

CLIMATE CHANGE AND SUSTAINABLE WATER MANAGEMENT IN CENTRAL ASIA

FCG International

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Climate Change and Sustainable Water Management in Central Asia

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INTRODUCTION

1. Climate change has been well documented all over the world in a vast number of scientific investigations and global climate model simulations. Field observations in Central Asia indicate that the climate has been warming for several decades and the consequences of this trend have already been observed in the everyday life of the population. However, there is still a substantial lack of knowledge on the phenomena related to climate change and its impacts on the environment and human life.

2. New climate and hydrological models show that river water must be seen partly as a nonrenewable resource in Central Asia. Today, about one-third of the water in rivers originates from mountain glaciers that are quickly losing their volume due to global climate warming. During past decades the rivers received a significant amount of excess water from glacial melt, but in the future this source will increasingly be lost as a consequence of vanishing glaciers.

3. Climate change will also make the plains hotter and drier. In the future, water shortages will be a serious problem for the national economy and the environment. Demand for water will increase at the same time as river discharges diminish. This situation may generate water management disputes and conflicts between people living in the mountains and on the plains.

4. Increasing temperatures in the mountains will also result in the thawing of permafrost, which may mobilize massive landslides and mudflows. Every year, these disasters destroy settlements, agricultural land, and infrastructure. In river basins where snowmelt is the main source of water, spring floods may become more frequent. The Central Asian mountains have unique landscapes and nature. Climate change will degenerate these ecosystems and their biodiversity, including rare animals and plants.

5. It is important that all countries have strategies to mitigate climate change by, for example, controlling greenhouse gas emissions and protecting vegetation resources. Especially in Central Asia, countries should also implement strategies to develop resilience and adapt to climate change. Most existing strategies underestimate the problems caused by climate change and have presented incorrect conclusions.

6. This working paper describes the results of research conducted by a technical assistance (TA) in Central Asia funded by the Asian Development Bank (ADB). The TA on Water and Adaptation Interventions in Central and West Asia combined field observations with sophisticated satellite-based data and created models to demonstrate the impacts of climate change on the hydrology of the Aral Sea Basin (FCG International, 2012).*

7. The project collected past temperature and precipitation data to create a three-dimensional map matrix of the Aral Sea Basin. This baseline served as a reconstruction of past and present climate of the basin. The climate change models used were based on extensive international research on the physics of climate systems (global circulation models). Future climate change scenarios have been drafted by the Intergovernmental Panel on Climate Change (IPCC), and several research institutes have made projections of future climate. In the project, this information was used to model changes of the climate parameters in the map matrix.

* More information is available at <http://www.adb.org/sites/default/files/projdocs/2014/44066-012-dpta-01.pdf>

8. The hydrological model SPHY used the past and predicted climate data to analyze rainfall, snow formation and melt, and the mass balance of glaciers. The model's outputs included water discharges from all the rivers on a detailed scale. These hydrographs describe changes in water quantity during the annual water cycle and show future trends clearly.

9. A water allocation model analyzed the changing needs for water for different purposes in each river section using the WEAP framework. It demonstrates that at the same time as water demand increases, river discharges will decline dramatically.

I. ASSESSING CLIMATE CHANGE

10. Earth's climate exhibits natural variation; but during recent decades, anthropogenic climate change has become increasingly evident. Emissions of greenhouse gases have continued to rise, leading to a very rapid increase in global temperatures. This rapid change has many impacts on the earth's natural environment that are further reflected in human societies. Some of these impacts may be positive, but most of them have so far been found to be negative, and in some areas of the globe future living conditions may worsen very seriously.

11. The positive impacts foreseen relate to better growing conditions in cold and cool climatic regions where warming lengthens the growing season and increases temperatures. The areas of the globe that will experience the most serious negative effects are already suffering from the climate-related hazards. They are typically experiencing water shortages, leading to drought, or they are suffering from extreme weather events such as flooding. Sea-level rise is one of the future risks the coastal areas must prepare for (IPCC 2012).

12. Climate change is linked to an increase in the incidence of extreme weather events; i.e., more frequent extreme winds, heat waves, heavy snowfalls and torrential rains. These extreme events can lead to disastrous impacts on different sectors of society. The impact of extreme events on society is not dependent only on the frequency and magnitude of extreme weather events, but also on the vulnerability and exposure of the society to extreme events. Vulnerability and exposure depend on the country's infrastructure, including the capacity to operate efficient early-warning systems (IPCC 2012).

13. Climate models are the most important scientific tool for estimating future climate conditions. These very sophisticated models rely on the basic laws of physics, and have modules for atmospheric, ocean, and earth-surface processes. The models include the interactions between the constituent modules, such as the exchange of heat between the earth's surface and the atmosphere, evaporation, surface friction, and the flow of water from the continents to the oceans. Calculations are done on a grid covering the whole globe at several levels from the deep ocean up to top of the atmosphere. Running the models requires the extremely fast data processing capabilities of super computers. Global climate model simulations are therefore conducted in the few research centers that possess the necessary computer and human resources.

14. The ADB-supported Water and Adaptation Interventions in Central and West Asia technical assistance required detailed climate projections for future decades. The projections were based on the global climate model simulations reported in the fourth assessment report of the IPCC (Randall et al. 2007). Simulations of five different models of the intermediate emission scenario were used (Table 1). The criteria for the selection of these models were that their spatial resolution was 1.9° of latitude and longitude or higher and they originated from different countries. This ensured that the models are genuinely separate models and thus the results

obtained by employing them depicted the scale of variation different climate projections possess. In addition, in a comparison made among 19 different global climate models, the ability of these five models to simulate the past climate was found to be as good as any other model.

