SIC ICWC Policy brief

No.13 January, 2026

Role of Environmental Flow for Preservation of the Amu Darya and Syr Darya Ecosystems

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Abstract

This analytical brief examines the role of environmental flow in Central Asia's two principal river systems – the Amu Darya and the Syr Darya. An environmental flow refers to the portion of a river's near-natural discharge regime that must be maintained – with specific quantity, quality, and timing – to sustain freshwater ecosystems and the livelihoods of the communities dependent on them. This concept differs from a sanitary flow release, which merely provides the minimum discharge required to meet basic sanitary and economic needs [1,2]. The analysis indicates that water volumes in both rivers have declined in recent years, subsequently reducing the environmental flows necessary to support ecosystems in both the northern and southern Aral Sea regions. These impacts are particularly pronounced in the southern Aral Sea area, notably within the Amu Darya delta. Model calculations suggest that further reductions in environmental flows could trigger catastrophic consequences for delta ecosystems. As water shortages intensify, many wetlands and water bodies are drying up, driving profound ecological transformations. Existing ecosystems are being replaced by communities better adapted to increasingly arid conditions; native vegetation and wildlife are disappearing, supplanted by halophytic or desert-adapted species. Only a limited number of animal species can now find suitable habitats within remaining wetlands, riparian tugai forests, and other refugia. Against this backdrop, environmental flows assume critical importance for preserving Aral Sea ecosystems.

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Introduction

The drying up of the Aral Sea has triggered a cascade of environmental, socio-economic, public health, and humanitarian challenges for governments and communities across Central Asia. Over the past five decades, combined inflows from the Amu Darya and Syr Darya rivers to the Aral Sea have declined fivefold, while the sea's volume has shrunk more than fifteen-fold and its salinity has increased twenty-five-fold [3]. What was once a thriving fishery is now a vast salt desert covering more than 5.5 million hectares. Frequent dust and salt storms carry over 90 million tonnes of salt-dust mix into the atmosphere each year, transporting it hundreds of kilometres across the region. Toxic salts originating from the Aral Sea basin have even been detected as far away as Antarctica, the Greenland ice sheet, and the forests of Norway.

Historically, the Aral Sea region supported rich biodiversity. Its water bodies were home to 38 fish species and numerous rare fauna, including a saiga antelope population that once reached approximately one million individuals, while the local flora comprised 638 plant species.

However, the drying sea has resulted in the loss of over half of the region's genetic biodiversity. Eleven fish species, twelve mammal species, twenty-six bird species, and eleven plant species have virtually disappeared. Furthermore, due to water scarcity, deforestation, and intensive livestock grazing, around 90 percent of the region's tugai forests have been lost [4].

The Aral Sea disaster has also exacerbated regional climate conditions, increasing aridity and summer heat while prolonging severe winters. Climate projections indicate that average air temperatures in the region could rise by an additional 1.5-3.0°C between 2035 and 2050 [5].

South Aral Sea Region

The South Aral Sea region, encompassing the Amu Darya delta within the Muynak District of the Republic of Karakalpakstan, is currently one of the most severely affected areas in Central Asia.

Located at the interface of aquatic and desert ecosystems, the region is experiencing a profound, ongoing environmental crisis driven by both anthropogenic pressures and climate change. Owing to the transboundary, long-term consequences of this degradation, the area has become a focal point for ecologists, hydrologists, policymakers, and the international community.

