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ARAL SEA AND THE ARAL REGION

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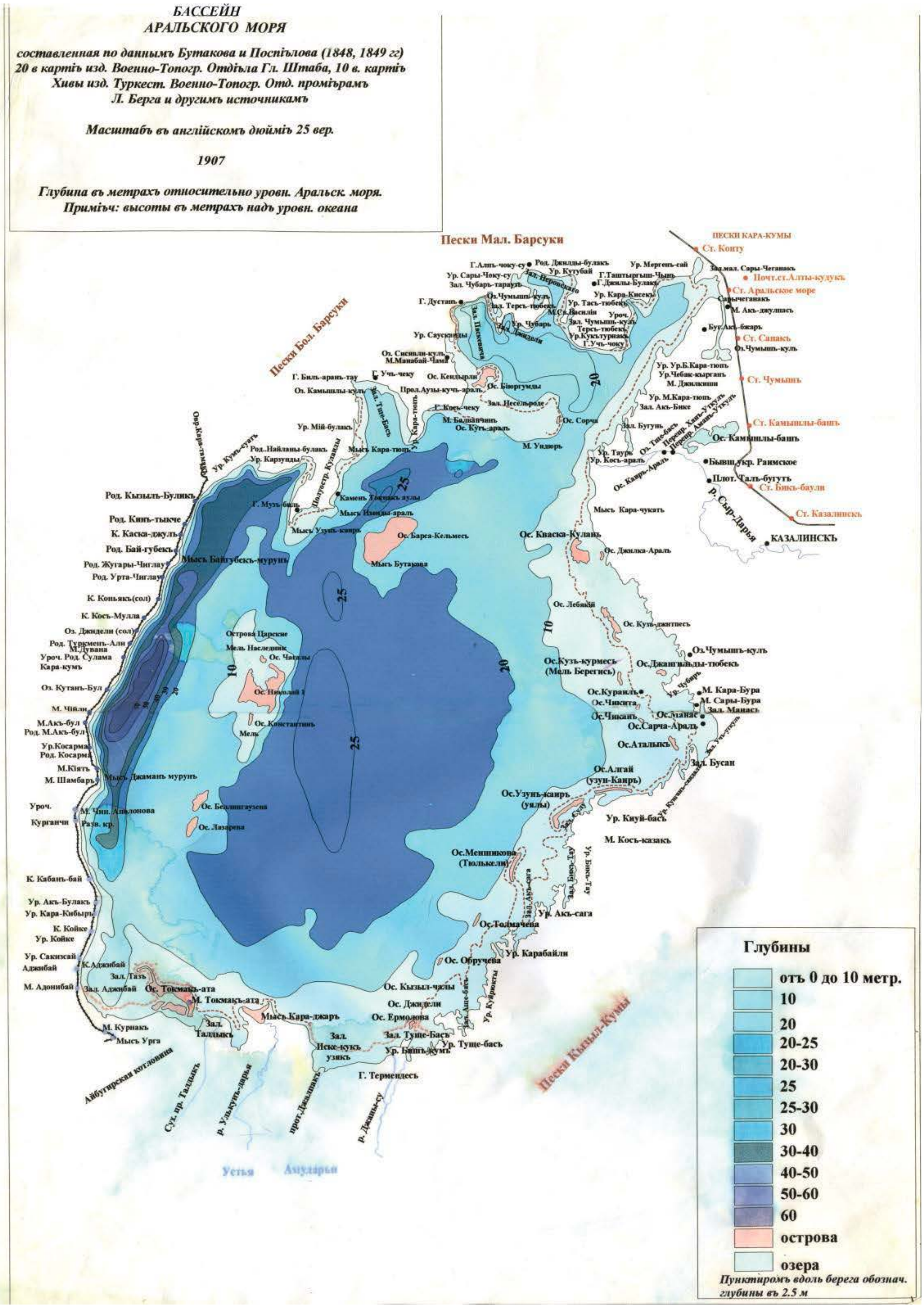
ARAL SEA AND THE ARAL REGION

Review of work undertaken by SIC ICWC
on monitoring and analysis of socio-economic
and environmental situation in the period from 1994 to 2018

Tashkent 2020



Map of the Aral Sea, 1907

(data of Butakov and Pospelov for 1848, 1849)

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Foreword to English edition

This publication was initiated by UNESCO to present to native English-readers. The.studies undertaken by SIC ICWC and its partners and they were earlier published in Russian in 2018.

The issue of this publication coincides with the mobilization of efforts initiated by the President of Uzbekistan Sh. M. Mirziyoyev for the transformation of the Aral Sea and Prearalye into an area of environmental innovations and technology as voiced at the Summit of the Heads of Central Asian State in the city of Turkmenbashi on August 24, 2018. As part of this mobilization, the Uzbek Government has started extensive work, including afforestation of the dried bed of the Aral Sea.

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INTRODUCTION

The water resources development in the Central Asian region made it impossible to restore the Aral Sea in its biologically active form on the former scale. At the earliest stage of independence, the Central Asian states recognized this fact in the two following documents:

- The concept of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan on the Solution of the Aral Sea and Prearalye Problem through the lens of Socio-Economic Development in the Region[2] (1992)
- Program of Concrete Measures for Environmental Improvement in the Aral Sea Basin in the next 3-5 years[3] (1994).

Additionally, the countries confirmed the importance of focusing their efforts on social and environmental protection in Prearalye. The governments of Kazakhstan and Uzbekistan adopted relevant measures and implemented projects that markedly helped to stabilize the situation in Prearalye and continue developing both living and natural capacities of this territory.

Meanwhile, the future of the Aral Sea itself is vague and cannot be omitted in the regional agenda. The need to create and maintain sustainable environmental conditions and avoid further deterioration was repeated by the then President of Uzbekistan Islam Karimov. However, yet little has been done in situ in this respect. The nature itself, as capable of self-preservation and adaptation to new conditions of still shrinking sea, improved the dire forecasts of million tons of salt and dust transport annually, by becoming gradually more stabilized and initiating natural plant growing processes in some zones. Here and there, the nature's survival capacity is supported by natural and artificial watering of the deltas of the Amu Darya and the Syr Darya, which was increased substantially as a result of constructed infrastructure compensating the widely varying natural surface water inflow. We achieved significant progress in stabilization of the Northern Aral Sea and the Syr Darya delta thanks to the "Regulation of the Syr Darya River and Maintenance of the Northern Aral Sea" Project[4]. The delta of the Syr Darya River also has seen certain improvements. The project "Integrated Water Resources Management for Wetlands Restoration in the Aral Sea Basin (South Prearalye)" (NATO Science for Peace Program, SFP 974357 grant) [1] provided for expansion of the wetland area to 230,000-250,000 ha against the previous area variations from 80,000 to 127,000 ha, whereas, according to RS-based observations, the wetland area extended to 347,200 ha in the delta in some years (2005). Field expeditions undertaken by SIC ICWC with the support of GTZ to the south and eastern parts of the former sea area have identified the intensive natural growing of saxaul, saltwort and various solonchak-based plants [2].

Given work describes several thematic research carried out by SIC ICWC jointly with international partners, mainly through donor support. In the recent several years the Aral Sea crisis was addressed by researchers from the Netherlands, Belgium, and Russia. This made it possible to compare the research results of different countries and incorporate in given review investigations of our colleagues from Russian research centers dealing with the Aral Sea (Zavialov, Aladin). In this context, we want to thank all partners and donors for this invaluable contribution.

At the same time, the research efforts on the Aral Sea are not regular and discrete and, to a larger extent, depend on donor's interest in the problem of the sea shrinkage. However, deeper, consistent and systems approach is needed to study and monitor the ongoing processes in once fourth largest inland lake in the world. The Aral Sea shrinkage is not a single case in the world

[2] http://www.cawater-info.net/library/rus/gov8.pdf

[3] http://www.cawater-info.net/library/rus/asbp1.pdf

[4] http://www.cawater-info.net/bk/water_law/pdf/kz-307-2002.pdf

practices. Our summary [3] demonstrates the sea's "companions in misfortune" like lakes Victoria and Chad in Africa, lakes Mono and Tulare, the Gulf of Mexico and the San Joaquin Delta in USA, several lakes in Iran, etc. Moreover, the countries in the region face multiple burning issues in socio-economic and geopolitical spheres and growing external destabilizing factors; that is why the problem of the Aral Sea and Prearalye is not among the national first-priority interests. On the other hand, donors also do not keen to fill this gap.

Nevertheless, it is necessary to have a clearly defined picture of the Aral Sea and Prearalye problems and of their future: What may happen under business as usual? What threats these problems pose to the nature and population? This way, we will have the possibility to develop proposals that will be feasible to implement, first of all, by Kazakhstan and Uzbekistan in order to ensure environmental stabilization and bioproductivity of the remaining Aral Sea and its natural environment. Large-scale expeditions and permanent in-situ observations are needed over the sea water area, more correctly of its three poorly linked parts, and the exposed seabed and river deltas. Undoubtedly, the research and permanent in-situ observations along with RS over the sea itself will attract their donors and we will be able to have systematic rather than fragmented data on the state of the sea. As we know, thorough monitoring is needed for serious patients so that to know how to treat them or, at least, reduce the suffering.

1. ARAL SEA AND ITS BASIN – HISTORICAL BACKGROUND

Apparently, substantial research in the world and the Soviet-period literature has been devoted to the Aral Sea chronology and phenomenon. Although none of Greek or Roman authors mentioned the Aral Sea, the Arab literature, ancient scholars of Khorezm and the holly Avesta refer to the Aral Sea (as Varakhsha in Avesta, Denghiz by Al-Biruni) in the context of Oxus (the Amu Darya) and Jaxartes (the Syr Darya). Rene Letolle and Monique Mainquet gave a very detailed description of bibliography on the Aral Sea [4]. In 1995, Dr. Marinus Boss also made a contribution to the synthesis of literature sources on the Aral Sea and its basin in his book "The Inter-relationship between Irrigation, Drainage, and the Environment in the Aral Sea Basin". Finally, in 1999 SIC ICWC published the detailed bibliography "Problems of the Aral Sea Basin" (UNDP), which listed more than 2000 literature sources.