Table 1: Global Climate Models Used in the Study

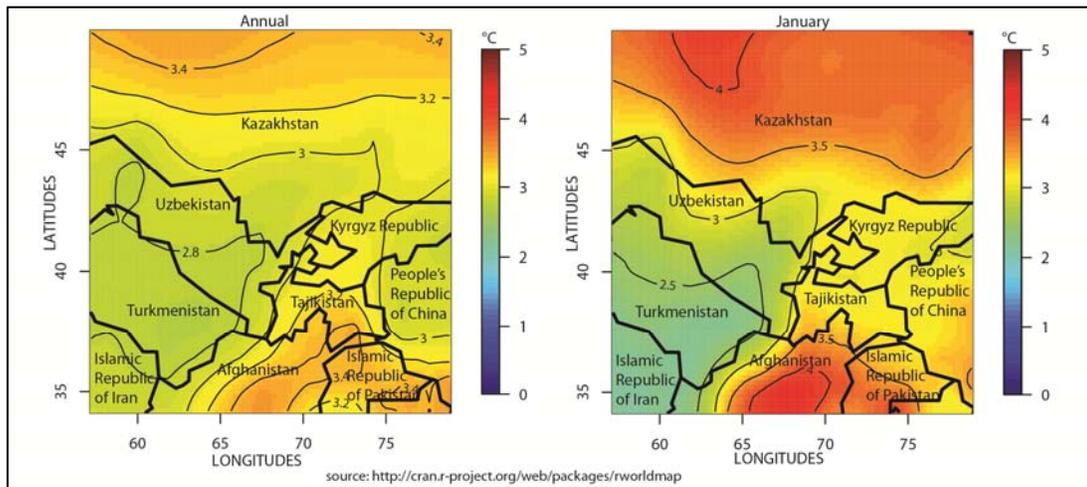
Model	Institute	Country	Resolution
CGCM3(T63)	Canadian Centre for Climate Modelling and Analysis	Canada	1.9° x 1.9°
CNRM-CM3	Météo-France	France	1.9° x 1.9°
ECHAM5/MPI-OM	Max Planck Institute for Meteorology	Germany	1.5° x 1.5°
MIROC3.2(HIRES)	Center for Climate System Research (University of Tokyo)	Japan	1.1° x 1.1°
NCAR-CCSM3	National Center for Atmospheric Research	United States	1.4° x 1.4°

Source: Randall et al. 2007. "Climate Models and Their Evaluation." In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, USA: Cambridge University Press.

15. The climate scenarios produced by the five selected general circulation models were generated to daily temperature and precipitation data sets for 2011–2050 using the delta change method (e.g., Arnell 1996). The use of this method for estimating change in the near future is well justified (Räisänen and Rätty 2012). First, the differences between the simulated current and future climates were computed; then these changes were added to the high resolution (0.2° x 0.2°) daily temperature and precipitation data sets for 2001–2010. The gridded daily mean temperature data, which are used as a base of generating scenarios for the future, were produced by kriging interpolation (e.g., Krige 1951) from daily temperature observations during 2001–2010. The gridded daily precipitation data for 2001–2010 originates from satellite-based data of the Tropical Rainfall Measuring Mission (Huffman et al. 2007, Huffman et al. 2012) and Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (Sorooshian et al. 2000). The processing of climate data, interpolation, and downscaling in the project was done using the R software environment.

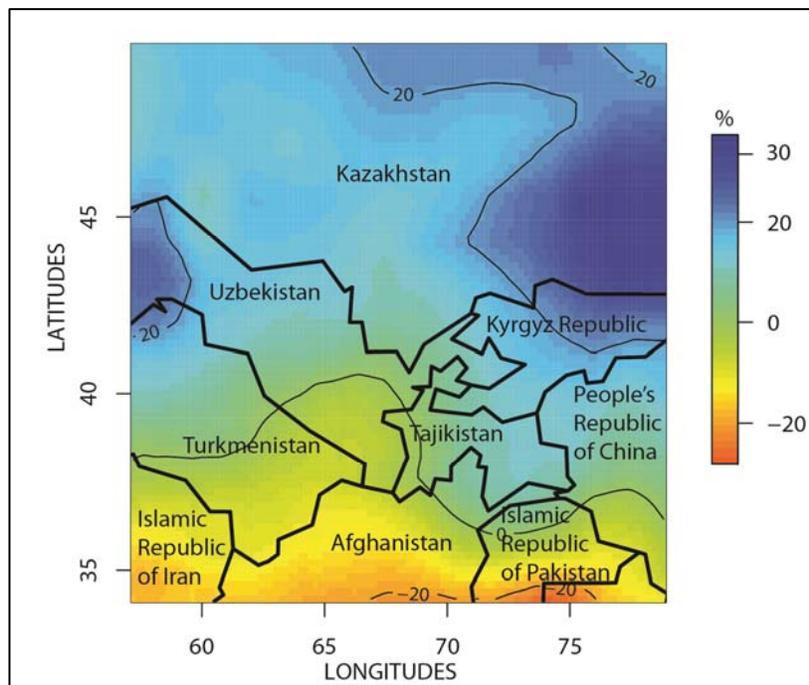
16. Until 2050, mean temperatures were projected to rise throughout the year in the Central Asian region, with an annual mean temperature rise of about 3 degrees Celsius. The warming was projected to be strongest in the mountains and in the more northerly latitudes (Figure 1).

Figure 1: Average Change of Annual and January Mean Temperatures between Control Simulations for 1971–2000 and Simulations for 2045–2065



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 Source: FCG International

Figure 2: Average Change in January Precipitation between Control Simulations for 1971-2000 and Simulations for 2045-2065



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 Source: FCG International

17. The projected changes in annual precipitation were relatively small until the year 2050 and varied from model to model. The already-dry southwestern parts of the region were projected to become even drier, especially during summertime. In contrast, in the northern parts and the mountains, annual total precipitation was projected to increase by 5%–10% during winter months (Figure 2).

18. The predicted climate changes in Central Asia may lead to more favorable conditions in parts of Kazakhstan (Lioubimtseva and Hennebry 2012). The growing season is projected to become longer and water availability may improve. However, in the regions that are already experiencing water shortages, the conditions will become even more difficult because temperatures and evaporation will rise and precipitation will decrease. Parts of the region are predicted to become more arid. These areas include Turkmenistan, Uzbekistan and western Kazakhstan. For example, Uzbekistan's economy is very dependent on irrigated agriculture, which uses substantial amounts of water from the Amu Darya River; and thus the foreseen decrease of these water resources could have a severe impact on the the country's economy (Schlüter et al. 2010).

19. Understanding climate change and its impacts is essential in Central Asia. Adaptation to the large predicted risks requires coordination among the Central Asian countries, as in case of the Aral Sea water system, where water management involves Kazakhstan, the Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan (Ibatullin et al. 2009).

II. IMPACTS OF CLIMATE CHANGE

20. The scientific community is starting to understand better how the climate system works and hydrologists are able to evaluate the impact of changes in climate on water resources. Climate change is expected to exacerbate current stresses on water resources created by population growth, and economic and land-use change. In Central Asia, mountain snowpack, glaciers, and small ice caps play a crucial role in freshwater availability. The glacial retreat and snow cover reductions observed over recent decades are projected to accelerate throughout the 21st century. The consequences will be a reduction in overall water availability, lower hydropower potential, and changing seasonality of flows in regions supplied by meltwater from the Tien Shan and Pamir mountains.

21. Besides projected changes in precipitation, rising temperatures are an important factor for Central Asia. The large-scale irrigation systems are already suffering from water shortages, and higher temperatures will increase the volume of water required by the irrigated crops. Moreover, higher temperatures will also have an impact on the natural vegetation, and evaporation from these areas will increase so that less water will be available to flow into the streams and rivers.