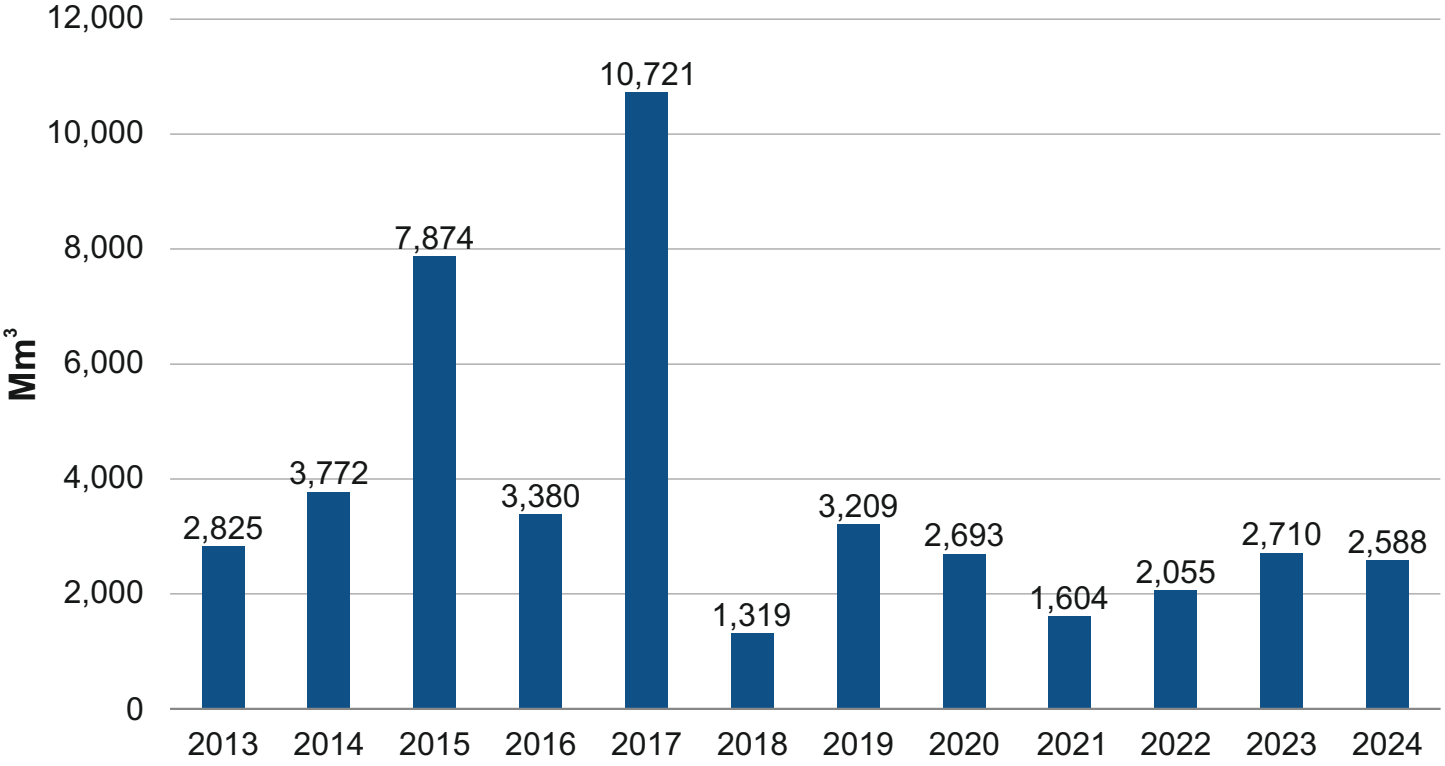
The principal driver of environmental degradation in the region is the drastic reduction in water inflow to the Amu Darya delta. Between 2013 and 2024, a total of 44.15 km³ of water reached the Southern Aral Sea area, averaging a mere 4.42 km³ per year. Annual inflow fluctuated significantly, ranging from a critically low 1.32 km³ during 2018-2021 to a maximum of 10.72 km³ in 2017. Such high variability undermines hydrological stability and severely disrupts the water-salinity balance of delta lakes and wetlands. The current water supply regime accelerates the degradation of individual lake ecosystems and the continued decline of biodiversity throughout the delta [6].

Many lakes and water bodies within the Amu Darya delta are undergoing severe shrinkage, while others have dried up completely. Those that remain are sustained primarily by collector-drainage water and residual river flows left after meeting the demands of irrigated agriculture. This mode of water supply is inherently unstable; collector-drainage water frequently has high salinity, and its volume is determined by irrigation schedules rather than natural hydrological processes. As a result, the region has experienced a sharp decline in the biological productivity of aquatic ecosystems, widespread degradation of delta landscapes, the loss of tugai forests, the dieback of reed beds, and a reduction in the abundance and diversity of plant and animal species, including rare and endemic taxa. Equally concerning is the loss of vital ecosystem services, ranging from natural water purification to local climate regulation.

One of the most alarming consequences of this environmental degradation is the rapid decline in biodiversity. Historically, the Amu Darya delta

Figure 1

Water Inflow from the Amu Darya into the South Aral Sea Region



contained some of the most important wetland habitats in Central Asia, serving as critical breeding and nesting grounds for numerous rare and endangered bird species, including the mute swan, white-headed duck, great white pelican, Dalmatian pelican, and pygmy cormorant. Today, these species are increasingly displaced as their habitats become fragmented or disappear altogether. Dozens of other endemic and locally adapted vertebrate and invertebrate species face a growing risk of extinction [7].