Proceeding from available information, we generalized the present understanding of dynamics of the Aral Sea in the work "South Prearalye – New Perspectives" [1] and some quotations from this work are given below.

The hypothesis on the prehistorical period is based on geological surveys of Russian scientists in the late XIX and early XX. They confirmed that in the post-Pliocene period the Great Aral Sea flooded the part of the Kara Kum Desert located between the Usturt Plateau in the north, the mouths of the Murgab and Tedjen rivers in the south and the foothills of the Kopet Dagh Ridge in the west. In their opinion, the Unguz cliffs were the border of the former Karakum Bay on the eastern half of the Aral-Caspian Sea. This unified sea would have covered a wide strip of the present day Trans-Caspian area to the foothills of the Kopet Dagh Ridge, and was linked with the Karakum and Chilmetkum bays through the two sea straits Big Balkh and Small Balkh. At that time, the Aral part of this sea filled the whole Sarykamysh depression and formed the Pytnayk Bay that is now the Amu Darya delta and the Khiva oasis (this is also explains the origin of shor deposits near the Pytnayk). The Uzboy was the strait that linked both these water-filled areas, but obviously its present-day channel with its large gradients was formed during the gradual separation of the Caspian Sea from the Aral Sea and the resulting increasing difference in their respective water surface elevation. The process that saw the division of the united Aral-Caspian basin into separate parts – and its gradual reduction in size – continued during the next geological period and practically remained in progress until today. First, the watershed ridge between the Aral Sarykamysh depression and the Caspian Sea near Balla-Ishem arose on the Usturt Plateau, and then the Uzboy channel was gradually formed. The sequence of the drying-up of this territory is confirmed by transitional deposits, starting from the most recent deposits of Caspian mollusks (along the Uzboy channel in the sands of Chilmetkul and the south-eastern coast of the Caspian Sea) that were overlaid by unfixed sands with rare vegetation, up to the ancient formations in the Central Kara Kum Desert. These have eventially transformed into shors, takyrs and compacted sandy hillocks fixed by arboreous plants. Shors, the lowest sites on the seabed that were fed by artesian brackish waters, have preserved the shape of the ancient coastal lakes.

As to the geological age, the Aral Sea is young – its absolute age is estimated at 139±12 thousand years. In the Neogene period, strong tectonic movements within the Central Asia in the center of the Turan Plain formed three deep depressions – Aral, Khorezm and Sarykamysh. In the Early and Middle Pleistocene, these depressions developed under the subaerial conditions. At the same time, the foreriver of the Amu Darya – the pre-Amu Darya – flowed through the Kara Kum Desert westward towards the Caspian (Khvalyn) Sea. In the Late Pleistocene there was a shift in direction of the Amu Darya to the north and new flooding of the Aral Sarykamysh depression. Eventually, this has led to formation of the original Aral Sea about 70,000 years ago. That time, the river cut a canyon near Tuyamuyun and reached the Khorezm depression, where it formed a vast lake. 10-12 thousand years ago the Amu Darya (that time Jeyhun) turned westward and reached the Sarykamysh depression by transforming it into a lake. Nearly 4 thousand years ago the Amu Darya turned back to the north and flowed into the big Aral depression, which was already filled by the Syr Darya. That time, a broad rugged plain spread in place of the Aral depression and bordered the Usturt cliffs on the west, the Prearalye hills on the north, the Betpak Dala Desert and Karatau ridge on the east, and the Kara Kum and Kyzyl Kum deserts on the south. That territory accomodated the Aral Sea, which we saw in the XVIII and early XX centuries.

Figure 1.1 Redrawn Aral-Caspian Sea (based on GIS data by Roschenko) of the post-Pliocene period

During the Late Pleistocene, when the Amu Darya fed both the Caspian Sea and the Aral Sea through Sarykamysh, the Aral Sea did not reach a level more than +35 - +40 m. However, in the Holocene period of the earliest (ancient Aral) transgression the sea reached a level of +60 - +73 m BSL, followed by repeated falls and rise. The lowest level was recorded 1,500 years ago, when with the great Oks regression the sea level dropped to +25 - +27 m and the so-called "Oks swamp" was formed in the center of the Aral Sea on an area of 5,000 km^2. At present, our generation sees similar shallow body in place of the Eastern Aral Sea, which is periodically transformed into saline wetland during dry years.

Since ancient times, explorers and historians have attributed the transformation of the Aral and Caspian seas to the changes in the volumes of water in the rivers in their joint basin – changes that are in part the result of irrigation development. They noted the complete disappearance of Sarykamysh Lake at the end of the XVI century, when inflow of the Amu Darya River into the lake via the Kunya-Darya and Daudan and further onwards through the Uzboy channel had stopped. The Uzboy channel from the Caspian Sea to the watershed at Balli Item rose 40 m over a distance of more than 200 km. According to Obruchev, Sarykamysh Lake existed from the VII century BC until XVI century. Jenkinson, when travelling to Khiva in 1559, wrote about Sarykamysh Lake, which he took for the estuary of the Oxus River leading to the Caspian Sea. Obruchev was also guided by similar testimony of Abdulgazi-khan, Gaydula and other Khorezm chroniclers [5].

Based on geological and historical surveys, most researchers (Andrianov, Kes, Fedorov, Fedorovich, Maev, Rubanov and others) shared the conclusion, which was articulated by Aladin [6]: "*in prehistoric times, the salinity and level of the Aral Sea were subject to impacts of natural climatic factors*." This is why during the humid climatic phase, the Syr Darya and the Amu Darya rivers were abundant with water and the sea reached a maximum level of some 72-73 m +BSL (Baltic Sea Level). In contrast, during the arid climatic phase, both rivers became very shallow, and the Aral Sea level also dropped and salinity levels increased in Prearalye. In historical times, during the period of ancient Khorezm, the changes in the water level of the sea depended in some extent on climate changes but mainly on the irrigation activities in the basins of the two rivers. In the period of intensive development in the Aral Sea basin, the increase in land area under irrigation resulted in much more water being diverted from the rivers leading to a further lowering of the sea level. During adverse periods in the region (periods of wars, revolution, etc.), irrigated land area decreased and the rivers discharged more water again.

The Amu Darya and the Syr Darya have regularly changed direction and shifted location in the Central Asia throughout their history. They did often not reach the Aral Sea and, as a result, the sea dried up with desert areas forming on the dried out land. As water levels in the sea fell, salinity sharply increased, producing the salt depositions that have been found by geologists on the Aral Sea bed. The thick layers of sedimentary mirabilite found by Rubanov [7] are especially interesting. The shifting river deltas of the Amu Darya and Syr Darya have created a very peculiar terrain in the lower reaches, where depressions that were filled with marsh sediments alternated with significant desert sandy-loam deposits. These have shaped the delta and most of the river channel and anabranches of the Amu Darya.

Drawing on numerical historical sources and recent research, Table 1.1 shows the interaction between the rivers, the Aral Sea and the Uzboy channel, through which a part of the Amu Darya waters discharged into the Caspian Sea. In late Stone Age, about 20% of the Amu Darya water ran into the Caspian Sea through two linked lakes – Sarykamysh and Assake-Daudan and the Uzboy channel which created a unique but irregular connection between the Aral Sea and the Caspian Sea.

Today, it is more or less clear that the Aral Sea has had five or seven transgressions (according to recent investigations of botton deposits using carbon tracing methods), with the most strongest of them reaching the highest terraces (72-73 m +BSL) that apparently dated to the early Pliocene (Shitnikov) or to the Aktchagyl period (Fig.1.2). Based on various sources, the Aral Sea almost disappeared or its level dropped to the present state, at least, three times.

Table 1.1 Historical sources with information on the water systems in Central Asia

Period	Source	Status of the Aral Sea	Status of the Uzboy Channel	Level of the Caspian Sea with respect to that of the Aral Sea in 1990, m+BSL	Note
XV century BC	The Avesta	A dry area			Wetlands
V century BC	Herodotus	The sea exists	The Amu Darya through Uzboy into the Caspian Sea		
III century BC	Patroclus	The sea is filled up with water	A dry channel		The Amu Darya and Syr Darya flow into the Aral Sea
I century BC	Strabo	The Amu Darya and Syr Darya rivers flow into the Aral Sea, but the latter not completely	Amu Darya	+ 25	
891 AD	Al-Balhi	The sea exists	Along the Uzboy Channel to the Caspian Sea	+ 9.28	
X	Idrisi	The sea exists		- 4.2	
1211	Jiveni Murkhand	Almost dry	With a flow		Descendants of Genghis Khan diverted the Amu Darya aside
1320	Marino Sanuto	At mean level	There is a flow from the Uzboy Channel from Sarykamysh Lake into which the Amu Darya empties		The Small Aral Sea is identical to the small lake (Sarykamysh)
1375	Catalan Atlas	The sea exists	With a flow	+ 5.64	The Syr Darya flows into the Aral Sea and Amu Darya flows into Sarykamysh
	Sanuto	The sea exists	With a flow		
1400	Merashi	A low level			
1575	Abdul Ghazi	A high level	A dry channel		
1638	Olirey	A low level	With a flow	+ 5.34	The Amu Darya and Syr Darya flow into the Aral Sea
1680	Abdul Ghazi Baghadur	The sea exists			The Amu Darya empties into the Caspian Sea since 1220 and finally they were separated in 1575
1734	Kirilov	Not mentioned	They alternated	+ 4.03	
1826	Kolodkin	At high level	Not shown	+ 3.12	
1858	Ivanichev	At high level	A dried channel	+ 0.99	