A. Glaciers

22. Glaciers cover 18,128 square kilometers (km²) in the Aral Sea Basin, and they have an important hydrological role because they release meltwater, especially during the dry summer months. Mountain glaciers include (i) small cirque glaciers resting on steep mountain slopes; and (ii) large ice caps covering mountain tops, and their associated valley glaciers - long, narrow ice tongues flowing down U-shaped valleys.

23. The glaciated area of the catchments of the Amu Darya and Syr Darya basins differs significantly. In the Amu Darya Basin, glaciers cover 15,500 km² (2% of the area); whereas in the Syr Darya Basin they spread over only 1,800 km² (0.15% of the area). The biggest glaciers are located in the Pamir Mountains in Tajikistan (Figure 3).

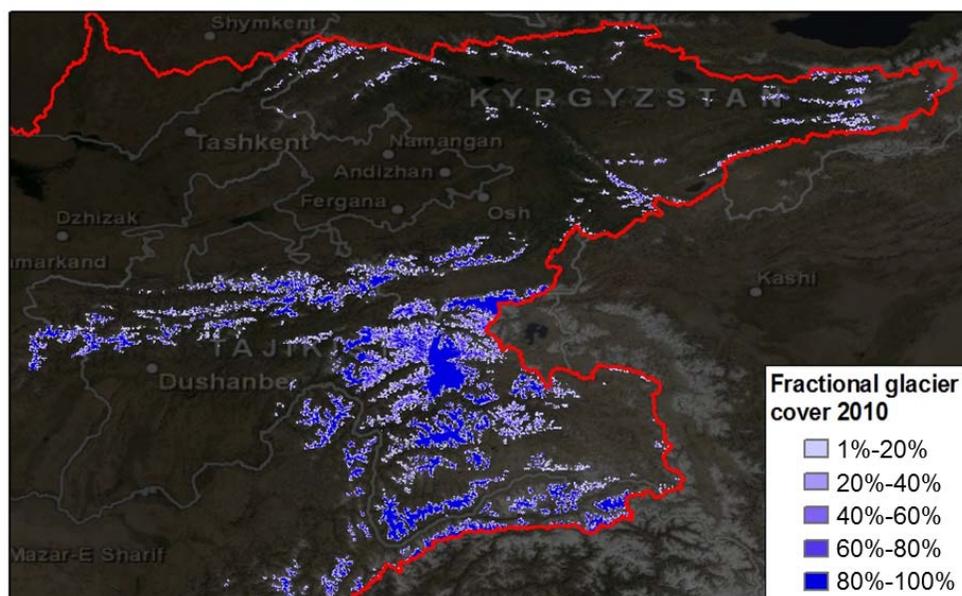


Figure 3: Occurrence of Glaciers in the Upper Watersheds of the Aral Sea Basin in 2010

24. During the Holocene (the interglacial period since the last ice age) the glaciers reached their maximum extent during the Little Ice Age (about 1650–1850). In most glaciers, the terminal moraine, which marks the maximum extent of the glacier, can clearly be seen in the valleys, especially on satellite images (Figure 4). Glaciers respond quite quickly to changes in climate (temperature, precipitation, humidity, and cloud cover). If the snowfall (accumulation) sustaining a glacier declines, or there is an increase in ice loss (ablation), the glacier will recede and/or there will be an overall thinning of the ice mass. The melting of glaciers has accelerated since the Little Ice Age due to the gradual climate warming (Seversky 2006, Kutuzov and Shahgedanova 2009, Kerr 2013).

25. As temperatures have risen almost everywhere, the retreat of glaciers from mountain valleys is one of the most visible signs of global warming. The overall picture of widespread glacial recession is unequivocal and reflects the well-known record of global warming.

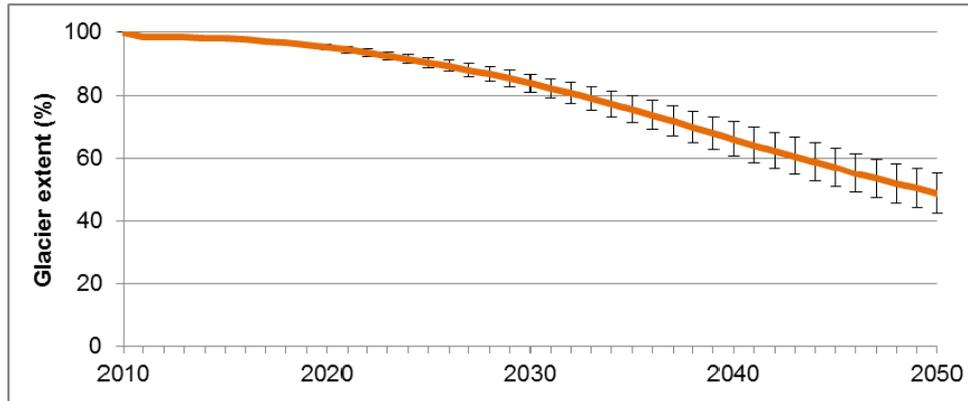
Figure 4: The Fedchenko Glacier in the Pamir Mountains of Central Tajikistan



The Fedchenko Glacier is the largest mountain glacier in the world. The glacier is about 2 kilometers wide. During recent decades, the glacier has thinned by 1 meter per year, its surface area has decreased by 11 square kilometers, and it has lost about 2 cubic kilometers of ice. (Source: 3D visualization 2013, Google Earth).

26. In this study, the future melting rate of glaciers in the Aral Sea Basin was predicted using Global Climate Model Projections and hydrologic modeling. The modeling revealed what will happen to the glaciers and runoff up to 2050 (Figure 5). The simulations show that small ice caps, especially in the Tien Shan Mountains (Figure 6), will disappear and the volume of glacial meltwater will be dramatically reduced. It is important to realize that climate warming and melting of glaciers have been going on for some time, especially since 1940. However, the melting of glaciers is accelerating.

Figure 5: Change in Glacier Extent in Central Asia according to Various General Climate Model Projections



Source: FCG International

Figure 6: Old Terminal Moraines Representing Earlier and More Extensive Glaciers



The moraines provide geomorphological evidence that glaciers have already receded substantially during the last 150 years. In this case, only one-third of the maximum extent is left (Kazakh–Kyrgyz border, Almaty; 3D visualization 2013, Google Earth).

B. Glacial Lakes

27. Because of the rapid melting and retreat of glacier margins, new proglacial lakes may be generated. It is common for old ice-cored moraines to create dams in front of rapidly receding

valley glaciers (Figure 7). Also, the glacier itself may act as a dam for waters from an adjacent valley. An ice dam may be formed as a result of a surging glacier. Such lakes may contain a large amount of water; and when the dam collapses, the flooding may be catastrophic.

