000
6000
4000
2000
0
Jan
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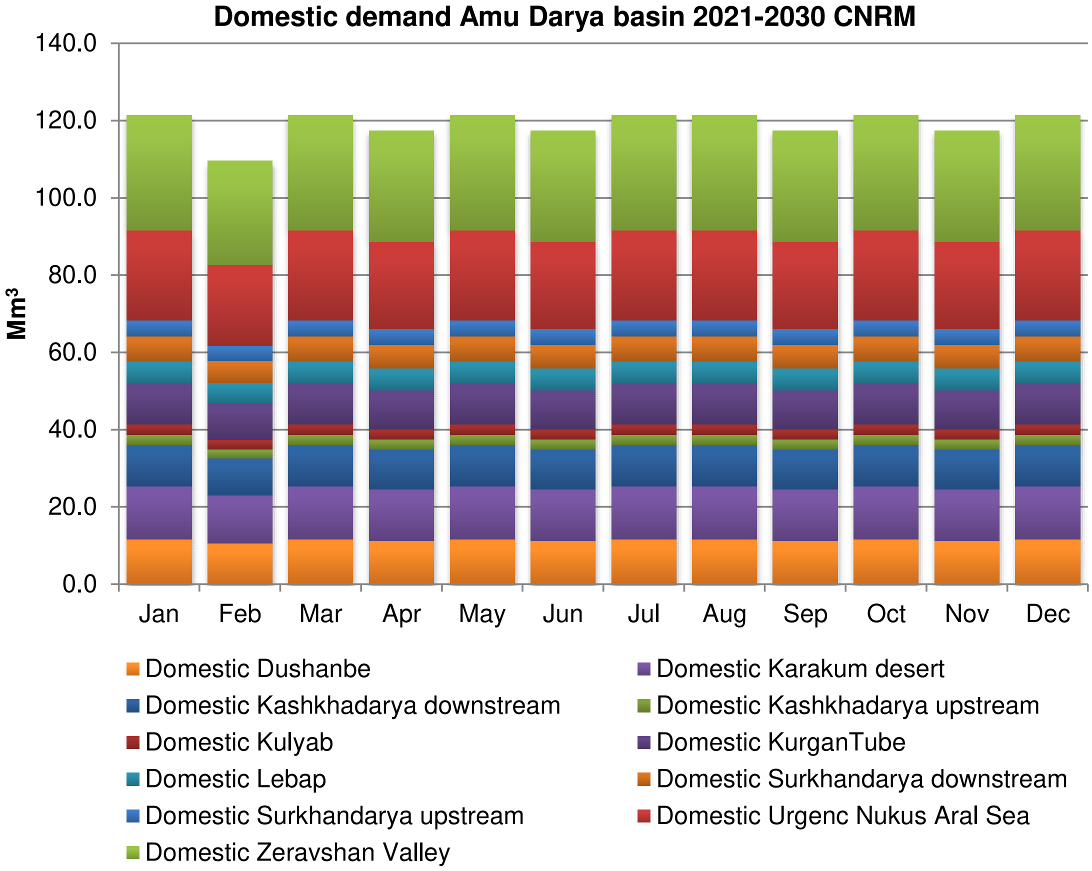
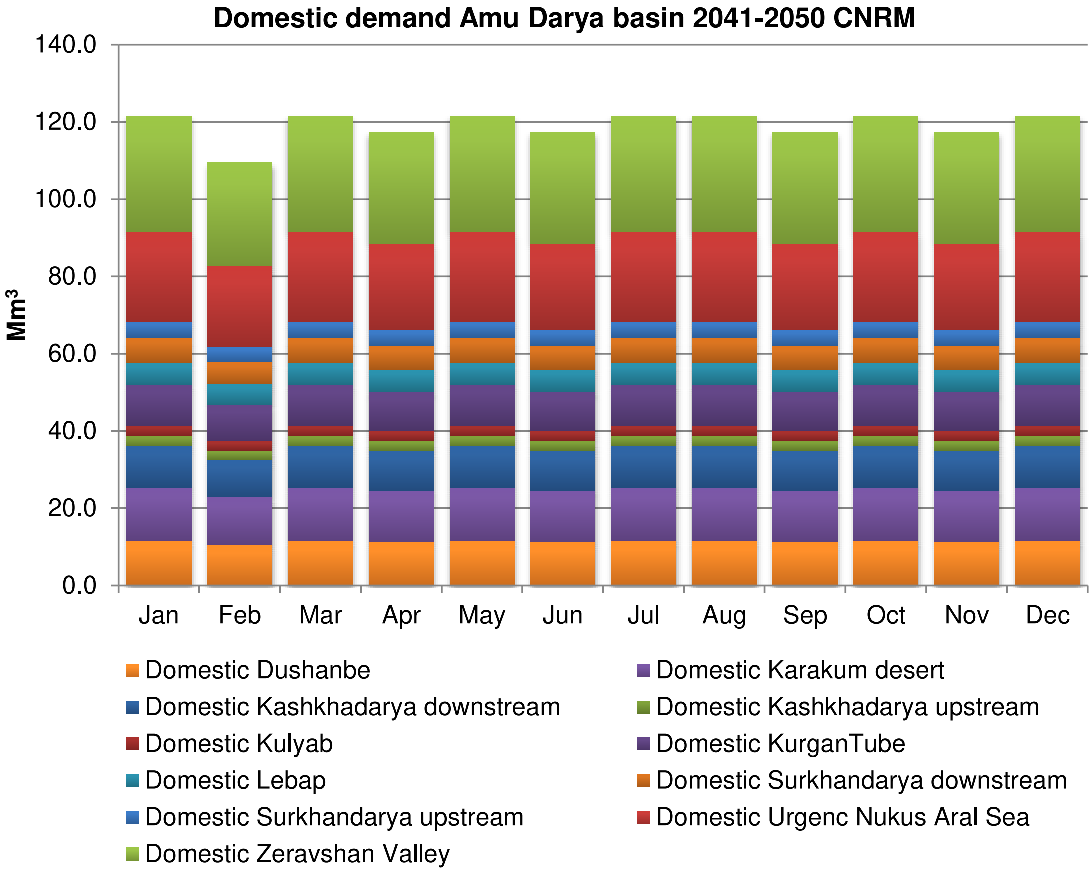
Aug
Sep
Oct
Nov
Dec
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Domestic demand Amu Darya basin 2021-2030 CNRM
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Mm³
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
Domestic Kulyab
Domestic KurganTube
Domestic Lebap
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley


Domestic demand Amu Darya basin 2041-2050 CNRM
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Mm³
Jan
Feb
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May
Jun
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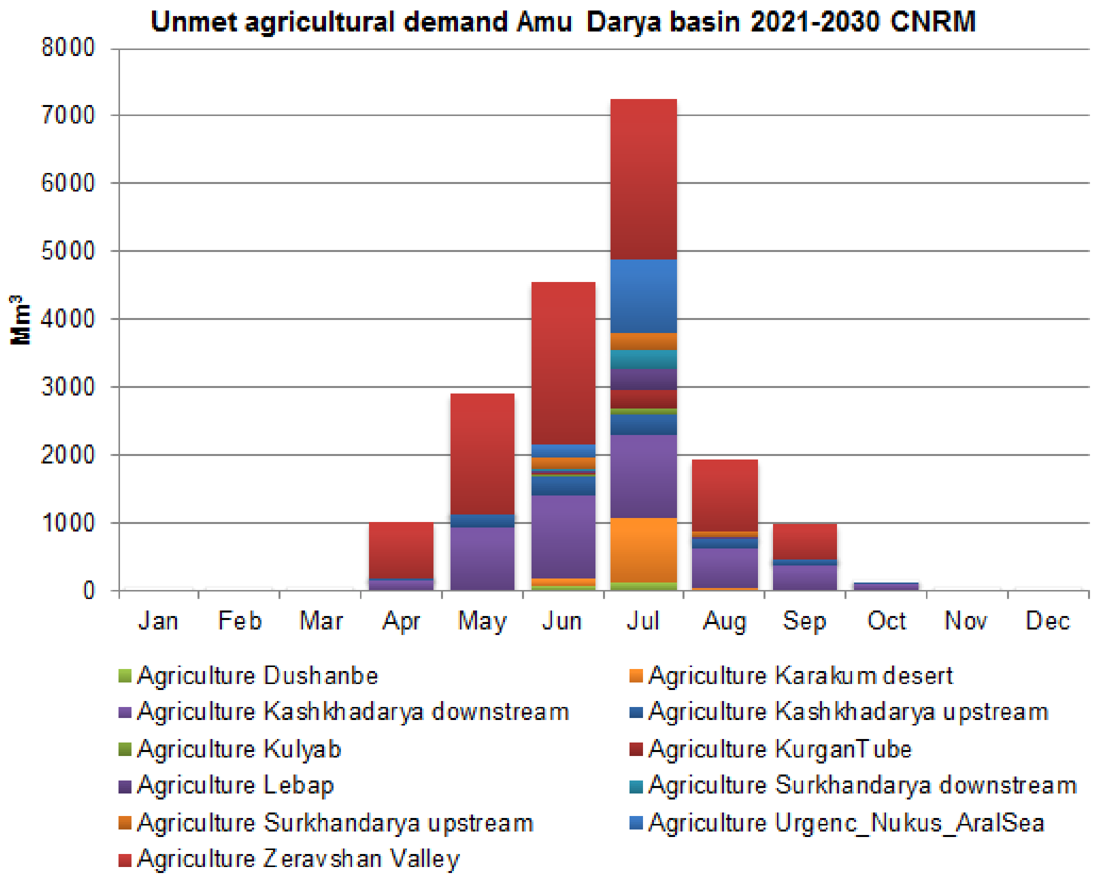
Sep
Oct
Nov
Dec
Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
Domestic Kulyab
Domestic KurganTube
Domestic Lebap
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley


Unmet agricultural demand Amu Darya basin 2021-2030 CNRM
Mm3
8000
7000
6000
5000
4000
3000
2000
1000
0
Jan
Feb
Mar
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May
Jun
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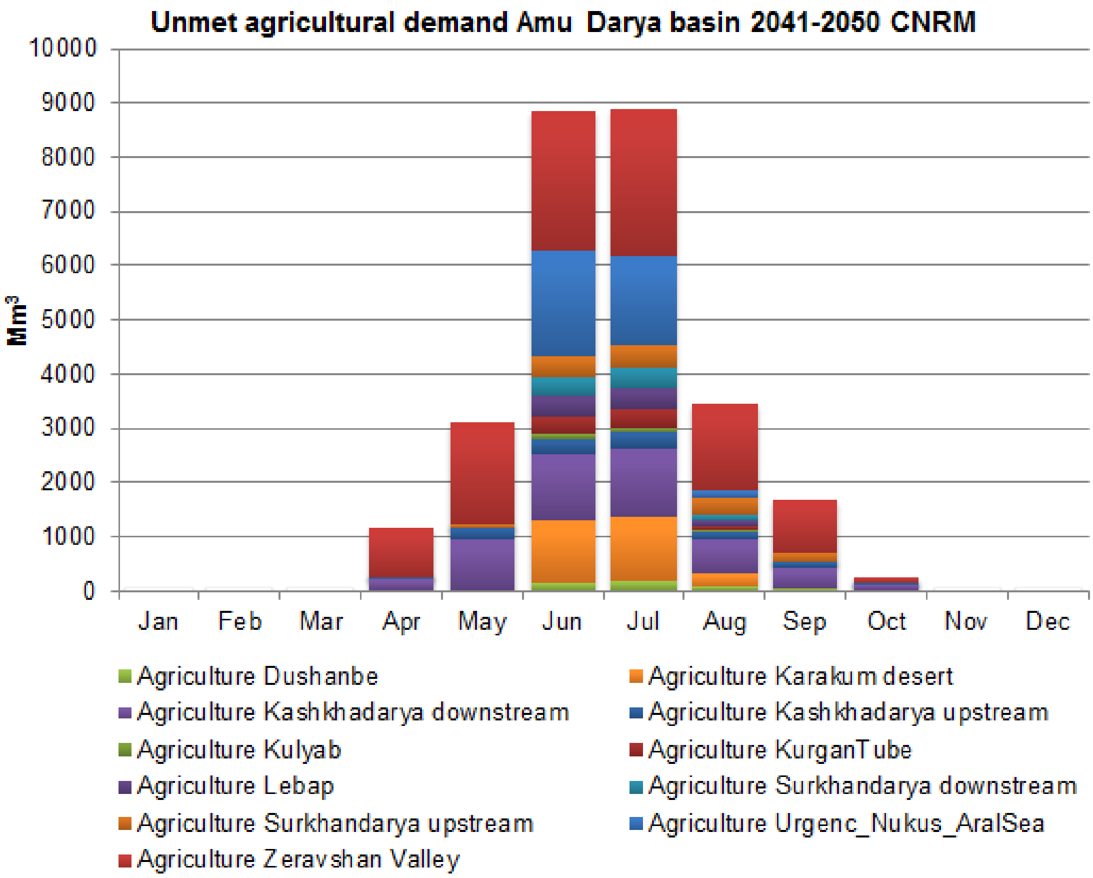
Sep
Oct
Nov
Dec
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Unmet agricultural demand Amu Darya basin 2041-2050 CNRM
Mm3
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Jan
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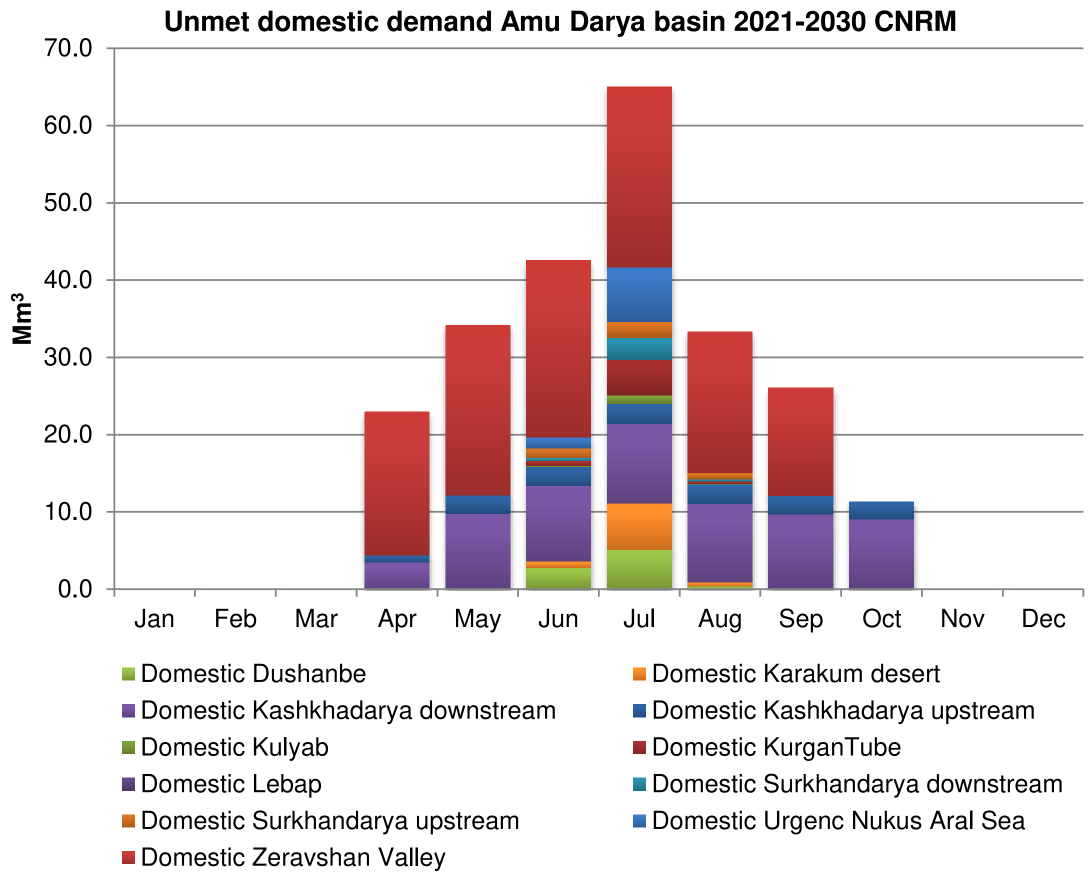
Nov
Dec
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley



Unmet domestic demand Amu Darya basin 2021-2030 CNRM
Mm³
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
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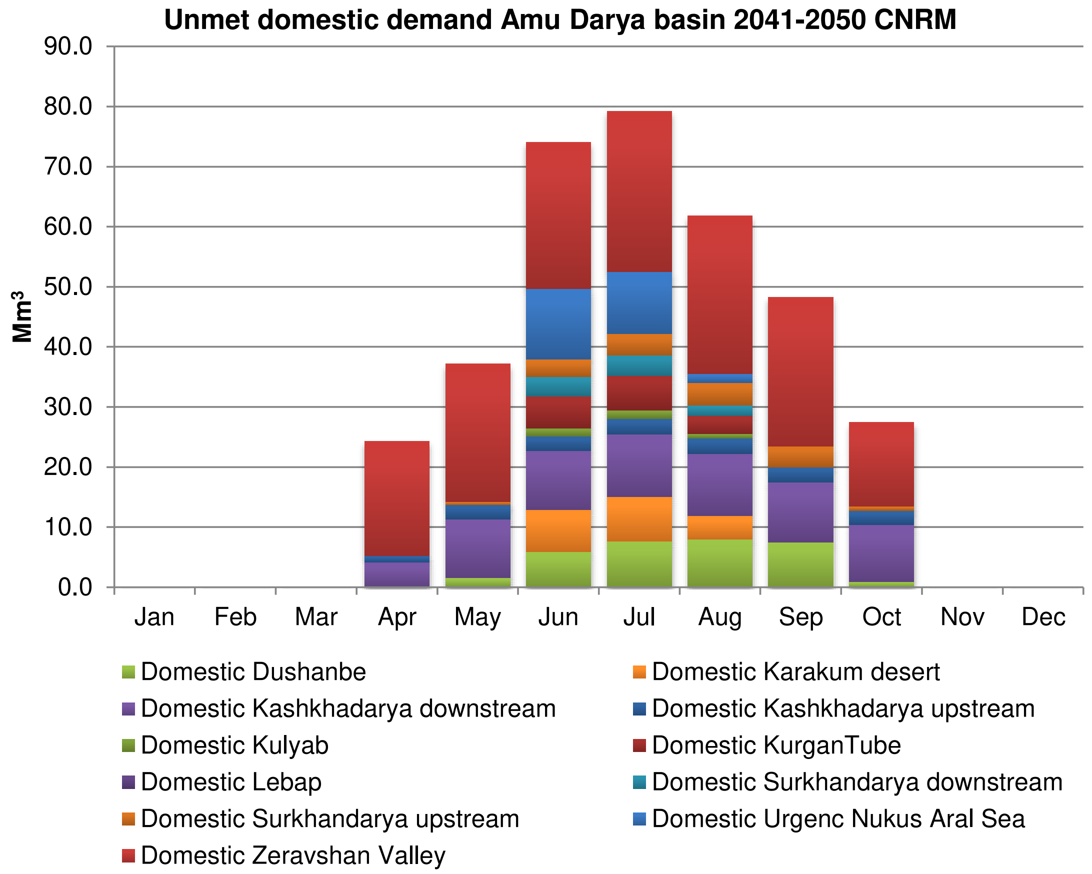
Sep
Oct
Nov
Dec
Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
Domestic Kulyab
Domestic KurganTube
Domestic Lebap
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley



Unmet domestic demand Amu Darya basin 2041-2050 CNRM
Mm³
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Jan
Feb
Mar
Apr
May
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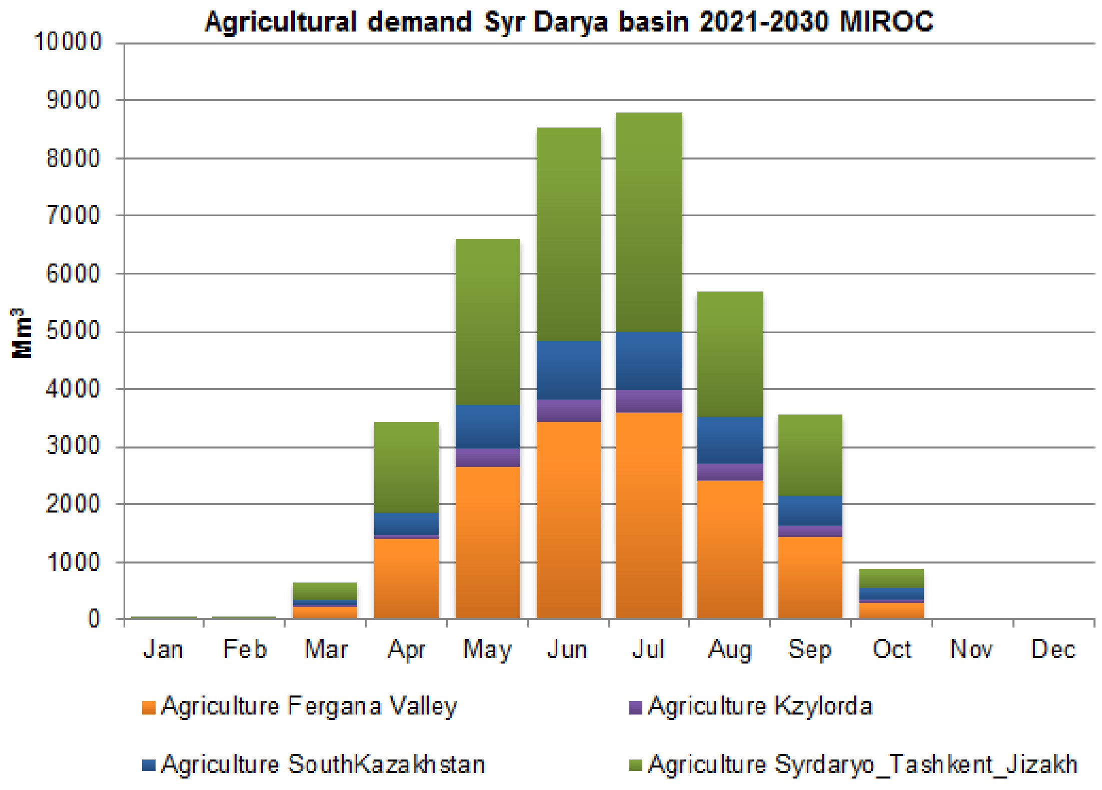
Nov
Dec
Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
Domestic Kulyab
Domestic KurganTube
Domestic Lebap
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley


Agricultural demand Syr Darya basin 2021-2030 MIROC
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Mm3
Jan
Feb
Mar
Apr
May
Jun
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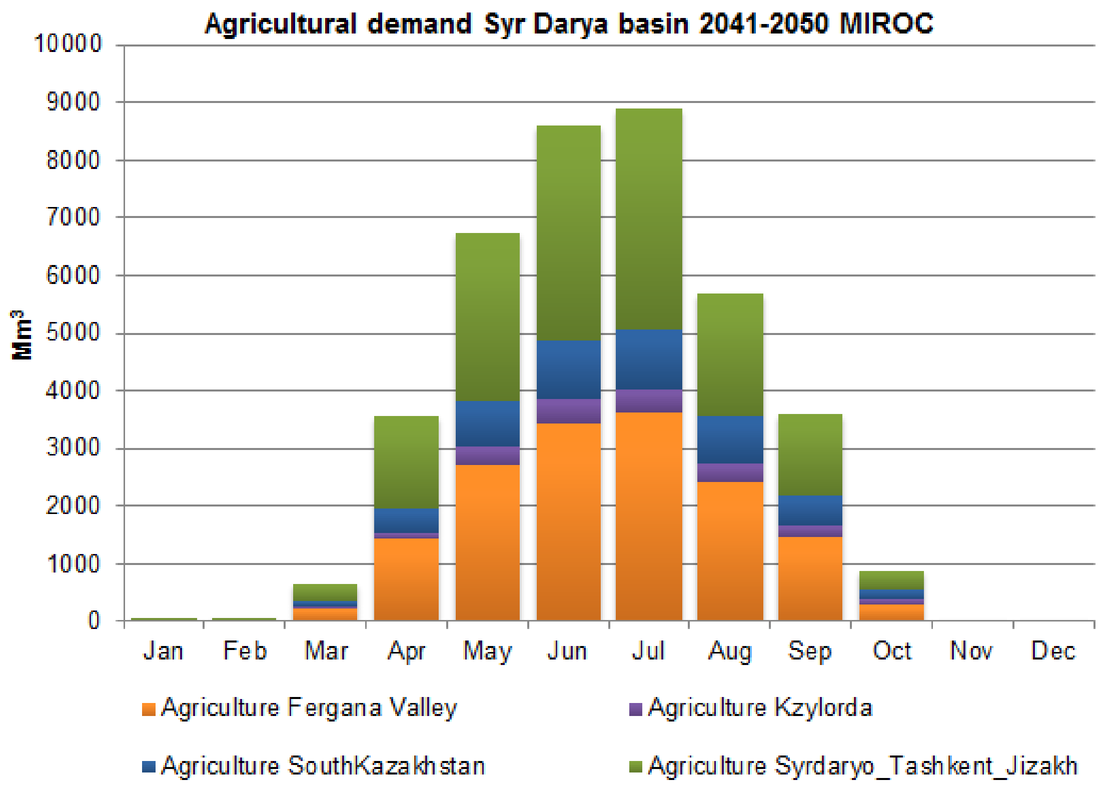
Aug
Sep
Oct
Nov
Dec
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Agricultural demand Syr Darya basin 2041-2050 MIROC
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Mm3
Jan
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Mar
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Jun
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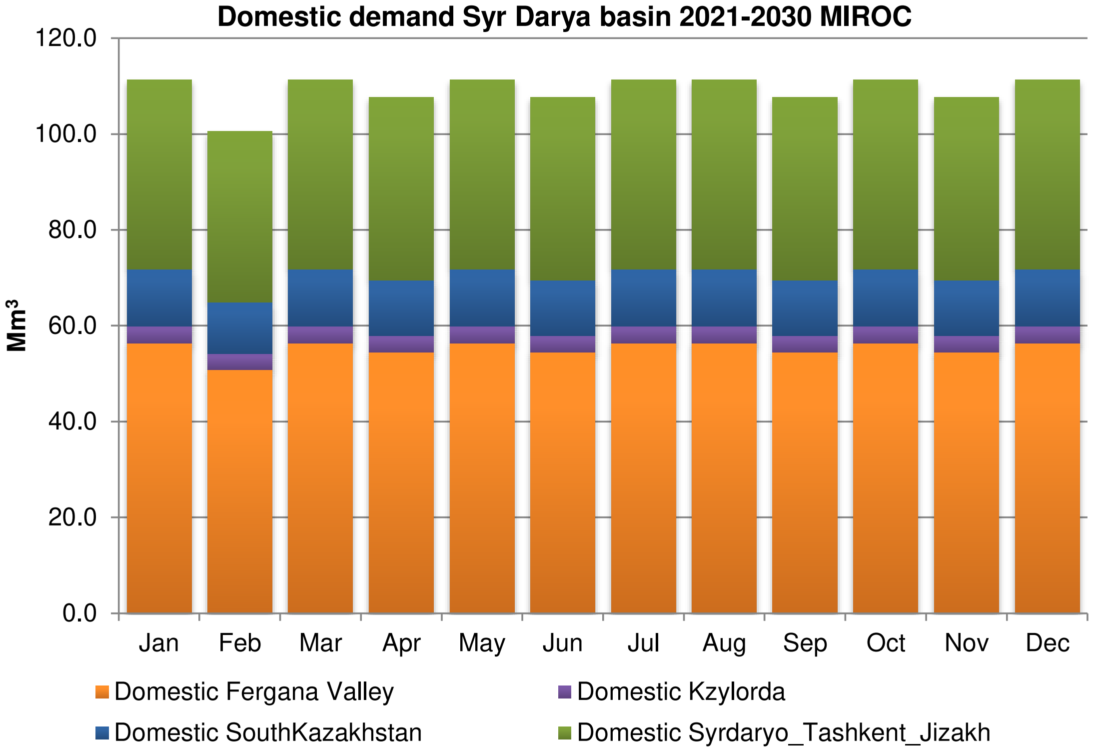
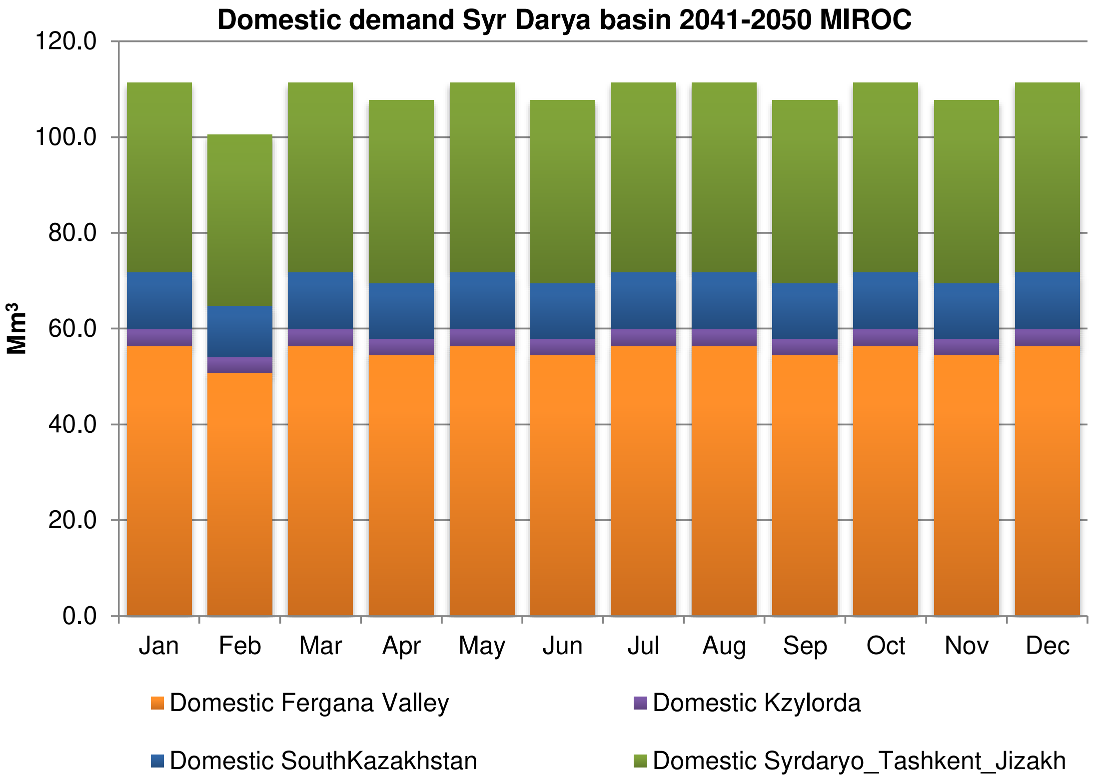
Dec
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Domestic demand Syr Darya basin 2021-2030 MIROC
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Mm³
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Domestic demand Syr Darya basin 2041-2050 MIROC
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Mm³
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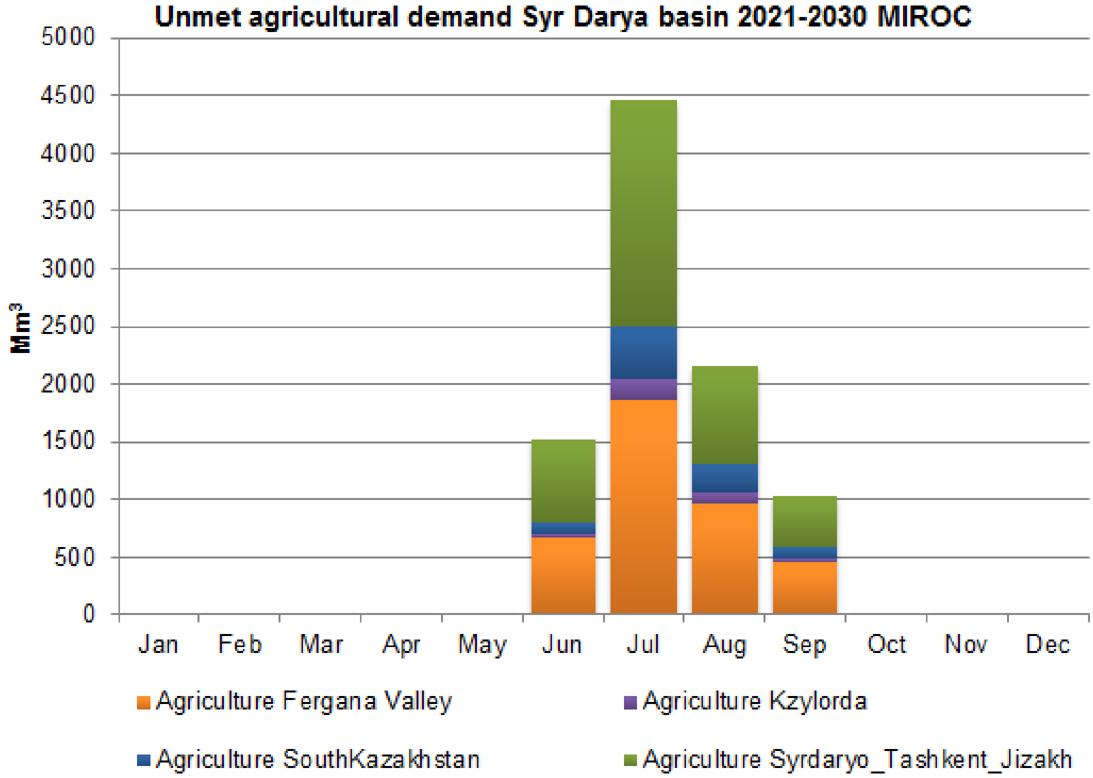
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh



Unmet agricultural demand Syr Darya basin 2021-2030 MIROC
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Mm³
Jan
Feb
Mar
Apr
May
Jun
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Aug
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Oct
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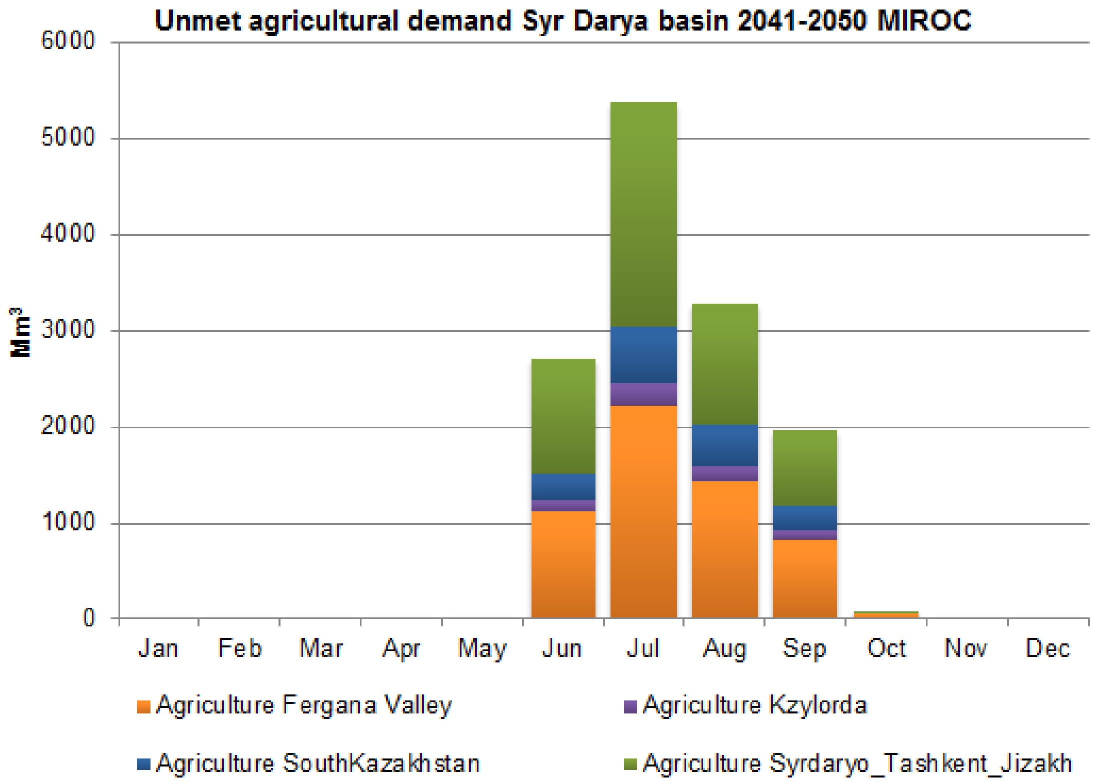
Dec
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh