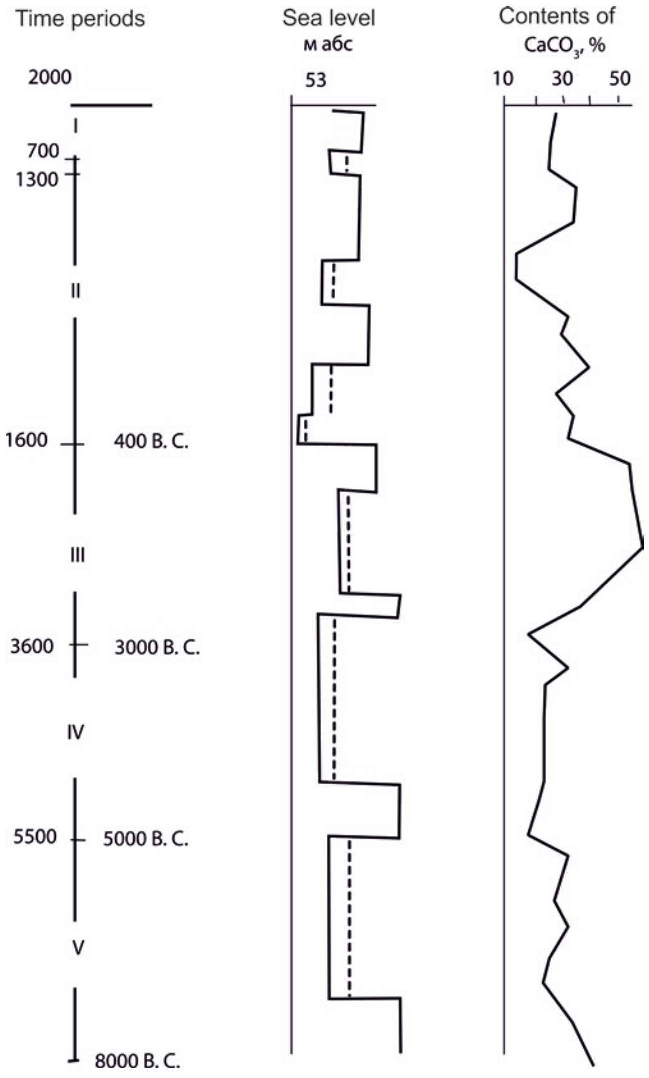


Figure 1.2 Hystorical evolution of the sea level and $CaCO_3$ concentration

The source of such strong flooding is not clear. This might be either as a consequence of melting the northern ice masses, as Kovda and Yegorov have supposed in their work “Salt accumulation patterns in the Aral-Caspian lowland” (AN SSSR, 1956) or due to discharge of the pre-Amu Darya, which is mentioned in the Avesta. Supposedly, this river, known as the Ariya in the Zoroastrianism, combined waters of all former tributaries of the Amu Darya, including the Zeravshan, Tedjen, Murghab but also the Syr Darya and the Chu prior to damming the Buam strait.

In this context, the results of revising the investigations described in Chalov et al. (1966) undertaken by Kes are of interest. The first stage of flooding the Aral depression began in the late Pliocene. That time, western plains in Central Asia were flooded at first by waters of the large Akchagyl Sea and then by the Apsheron Sea. Their eastern border was not identified, but fauna, terraces and beach ridges dated to this age were found in Sarykamysh and Assaka-Audan, in the Aral Sea depression and in some depressions of the Kyzyl Kum desert.

The modern period of the Aral Sea began in the 1st millennium B.C., when the Amu Darya having formed the pre-Sarykamysh and Akchadarya deltas flowed towards the Aral Sea depression and together with the Syr Darya flowing through the Janadarya and Kuvandarya channels, started filling the depression and formed the modern sea. At the beginning of the 19th century, the level in the Aral Sea was low. In 1845 and after the 1860s, some increases in the water level were observed.

In the early 1880s, the water level became unusually low. Researchers of that time have come to the conclusion on progressive depletion of water resources in Central Asia.

However, since the 1880s the level in the Aral Sea began rising, at first rather slowly, then more quickly till 1906. The water level stopped changing in 1907, and then it increased again in 1908 and lowered in 1909. The upward trend in the water level was registered once again in the period since 1910 until 1912, and then the water level slightly changed till 1917. The level began dropping since the very arid year 1917 in Central Asia. By 1921, the level of the sea lowered by 1.3 m as compared to 1915. However, the observations in 1924 showed a new increase in water (a little less than half a meter).

During the sustainable period, the sea width at the latitude 45^o was 265 km and the shoreline exceeded 4,430 km. Before drop of the sea level, in the 60s of the twentieth century, the water area of the Aral Sea constituted 64,790 km^2; the maximum depth was 69 m, and the water volume was about 1,056 km^3.

That time, the aquatic area of the Aral Sea encompassed approx. 1,100 islands of continental origin. The total area of the islands was 2,235 km^2. The largest islands were:

- Kokaral - 311 km^2
- Barsa-Kelmes - 170 km^2
- Vozrozhdeniya - 169 km^2
- Small coastal islands submerged periodically – 1,585 km^2.

The Akpetki (Karabaili) archipelago was located in the south. More than 50 islands of the archipelago were the sand waves of the Kyzyl Kum. Small coastal islands together with bays, capes, gloe lakes and large islands shaped specific pattern of the coast that contributed to stabilization of chemical regime in the sea.

Since the end of the nineteenth century, first the tsarists Russia and later the Soviet government have used intensively the Aral Sea Basin in the development of irrigation. Until 1960, the increased diversions of water for irrigation have been compensated by large return flow thanks to large-scale construction of collector and drainage networks in the old and new irrigation territory. The inter-relationships between rivers and the sea can be seen in Table 1.2.

Table 1.2 Mean annual water balance values of the Aral Sea for different periods (km^3)

Period, years	**Inflow**		**Outflow (evaporation)**	**Water balance**	**Actual increment in volume**	**Overall balance**
	river runoff	**precipitation**				
1911-1960	56.0	9.1	68.76	-3.66	0.06	-3.72
1961-1980	30.0	7.1	61.59	-24.49	-23.54	-0.95
1981-1990	3.45	7.1	42.53	-31.98	-35.94	3.97
1991-1999	19.30	5.8	34.68	-9.58	-11.60	2.02
2000-2014	13.10	2.6	19.26	-3.56	-3.58	0.02

2. CURRENT STATUS OF THE ARAL SEA

The modern period of the Aral Sea, since 1961, may be described as the period of active anthropogenic impacts. The drastic increase of irretrievable river water diversions (which amounted to 70-75 km^3/year in recent years), exhaustion of compensating capacities of the rivers and natural aridity in 1960 to 1980 (92 %) have resulted in disequilibrium of water and salt balances. Typically, evaporation was well higher than the sum of all inflow constituents[5] in the period from 1961 to 2002. The river water inflow into the sea decreased, on average, to 30.0 km^3/year in 1965; in 1971-1980, the inflow averaged 16.7 km^3/year only or 30 % of the mean annual runoff, and over the period since 1980 till 1999 it made up 3.5 to 7.6 km^3/year or 6 to 13 % of the mean annual runoff. In some of dry years, runoff of the Amu Darya and Syr Darya rivers actually did not reach the sea.

As a result, since 1961, the water level of the sea has begun dropping steadily. The sea level drop, in comparison with the average annual value (prior to 1961), totaled 12.5 m by the beginning of 1985. The average annual rate of level lowering was about 0.5 m, reaching 0.6-0.8 m/year in dry years. The annual water level fluctuation patterns of the sea changed as well. At present, the sea level rise is practically not observed annually; at best, the level does not change in winter, and an abrupt drop takes place in summer.

The gradual lowering of water level in the sea has considerably exceeded predicted rates. In fact, the water level has dropped below 28 m +BSL instead of 38.5 m predicted by 2000. Similarly, the seawater salinity has increased at higher rates.

The lowering of the water level and the growth of seawater salinity resulted in increase in the amplitude of annual temperature over water column and in shift in phases of the temperature regime. Modification of winter thermal conditions is the most important factor for the biological regime of the sea. Further lowering of a freezing point and modification of the autumn-winter convection mixing process under transition from brackish to high saline waters cause intensive cooling of all sea water mass to very low temperatures (-1.5 to - 2.0^{o}C).

The extremely low influx of biogenic substances into the sea results in their small concentrations in the seawater, poor photosynthetic processes in the sea, and low biological productivity of the sea. Degradation of the sea's oxygen regimen in summer through decreased photosynthetic production and increased oxygen demand leads to formation of oxygen deficiency zones and to kill phenomena.

Further increase in salinity causes both reduction of species of phyto- and zooplankton, phyto- and zoo benthos, and respective lowering of their biomass, with the consequent degradation of food resources for aquatic life. Thus, endemic fauna cannot exist anymore in the increasingly saline water of the Aral Sea.

Quantitative assessment of anthropogenic factors affecting the current water regime of the Aral Sea was made by means of calculation of reconstructed values of sea levels and salinity for the period from 1961 to 1980 using the reconstructed conditional-natural inflow into the sea. According to these calculations, more than 70 percent of the current sea level lowering and of salinity increase are caused by the anthropogenic factors, while the rest of these changes refers to climatic factors (natural aridity).

The major consequence of the Aral Sea shrinkage, apart from the decrease of its water volume and area, increase in water salinity and modification of salinity pattern is the formation of a vast saline desert on an area of almost 5 million ha on the place of the exposed seabed. As a result,

[5] It was in 1998 only, when the inflow of 29.8 km^3 exceeded evaporation of 27.49 km^3

three bitter-saline lakes and the gigantic saline desert located at the interface between two sand deserts have replaced the unique freshwater water body.