28. There are hundreds of proglacial lakes in Central Asia and many of them have been classified as dangerous. Recent ice surges, outbursts of glacier-dammed lakes, and floods by glacial rivers have caused major disasters. The increasing incidence of glacial lake outbursts can be related to climate warming, because receding glaciers generate proglacial lakes. Thawing of an ice core in a terminal moraine damming a lake may cause a breach, leading to the sudden release of a mudflow down to the valley. Government institutions in Central Asian countries map and manage emergency situations. Flood protection interventions and early warning systems are needed in areas that are found to be vulnerable to glacial instability and lake outbursts.

Figure 7: Old Ice-Cored Moraines Create Dams in front of Rapidly Receding Valley Glaciers



When an ice core in a terminal moraine damming a proglacial lake melts, a catastrophic flood and mudflow may occur. The lake is 2 kilometers in diameter. (Petrov Lake, Kyrgyz Republic. 3D visualization 2013)

Source: Google Earth

C. Water Resources

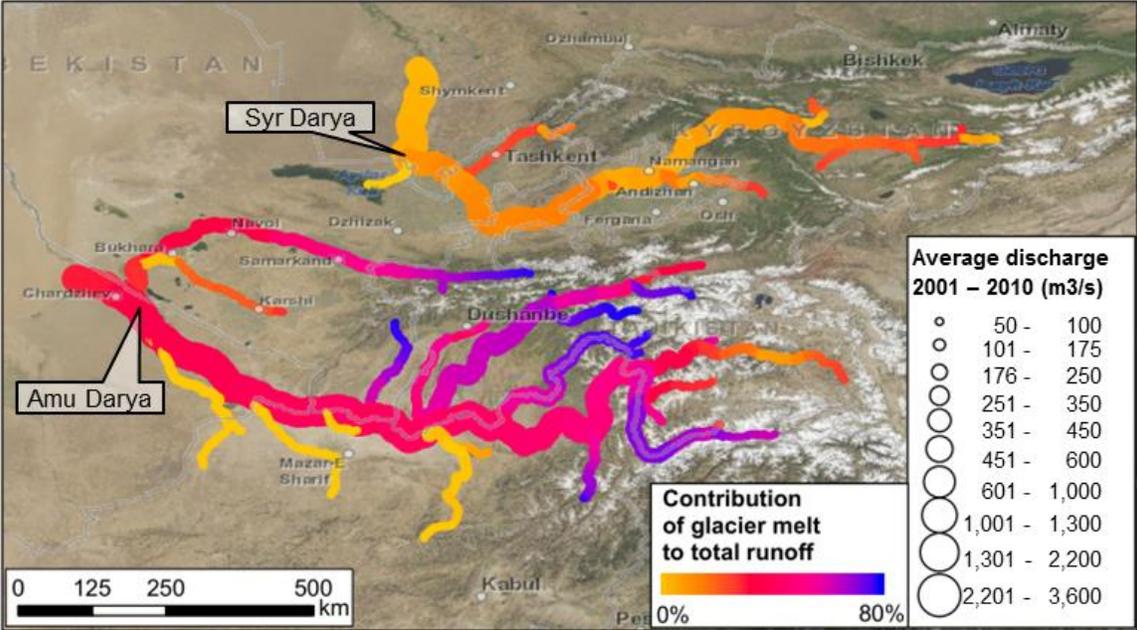
29. The two main rivers in Central Asia, the Syr Darya and the Amu Darya, play a prominent role in the region. People depend on their water for domestic use, farmers rely on it for irrigation, the environment alters if water resources change, and hydropower requires it to supply the region with energy. Besides ongoing economic development with associated changes in water requirements, it is clear that climate change is an additional challenge to the planning and management of water sources.

30. Currently, most water in the region is generated in the upstream mountainous areas. Water flows from smaller streams into bigger streams and finally into the Amu Darya and Syr Darya rivers. The water is supplied as (i) rainfall flowing overland directly into the streams; (ii) rainfall infiltrating into the soil and flowing through the soil into the streams, or available as groundwater; (iii) precipitation falling as snow and flowing into the streams when it melts; and (iv) precipitation feeding glaciers and that eventually melt and flow into the streams.

31. Knowledge of those four hydrological components is highly relevant for understanding current and future water resources. When rainfall flows directly into a stream it can cause rivers to fill up quickly and can cause flooding. However, rainfall that infiltrates into the soil is buffered and will generate a much more constant inflow into the streams. (This is why fighting land degradation is so important.) Precipitation that falls as snow represents a useful natural buffer, because only when temperatures increase during spring and summer will this snow melt and become available as liquid water for downstream users, coinciding with the period of peak demand. Finally, water stored in glaciers is released very gradually, providing a stable flow during spring and summertime even if rains have been low.

32. Figure 8 shows the contribution of glacial melt to total flow. In the Amu Darya River, glacial melt is an important contributor to the entire flow, especially in the smaller streams at higher elevations. Total water resources generated in the upstream parts of the Aral Sea Basin indicate that for the upstream Amu Darya almost 40% of the total flow is generated by glacial melt, while for the upstream Syr Darya this figure is just over 10% (Table 2). It is clear that glacial recession caused by climate change will have a major impact on total flow and the timing of flows.

Figure 8: The Relative Contribution of Glacial Melt to the Total Flows in Streams and Rivers of the Amu Darya and Syr Darya Rivers



The upper reaches of the Amu Darya river are mostly fed by meltwater from the glaciers of the Pamir Mountains
 Source: FCG International

Table 2: The Relative Flow Contribution of the Four Components for the Upstream Syr Darya and Upstream Amu Darya Rivers, 2001-2010 (%)

Hydrological Component	Syr Darya River	Amu Darya River
Direct runoff	31	16
Base flow	23	19
Snow melt	35	27
Glacial melt	11	38

Source: FCG International

D. Future Water Availability in Syr Darya and Amu Darya Basins

33. To support appropriate planning, scientists have developed advanced impact assessment tools that project future water resources. These have been developed to mimic the real world at various scales from global to individual farmer plots, and can also be used to look at the future under different climate change scenarios. In this study, impact assessment tools were used to evaluate the future of Central Asia's water resources.