In recent years, the Government of the Republic of Uzbekistan has made the restoration of the Amu Darya delta a national priority. Significant efforts have been undertaken to rehabilitate hydraulic infrastructure, create artificially flooded landscapes on the exposed seabed of the former Aral Sea, and restore elements of the natural hydrological regime in the Southern Aral Sea region.

On 24 August 2018, during the Summit of the Heads of State of Founder States of the International Fund for Saving the Aral Sea (IFAS) in Turkmenistan, the President of Uzbekistan, Shavkat Mirziyoyev, put forward a number of strategic initiatives aimed at improving environmental conditions in the Aral Sea region. These initiatives focused on strengthening regional cooperation, mobilizing international support, and implementing concrete environmental and socio-economic measures to address the consequences of the Aral Sea crisis. Subsequently, the Government of Uzbekistan approved a practical action plan (a “roadmap”) to facilitate the implementation of these measures [8]. According to the provisions of this roadmap, SIC ICWC organized an expedition and conducted field investigations to assess the environmental condition of the South Aral Sea region.

The findings confirmed that the Amu Darya delta within the Muynak District of the Republic of Karakalpakstan continues to face significant environmental challenges associated with declining water inflows, high salinity levels, and ongoing biodiversity degradation.

The study revealed a substantial deficit in water resources reaching both the delta and the wider Aral Sea region. Even the minimum annual volume of 3.5 km³ established for sanitary releases is not consistently maintained. This unstable delivery of water has severely impacted wetlands and lake ecosystems, undermining their ecological functioning and long-term sustainability.

Recommendation. In light of these findings, it is proposed to consider the initiative advanced by JSC Uzsuvloyiha and SIC ICWC to divert water from the Lake Collector in Khorezm province to the Amu Darya delta and the Aral Sea region. Implementation of this project would provide an additional inflow of at least 4.5 km³ of water annually, helping to sustain the biological productivity of the delta's lake systems. The proposal is currently under consideration by the Cabinet of Ministers of the Republic of Uzbekistan, as reported by A.O. Mamatkarimov, Director of the IFAS Branch in Nukus.

Furthermore, Resolution No. 50 of the Cabinet of Ministers of the Republic of Uzbekistan mandates UzGIP, in cooperation with the IFAS Branch in Nukus, to prepare by 1 December 2025 a project design and feasibility study for the diversion of the Southern Collector. The objective is to improve the ecological condition of the lake systems in the Aral Sea region and enhance their long-term environmental sustainability.

Analysis of Landsat 8 images for 2015-2025 indicates that the vast majority of water bodies within the South Aral Sea system are experiencing a persistent decline in surface area. Particularly severe shrinkage has been recorded in Lake Makpalkul (–79.41%), the Mezhdurechie Reservoir (–65.11%), and Lake Sudochye (–64.62%). These water bodies have undergone substantial reductions in open-water extent, reflecting ongoing environmental degradation and raising the prospect of their eventual disappearance should current climatic and water management conditions persist.

Measurements of water salinity reveal pronounced spatial variability across the delta system. While some water bodies exhibit local improvements associated with reduced electrical conductivity, others show a marked deterioration in water quality and rising salt concentrations. Of particular concern are stagnant and hydrologically isolated water bodies – including the Bukhara Canal, Kazakdarya, and parts of the Sudochye lake system – where salinity levels have reached critical thresholds.

Recommendation. In the context of growing climate variability and intensifying water scarcity, establishing a continuous, operational water-quality monitoring system is now a critical priority. Monitoring and control mechanisms should be strengthened across all key water bodies of the delta, including irrigation canals, collector-drainage networks, and lake systems. Particular attention must be paid to stagnant or slow-flowing waters, where the risk of salinization is highest.

Water infrastructure and monitoring. A significant challenge remains the absence of, or non-compliance with, national technical standards (GOST) for hydrometric equipment used to measure water levels and discharge in canals and collector-drainage networks. It is necessary to restore the design cross-sections of canals and collectors and conduct regular monitoring of water levels and flow velocities to update discharge rating curves Q = f(h).

It is recommended that gauging stations be equipped with automated sensors capable of continuous, real-time data transmission. In parallel, the dispatch and operational control system should be modernized, alongside efforts to rebuild and strengthen the qualified technical personnel.

Institutional and human resource challenges. In 2025, nearly half of the staff of the Delta Administration of the Aral Sea Region was laid off, adversely affecting the operation and monitoring of water resources. More broadly, the sector continues to face a shortage of qualified specialists and insufficient financial resources.