After separation of the Small (Northern) Aral Sea from the Large (Southern) Aral Sea, their regimes started developing according to different scenarios. Since the inflow from the Syr Darya was higher than that from the Amu Darya, the Small Aral Sea level started rising and water salinity decreasing. A break in the temporary dam of the Small Aral Sea caused the water level to lower; however, previous filling has proved the correctness of the decision to create the separate Small Aral Sea at the elevations of 41 to 42.5 m + BSL. The engineering project of a dam, with a regulated spillway in the Berg's Strait, has already created a sustainable ecological profile of this water body and its environment.

Thus, the Aral Sea has transformed from being an integral water body in the past into a series of separate water bodies, each with its own water-salt balance and own future, depending on policies to be selected by five riparian countries.

The detailed dynamics of water level, area and volume of the Aral Sea is shown in Table 2.1 and Figures 2.1-2.3. This data shows that from 1960 to 1970 the water level lowered by 10 cm a year on average; however, since 1971 to 1985, the level decreased within 67 cm a year. When the water level reached 42 m +BSL, the original sea has separated into 2 water bodies – Large Aral Sea and Small Aral Sea. Next 20 years, the water level lowering in the Large Aral Sea changed slightly to 50 cm. That time, through higher discharge from the Syr Darya, the Small Aral Sea had stable variations between 42.5 and 36 m +BSL and eventually stabilized at 42.5–43 m in 2006 because of the dam built in the Berg's Strait. Same year, the Large Aral Sea also separated into two water bodies – the deep Western body and shallow Eastern body, with the Western sea slowly lowering from 29 m +BSL to 26 m +BSL and the Eastern sea stabilizing within 28-29 m +BSL. Consequently, the water surface area of the Aral Sea, which previously covered 68,900 km^2, has shrunk 10 times by present and was divided among the three water bodies as follows: Western Sea - 3,380 km^2, Eastern Sea 1,710 km^2, and Small Sea –3,100 km^2. The volume of the Aral Sea decreased accordingly 11.2 times from 1,083 km^3 in dry 2014.

Tables 2.3 and 2.4 on inflow to the Large and Small Aral Sea show clearly that the current regime of the sea fully depends on inflow from the Amu Darya and collectors to Eastern and Western bodies and flow from the Syr Darya into the Small Aral Sea. Additionally, the Small Aral Sea is stable, the Western body gradually shrinks but keeps its depth at more than 20 m, and shallow Eastern body fully depends on inflow to the Amu Darya delta and varies between 1 and 17 billion m^3, with the difference in water level of almost 3 meters. According to hydrological regime, the Small Aral Sea has fully fresh waters suitable for freshwater fish, while Western and Eastern bodies are heavily saline, with the water salinity ranging from 130 to 350 g/l. It is also important that up to 2008, a natural hydraulic channel have existed between Western and Eastern Aral Sea, about 7 m deep and at elevation of 26.5 m. This channel was a product of intensive cross-flow between Western and Eastern bodies and bottom sediment erosion [8].

Given the lack of regular observations over discharge into the Large Aral Sea from the Syr Darya basin, we can rely on RS-based data only. According to this data, since 2001, no water has been discharged from the basin. In 2010, there was a discharge of water downstream the dam at the Bergh's Strait, but this volume was fully absorbed by a depression on the northern line of the former sea.

Table 2.1. Dynamics of water level, surface area and volume of the Large Aral Sea

Water level, m +BSL	
Year	**Aral Sea**
1960	53.4
1961	53.29
1962	52.97
1963	52.61
1964	52.49
1965	52.3
1970	51.43
1971	51.06
1972	50.54
1973	50.22
1974	49.85
1975	49.01
1980	45.75
1981	45.18
1982	44.39
1983	43.55
1984	42.75
1985	41.94

Water surface area, thousand km^2	
Year	**Aral Sea**
1960	68.9
1961	68.5
1962	65.9
1963	64.3
1964	64.8
1965	62.38
1970	58.92
1971	57.73
1972	56.85
1973	56.17
1974	56.01
1975	54.67
1980	49.21
1981	48.63
1982	47.13
1983	46.07
1984	44.92
1985	43.08

Water volume, billion m^3	
Year	**Aral Sea**
1960	1083
1961	1079
1962	1060
1963	1038
1964	1030
1965	972.47
1970	941.23
1971	902.43
1972	875.12
1973	845.47
1974	844.46
1975	802.74
1980	631.81
1981	625.78
1982	578.65
1983	532.58
1984	487.66
1985	444.58

Year	Large Aral Sea	Small Aral Sea
1986	41.02	40.9
1987	40.19	40.8
1988	39.67	40.5
1989	39.1	40.2
1990	38.24	40.5
1991	37.66	40.4

Year	Large Aral Sea	Small Aral Sea
1986	38.56	2.83
1987	37.13	2.81
1988	36.18	2.75
1989	35.3	2.71
1990	33.67	2.75
1991	32.02	2.73

Year	Large Aral Sea	Small Aral Sea
1986	380.63	22.47
1987	343.17	22.39
1988	312.65	21.84
1989	306.92	20.28
1990	280.44	21.84
1991	257.16	20.92

1992	37.2	40.2
1993	36.95	39.37
1994	36.9	40.1
1995	36.5	40.5
1996	35.48	40.5
1997	34.8	41.2
1998	34.21	42.5
1999	33.98	36.8
2000	33.5	39.8
2001	32.4	39.2
2002	32	39.3
2003	31.5	40
2004	31.09	40.8
2005	30.7	41
2006	30.4	41.8

Year	Western body	Eastern body	Small Aral Sea
2007	29.3	30.4	42.5
2008	28.7	28.9	42.5
2009	28.0	28.4	42.5
2010	27.8	29.4	43.0
2011	28.0	27.8	42.5
2012	27.0	27.2	42.7
2013	27.0	27.1	43.0
2014	26.0	27.0	43.0
2015	27.1	28.0	41.9
2016	26.5	26.5	41.8
2017	25.0	27.6	42.1
2018	24.9	26.5	41.7

1992	31.83	2.71
1993	31.42	2.57
1994	31.31	2.69
1995	30.04	2.75
1996	28.54	2.75
1997	26.91	2.91
1998	25.75	3.24
1999	24.12	2.09
2000	22.93	2.62
2001	21	2.55
2002	18.7	2.58
2003	17.3	2.65
2004	16.4	2.81
2005	15.77	2.86
2006	13.47	2.99

Year	Western body	Eastern body	Small Aral Sea
2007	4.45	7.03	3.28
2008	4.14	4.11	3.27
2009	3.96	2.78	3.29
2010	3.87	4.41	3.41
2011	3.87	2.12	3.27
2012	3.69	2.15	3.38
2013	3.67	1.51	3.42
2014	3.27	0.96	3.43
2015	3.01	3.13	3.07
2016	2.92	1.25	3.05
2017	2.71	2.51	3.13
2018	2.68	1.28	3.03

1992	240.17	20.28
1993	231.7	18.43
1994	229.87	20.01
1995	217.25	21.84
1996	195.63	21.84
1997	173.44	22.67
1998	168.43	27.03
1999	147.62	12.03
2000	139.53	19.26
2001	131.16	17.97
2002	110.84	18.44
2003	97.23	19.77
2004	93.46	22.39
2005	89.79	22.52
2006	81.35	24.01

Year	Western body	Eastern body	Small Aral Sea
2007	57.22	16.29	26.33
2008	55.41	7.81	25.28
2009	53.14	5.67	26.27
2010	52.50	10.30	27.35
2011	53.14	3.54	25.82
2012	50.00	1.91	25.70
2013	50.00	1.68	24.43
2014	46.95	1.47	24.71
2015	50.26	4.30	25.61
2016	48.45	0.64	25.42
2017	44.11	2.95	26.45
2018	43.59	0.68	25.04