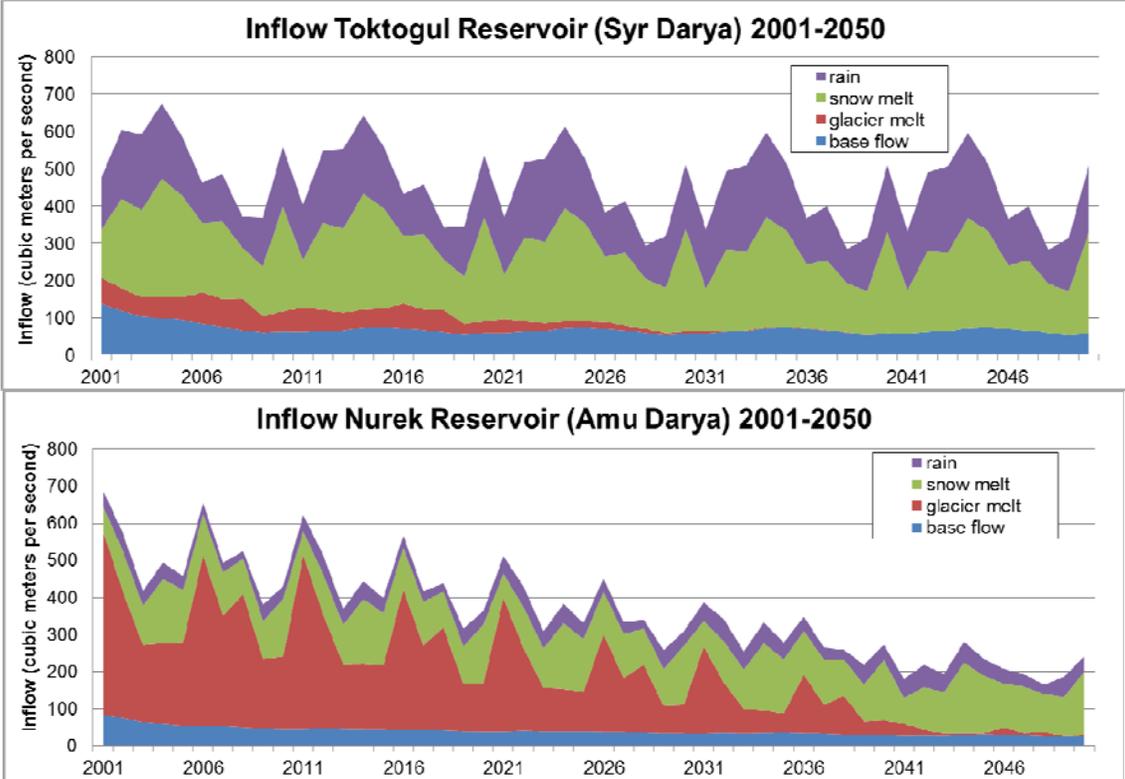
34. The impact assessment was based on two modeling approaches. Current and future water resources were assessed using the SPHY model, which is a revised high-resolution version of the PCR-GLOBWB hydrological model. SPHY is a conceptual, dynamic, and distributed model. Changes in irrigation water requirements are based on changes in irrigated area and changes in crop water demand as a consequence of a changing climate. Projected changes in domestic and industrial demands are based on the relationships between gross domestic product and gross domestic product per person. A water allocation model was used to link water supply and water demand, and to explore adaptation strategies. This model was developed using the WEAP package which considers streams, reservoirs, groundwater, irrigation demands, domestic demands, and industrial demands. The cost-effectiveness of various adaptation measures for closing the supply–demand gap was assessed by means of the water marginal cost curve. Such cost curves show the cost and water saving potential of a range of different measures, from productivity improvements to demand reduction and supply expansion.

35. The relative contribution of the four different sources of water in the rivers is likely to change in the future. Rainfall patterns will alter and temperatures will increase, resulting in a lower contribution of snowmelt and especially of glacier melt. Figure 9 indicates that glacier melt will be reduced substantially. Even though more than 50% of the glacier ice volumes will remain, they will be in the higher altitudes so melt will be lower (Immerzeel et al., 2013). The analysis shows that inflow into the downstream areas will decrease by 22%–28% for the Syr Darya and 26%–35% for the Amu Darya by 2050. The range of the projected decreases reflects the uncertainty in the climate projections.

36. The major user of fresh water in the region is irrigated agriculture. About 97% (93,800 million m³ per year) is consumed by irrigated agriculture, while other sectors such as households and industry consume about 2,700 million m³ per year. Climate change will not only reduce available water resources, as explained in the previous sections, it will also increase the demand by crops as higher temperatures lead to elevated evaporation rates. Based on the assessment tools developed for the regions, total water demand in the Syr Darya Basin is projected to increase by about 3%–4% by 2050, while demand in the Amu Darya Basin will increase by about 4%–5% (Figure 10).

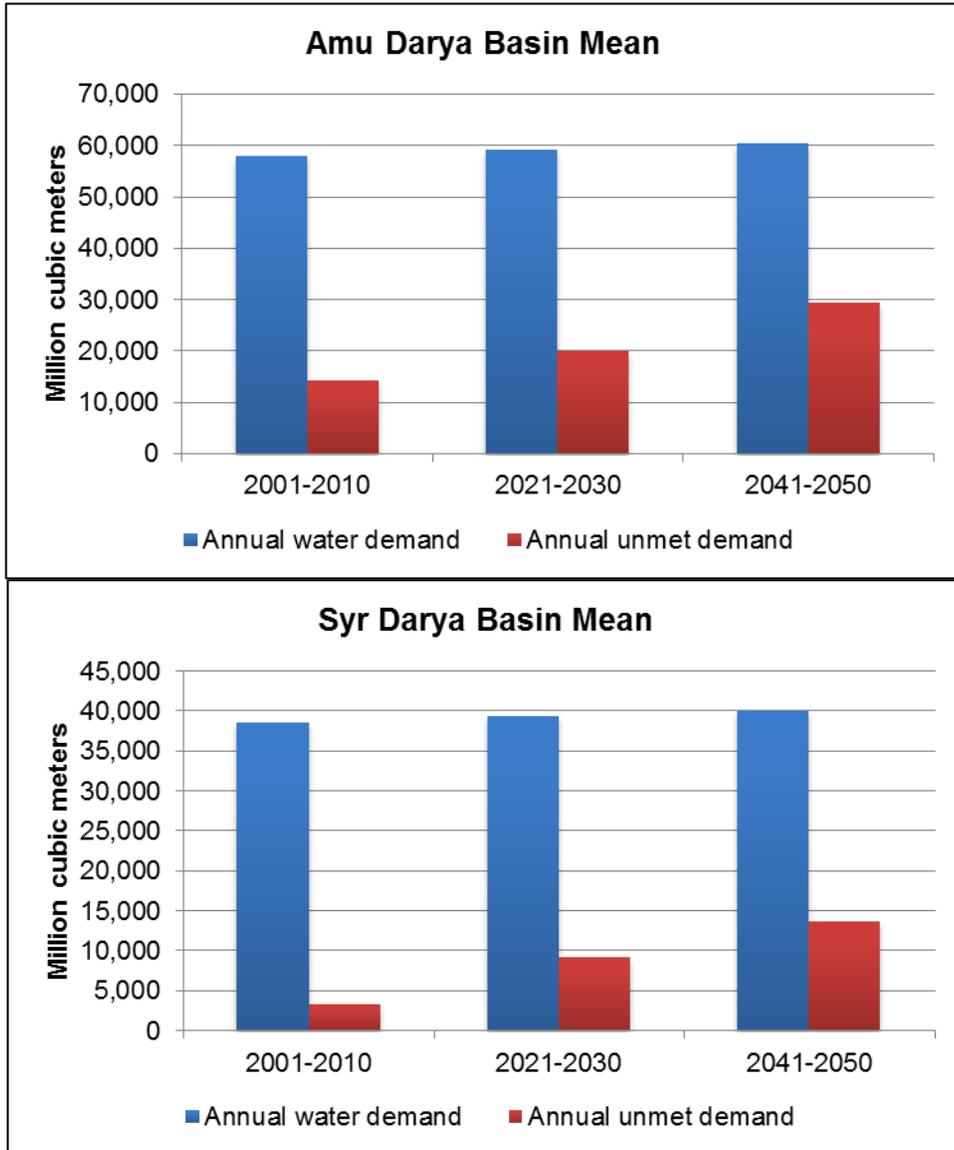
37. The combined effect of higher demand and lower inflow will amplify the current water shortages in the two river basins. For the Syr Darya Basin, the assessments show that the total water shortage will increase to 13,700 million m³ per year in 2050; this is about 35% of total demand. For the Amu Darya Basin, annual unmet demand will increase to 29,400 million m³ per year in 2050 (about 50% of total demand). It is clear that such a reduction will create substantial challenges for the region (Figure 11).