While water delivery and infrastructure operation are managed by the Delta Administration, the lake systems fall under the jurisdiction of the Fisheries Committee of Karakalpakstan. Consequently, responsibility for the ecological condition of these water bodies remains unclear and poorly coordinated. At the same time, fisheries enterprises invest little to nothing in ecosystem conservation and restoration, focusing primarily on fish harvesting, which in some cases is conducted without adequate regulatory oversight.

Recommendation. An institutional review should be undertaken to establish a clear division of responsibilities and a framework for shared accountability among all relevant stakeholders. Such a framework should include mechanisms for sustainable financing and incentives for private-sector participation. One possible approach would be the introduction of a co-management

model through a 50/50 participation scheme under which fishing communities assume both commercial and environmental stewardship responsibilities.

Protection of natural areas. The effectiveness of conservation efforts in the Southern Aral Sea region is increasingly undermined by violations of the protection regimes governing protected natural areas, nature reserves, and wildlife sanctuaries. Consequently, the risks of wildfires, illegal hunting and fishing, and unauthorized land use are rising.

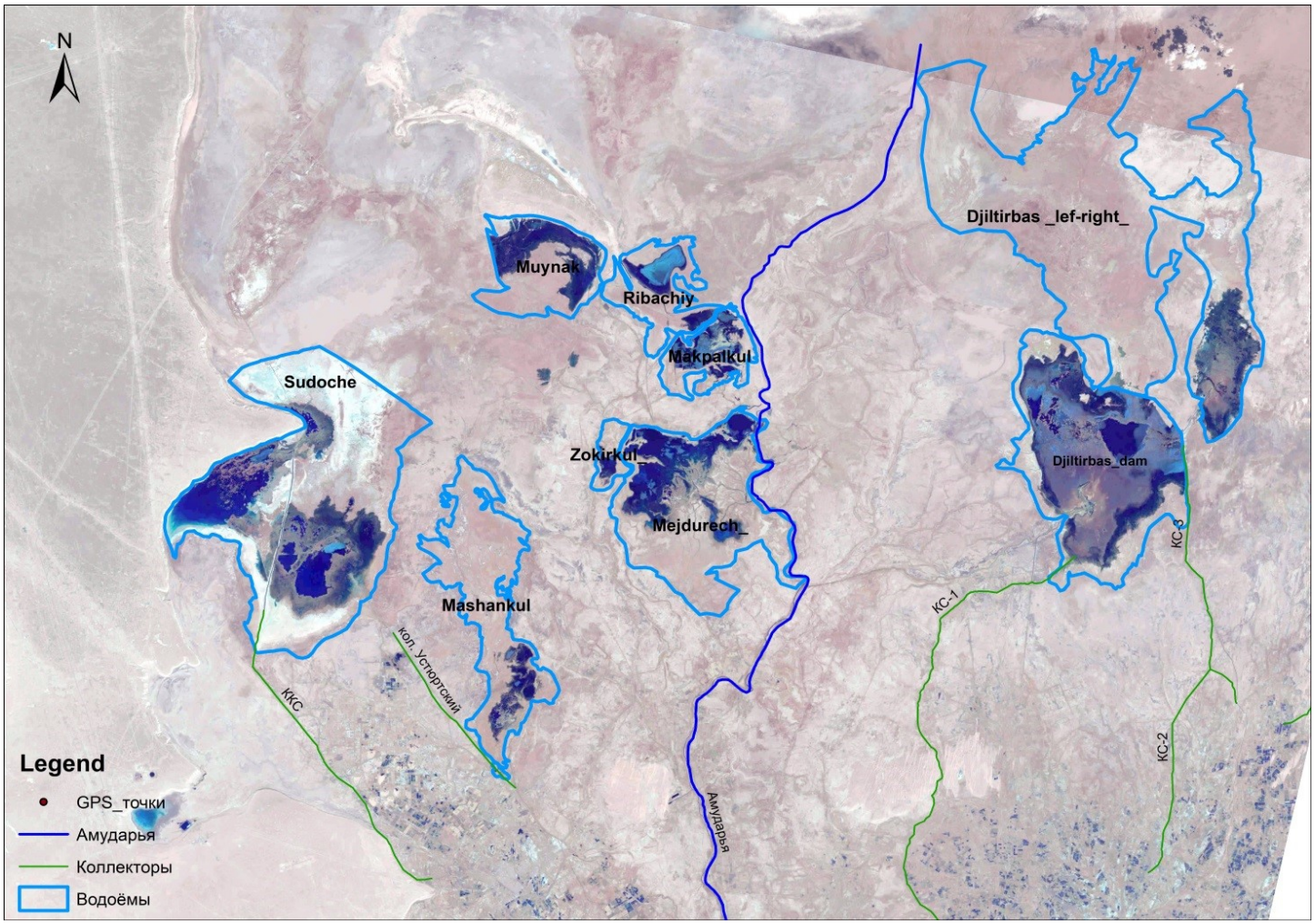
Recommendation. Strengthened enforcement of environmental legislation is required, specifically the provisions of the Laws of the Republic of Uzbekistan "On Forests" and "On Protected Natural Areas." In addition, greater emphasis should be placed on public awareness targeting local communities. Administrative enforcement measures should also be enhanced, including the imposition of penalties under Article 82 of the Code of Administrative Responsibility of the Republic of Uzbekistan for violations of protected-area regimes.