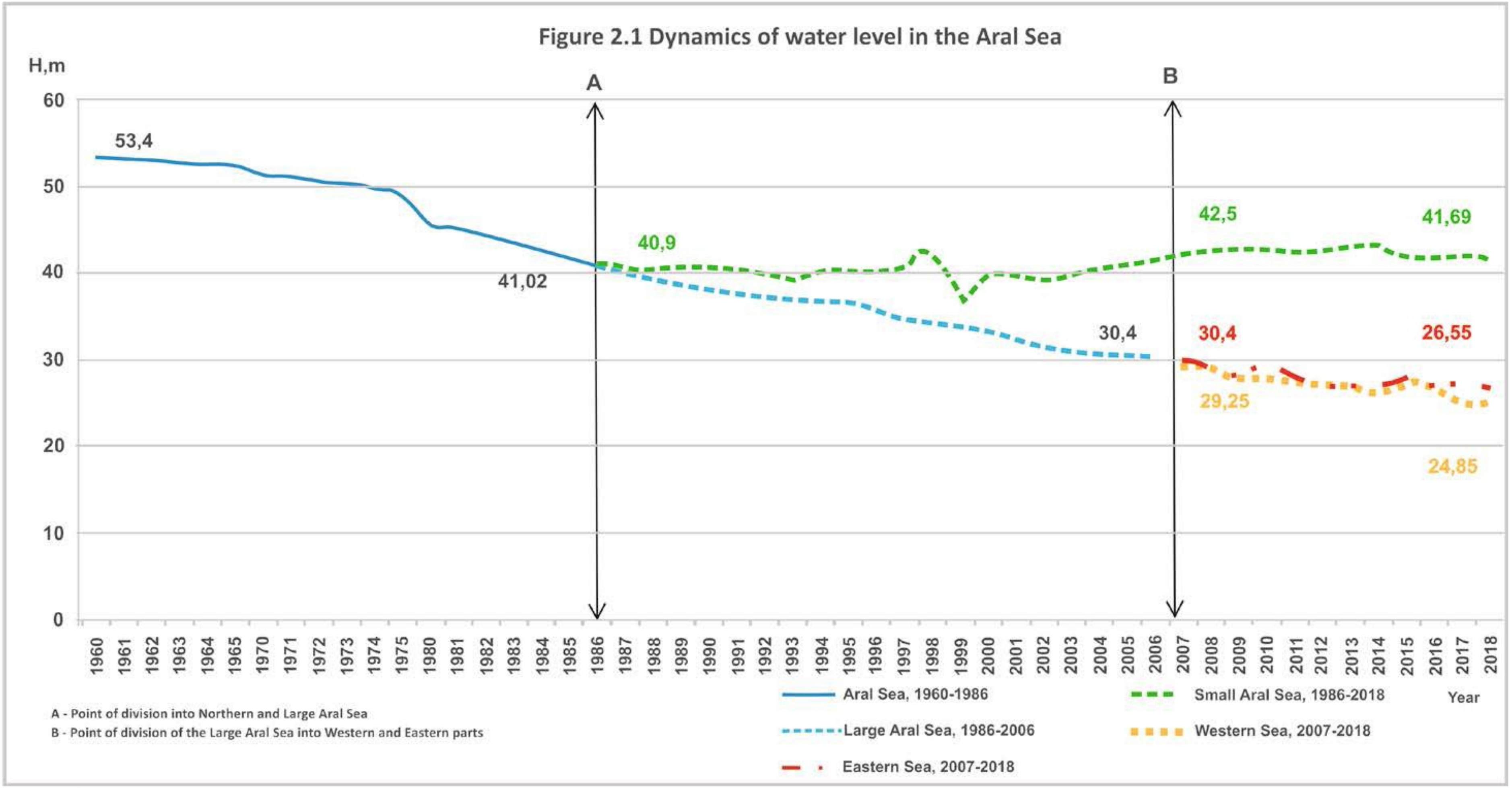


Figure 2.1 Dynamics of water level in the Aral Sea

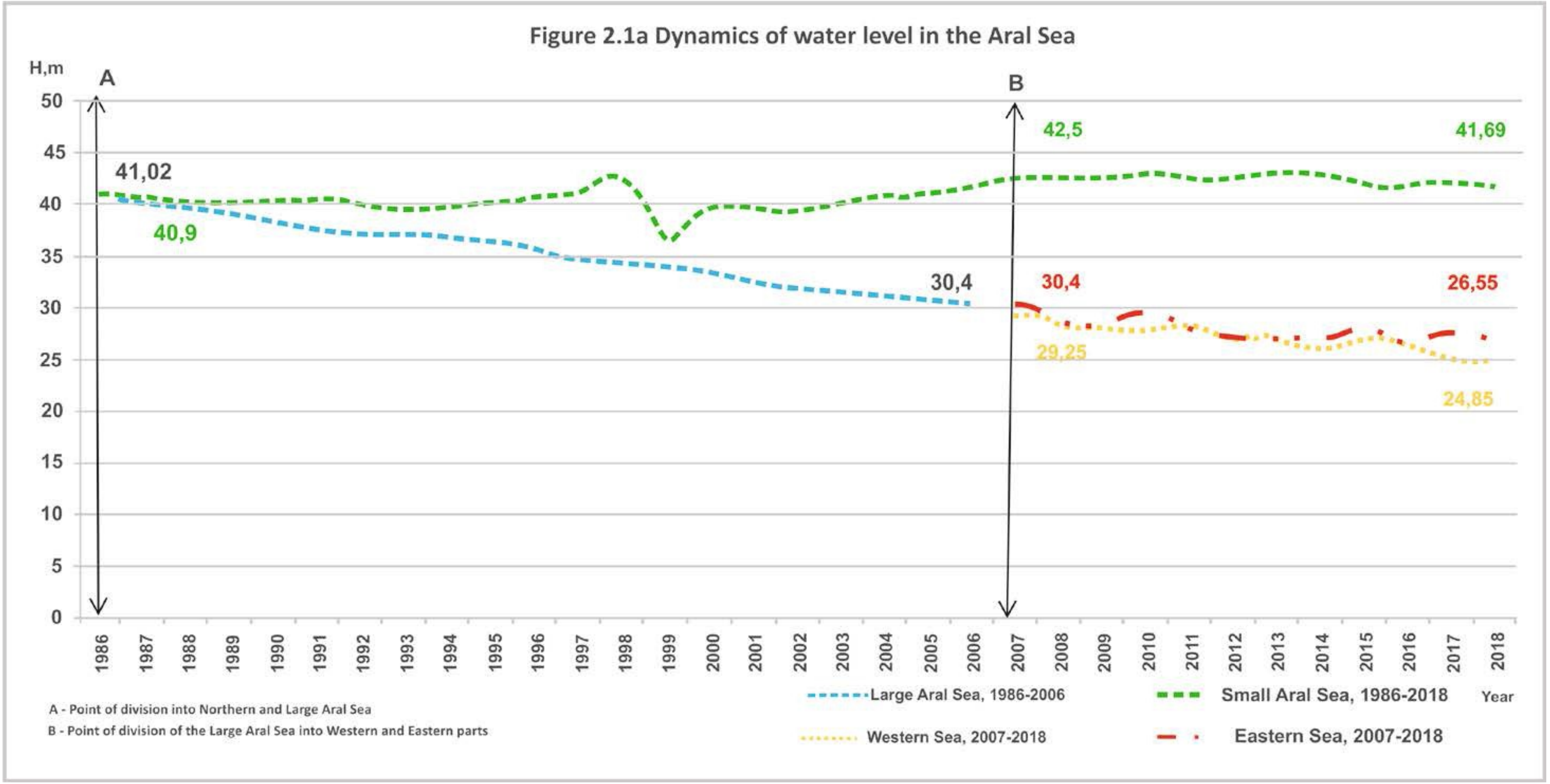


Figure 2.1a Dynamics of water level in the Aral Sea

Table 2.1. Dynamics of water level, surface area and volume of the Large Aral Sea

Water level, m +BSL	
Year	Aral Sea
1960	53.4
1961	53.29
1962	52.97
1963	52.61
1964	52.49
1965	52.3
1970	51.43
1971	51.06
1972	50.54
1973	50.22
1974	49.85
1975	49.01
1980	45.75
1981	45.18
1982	44.39
1983	43.55
1984	42.75
1985	41.94

Year	Large Aral Sea	Small Aral Sea
1986	41.02	40.9
1987	40.19	40.8
1988	39.67	40.5
1989	39.1	40.2
1990	38.24	40.5
1991	37.66	40.4

Water surface area, thousand km^2	
Year	Aral Sea
1960	68.9
1961	68.5
1962	65.9
1963	64.3
1964	64.8
1965	62.38
1970	58.92
1971	57.73
1972	56.85
1973	56.17
1974	56.01
1975	54.67
1980	49.21
1981	48.63
1982	47.13
1983	46.07
1984	44.92
1985	43.08

Year	Large Aral Sea	Small Aral Sea
1986	38.56	2.83
1987	37.13	2.81
1988	36.18	2.75
1989	35.3	2.71
1990	33.67	2.75
1991	32.02	2.73

Water volume, billion m^3	
Year	Aral Sea
1960	1083
1961	1079
1962	1060
1963	1038
1964	1030
1965	972.47
1970	941.23
1971	902.43
1972	875.12
1973	845.47
1974	844.46
1975	802.74
1980	631.81
1981	625.78
1982	578.65
1983	532.58
1984	487.66
1985	444.58

Year	Large Aral Sea	Small Aral Sea
1986	380.63	22.47
1987	343.17	22.39
1988	312.65	21.84
1989	306.92	20.28
1990	280.44	21.84
1991	257.16	20.92

1992	37.2	40.2
1993	36.95	39.37
1994	36.9	40.1
1995	36.5	40.5
1996	35.48	40.5
1997	34.8	41.2
1998	34.21	42.5
1999	33.98	36.8
2000	33.5	39.8
2001	32.4	39.2
2002	32	39.3
2003	31.5	40
2004	31.09	40.8
2005	30.7	41
2006	30.4	41.8

Year	Western body	Eastern body	Small Aral Sea
2007	29.3	30.4	42.5
2008	28.7	28.9	42.5
2009	28.0	28.4	42.5
2010	27.8	29.4	43.0
2011	28.0	27.8	42.5
2012	27.0	27.2	42.7
2013	27.0	27.1	43.0
2014	26.0	27.0	43.0
2015	27.1	28.0	41.9
2016	26.5	26.5	41.8
2017	25.0	27.6	42.1
2018	24.9	26.5	41.7

1992	31.83	2.71
1993	31.42	2.57
1994	31.31	2.69
1995	30.04	2.75
1996	28.54	2.75
1997	26.91	2.91
1998	25.75	3.24
1999	24.12	2.09
2000	22.93	2.62
2001	21	2.55
2002	18.7	2.58
2003	17.3	2.65
2004	16.4	2.81
2005	15.77	2.86
2006	13.47	2.99

Year	Western body	Eastern body	Small Aral Sea
2007	4.45	7.03	3.28
2008	4.14	4.11	3.27
2009	3.96	2.78	3.29
2010	3.87	4.41	3.41
2011	3.87	2.12	3.27
2012	3.69	2.15	3.38
2013	3.67	1.51	3.42
2014	3.27	0.96	3.43
2015	3.01	3.13	3.07
2016	2.92	1.25	3.05
2017	2.71	2.51	3.13
2018	2.68	1.28	3.03

1992	240.17	20.28
1993	231.7	18.43
1994	229.87	20.01
1995	217.25	21.84
1996	195.63	21.84
1997	173.44	22.67
1998	168.43	27.03
1999	147.62	12.03
2000	139.53	19.26
2001	131.16	17.97
2002	110.84	18.44
2003	97.23	19.77
2004	93.46	22.39
2005	89.79	22.52
2006	81.35	24.01