Figure 9: Typical examples of Changes in Total Flow and Flow Composition of Two Main Reservoirs in the Syr Darya (top) and Amu Darya (bottom)



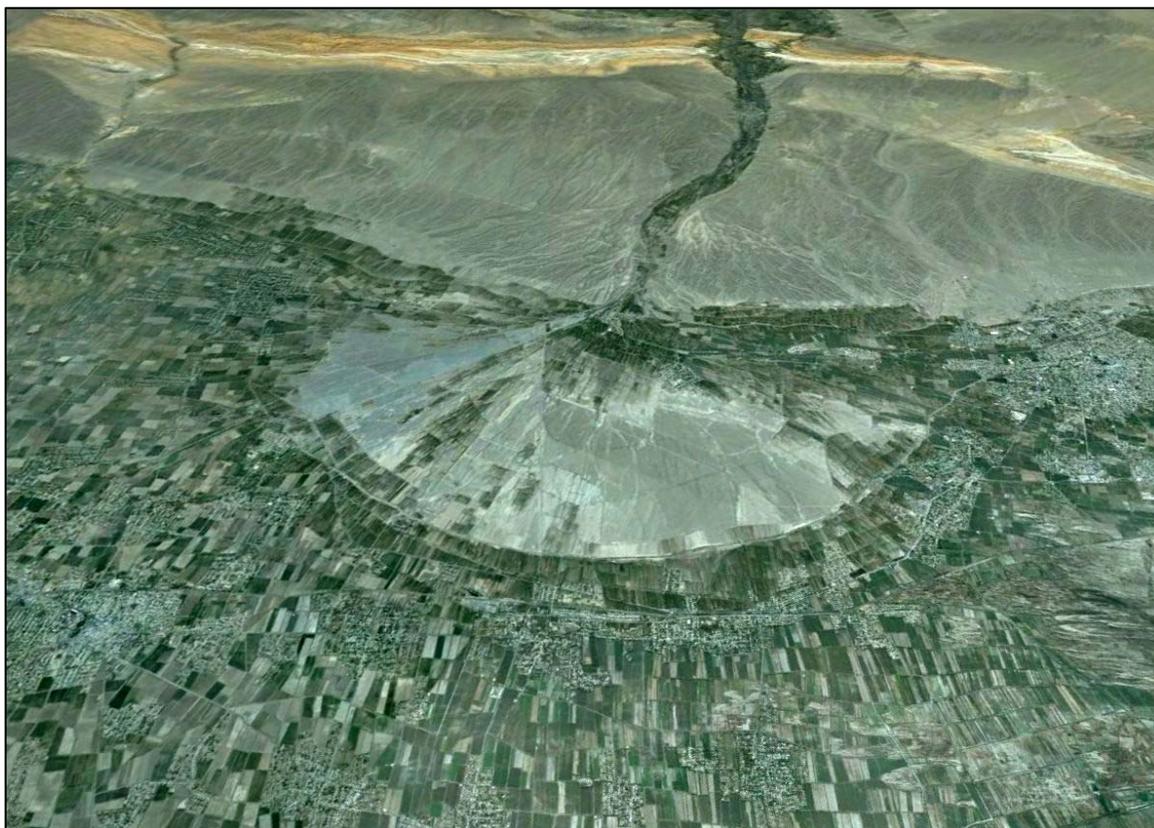
Note that after 2050, about 50% of the glacier extent will have been lost and the remaining glaciers will be above the 0°C level, so they will contribute very little to stream flow.
 Source: FCG International

Figure 10: Changes in annual water demand and unmet demand (water shortage) under climate change for the two main basins in Central Asia



Source: FCG International

Figure 11: Satellite Image from the Isfara River, Fergana Valley (Tajikistan–Uzbekistan border)



During the irrigation season, the rivers flowing down from the mountains receive most of their water from melting glaciers. All the river water is used for irrigation (3D visualization 2013)
Source: Google Earth

E. Floods

38. Floods have caused major disasters in Central Asia, destroying roads, bridges, and villages; and there have been many human casualties. An important question is whether in the future floods will become less frequent as the overall volume of water in the rivers decreases. The modeling results show that in most rivers springtime floods will remain the same as in the recent past. However, there will be major differences in flooding between the river basins and these should be understood whenever flood management is developed.