Note. Under Article 82 of the Code of Administrative Responsibility of the Republic of Uzbekistan, violations of the protection regime of state nature reserves, landscape reserves, natural parks, state natural monuments, and other protected areas are subject to administrative liability, including monetary fines imposed on both private individuals and public officials.

Alongside the negative trends observed in the condition of the region's water bodies, several positive developments warrant recognition. In recent years, with the active involvement of IFAS and its Nukus branch, substantial efforts have been undertaken to restore and modernize hydraulic infrastructure within the Amu Darya delta.

Figure 2

Map of water bodies in South Aral region



As part of these initiatives, riverbank protection works have been carried out along the most vulnerable sections of the Amu Darya River. Steel and reinforced concrete structures were installed to stabilize riverbanks. Similar interventions were implemented on the Kipchakdarya, Kazakhdarya, and Akdarya rivers, where active bank erosion threatened channel stability and the safety of adjacent areas.

In addition, a key gauging station (water outlet) at Rybachiy Bay was reconstructed, improving the regulation and monitoring of water deliveries while enhancing the management of the hydrological regime in the lower delta.

These measures contribute to strengthening the resilience of the region's water management system, improving hydrological monitoring, and mitigating the impacts of ongoing resource degradation.

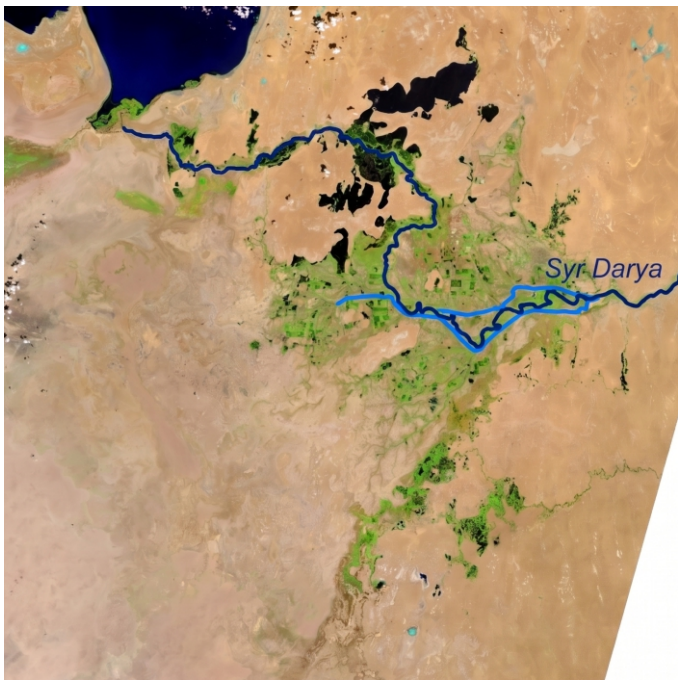
The ecological, hydrological, and field investigations conducted in the South Aral Sea region clearly demonstrate the need for a **regular, systematic, and interdisciplinary monitoring framework**. Under conditions of increasing water scarcity, rising salinity, and continued ecosystem degradation, a continuous oversight of key indicators across the water bodies of the South Aral Sea region is needed [9].

North part of the Aral Sea

A distinctive feature of the Syr Darya delta system is that, unlike the Amu Darya delta – which is regulated by a central control structure in the form of the Mezhdurechie Reservoir – it terminates in the North Aral Sea. Here, all downstream discharges from the river ultimately accumulate after passing through the delta. The Berg Strait Dam, together with the Kokaral Hydroscheme, was constructed in line with a design by Kazgiprovodkhoz between 2002 and 2005.