Year	Western body	Eastern body	Small Aral Sea
2007	57.22	16.29	26.33
2008	55.41	7.81	25.28
2009	53.14	5.67	26.27
2010	52.50	10.30	27.35
2011	53.14	3.54	25.82
2012	50.00	1.91	25.70
2013	50.00	1.68	24.43
2014	46.95	1.47	24.71
2015	50.26	4.30	25.61
2016	48.45	0.64	25.42
2017	44.11	2.95	26.45
2018	43.59	0.68	25.04

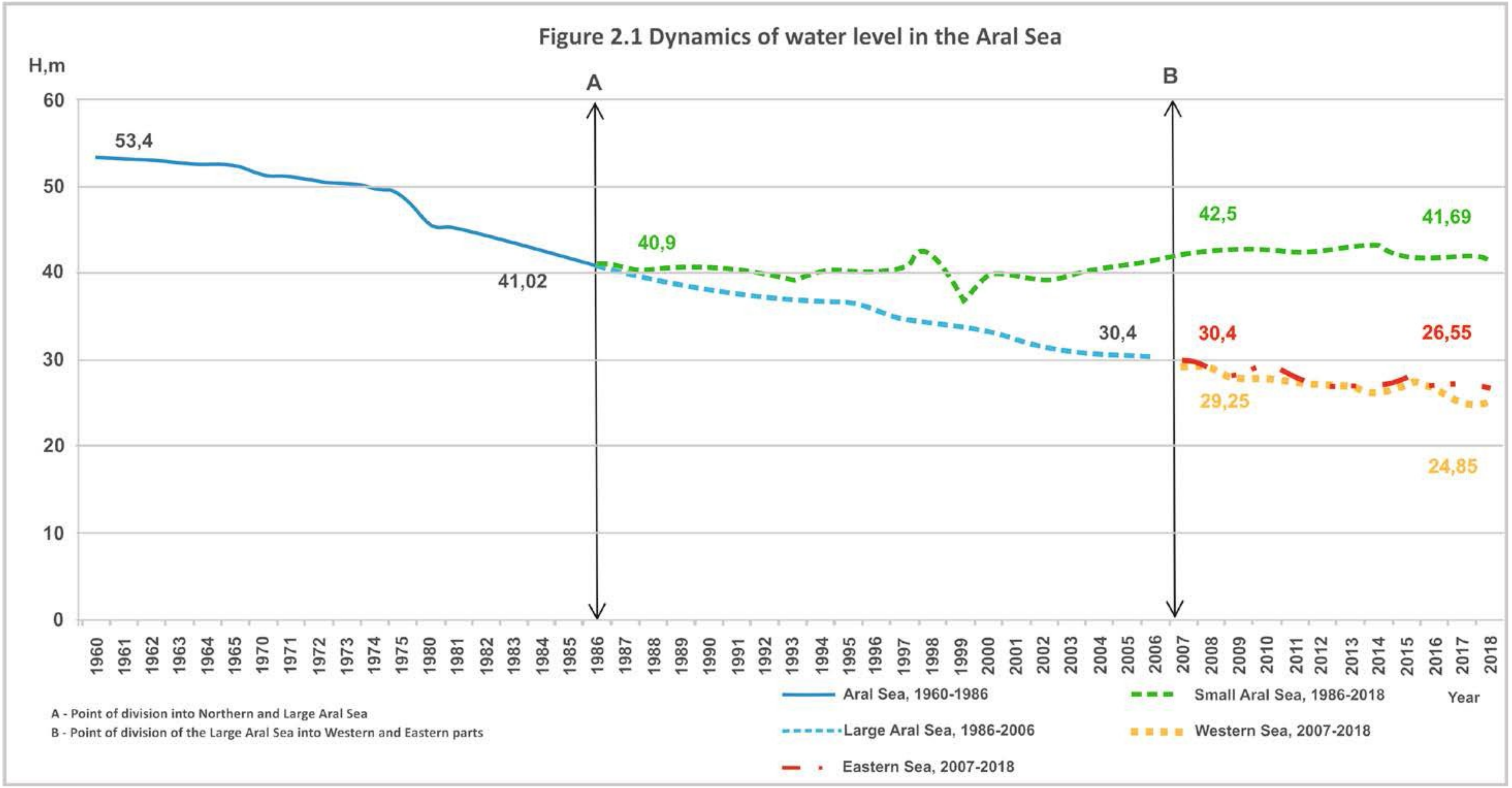


Figure 2.1 Dynamics of water level in the Aral Sea

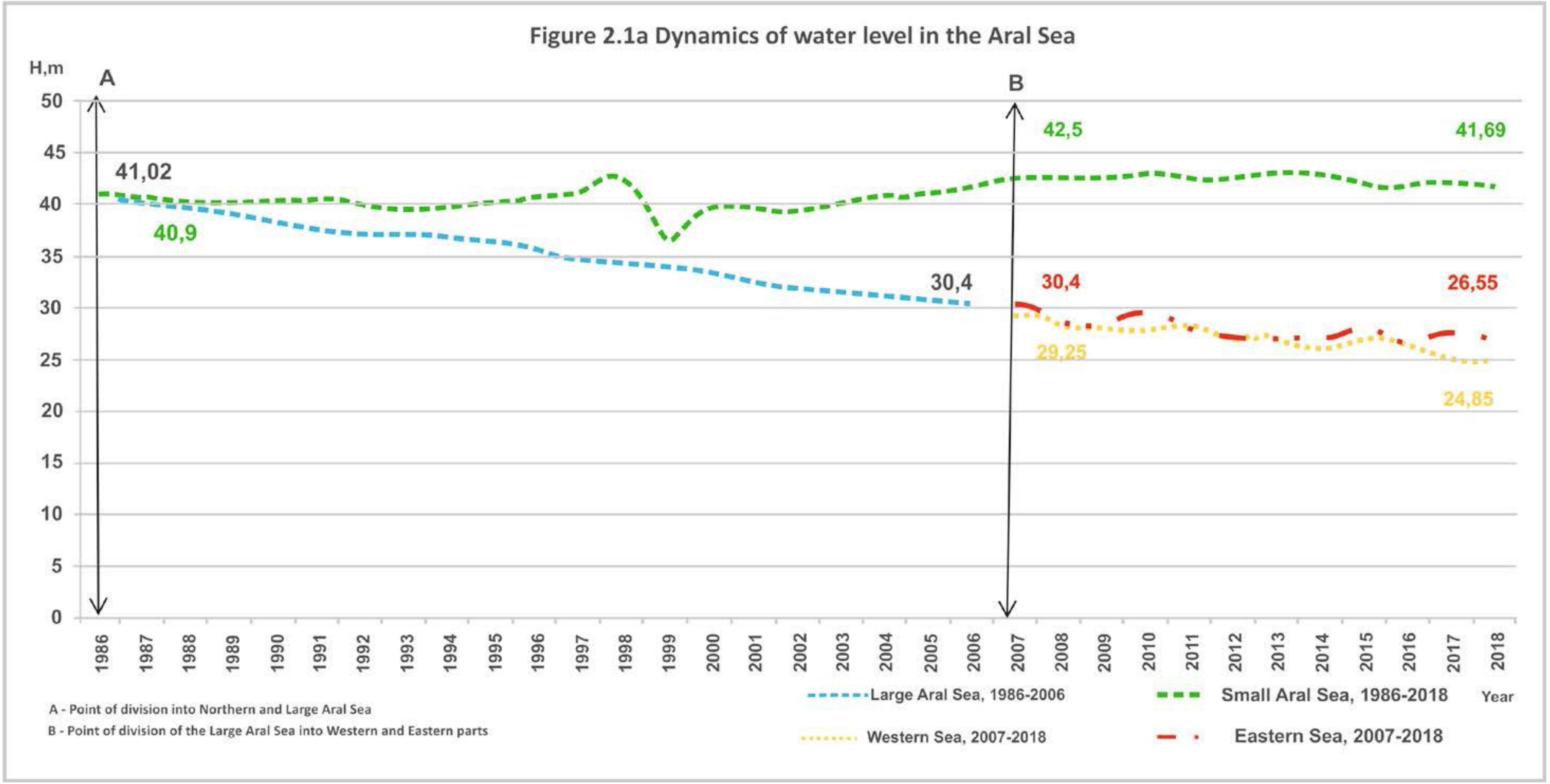


Figure 2.1a Dynamics of water level in the Aral Sea

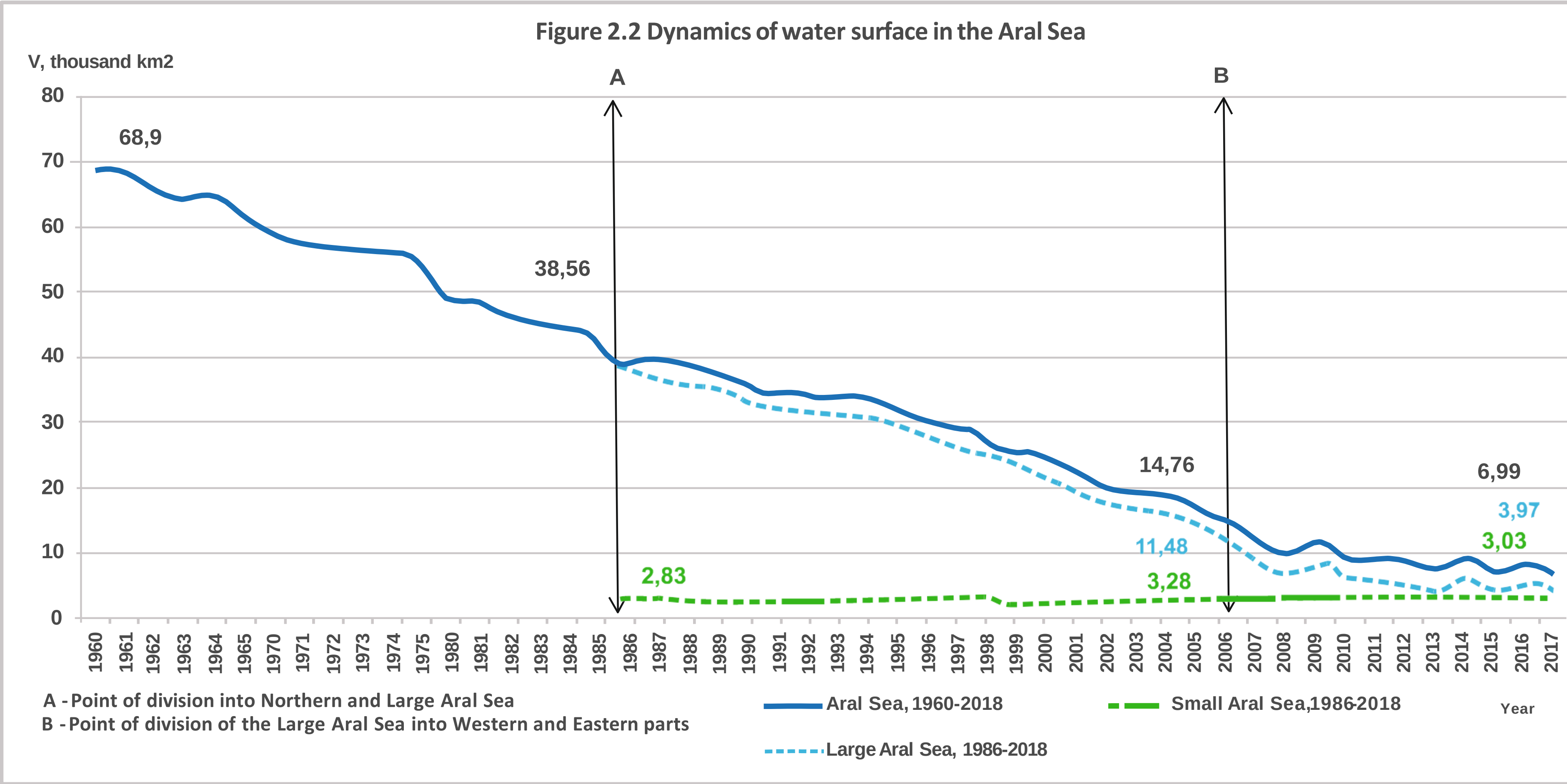


Figure 2.2 Dynamics of water surface in the Aral Sea

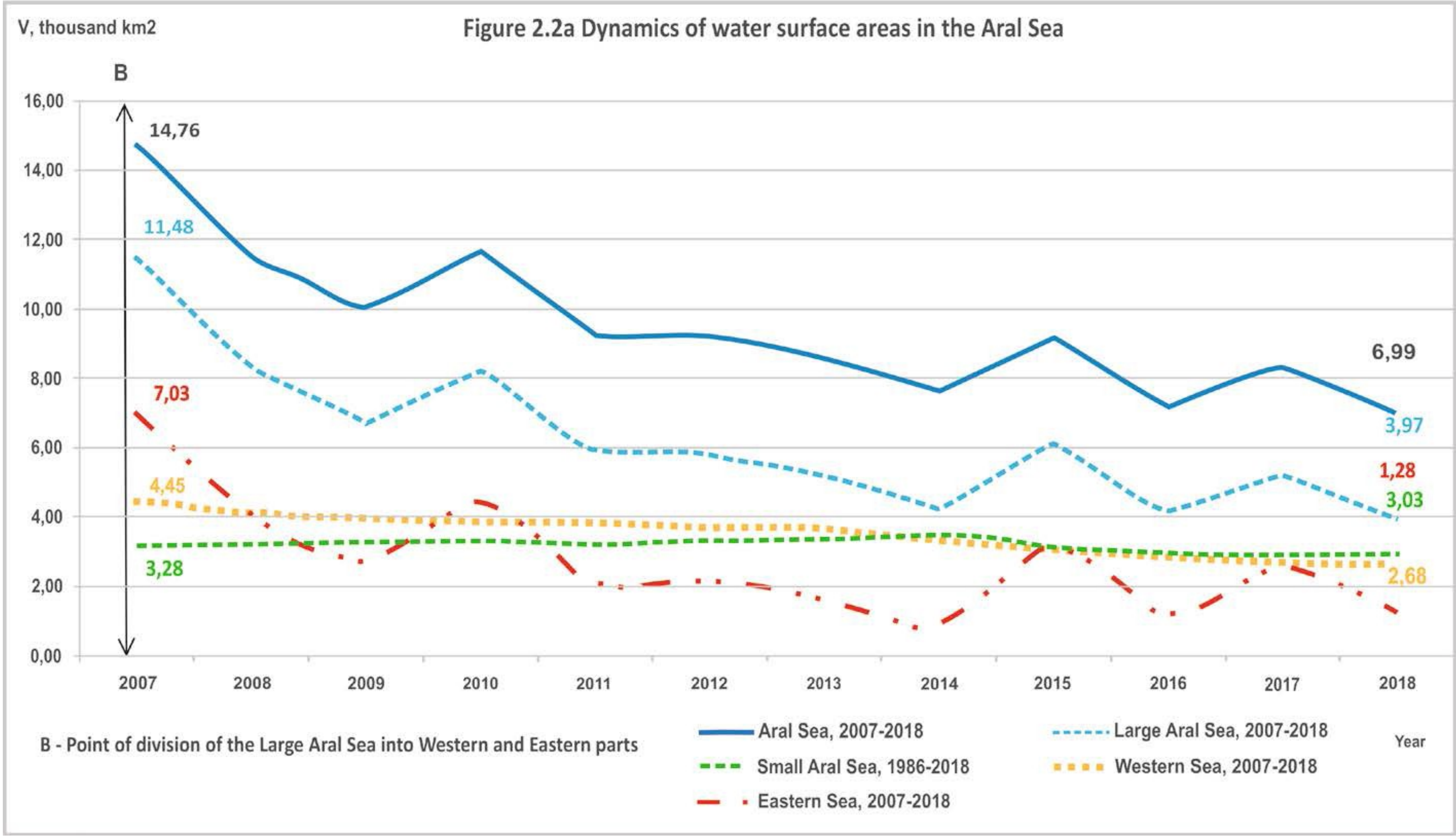


Figure 2.2a Dynamics of water surface areas in the Aral Sea

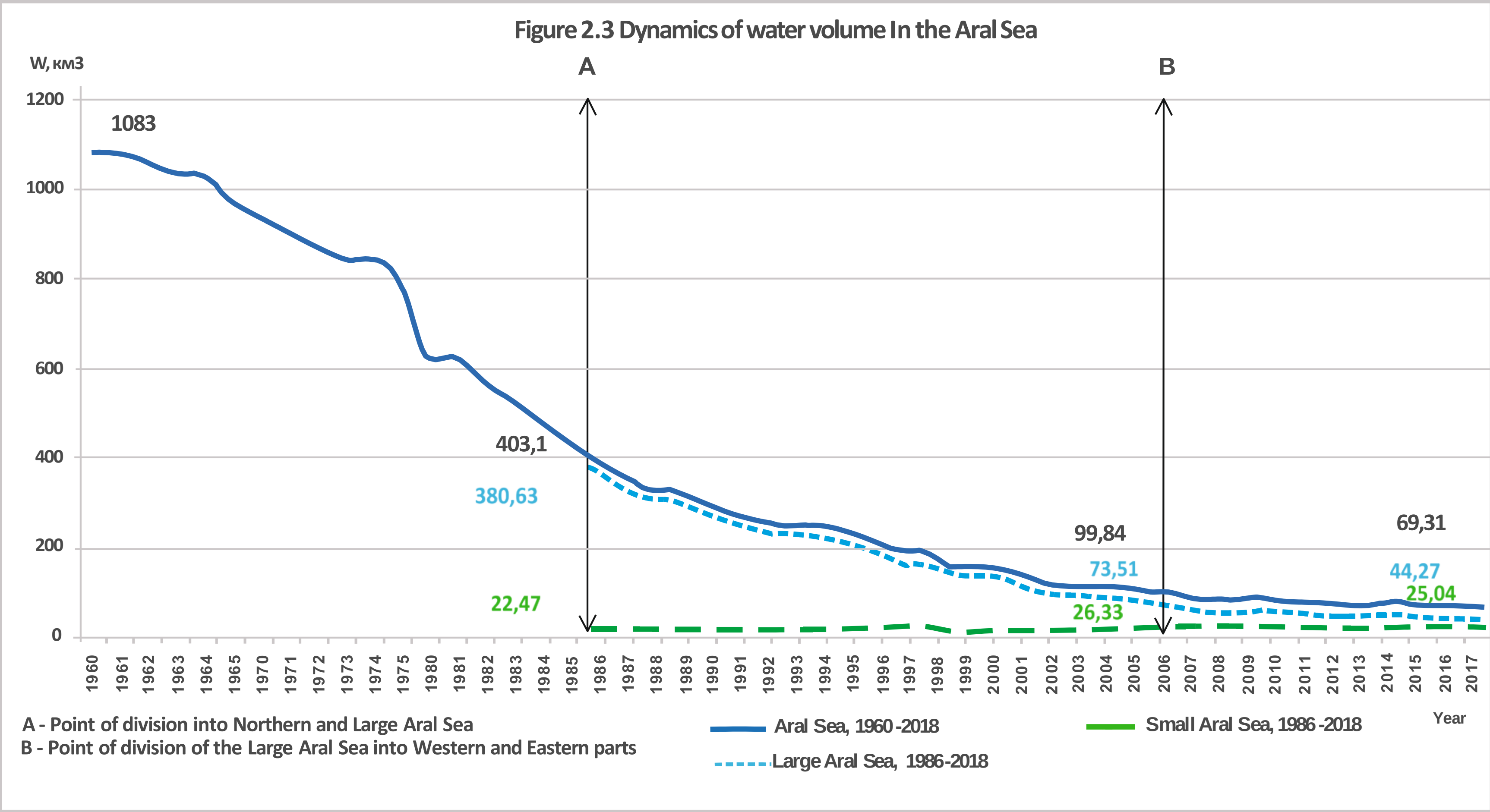


Figure 2.3 Dynamics of water volume in the Aral Sea

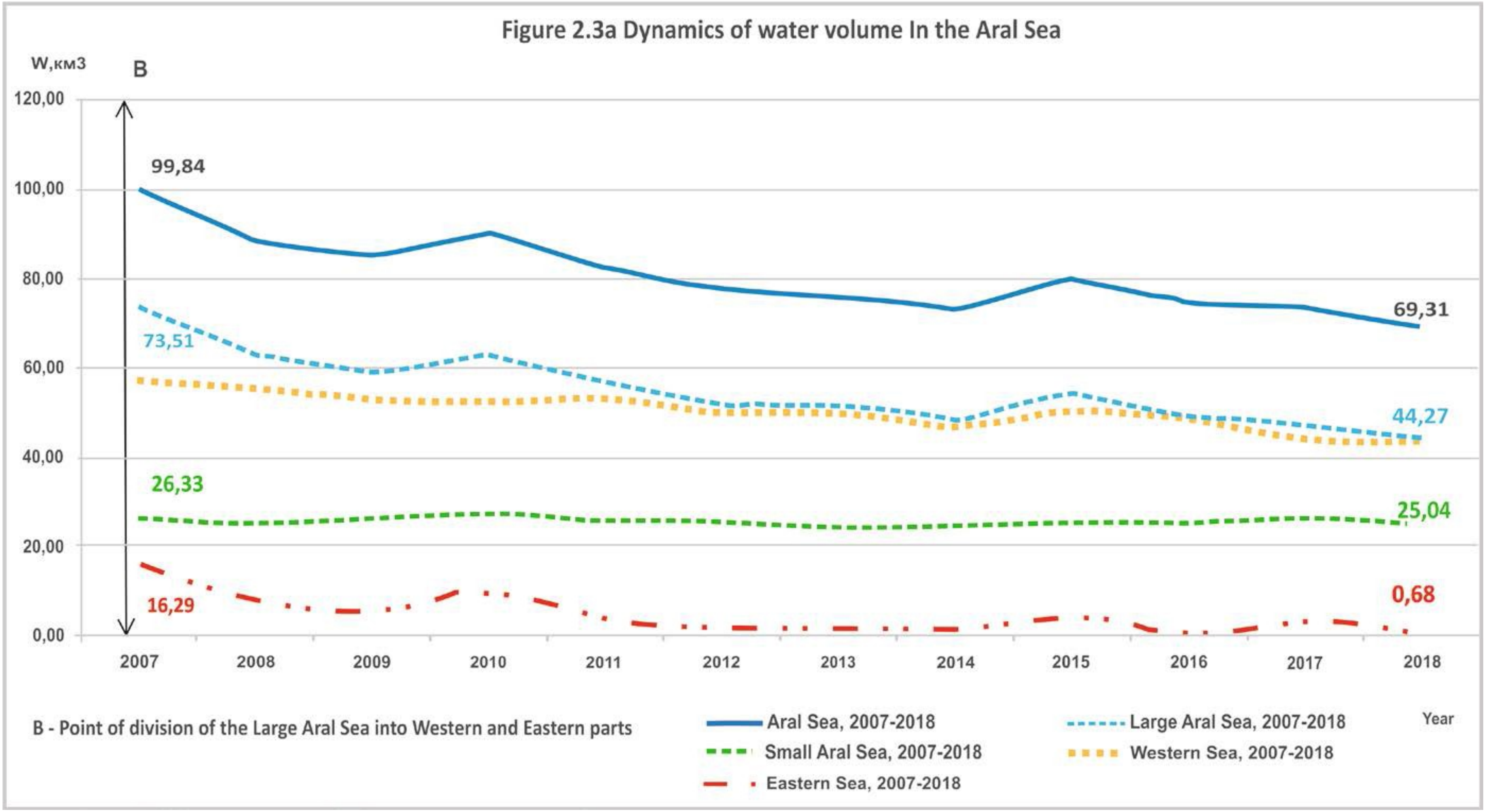


Figure 2.3a Dynamics of water volume in the Aral Sea

The above dynamics of the Aral Sea and its constitutive water bodies is undoubtedly the result of abruptly decreased inflow to deltas of the both rivers. Tables 2.2 and 2.3 show the changes in inflow to the Amu Darya delta through the Samanbai gauging station and to the Syr Darya delta through the Karateren gauging station. Over the period from 1992 to 2014, discharge from the Amu Darya river has averaged 9.04 km^3, varying from 17.6 km^3 (maximum flow in 2005) to 0.4 km^3 in 2001 and 0.537 km^3 in 2008. Accordingly, the discharge from the Syr Darya River has averaged 5.96 km^3 over the same period of time, with variations from 10.3 km^3 in wet years 2004 and 2005 to 2.5 km^3 in dry year 2000.

Salt accumulation changed also depending on inflow. Figure 2.4 shows dynamics of water salinity in the Amu Darya and consequent salt influx to the Aral Sea. It is clear that such change in the volume and chemistry of inflow had an impact on hydrochemistry of the Aral Sea. Unfortunately, no data of regular observations over the sea's hydrochemistry is