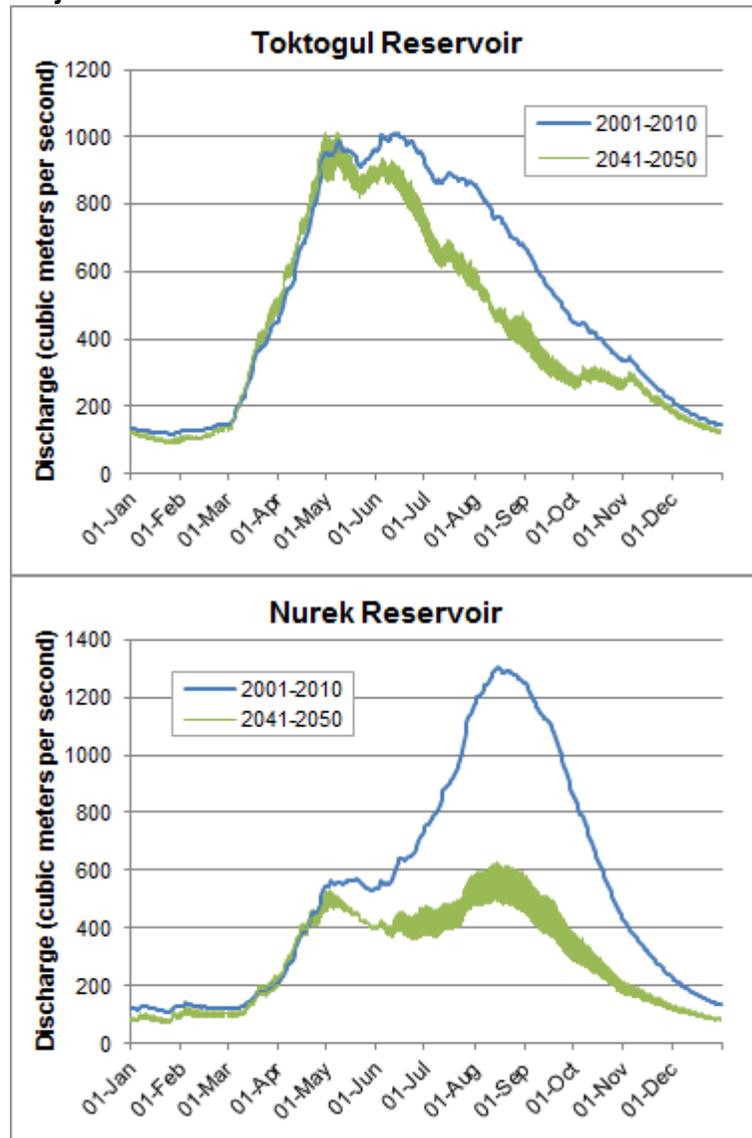
39. In basins that have extensive middle-altitude uplands and a lot of snow, the biggest flood risk is in May–June. This peak is the highest in the annual hydrographs and the situation will remain the same in the future. A typical example is the Naryn River Basin (the upper Syr Darya Basin above the Toktogul Reservoir) (Figure 12a). Torrential rain or a sudden warm period in spring or summer may cause major flooding-related disasters.

40. In the areas of high-altitude uplands, high mountains, and major glaciers, springtime flooding is less common. Glacial melt is a slow process, and it cannot generate floods. The highest discharges are measured in late summer, and glacial melt is the main contributor of water. In such basins, flood risk will decrease as the volume of the glaciers continues to

diminish. There is no reason to develop flood protection in these basins. A typical example is the Vakhsh River Basin (the upper Amu Darya Basin above the Nurek Reservoir) (Figure 12b).

41. In the areas of lower mountains and plains (in central parts of the Aral Sera Basin), thin snow and small cirque glaciers are typical. Here, snow accumulation will decrease and the small glaciers will disappear during the next few decades. In the future, water shortages will be severe and flooding will not occur at all. The Almaty, Bishkek, Shymkent, Dushanbe, Samarkand, and Tashkent regions are some of the areas likely to be affected.

Figure 12: (a) Annual Hydrographs for the Toktogul Reservoir (Kyrgyz Republic, Syr Darya Basin) and (b) Nurek Reservoir (Tajikistan, Amu Darya Basin) in 2001–2010 and in 2041–2050 Modeled Using Five Different Climate Change Projections



In January–May the discharges will remain similar to today, but major reductions will take place in the June–November discharges because of diminishing glaciers.

Source: FCG International

F. Permafrost and Slope Instability

42. As a result of climate warming, the snowline will retreat upslope by 200–300 meters on average by 2050. Extensive parts of hill slopes that have always been covered by snow or had frozen ground (permafrost) will melt. Thawing of permafrost in the higher mountains will make the slopes unstable, and this will generate landslides and mudflows. At first, only the surface layers of the ground will thaw and the underlying icy ground will form a slide surface. The thawed surface layers may destabilize and slide quickly to the valleys destroying forest, infrastructure, and settlements (Figure 13).

43. Landslides and mudflows are common in Central Asia; and every year settlements, infrastructure, agricultural lands, and natural areas are destroyed. Human casualties are also common in major disasters. Mass movements are also muddying water resources and filling reservoirs with sediments.

44. Risk assessments should be undertaken whenever infrastructure and settlements are planned, and emergency preparedness schemes developed.

Figure 13: Thawing of Permafrost in the Higher Mountains will Make slopes Unstable and Generate Landslides and Mudflows (Mailuu Suu, Kyrgyz Republic)



Source: M. Punkari, FCG International

G. Drying Environment

45. The lower parts of the Aral Sea Basin are mostly arid, with 40–200 millimeters of precipitation per year. Desertification is one of the most severe problems in Central Asia, and

huge areas of fertile land are lost every year. Land degradation from overgrazing, soil erosion, salinization of irrigated land, and desertification is directly affecting the livelihoods of nearly 20 million rural inhabitants.

46. Farm yields are reported to have dropped by 20%–30% across the region since the 1990s. About 70% of the total area of Turkmenistan has become desert, while salinized irrigated areas account for 50% in Uzbekistan and 37% in Turkmenistan (ADB 2006). In the future, the situation is projected to worsen due to a continuous increase in temperature and evaporation, combined with a slight decrease in precipitation in the most arid lowlands and a radical reduction in river discharges.

47. Environmental changes may have several feedback effects on climate, the final results of which are not yet fully understood. For example, more frequent and/or intense dust storms and wildfires increase aerosols in the atmosphere, which may cool the climate. However, deposition of these particles onto snow and glaciers will decrease their albedo and lead to faster melting.