Figure 3

Satellite image of lake systems in the Syr Darya delta



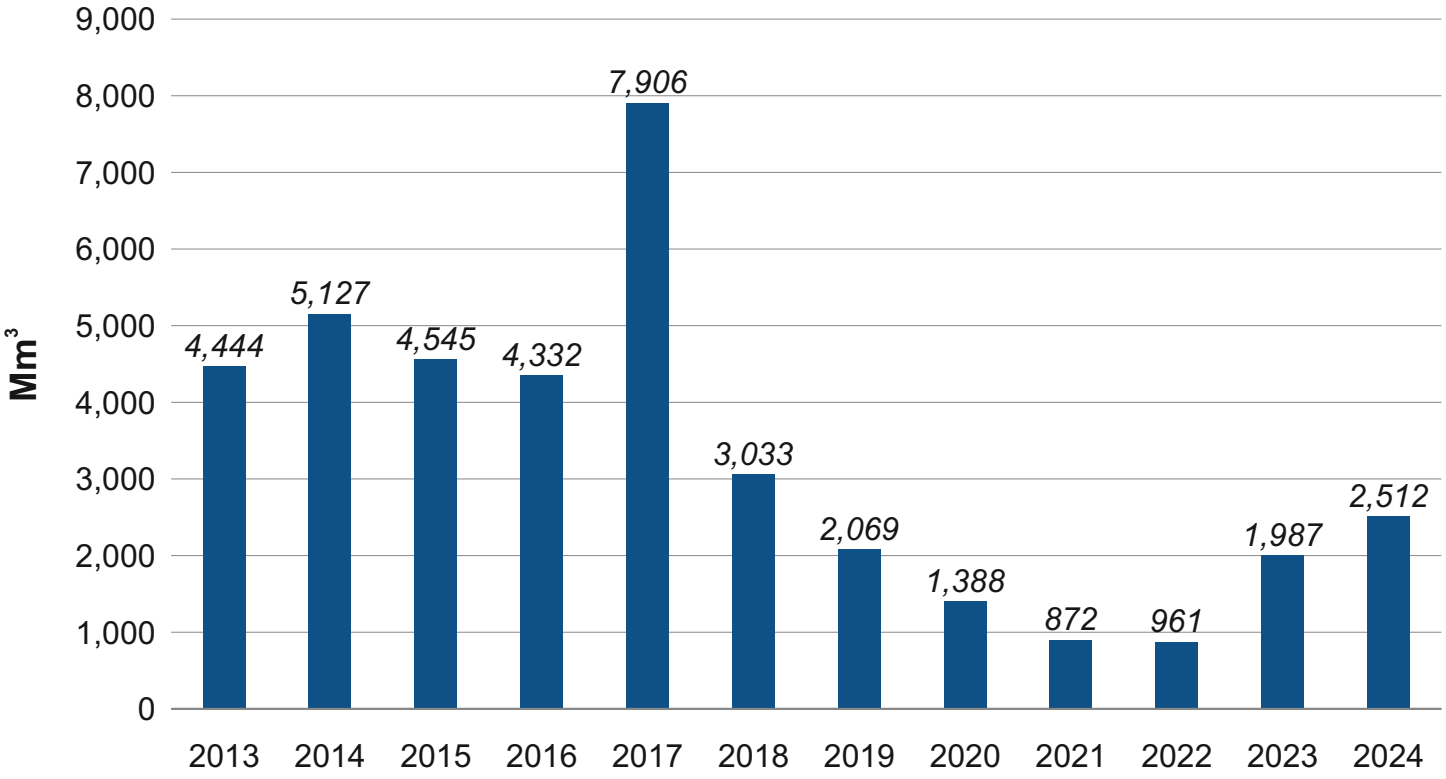
By the spring of 2006, the North Aral Sea had been refilled to its design water level. This achievement significantly slowed desertification in the Kazakh part of the Aral Sea region and created favorable conditions for the restoration and development of surrounding lake ecosystems. The deltaic system of the North Aral Sea comprises six distinct lake systems: Kuvandarya, Aksai, Kamystybas, Akshatau, Right-Bank Coastal, and Left-Bank Coastal systems. Each of these systems operates under its own hydrological regime, and all are currently undergoing further development (Figure 3) [10].

During 2013-2024, the average annual inflow to the Syr Darya delta amounted to 3.72 km³. In contrast, during 2013-2017, the average annual inflow was significantly higher, reaching 5.25 km³. Between 2021 and 2024, however, inflows plummeted, averaging a mere 1.56 km³ per year.