available. There are only fragmented data of both Uzbek and Russian researchers that indicate to considerable transformations in hydrochemical composition of the seawater. Table 2.4 below is based on the data of Zaviyalov, who took part in the CAWa Project on behalf of the Russian Academy of Sciences.

Rubanov, Bogdanova, Semyenov, Mavlyanov, Pinkhasov and other scholars have studied the salt accumulation processes in the Aral Sea waters. As mentioned above, the Aral Sea is the main water and salt receiver for the whole Syr Darya – Amu Darya catchment basin. A portion of salts in the sea returns back to Prearalye through wind activity. The original inland denudation-deflation Aral depression occurred about 2 million years ago, in the late Pliocene. First flooding of the depression took place in the late Akchagyl. Workable salt deposits of Kushkanatau and Akkala have been formed in this the most ancient water body (rather in its southern coastal area).

At the beginning of the last millennium, mirabilite was deposited in the pre-cliff deep-see trench and northern bays. Currently, mirabilite is bedded under the 48-265 cm layer of bottom silt (calcareous clay), on an area of 1,425 km^2 in the deep-sea trench; on 100 km^2 in the Tcshe-Bas Bay and on 200-225 km^2 in the Small Aral Sea. The total area where the salt spreads is 1,950 km^2. The penetrated thickness is not more than 80 cm, while the supposed thickness is the first few meters. With the salt layer thickness of 1 meter, the salt stock amounts to approximately 3 billion tons. The share of mirabilite in sediments is 24 to 96 wt%, gypsum – 0.49 wt%, other soluble salts – approx. 6 wt%, and silicate skeleton – about 26 wt%. The ion composition of salts is the following: sodium – 2.83 to 13.73%; sulphate-ion – 7.5-30.14%; calcium - about 1.08%; magnesium – 3.03%; potassium – 0.93%; carbonate-ion – 0.18%; chlorine – 2.09%; and, water – about 55.23%.