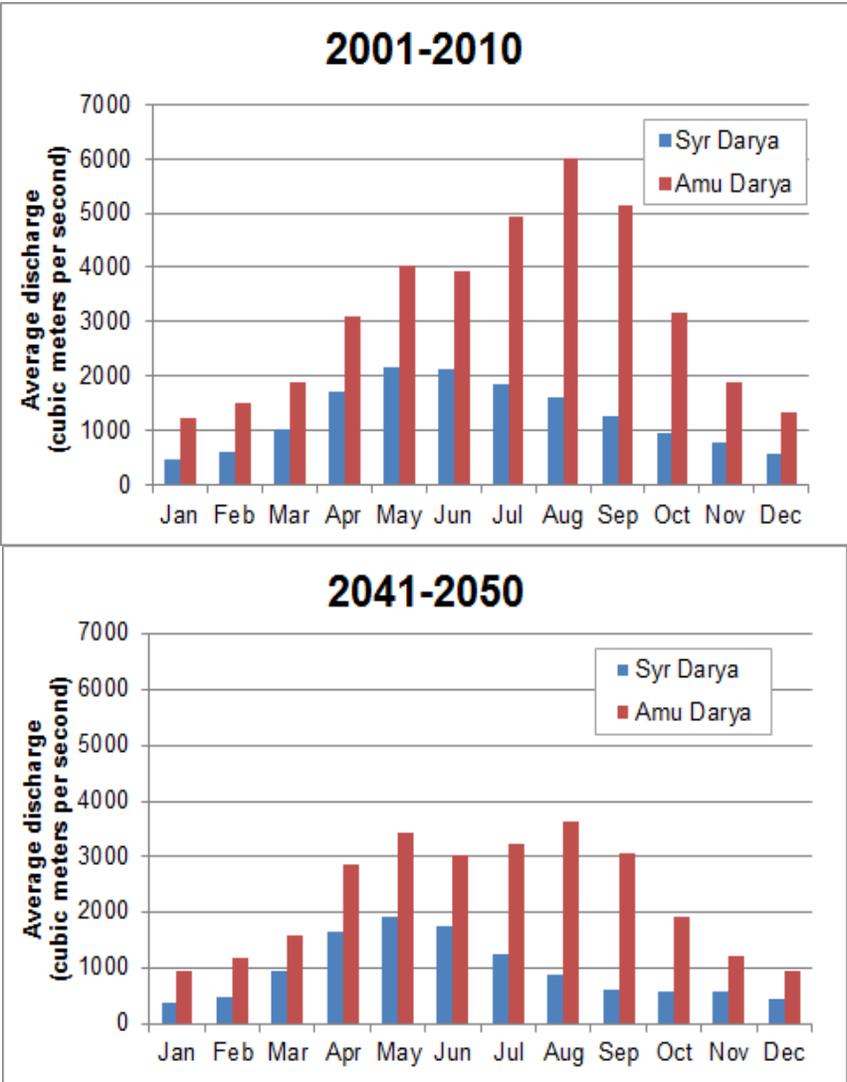
III. CONCRETE ADAPTATION OPTIONS IN CENTRAL ASIA

48. Adaptation strategies are very scale-dependent and location-specific. The assessment tools were used to analyze a range of adaptation actions that might be suitable for Central Asia. The options explored can be summarized in three broad categories: (i) expanding the supply of water available in the future, (ii) increasing the productivity of water, and (iii) reducing future demand for water. Within each category, typical options that can be chosen include increasing reservoir capacity, improving agricultural practice, increasing reuse of water in irrigated agriculture, increasing reuse of water for domestic use, reducing irrigated areas, reducing domestic demand, and employing deficit irrigation (the application of water below full crop requirements).

49. The ARAL–WEAP models for the Amu Darya and Syr Darya basins were used to evaluate the impact and effectiveness of these adaptation measures. The WEAP model was run for five different climate projections, based on five different global circulation models. For the two main rivers in Central Asia, it is expected that total water shortage in 2050 will be 43,000 million m³ per year. Moreover, monthly flow regimes will change quite substantially, especially for the Amu Darya River, due to glacial retreat and reductions in snowfall (Figure 14). By analyzing the potential adaptation strategies, the effectiveness of each measure can be assessed. A water marginal cost curve can be obtained by ranking the adaptation options according to their unit costs. However, its use is limited to comparing the financial costs of measures 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 as an input to decision making (Figure 15).

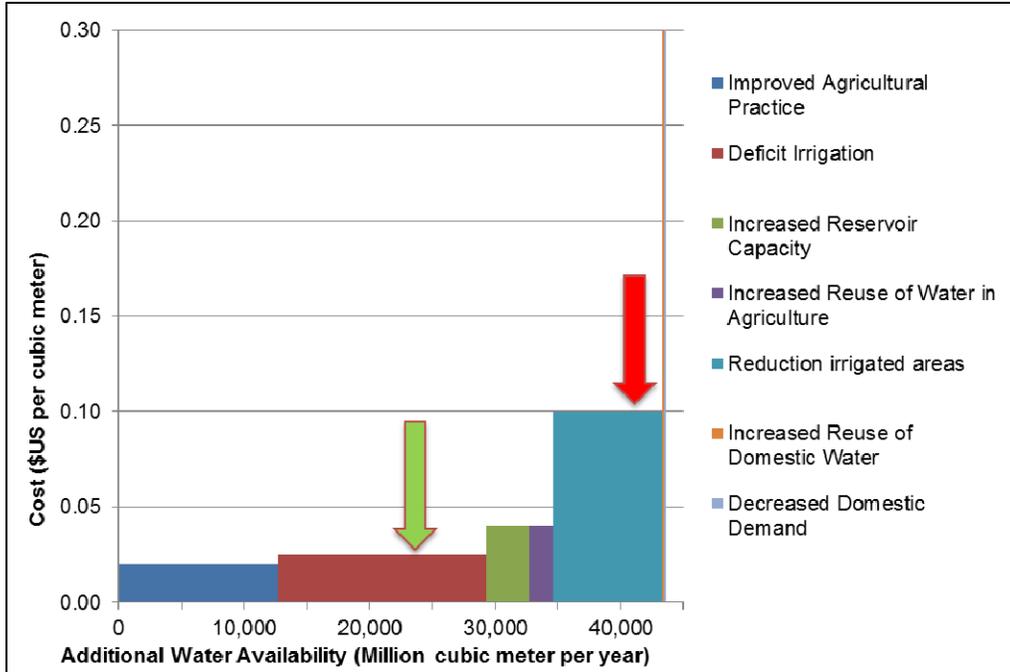
50. The simulations show that the most cost-effective adaptation measures for Central Asia are improving agricultural practices, adopting deficit irrigation, increasing the reuse of water in agriculture, and reducing the area under irrigation. In general, the measures applied to agriculture are much more effective than those relating to domestic water use. Applying the most cost-effective adaptation measures will close the water gap at a cost of \$1,730 million per year in 2050 (net present value).

Figure 14: Current and Future Monthly Flows in the Two Main Rivers in Central Asia if no Actions Are Taken



Source: FCG International

Figure 15: Water Marginal Cost Curve for the Amu Darya and Syr Darya Basins



Red arrow indicates total expected water shortage in 2050; green arrow indicates the hypothetical water shortage in case no climate change occurs. Note: Cost axis has been cut off at \$0.30. The cost of decreasing domestic demand is \$2.00 per cubic meter.

Source: FCG International

51. The technical assistance as summarized in this publication has substantially reduced the knowledge gap on the impact of climate change on water resources in the Aral Sea Basin. Results indicate that climate change will put additional challenges on decision makers to manage water resources in a beneficial way both to the environment and human life. The results of this technical assistance show that solutions are possible when decision makers will act adequately, resources are available and actions will be taken in common understanding of all countries.

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Climate Change and Sustainable Water Management in Central Asia

Field observations in Central Asia indicate that the climate has been warming and the consequences of this trend have already been observed. Disasters related to climate change destroy settlements, agricultural land, and infrastructure. Central Asian countries should therefore develop resilience and adapt to climate change. This report shows the results of the research combining field observations with sophisticated satellite-based data and created models to demonstrate the impacts of climate change on the hydrology of the Aral Sea Basin.

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