The project modeled the operation of the Kamystybas lake system and assessed the sustainability of its water supply under two primary scenarios: (i) construction of the Amanotkel hydraulic structure on the Syr Darya River, raising the minimum river level to 57.6 m; and (ii) construction of the Raim hydraulic structure, raising the minimum river level to 59.1 m. For both scenarios, alternative water delivery options were considered, including supply through the Zhasulan canal and supply exclusively through the Sovetzharma canal. Based on the modeling results, the option

Figure 4

Water inflow into the Northern Aral Sea and the Aral Sea region (Karatieren gauging station)



involving the construction of the Amanotkel dam was recommended as the preferred solution. The total annual water requirement for all lake systems is estimated at 2.7 billion m³ (2.7 km³).

Furthermore, future development of the delta is planned under the second phase of the World Bank project, with a total investment exceeding $120 million [11].

Water Deliveries to the Aral Sea and the Aral Sea Region

The principal document governing water allocation in the Amu Darya River basin remains a set of regulations developed during the Soviet period – specifically, Protocol No.566 of the Scientific and Technical Council of the USSR Ministry of Land Reclamation and Water Management (Minvodkhoz), dated 10 September 1987 and approved on 3 December 1987 by the Minister, N.F. Vasilyev (hereinafter "Protocol No.566"). This protocol approved the "Revised Scheme for the Comprehensive Use and Protection of Water Resources of the Amu Darya River," prepared by the Sredazgiprovodkhlopok Institute in 1984 on behalf of the USSR Ministry of Water Management.

These documents stipulate that interstate water management and allocation within the Amu Darya basin encompass the Amu Darya River itself and its principal tributaries – the Vakhsh, Panj, and Kafirnigan rivers (the so-called Small Amu Darya basin). The available water resources of the Amu Darya were estimated at 74.07 km³ per year, of which regulated water resources account for 62.10 km³ per year. In calculating available resources, deductions were made for withdrawals to Afghanistan (2.10 km³/ year), losses from rivers and reservoirs (3.48 km³/year), and sanitary releases along the Amu Darya (3.15 km³/year). The long-term average annual flow of the Amu Darya is estimated at 66.90 km³ per year. The interstate water-sharing arrangements established in this document continue to be recognized by all Central Asian states.

Since 1992, the approval of water withdrawal limits for both the non-growing and growing seasons – accounting for the protection of lower Amu Darya ecosystems, sanitary releases, and water deliveries to the Aral Sea – has been carried out by ICWC, while the implementation of

these allocations has been entrusted to the Basin Water Organizations (BWOs). Article 8 of the 1992 Almaty Agreement assigns the ICWC the responsibility to "develop and approve annual water-use limits for each republic and for the region as a whole."

In addition to national water withdrawal limits, water allocation in the Amu Darya Basin must account for the requirements of riverine and delta ecosystems. Protocol No.566 established a mandatory environmental (sanitary) flow for the Amu Darya River of 3.15 km³ per year, requiring its strict maintenance throughout the river system. The protocol further stipulated that water releases through the Takhiatash Hydroscheme must be maintained year-round at a minimum discharge of 100 m³/s [12].

Pursuant to Article 10 of the ICWC and its executive bodies were entrusted with implementing measures for the rational and efficient use of water resources. Their mandates include ensuring the passage of environmental and sanitary flows along main river and irrigation systems, delivering guaranteed volumes of water to river deltas and the Aral Sea to improve ecological conditions, and maintaining water quality in accordance with agreements reached among the participating states.

Protocol No.566 did not provide for differentiated environmental (sanitary) flow requirements based on annual water availability. However, the 1992 Almaty Agreement, which effectively formalized the continued application of the protocol's frameworks, introduced a requirement to "establish the volume of environmental flows for each specific year based on the hydrological conditions of interstate water sources" (Article 4). This mandate is inherently flexible and open to interpretation. Consequently, there was a need to clarify and operationalize the requirement by defining specific environmental flow volumes for years with different levels of water availability and ensuring that such volumes would be guaranteed in practice. At the request of ICWC, the SIC ICWC conducted a series of research studies to refine estimates of the water volumes required to sustain the ecological functions of the river and delta ecosystems, particularly the lake systems. The results of these studies led to adjustments of the figures originally established under Protocol No.566. In particular, the findings of a NATO-supported project recommended the following water allocations to maintain an ecologically sustainable profile for the Amu Darya delta and to support lake systems covering approximately 180,000 hectares: 8 km³ of water in high-flow years, 4.6 km³ in average-flow years, and a minimum of 3.1 km³ in low-flow years.

According to the latest assessments, the water requirements of the Syr Darya delta amount to 1,690 million m³ per year (53.5 m³/s) in an average-flow year, in addition to 3,000 million m³ per year (95 m³/s) required to maintain the North Aral Sea and 2,700 million m³ per year (85.6 m³/s) in high-flow years. Actual inflow from the Syr Darya during 2019-2022 amounted to 2,078, 1,641, 1,025, and 4,426 million m³, respectively.