Unmet agricultural demand Syr Darya basin 2041-2050 MIROC
6000
5000
4000
3000
2000
1000
0
Mm³
Jan
Feb
Mar
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May
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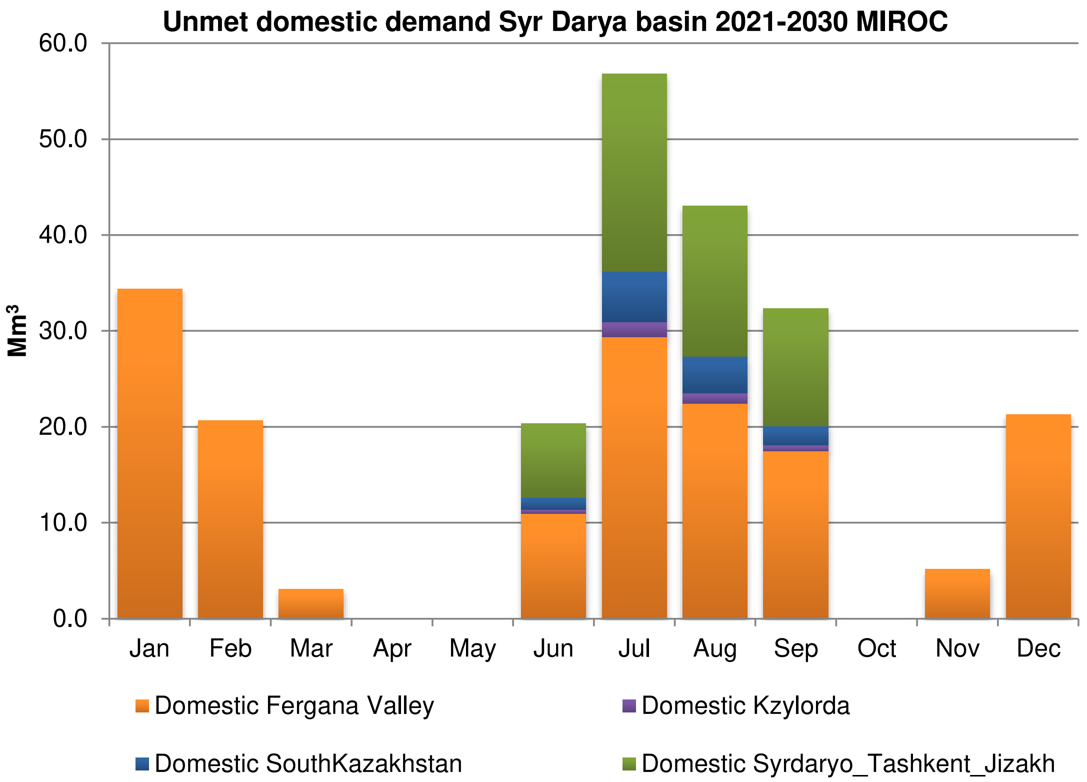
Nov
Dec
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Unmet domestic demand Syr Darya basin 2021-2030 MIROC
Mm³
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Jan
Feb
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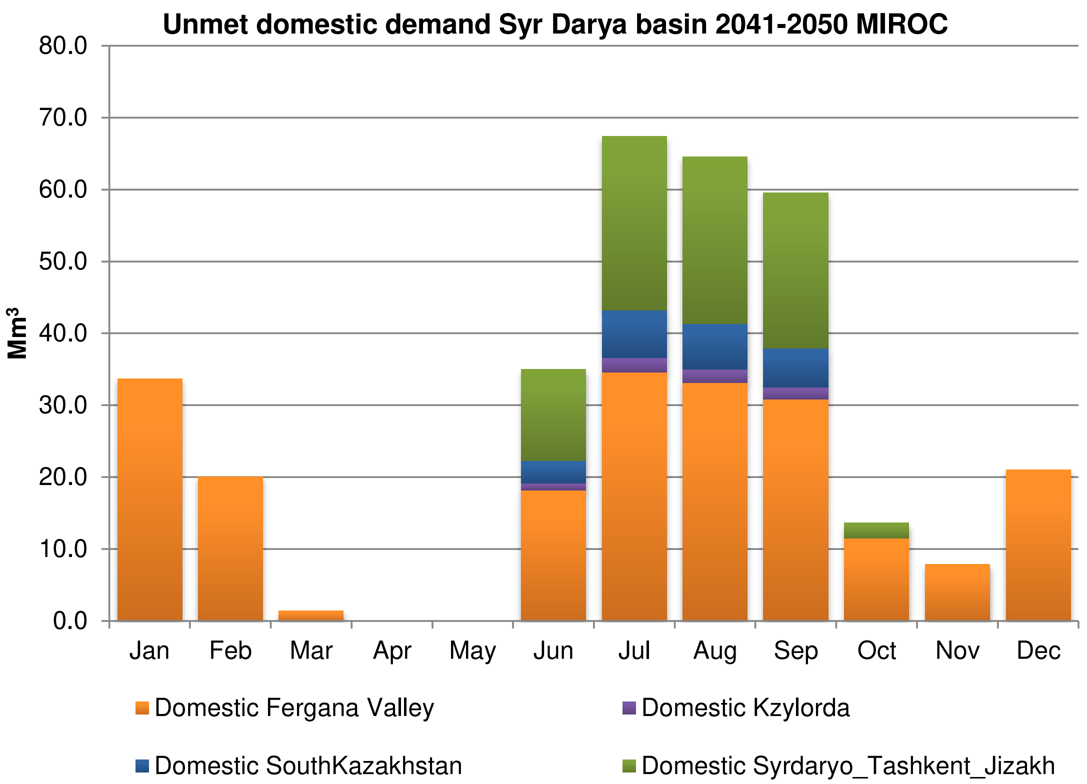
Dec
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Unmet domestic demand Syr Darya basin 2041-2050 MIROC
Mm³
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Jan
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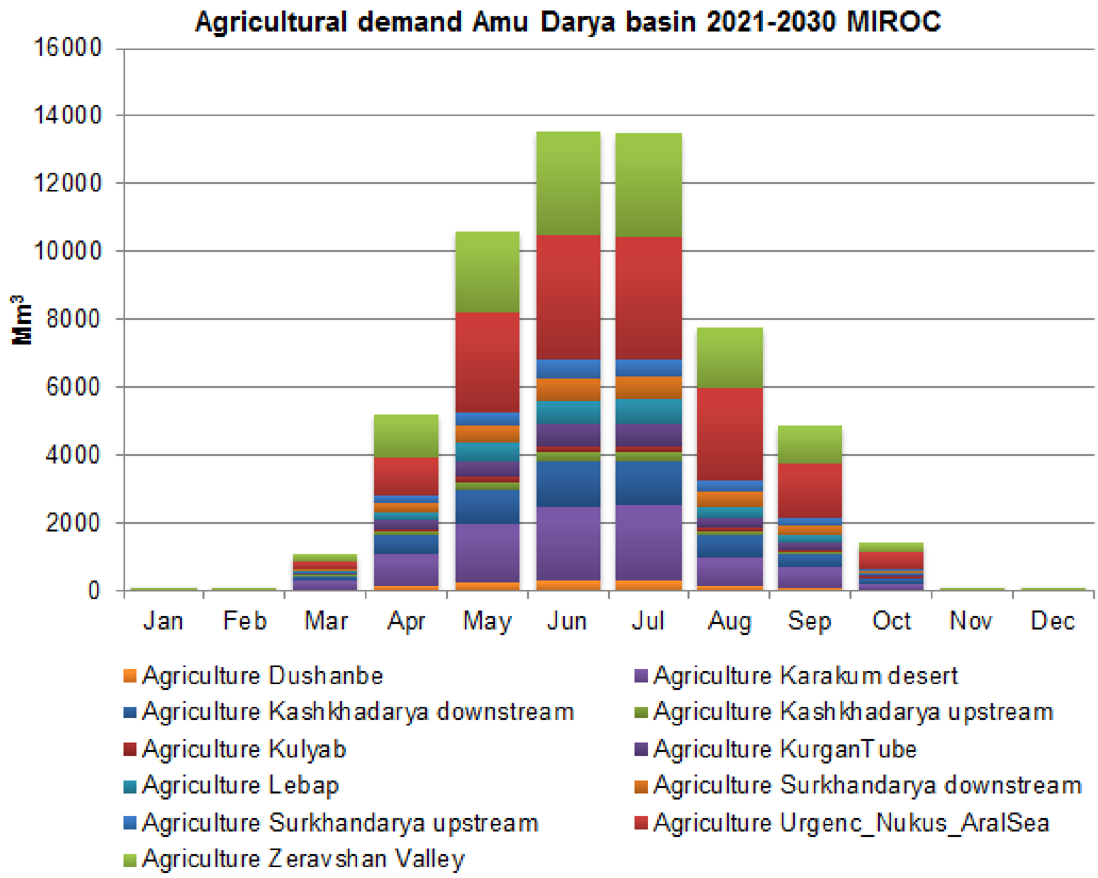
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Agricultural demand Amu Darya basin 2021-2030 MIROC
Mm3
16000
14000
12000
10000
8000
6000
4000
2000
0
Jan
Feb
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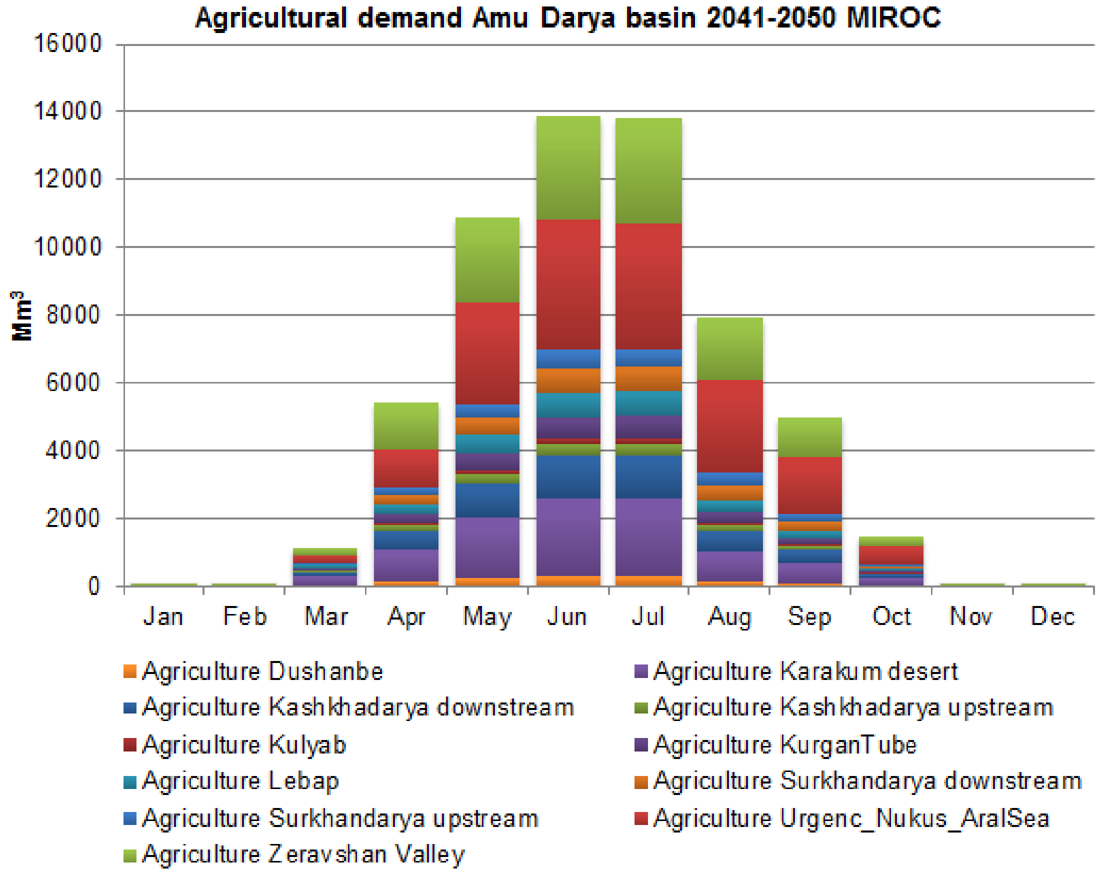
Nov
Dec
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Agricultural demand Amu Darya basin 2041-2050 MIROC
Mm3
16000
14000
12000
10000
8000
6000
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2000
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Jan
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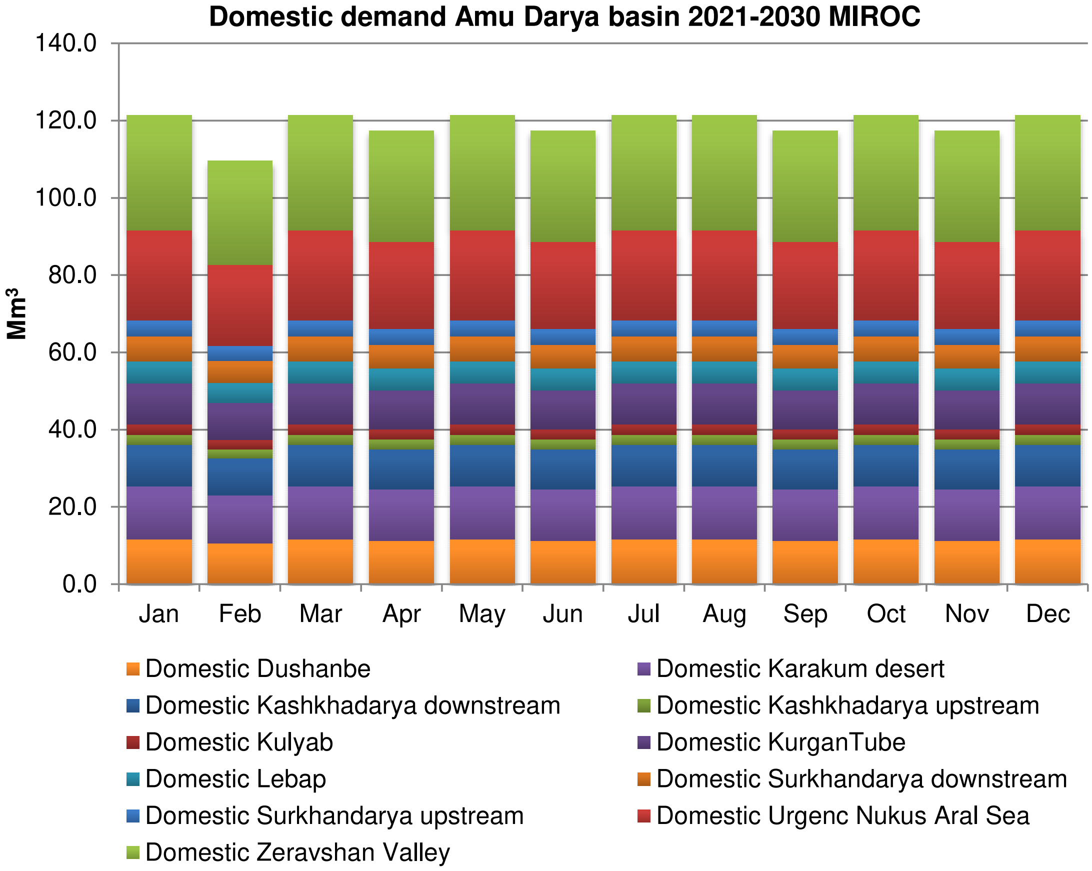
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley



Domestic demand Amu Darya basin 2021-2030 MIROC
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Mm³
Jan
Feb
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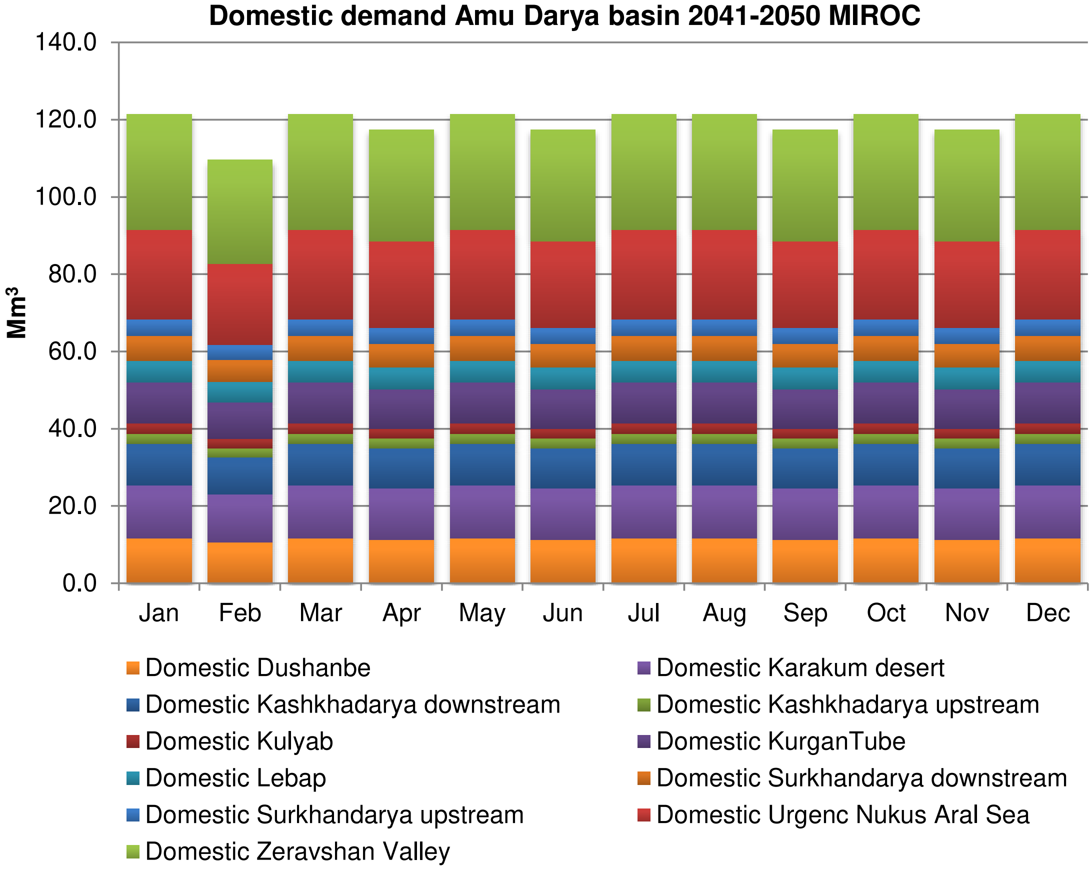
Dec
Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
Domestic Kulyab
Domestic KurganTube
Domestic Lebap
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley



Domestic demand Amu Darya basin 2041-2050 MIROC
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Mm³
Jan
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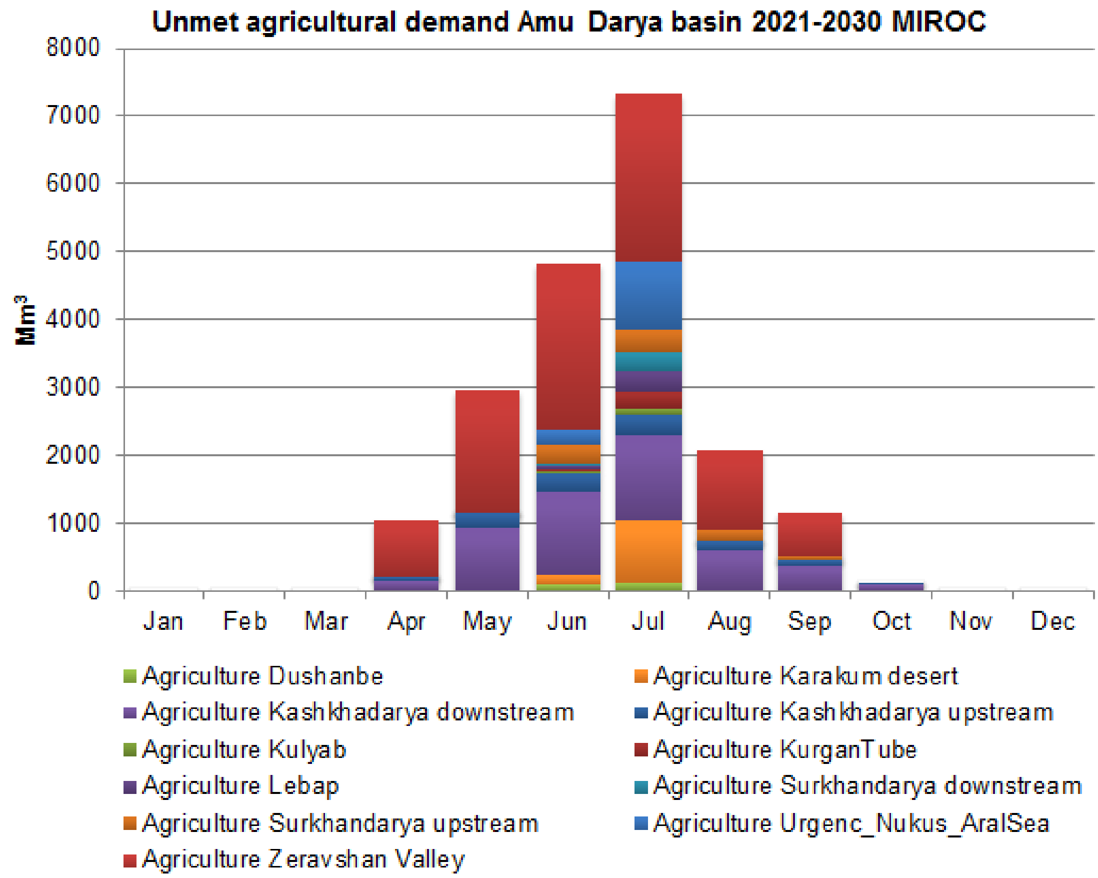
Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
Domestic Kulyab
Domestic KurganTube
Domestic Lebap
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley


Unmet agricultural demand Amu Darya basin 2021-2030 MIROC
Mm3
8000
7000
6000
5000
4000
3000
2000
1000
0
Jan
Feb
Mar
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May
Jun
Jul
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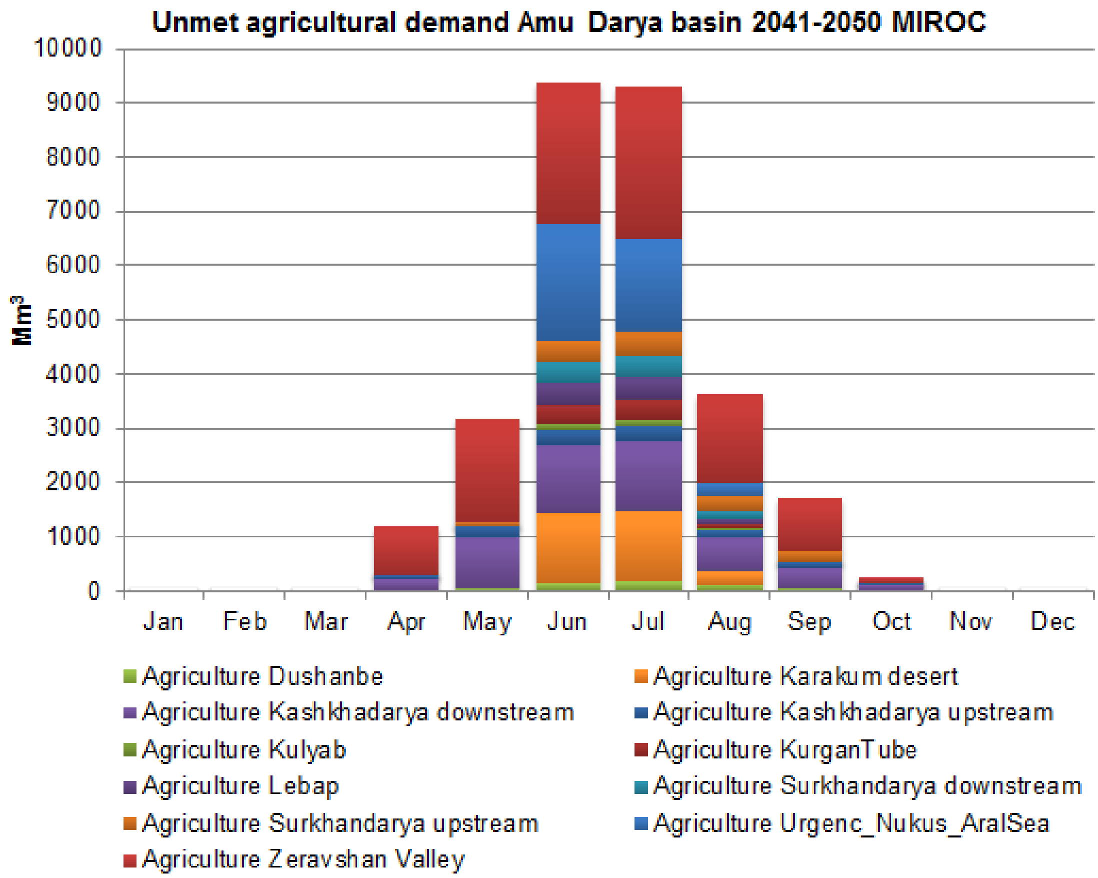
Sep
Oct
Nov
Dec
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Unmet agricultural demand Amu Darya basin 2041-2050 MIROC
Mm3
10000
9000
8000
7000
6000
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2000
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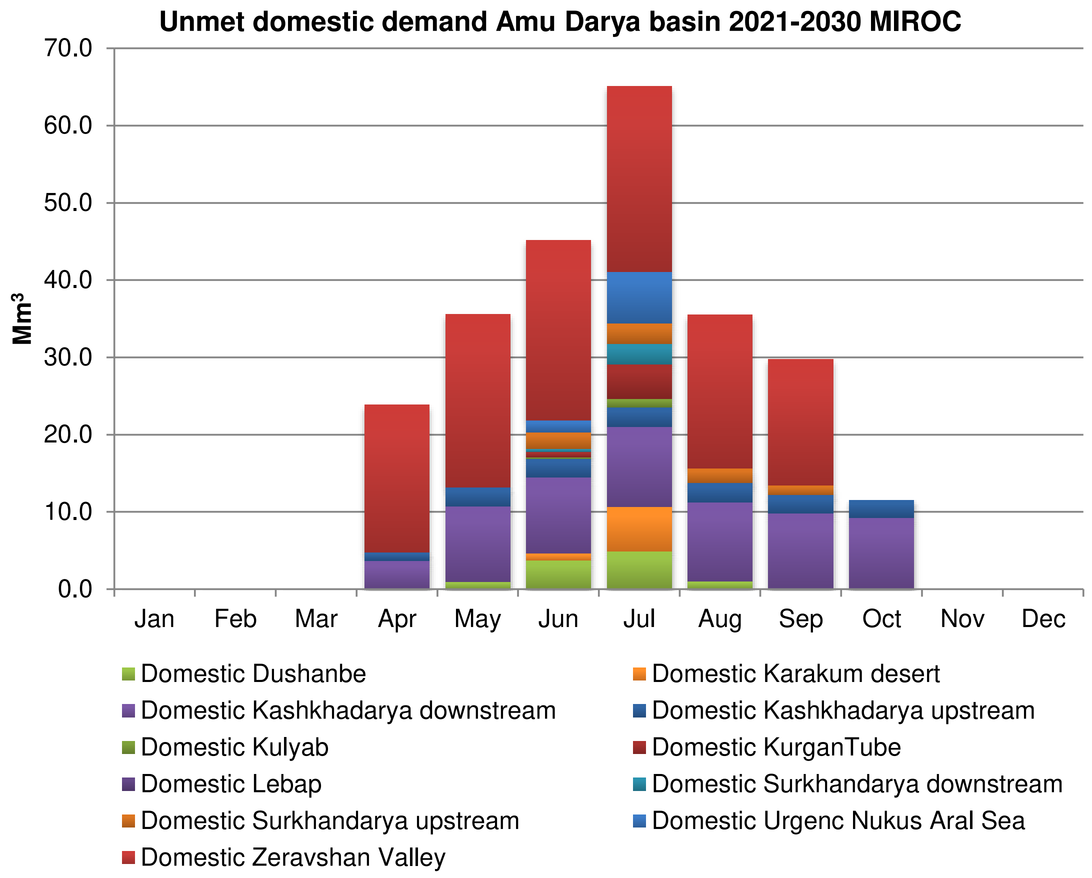
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Unmet domestic demand Amu Darya basin 2021-2030 MIROC
Mm³
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Jan
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Sep
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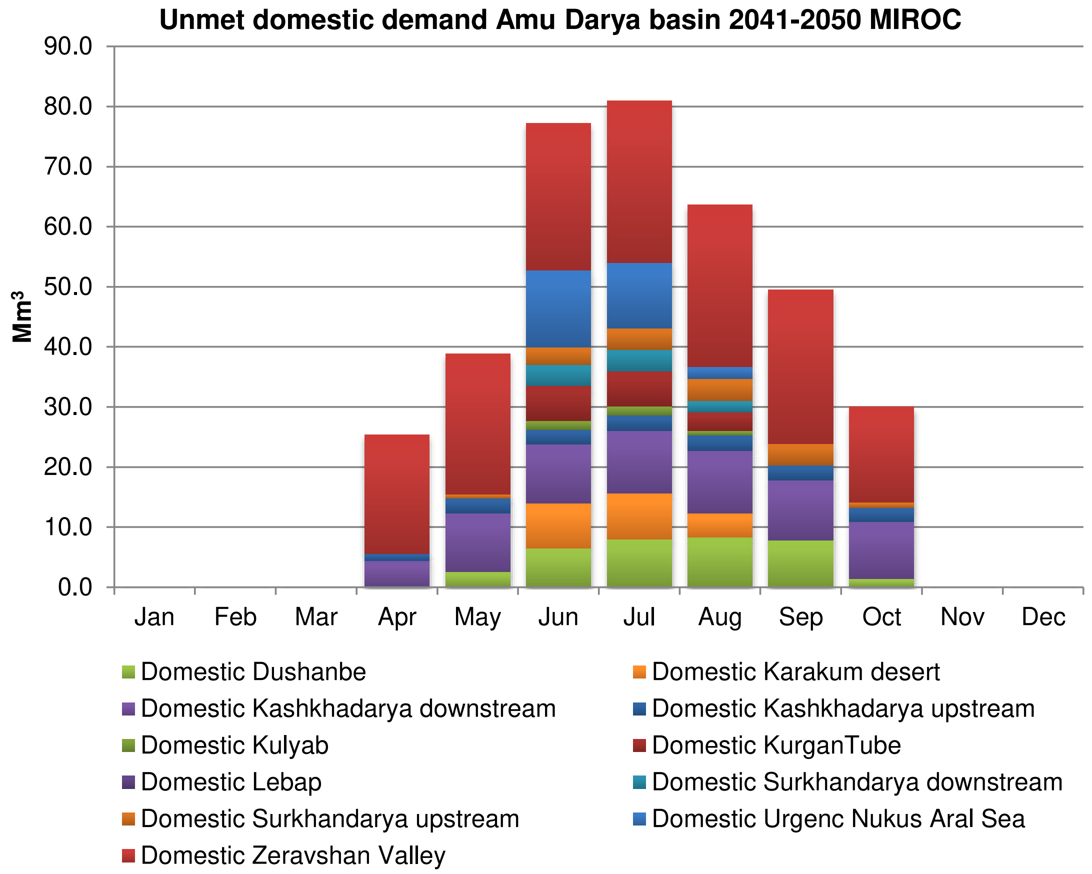
Nov
Dec
Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
Domestic Kulyab
Domestic KurganTube
Domestic Lebap
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley


Unmet domestic demand Amu Darya basin 2041-2050 MIROC
Mm³
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Jan
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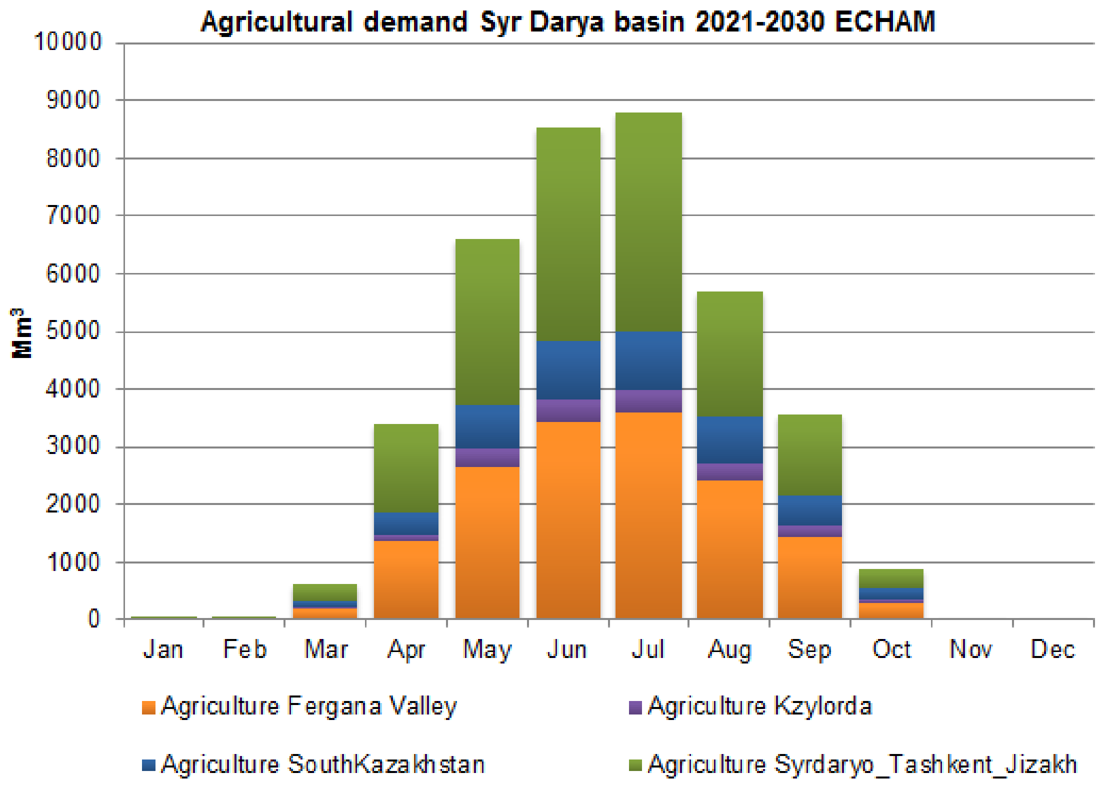
Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
Domestic Kulyab
Domestic KurganTube
Domestic Lebap
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley


Agricultural demand Syr Darya basin 2021-2030 ECHAM
Mm3
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Jan
Feb
Mar
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May
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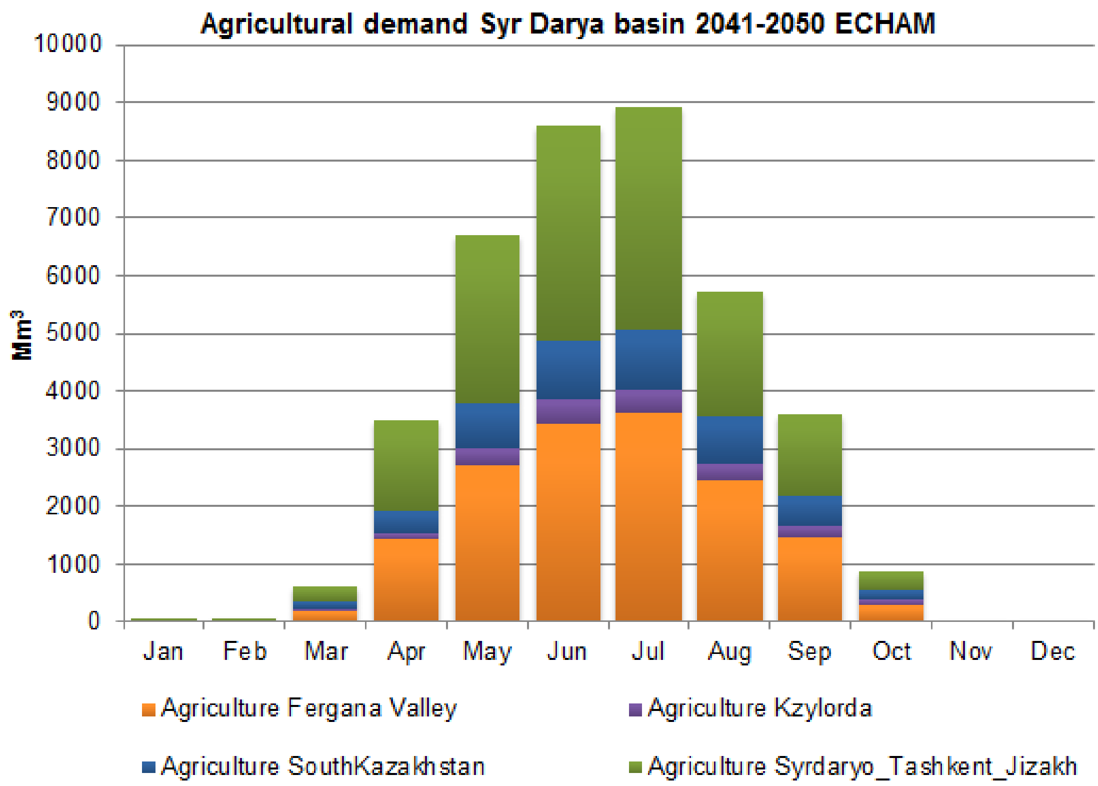
Oct
Nov
Dec
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Agricultural demand Syr Darya basin 2041-2050 ECHAM
Mm3
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
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Jan
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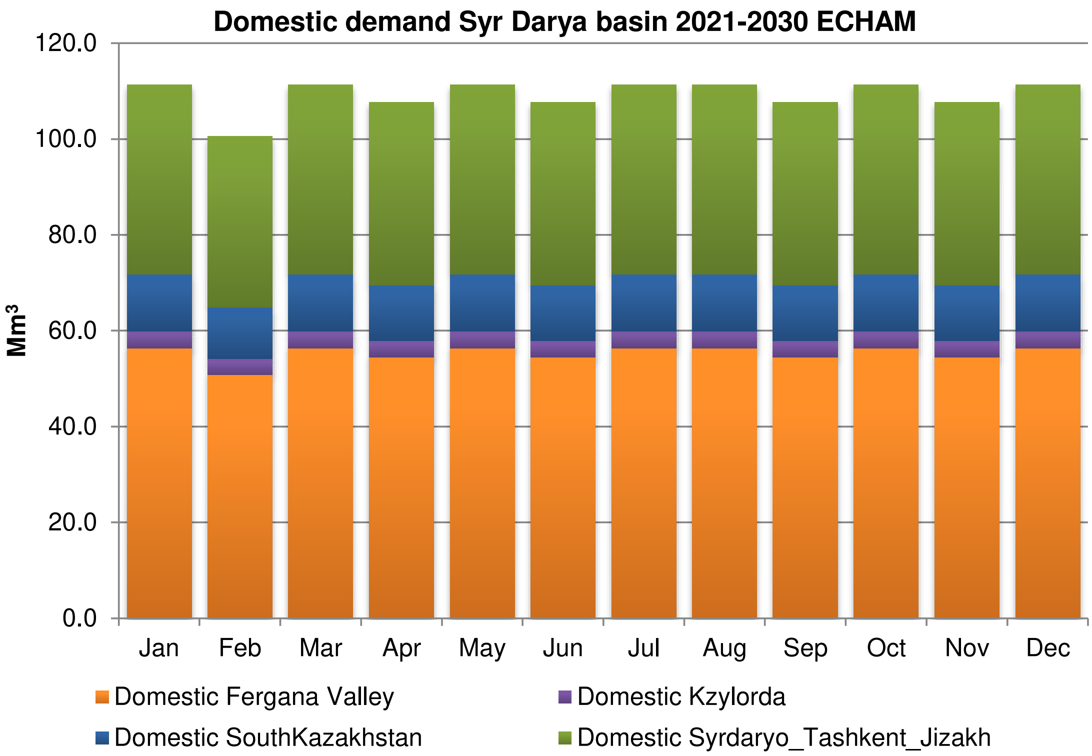
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Domestic demand Syr Darya basin 2021-2030 ECHAM
Mm³
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Jan
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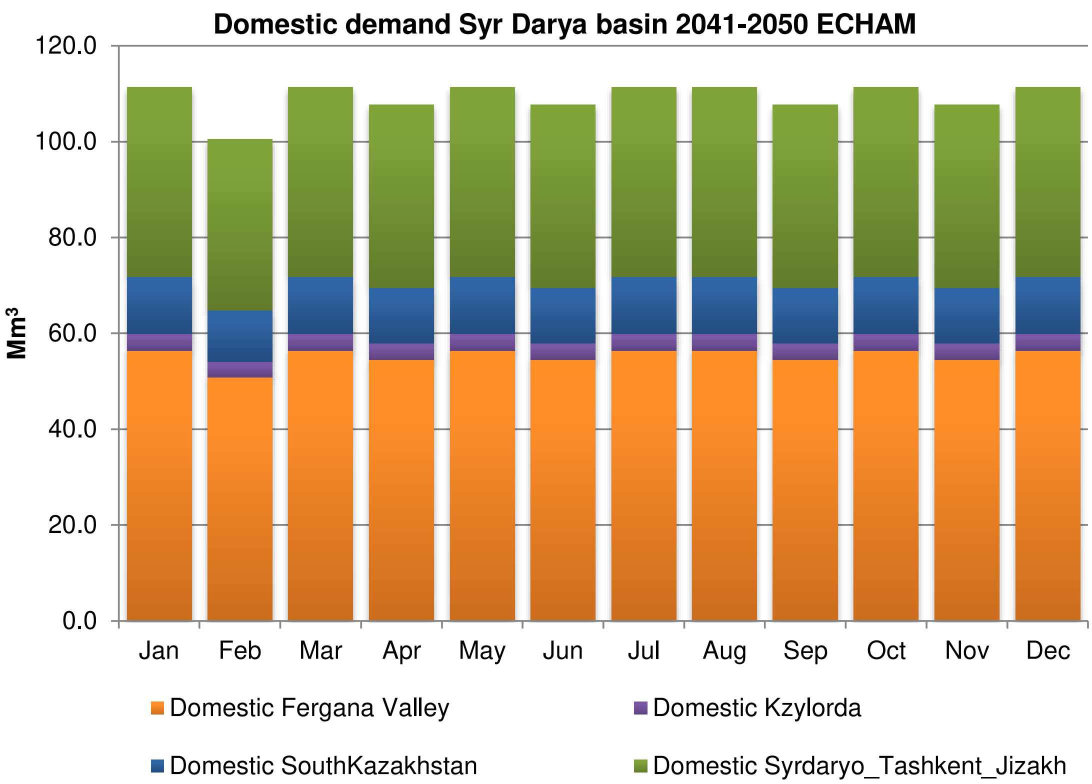
Dec
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Domestic demand Syr Darya basin 2041-2050 ECHAM
Mm³
120.0
100.0
80.0
60.0
40.0
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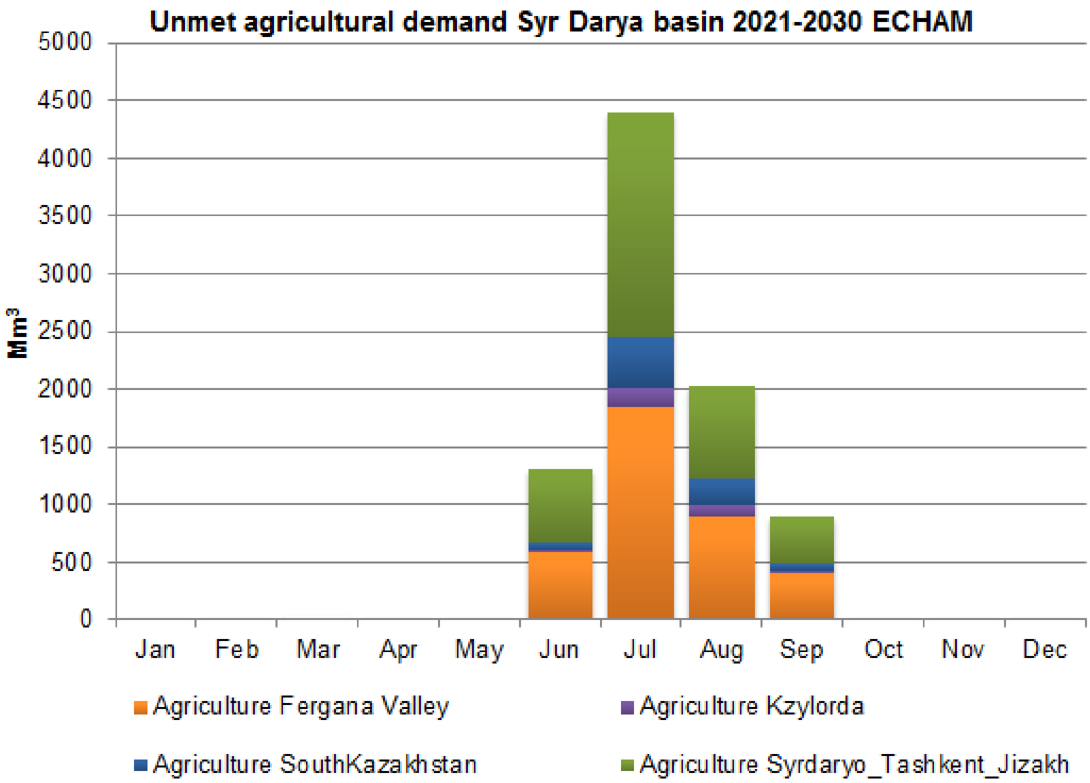
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Unmet agricultural demand Syr Darya basin 2021-2030 ECHAM
Mm3
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
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Jan
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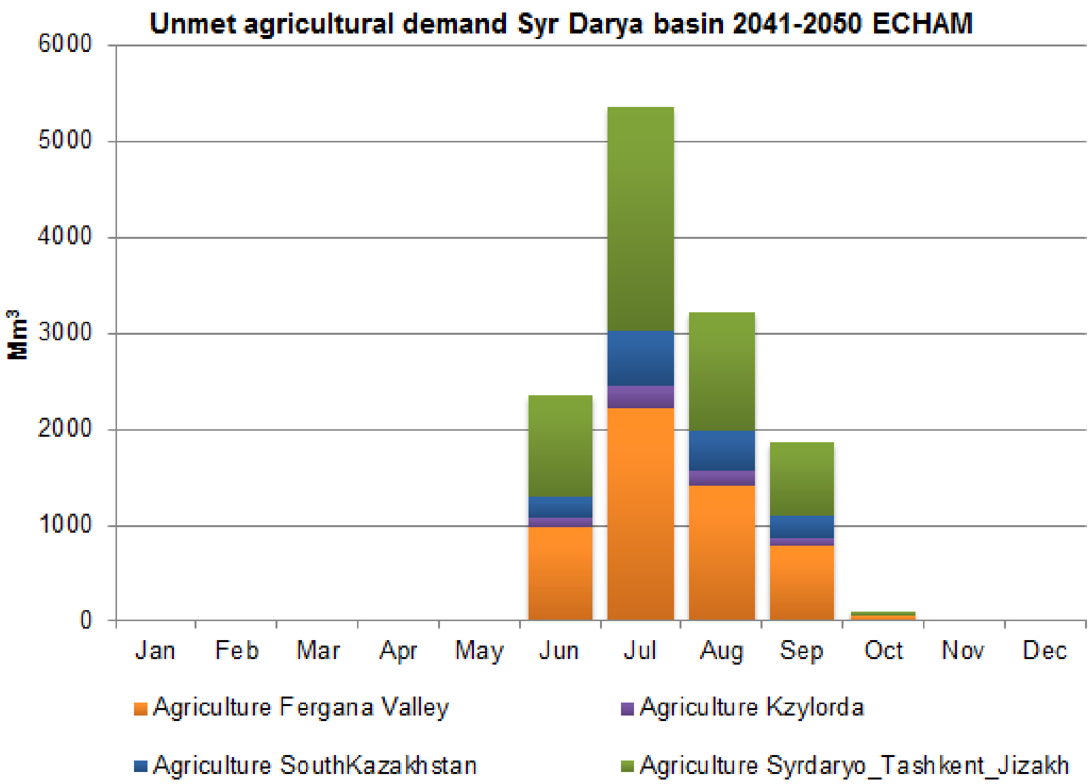
Nov
Dec
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Unmet agricultural demand Syr Darya basin 2041-2050 ECHAM
Mm3
6000
5000
4000
3000
2000
1000
0
Jan
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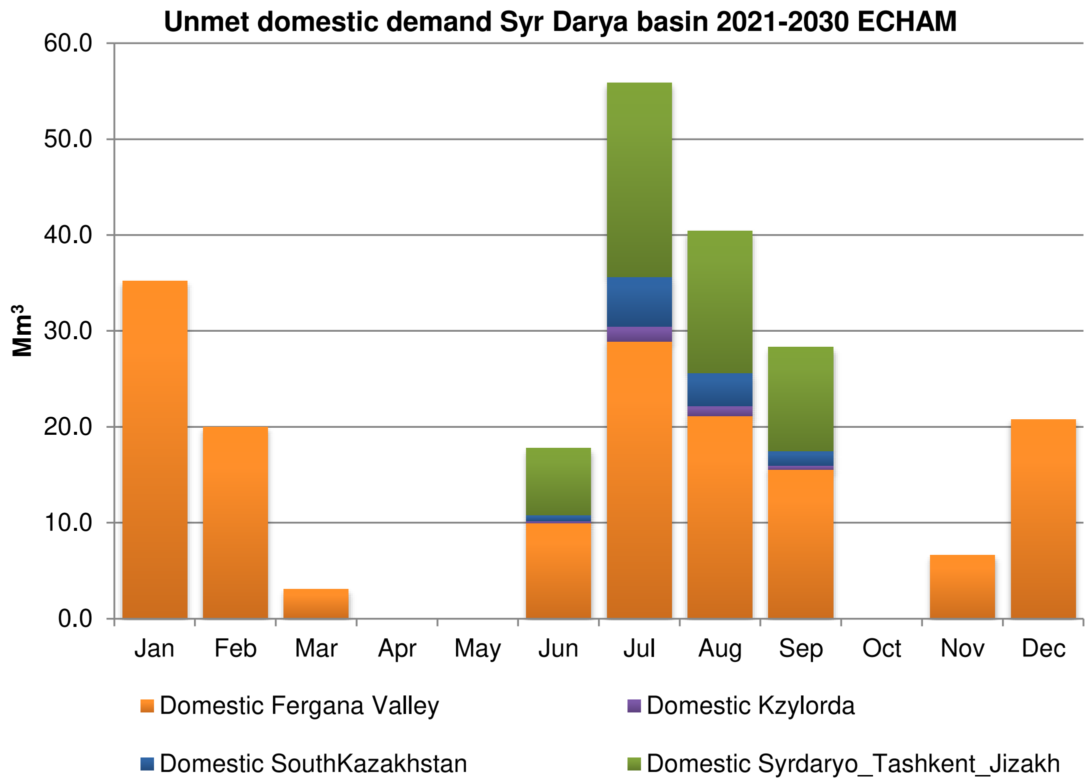
Nov
Dec
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Unmet domestic demand Syr Darya basin 2021-2030 ECHAM
Mm3
60.0
50.0
40.0
30.0
20.0
10.0
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Jan
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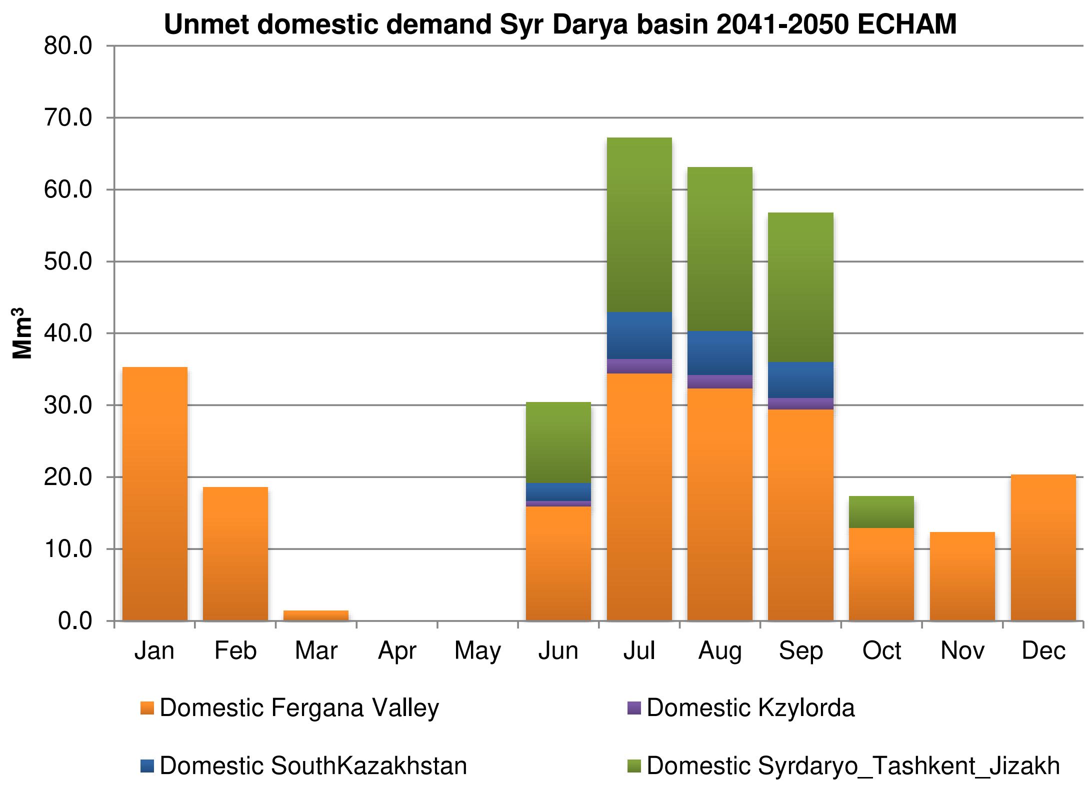
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Unmet domestic demand Syr Darya basin 2041-2050 ECHAM
Mm3
80.0
70.0
60.0
50.0
40.0
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10.0
0.0
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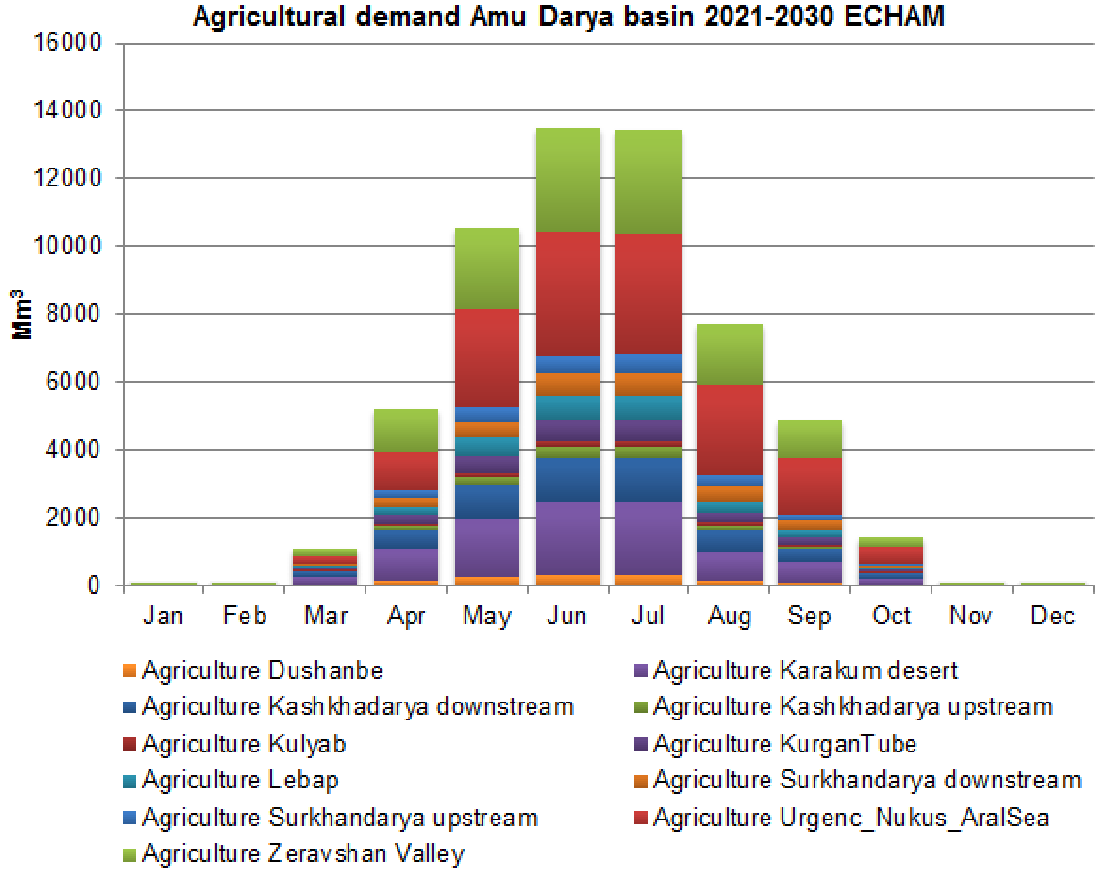
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Agricultural demand Amu Darya basin 2021-2030 ECHAM
Mm3
16000
14000
12000
10000
8000
6000
4000
2000
0
Jan
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May
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Nov
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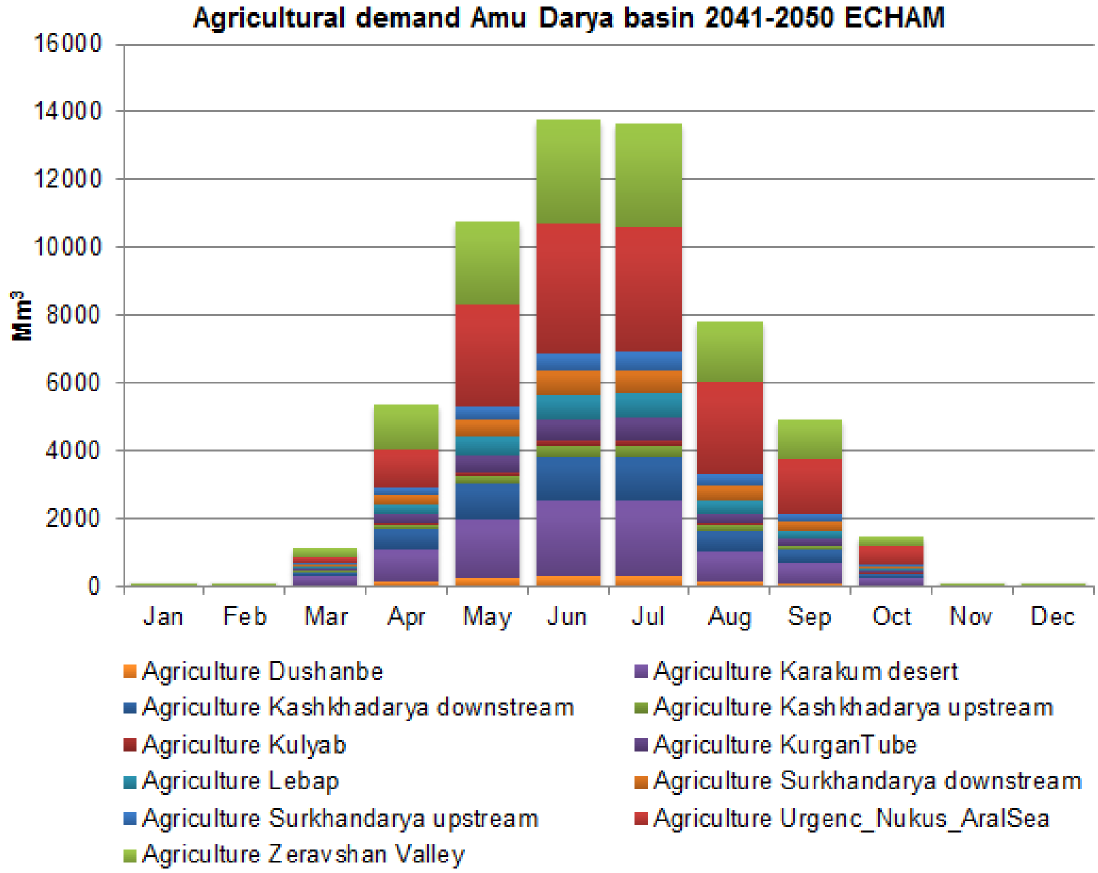
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Agricultural demand Amu Darya basin 2041-2050 ECHAM
Mm3
16000
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12000
10000
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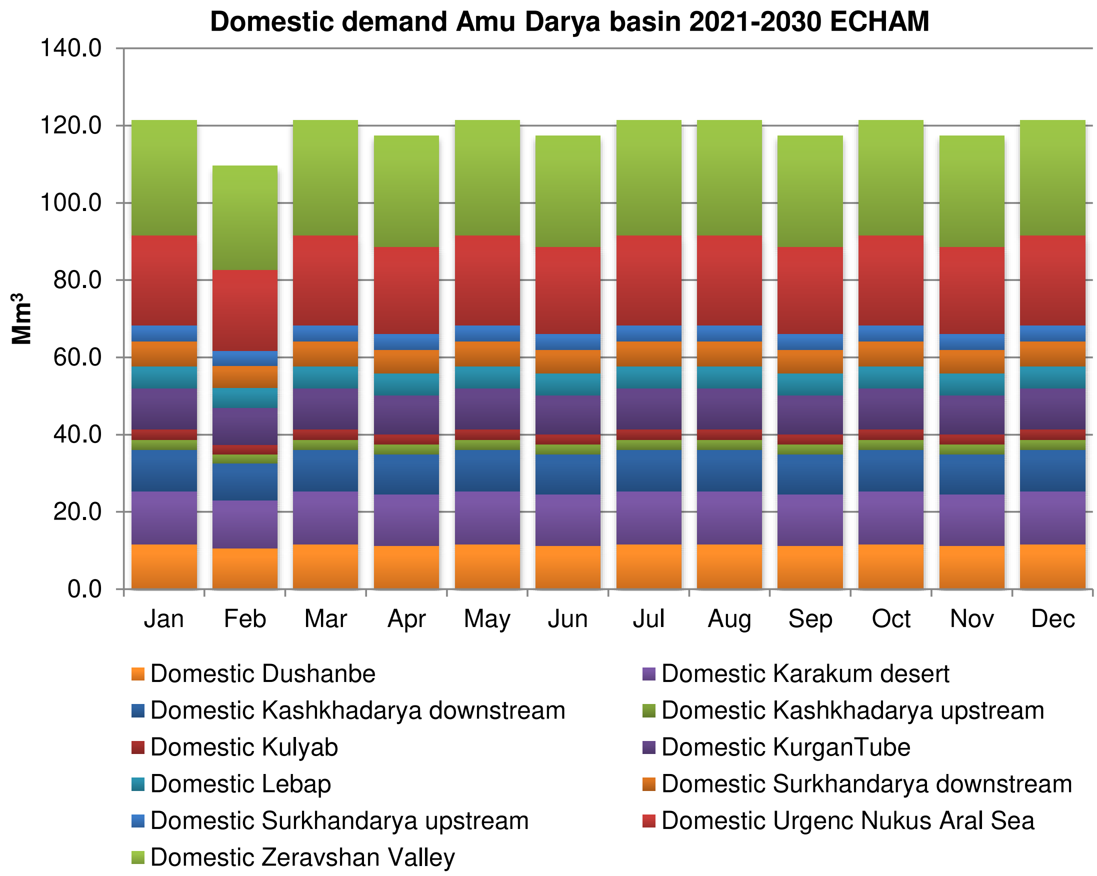
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Domestic demand Amu Darya basin 2021-2030 ECHAM
Mm³
140.0
120.0
100.0
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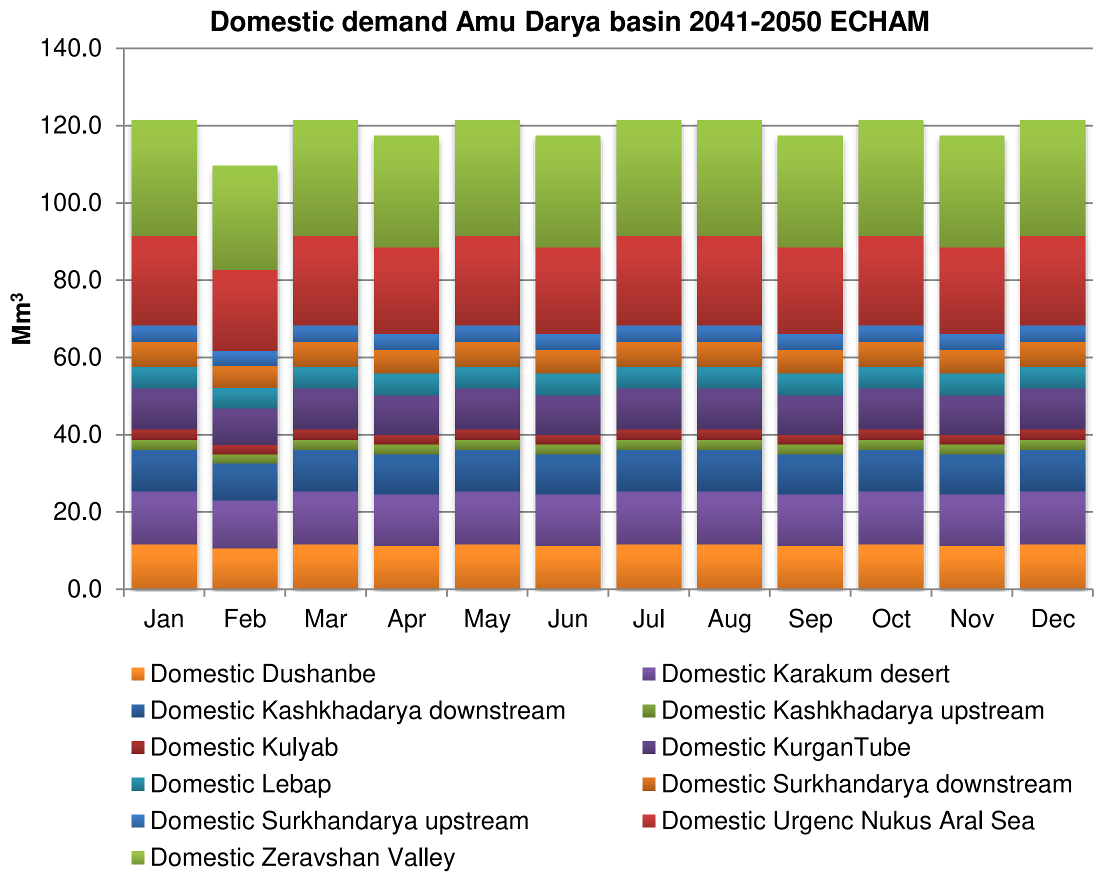
Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
Domestic Kulyab
Domestic KurganTube
Domestic Lebap
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley


Domestic demand Amu Darya basin 2041-2050 ECHAM
Mm³
140.0
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100.0
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Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
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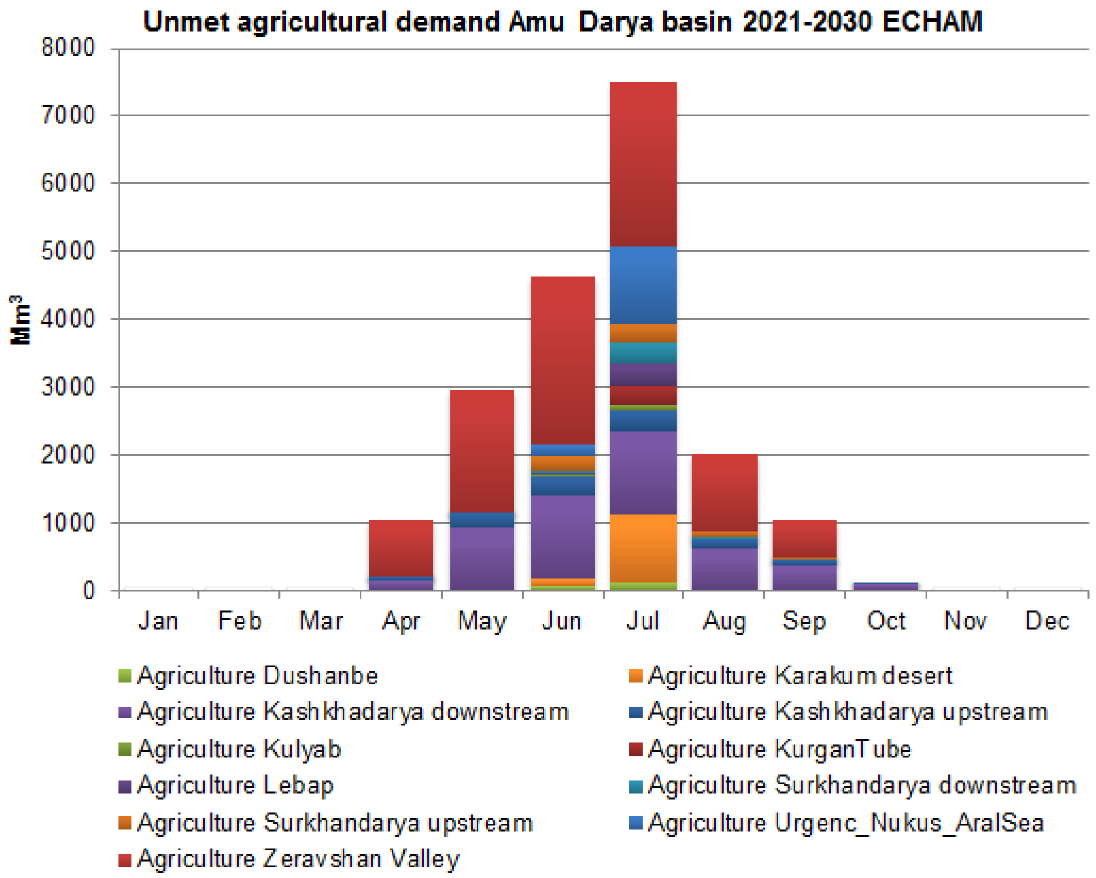
Domestic KurganTube
Domestic Lebap
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley


Unmet agricultural demand Amu Darya basin 2021-2030 ECHAM
Mm3
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7000
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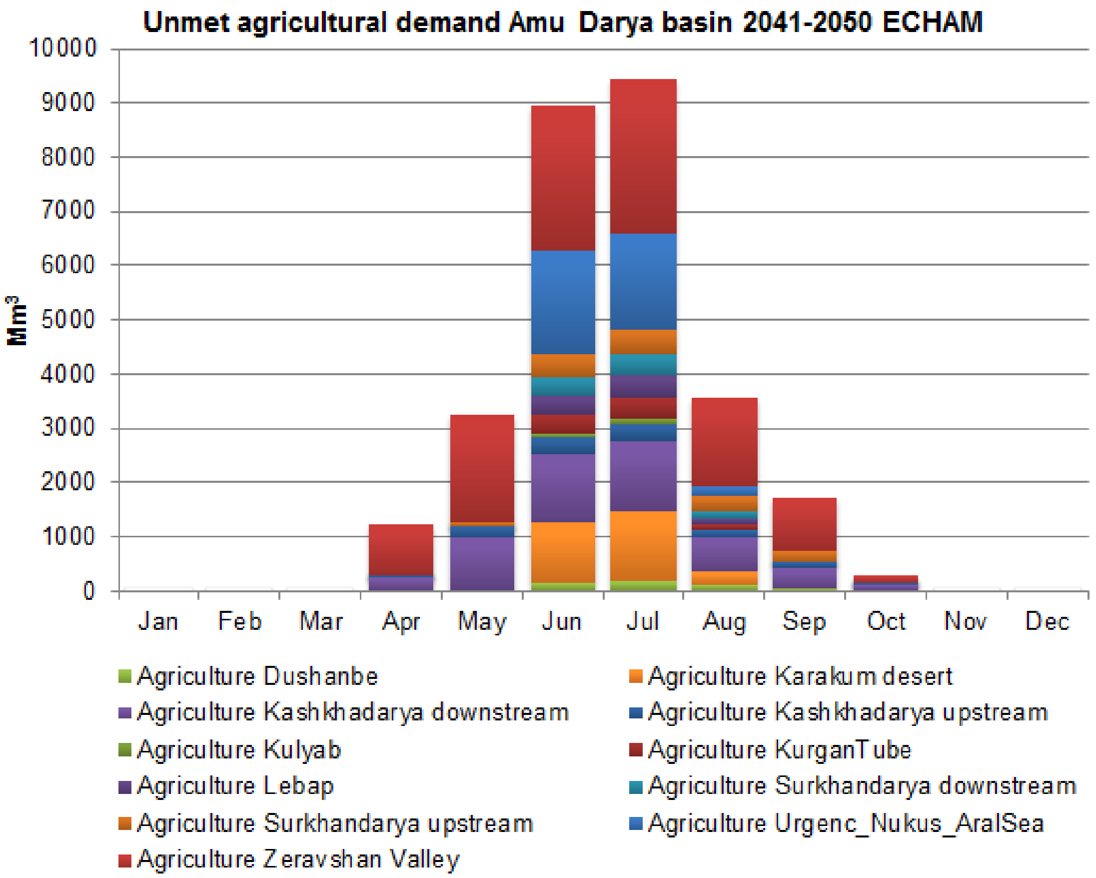
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Unmet agricultural demand Amu Darya basin 2041-2050 ECHAM
Mm3
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7000
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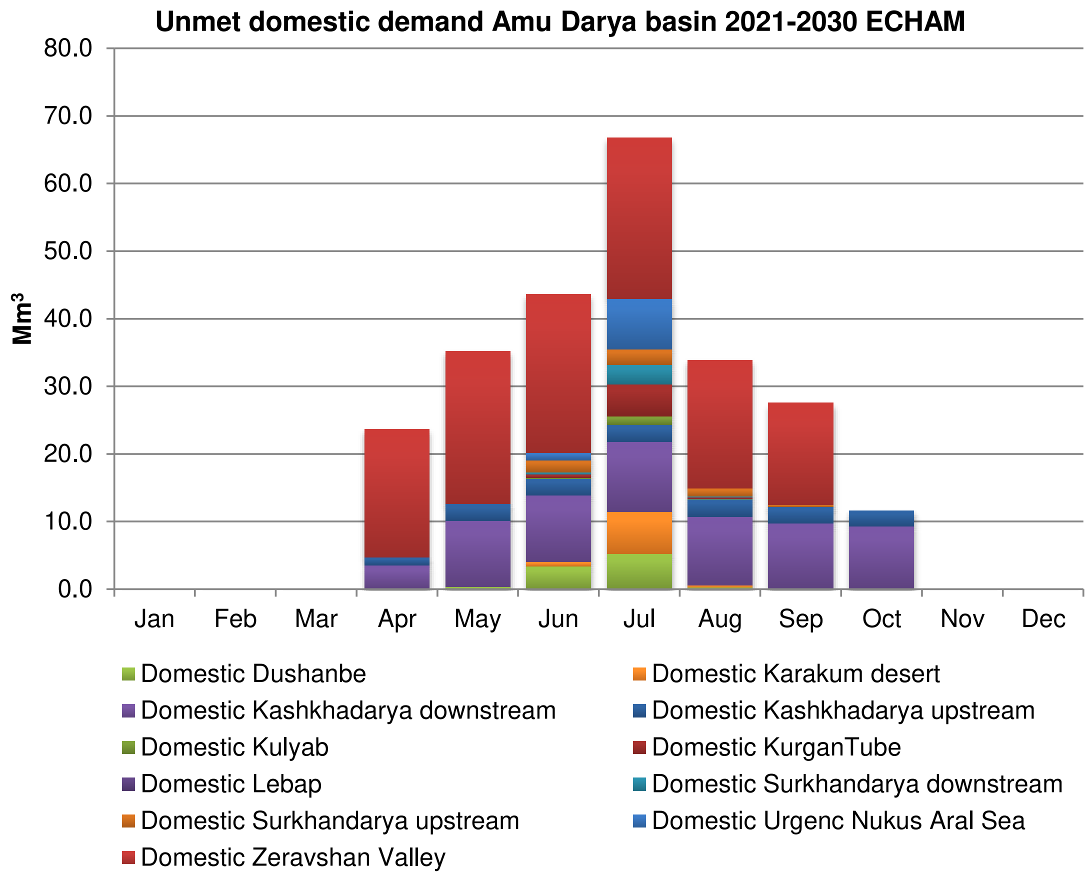
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Unmet domestic demand Amu Darya basin 2021-2030 ECHAM
Mm³
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Domestic Dushanbe
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Domestic Kashkhadarya downstream
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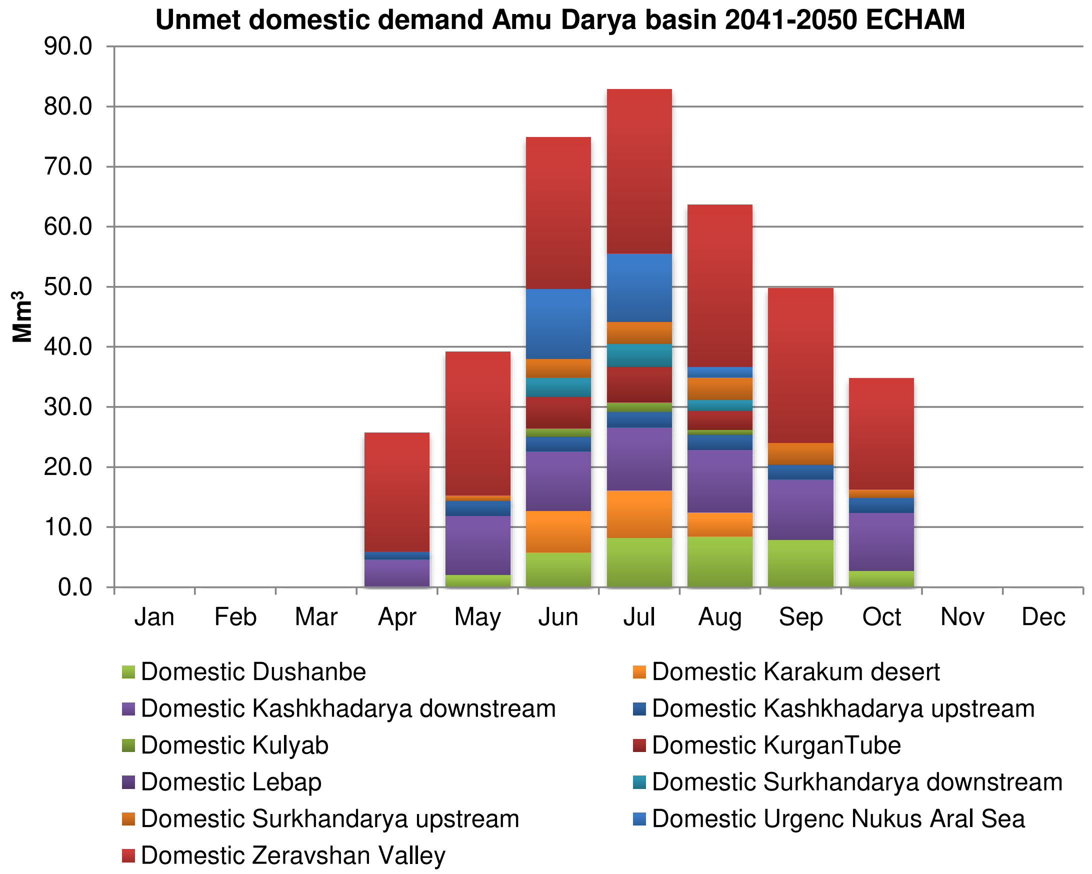
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley


Unmet domestic demand Amu Darya basin 2041-2050 ECHAM
Mm³
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Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
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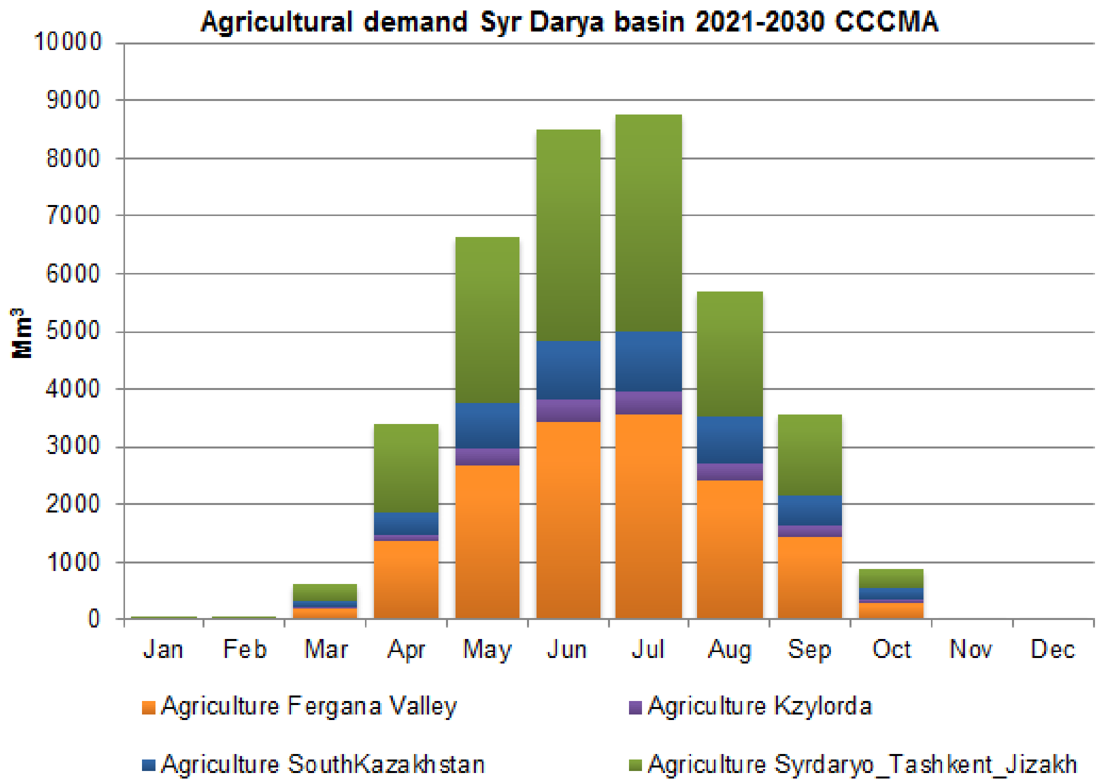
Domestic KurganTube
Domestic Lebap
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley


Agricultural demand Syr Darya basin 2021-2030 CCCMA
Mm³
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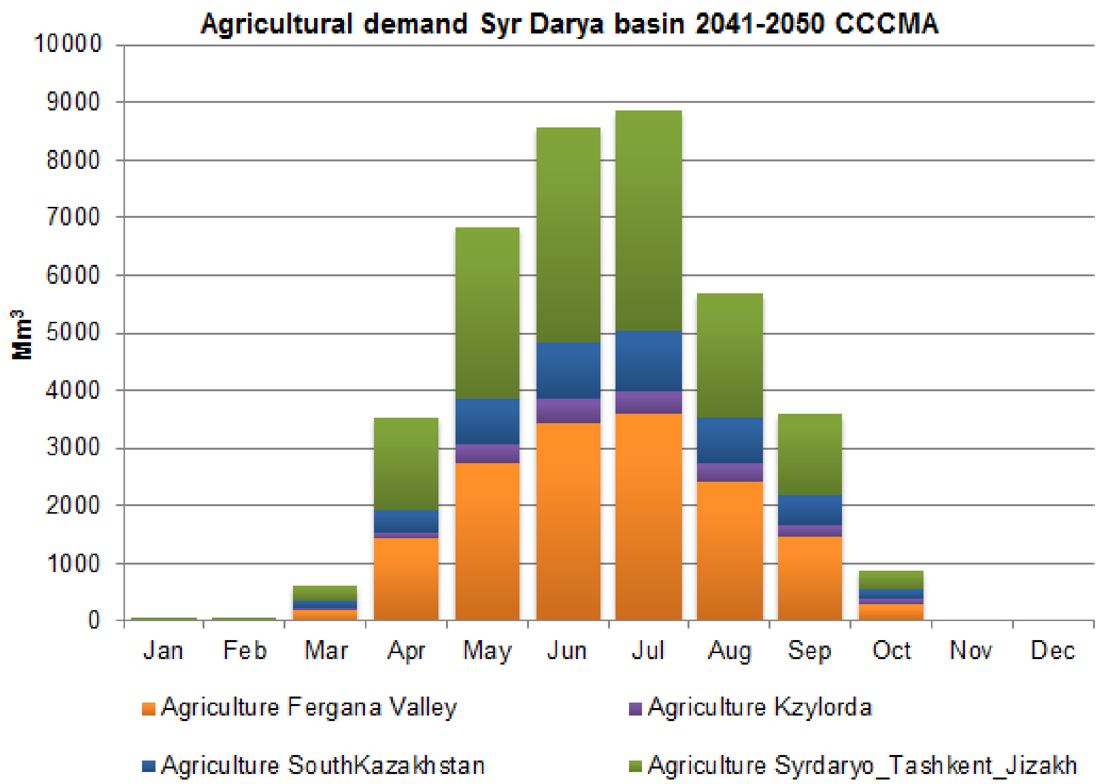
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Agricultural demand Syr Darya basin 2041-2050 CCCMA
Mm³
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Agriculture Fergana Valley
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Agriculture SouthKazakhstan
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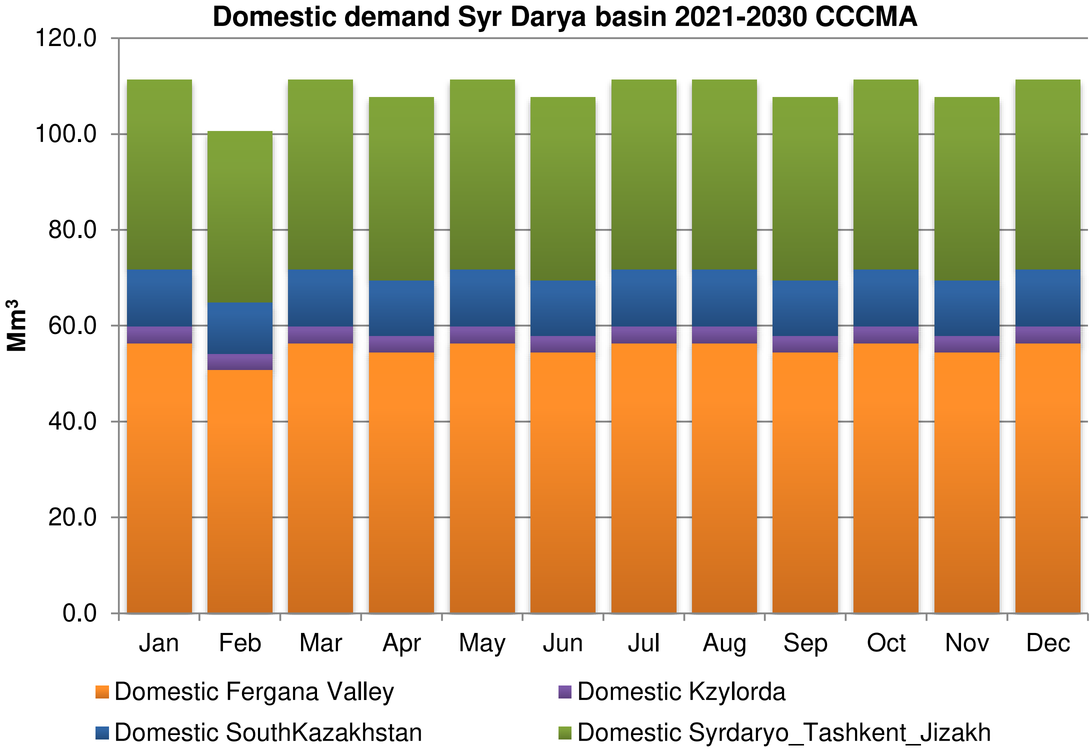
Domestic demand Syr Darya basin 2021-2030 CCCMA
120.0
100.0
80.0
60.0
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Mm3
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Domestic Fergana Valley
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Domestic SouthKazakhstan
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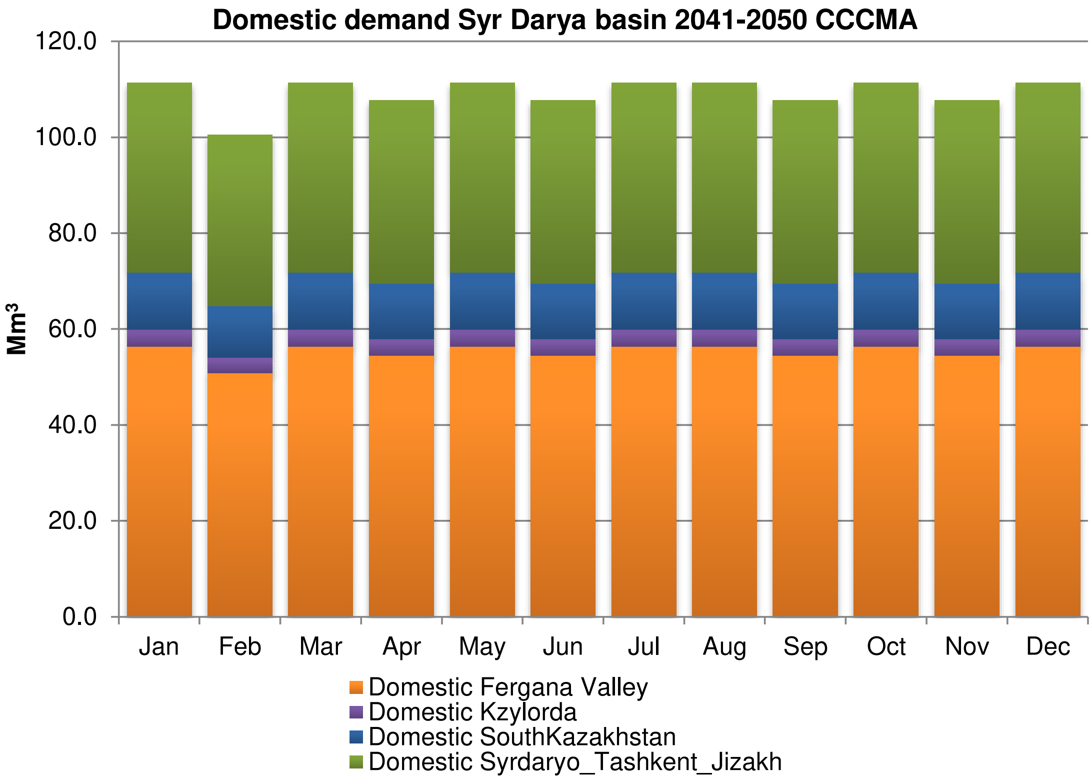
Domestic demand Syr Darya basin 2041-2050 CCCMA
120.0
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Mm3
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Domestic SouthKazakhstan
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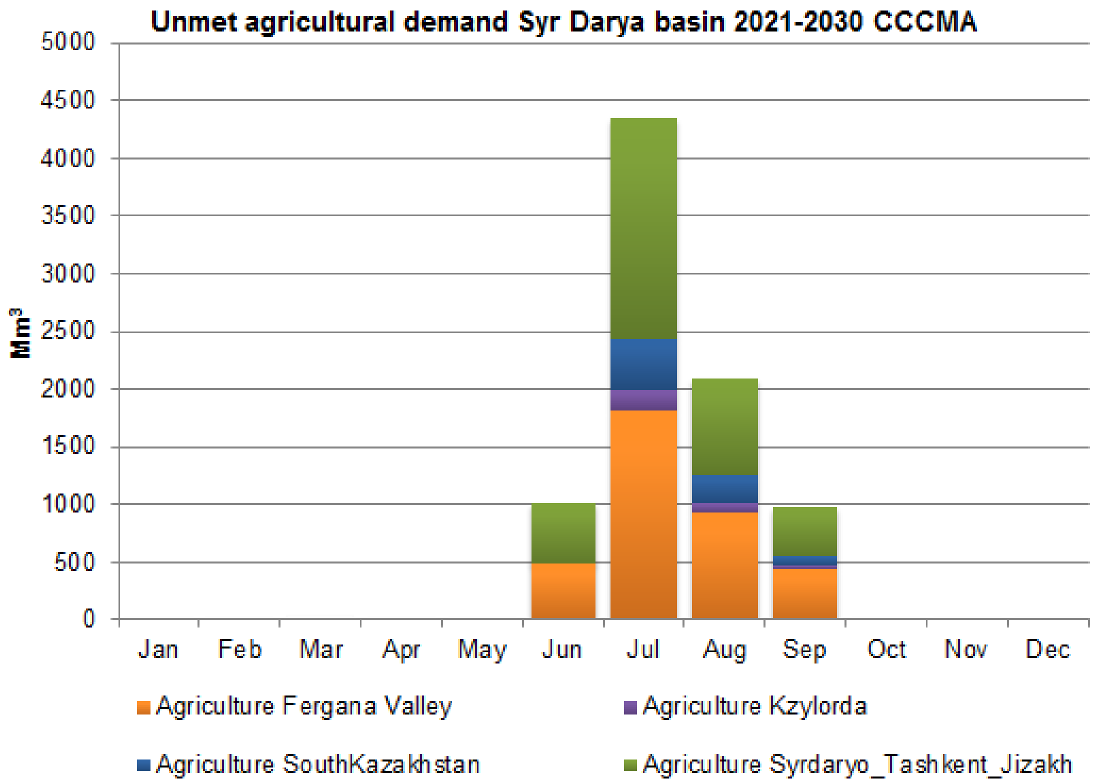
Unmet agricultural demand Syr Darya basin 2021-2030 CCCMA
Mm3
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Jan
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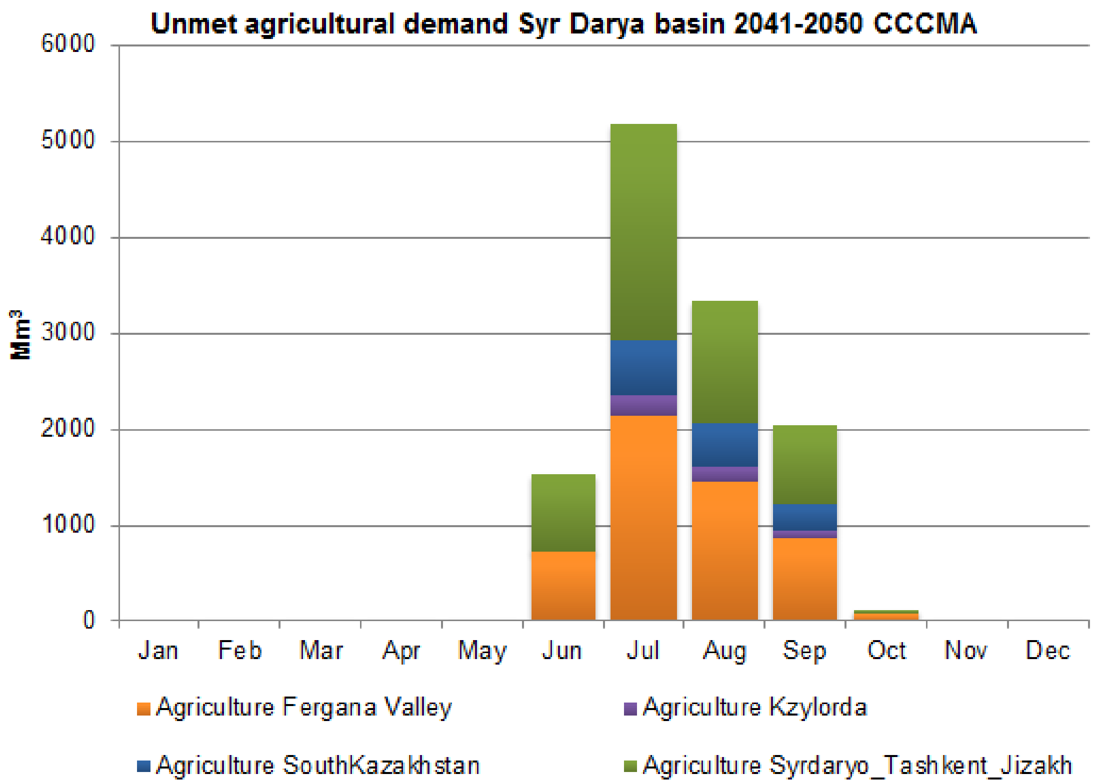
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Unmet agricultural demand Syr Darya basin 2041-2050 CCCMA
Mm3
6000
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3000
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1000
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Jan
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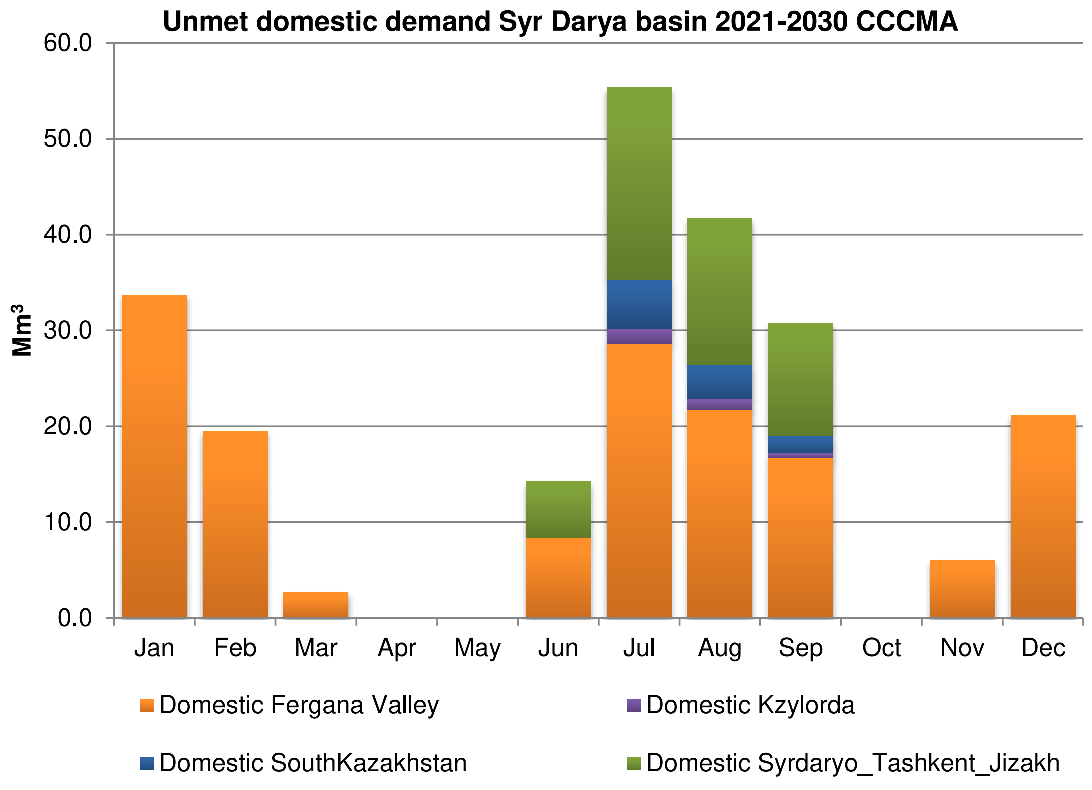
Agriculture Fergana Valley
Agriculture Kzylorda
Agriculture SouthKazakhstan
Agriculture Syrdaryo_Tashkent_Jizakh


Unmet domestic demand Syr Darya basin 2021-2030 CCCMA
Mm3
60.0
50.0
40.0
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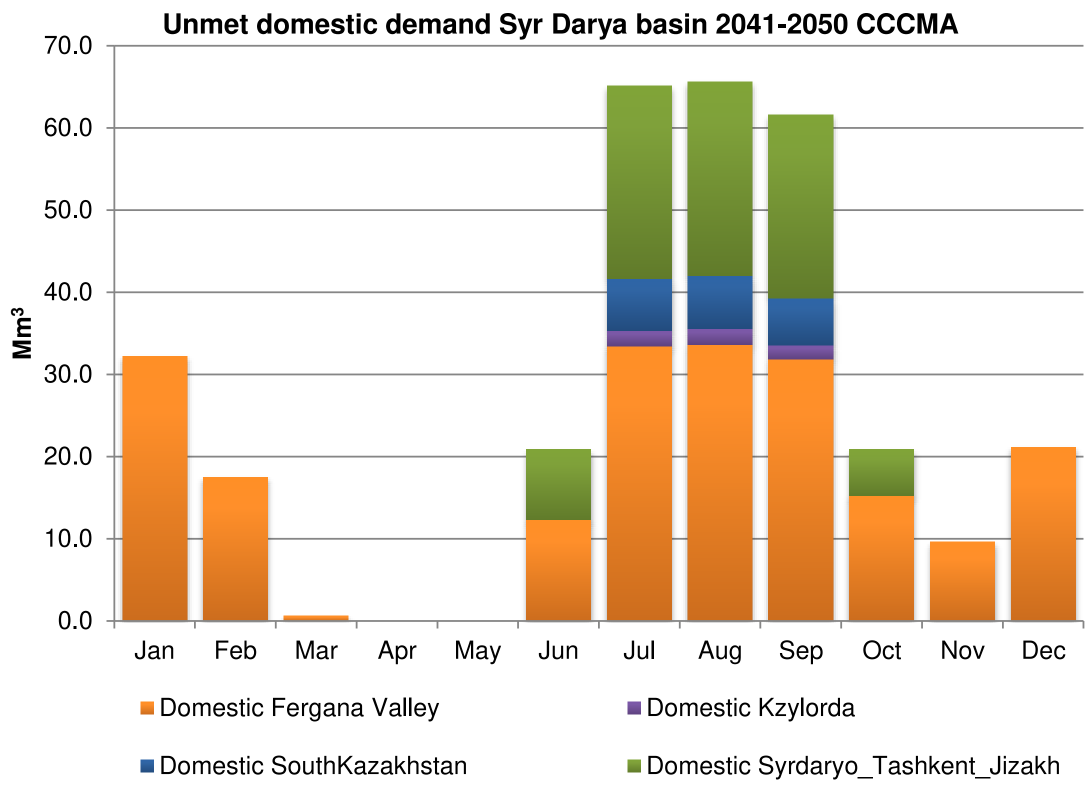
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Unmet domestic demand Syr Darya basin 2041-2050 CCCMA
Mm3
70.0
60.0
50.0
40.0
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20.0
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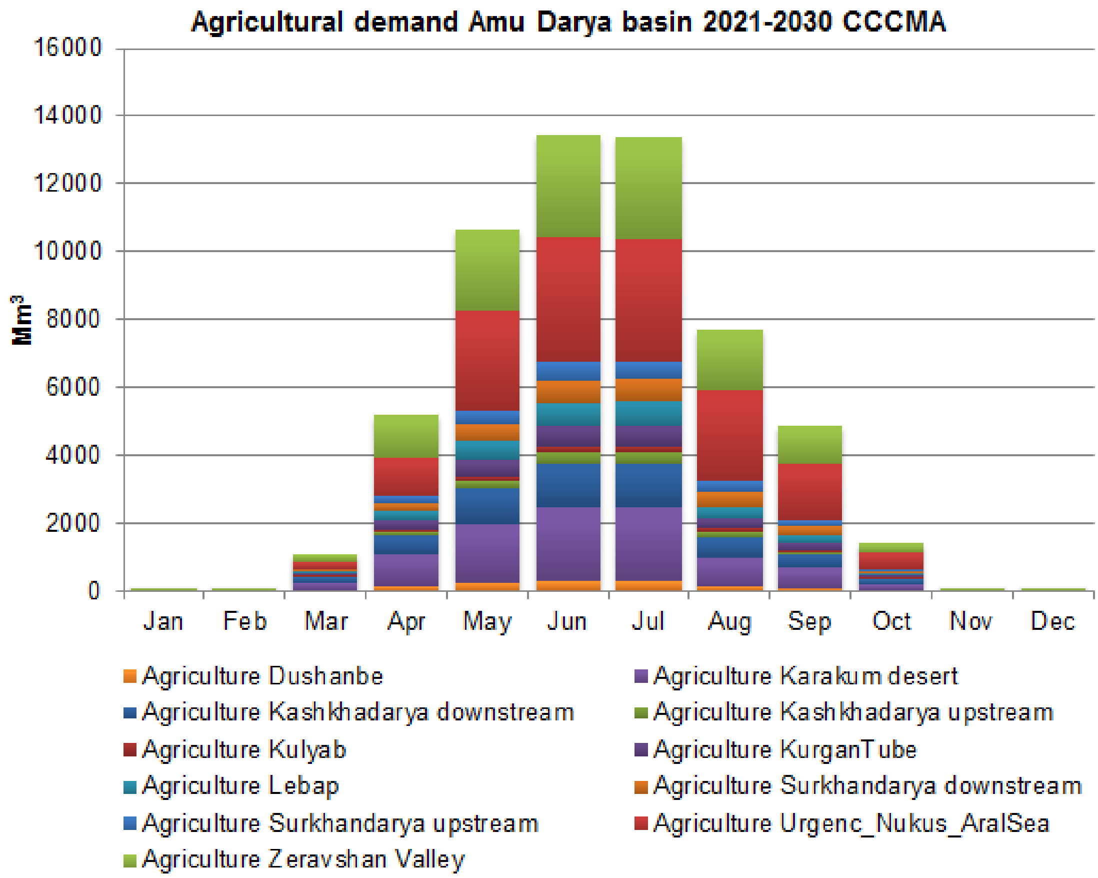
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Domestic Fergana Valley
Domestic Kzylorda
Domestic SouthKazakhstan
Domestic Syrdaryo_Tashkent_Jizakh