The 2013 National Report on the State of the Environment in Uzbekistan estimated the water requirements of the Amu Darya delta at 8 km³ per year and recommended increasing inflows to at least 11 km³ per year by 2025 [13].

On 26 March 1993, a conference of the Heads of State of Central Asia was held in Kyzylorda to address the problems of the Aral Sea and its surrounding basin. The meeting resulted in the signing of the Agreement on Joint Actions for Addressing the Problems of the Aral Sea and the Aral Sea Region, Environmental Rehabilitation, and Socio-Economic Development of the Aral Region. Among its key objectives, the Agreement called for:

- guaranteeing water deliveries to the Aral Sea in volumes sufficient to maintain a stable water body at an ecologically acceptable level, thereby preserving the sea as a natural environmental feature;

- resuming efforts, on the basis of newly agreed and mutually acceptable conditions, to secure additional water resources for the Aral Sea basin.

At the meeting of the ICWC held on 8-9 July 1993 in Kyzylorda, a decision was adopted requiring all water users to strictly comply with established water withdrawal limits and approved volumes of water deliveries to river deltas and the Aral Sea. BWO Amu Darya and BWO Syr Darya were instructed to treat water deliveries to the Aral Sea and its surrounding region as a **separate category of water user** and to ensure that these deliveries were made in line with approved allocation limits.

Following the designation of the “Aral Sea and the Aral Sea Region” as an independent water user, the question repeatedly arose as to who would represent and, when necessary, defend its interests during interstate water allocation.

The first candidate for this role was the Republic of Karakalpakstan, the region most severely affected by the Aral Sea crisis. Representatives of Karakalpakstan were invited to participate in ICWC meetings between 1992 and 1997. However, from 1998 onward, this practice gradually ceased, and Karakalpakstan was no longer regularly represented at Commission meetings.

As part of efforts to address this issue, SIC ICWC carried out studies to refine estimates of water volumes required to maintain the ecological functions of river systems and their deltas, particularly lake ecosystems. The studies concluded that preserving the ecological stability of the Amu Darya delta and supporting its lake systems would require approximately 8 km³ of water in high-flow years, 4.6 km³ in average-flow years, and at least 3.5 km³ in low-flow years. For the Syr Darya delta, the corresponding ecological water requirements were estimated at 2.61 km³ in high-flow years, 1.7 km³ in average-flow years, and a minimum of 0.8 km³ in low-flow years to safeguard deltaic ecosystems [14].

Conclusions

The analysis of water allocation in the two river basins shows that, for the Amu Darya - the South Aral Sea region (including both the western and eastern sub-basins), the water allocation limits approved by the ICWC for the Aral Sea as the sixth water user, as well as the established environmental flow requirements, have not been met in recent years. The required volumes have not been delivered either to the sea itself or to the surrounding Aral Sea region. In contrast, the situation in the Northern Aral Sea and the Syr Darya delta indicates that the approved environmental flow allocations and water deliveries to the North Aral Sea have generally been implemented in line with established targets. The main exceptions were the years 2021 and 2022.

Recommendations

1. It is critical to ensure strict accounting of water used across different sectors by BWO Amu Darya and BWO Syr Darya, particularly with regard to water use by each republic.

2. Continuous monitoring and analysis of data on the Syr Darya River enable more effective resource management, support the stability of the Aral Sea basin ecosystem, and mitigate potential adverse impacts. In this context, SIC ICWC recommends resuming water releases to the Arnasay lake system (AALS) in the range of 1.0-1.5 km³ per year, a volume validated through water-balance calculations.

3. It is proposed to advance the joint initiative of JSC Uzsuvloyiha and SIC ICWC to divert the lake collector from the Khorezm province to the Amu Darya delta and the Aral Sea region. Implementation of this project would yield an additional inflow of at least 4.5 km³, helping to sustain the biological productivity of the delta’s lake systems.

4. A portion of the funds allocated by the Russian Federation for the preservation of the Amu Darya and Syr Darya rivers should be directed toward the project envisaged under Resolution No. 50 of the Cabinet of Ministers of the Republic of Uzbekistan. This project concerns the diversion of the Southern Collector through the delta lake systems to the western sub-basin of the Aral Sea.

5. It is recommended to coordinate with Kazakh counterparts a limited volume of water releases from the North Aral Sea to the western sub-basin of the Aral Sea, where stabilizing water levels is necessary to preserve the area as a natural landscape for tourism development.

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