Agricultural demand Amu Darya basin 2021-2030 CCCMA
Mm3
16000
14000
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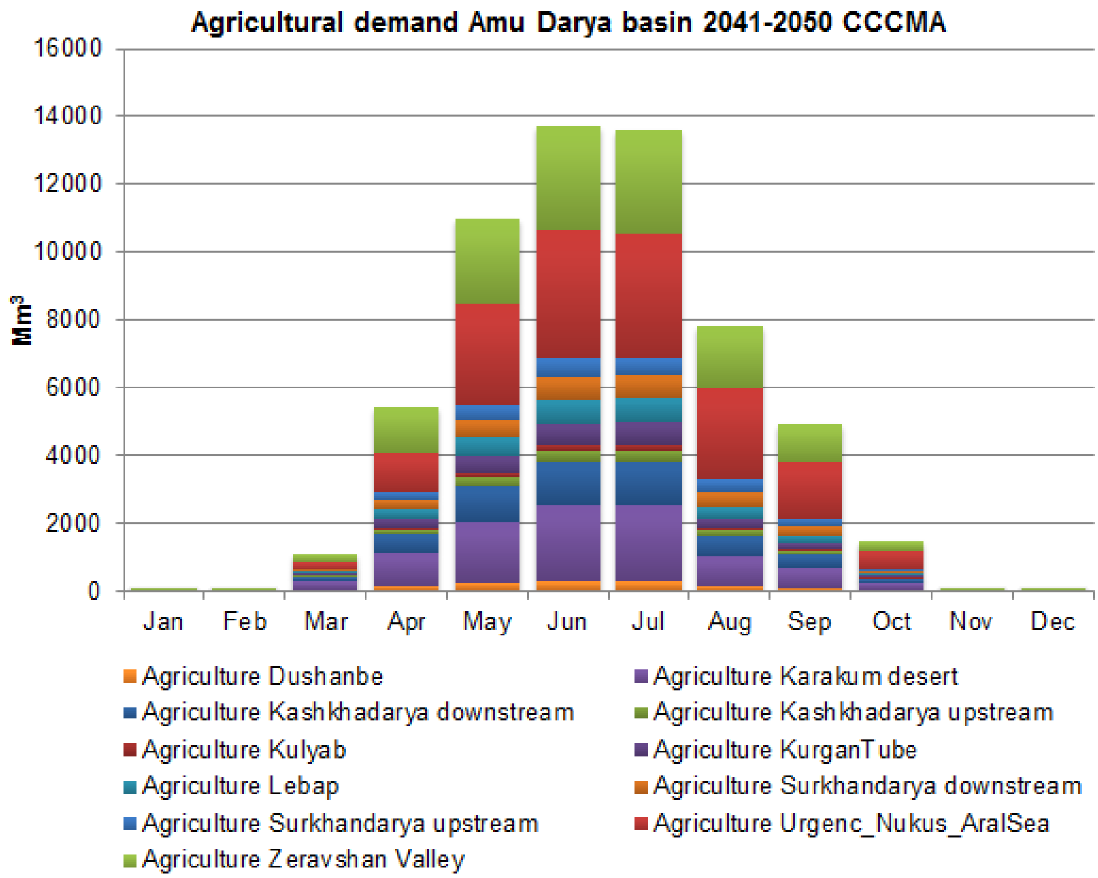
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Agricultural demand Amu Darya basin 2041-2050 CCCMA
Mm3
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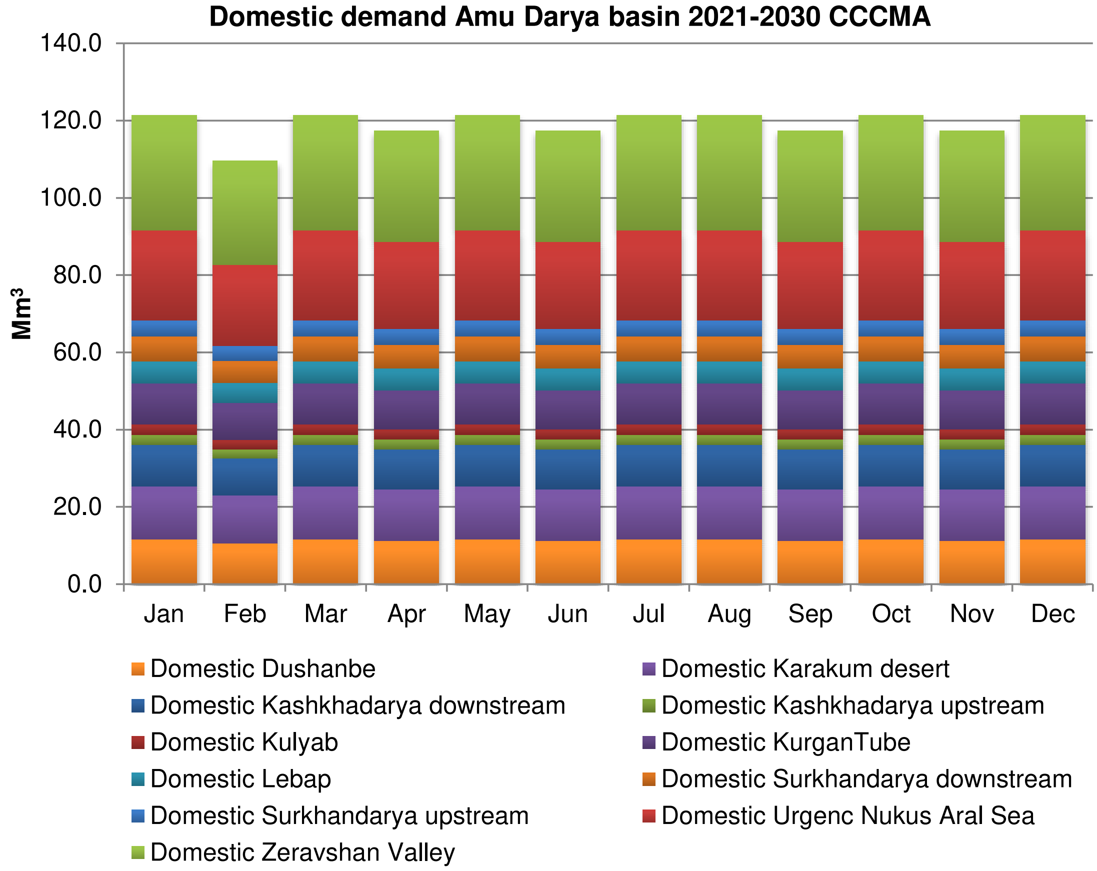
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Domestic demand Amu Darya basin 2021-2030 CCCMA
140.0
120.0
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80.0
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Mm³
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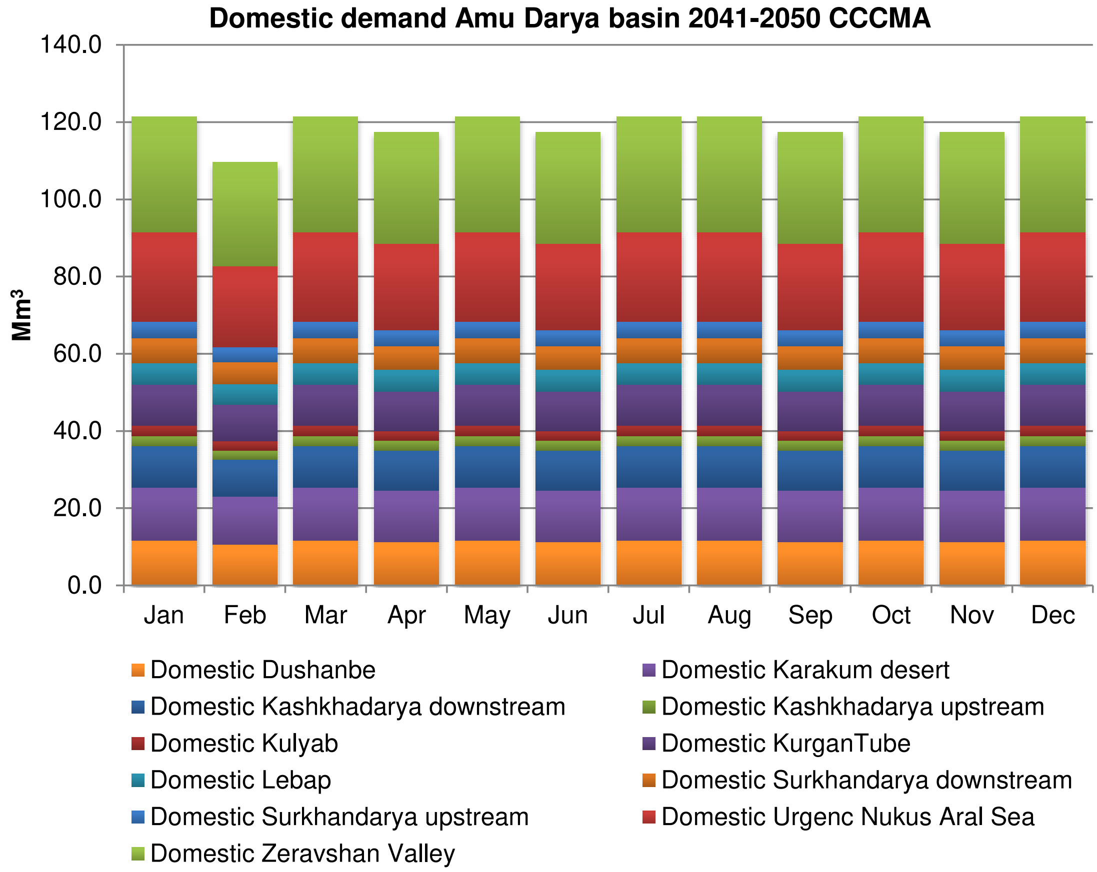
Domestic Dushanbe
Domestic Karakum desert
Domestic Kashkhadarya downstream
Domestic Kashkhadarya upstream
Domestic Kulyab
Domestic KurganTube
Domestic Lebap
Domestic Surkhandarya downstream
Domestic Surkhandarya upstream
Domestic Urgenc Nukus Aral Sea
Domestic Zeravshan Valley


Domestic demand Amu Darya basin 2041-2050 CCCMA
140.0
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Mm³
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Domestic Dushanbe
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Domestic Kashkhadarya downstream
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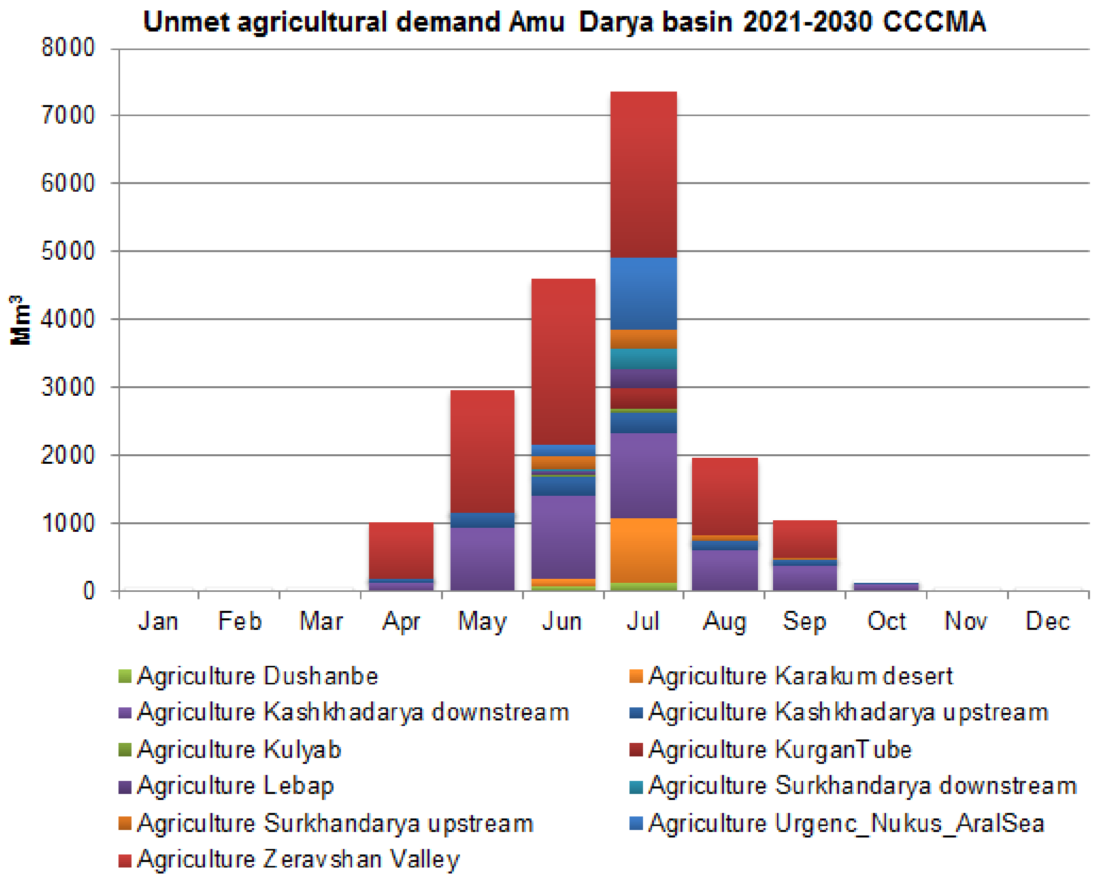
Unmet agricultural demand Amu Darya basin 2021-2030 CCCMA
Mm3
8000
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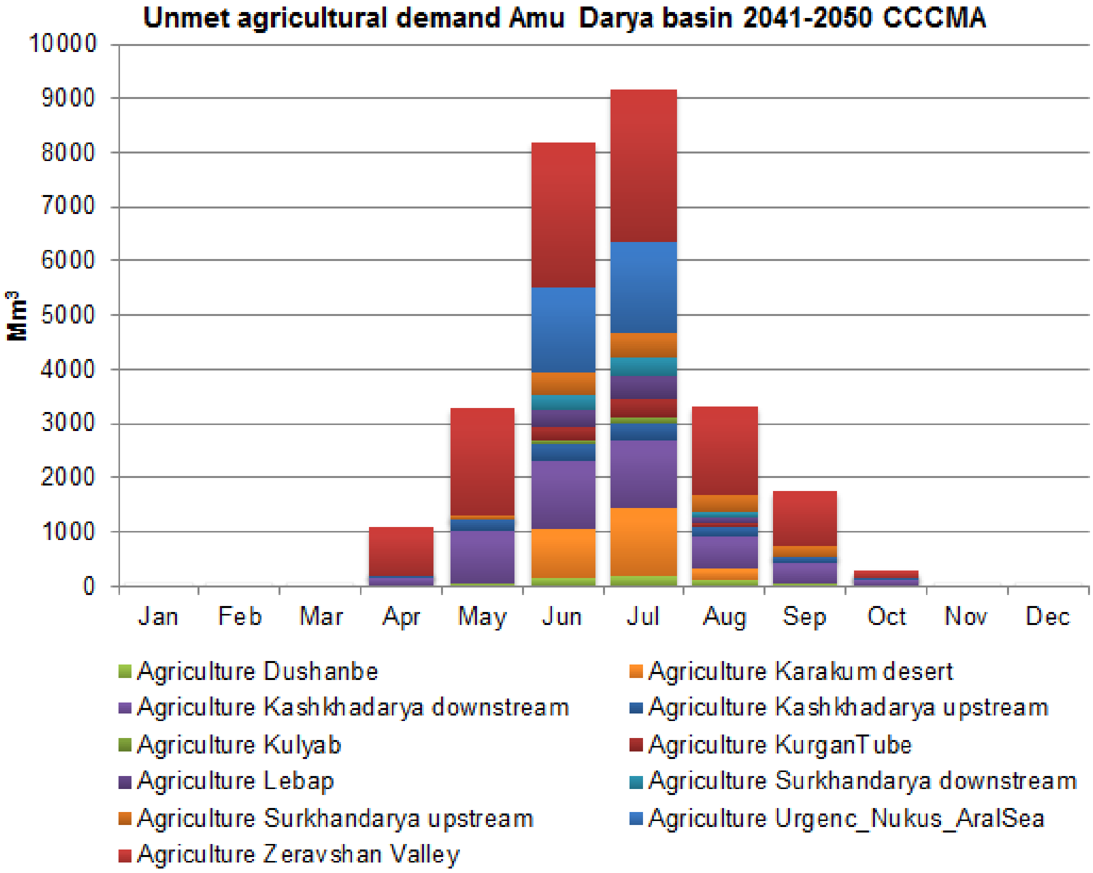
Agriculture Dushanbe
Agriculture Karakum desert
Agriculture Kashkhadarya downstream
Agriculture Kashkhadarya upstream
Agriculture Kulyab
Agriculture KurganTube
Agriculture Lebap
Agriculture Surkhandarya downstream
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Unmet agricultural demand Amu Darya basin 2041-2050 CCCMA
Mm3
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Agriculture Dushanbe
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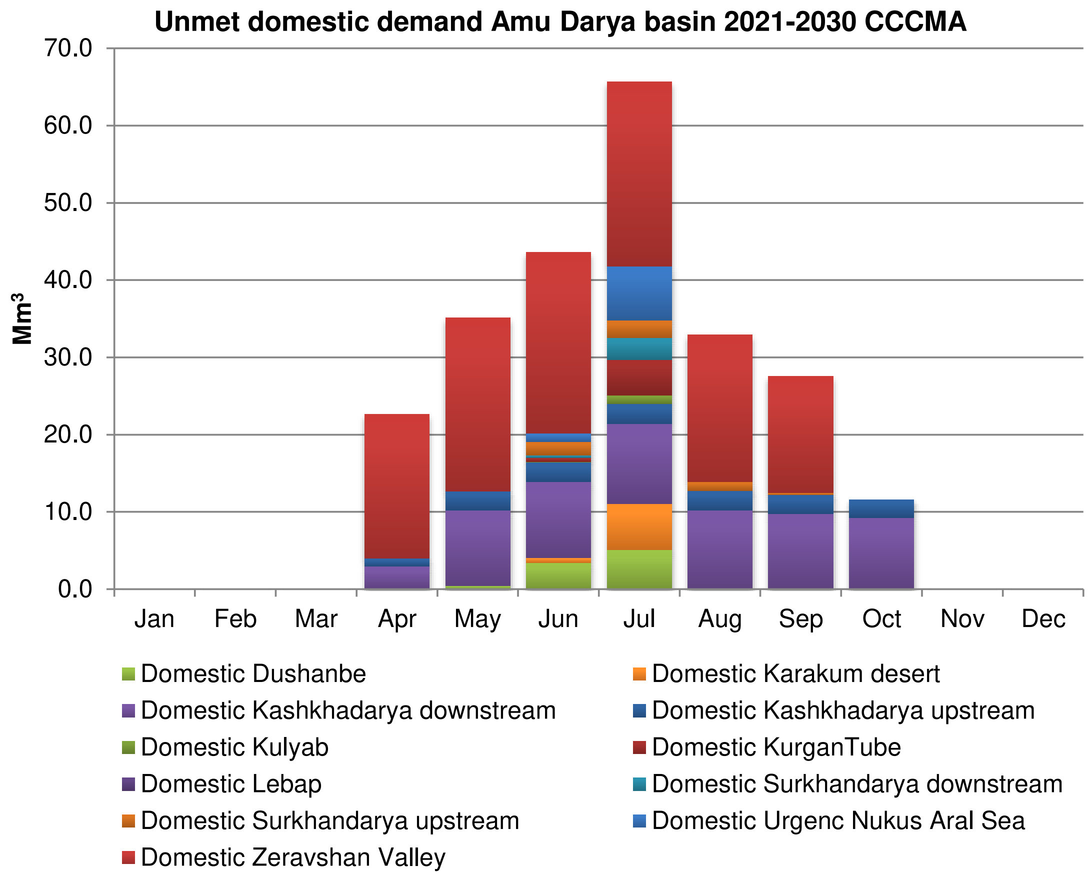
Agriculture Surkhandarya upstream
Agriculture Urgenc_Nukus_AralSea
Agriculture Zeravshan Valley


Unmet domestic demand Amu Darya basin 2021-2030 CCCMA
Mm3
70.0
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Domestic Dushanbe
Domestic Karakum desert
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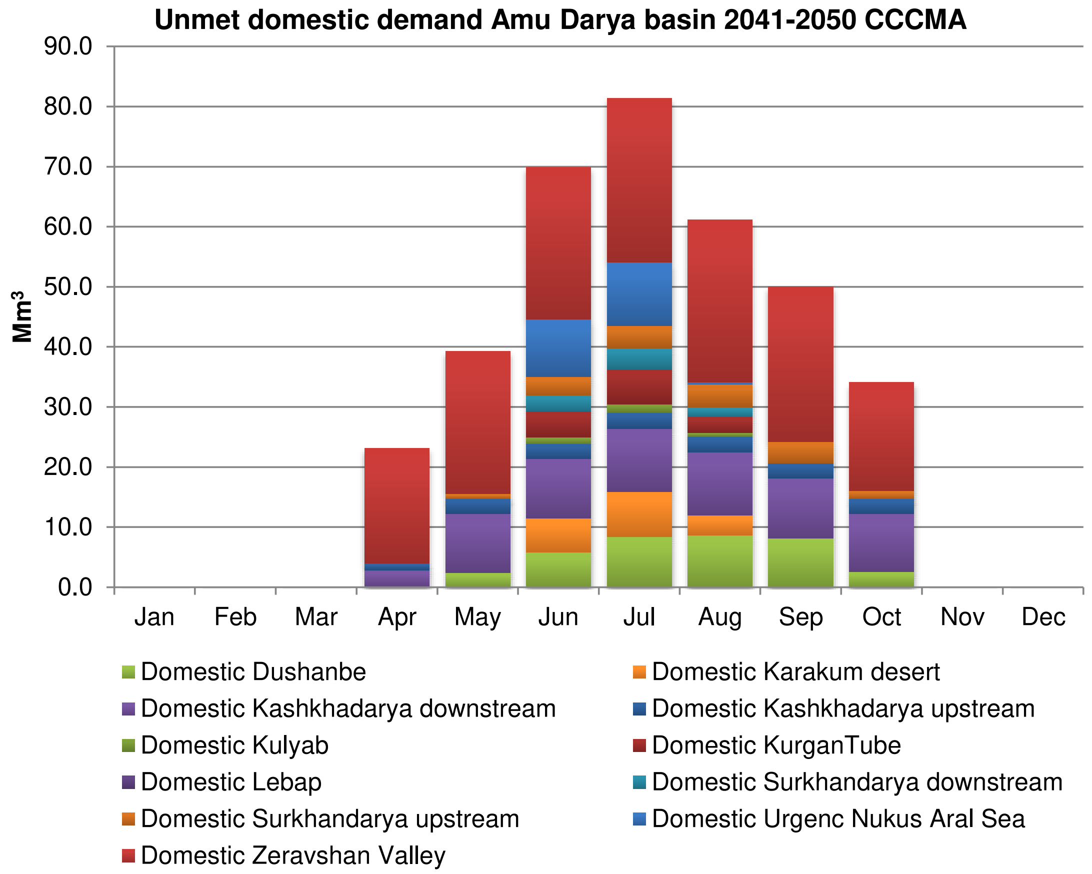
Unmet domestic demand Amu Darya basin 2041-2050 CCCMA
Mm3
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