Later, in the period of Novo-Aral transgression (up to the early 1960s), the Aral Sea was subjected to terrigenous-carbonate sedimentation, the carbonate stage, while the shallow Akpetkin archipelago and the deeply entrenched shallow Eastern-Aral Bays underwent gypsum sedimentation. The Novo-Aral sediments include terri-, chemo-, and organogenous formations. The terrigenous detrital sediments account for over 50-60% of their total mass. Sands, siltstone and clays predominate among them. The chemogenous sediments are comprised of carbonates, sulphates (gypsum) and soluble salts. Carbonates were accumulated in waters of the Aral Sea, except for the Akpetkin archipelago, where their precipitation was suppressed by gypsum sediments. Accumulation of gypsum had irregular character.

Table 2.2 Inflow to the Amu Darya Delta measured at Samanbai g/s, Mm^3

Year	October	November	December	January	February	March	Planned	Actual	%%
1991–1992	1855	574	635	1456	584	827	3500	5931	169.5
1992–1993	886	1536	397	641	529	1166	3500	5155	147.3
1993–1994	1140	666	1068	1545	1101	1457	3500	6977	199.3
1994–1995	1636	988	941	1244	401	499	3500	5709	163.1
1995–1996	673	557	282	128	161	133	3500	1934	55.3
1996–1997	964	724	483	304	294	130	3500	2899	82.8
1997–1998	179	165	156	96	512	471	1500	1579	105.3
1998–1999	1092	713	850	534	365	512	2000	4066	203.3
1999–2000	952	518	956	978	456	331	2000	4191	209.6
2000–2001	76	82	73	70	79	90	2000	470	23.5
2001–2002	17	13	8	36	79	121	1500	274	18.3
2002–2003	423	728	1043	732	274	255	3000	3455	115.2
2003–2004	350	341	363	328	409	315	3000	2106	70.2
2004–2005	249	169	144	481	1250	1063	2100	3356	159.8
2005–2006	1092.9	581	827	459	637.2	921	2100	4518.1	215.1
2006–2007	205	155	291	216	131	169	2100	1167	55.6
2007–2008	205	155	291	216	240	123	2100	1230	58.6
2008–2009	21	20	19	19	28	37	2100	144	6.9
2009–2010	335	292	353	644	148	150	2100	1922	91.5
2010–2011	947	451	510	205	190	180	2100	2483	118.2
2011–2012	71	97	167	129.3	185.8	398	2100	1048.1	49.9
2012–2013	650	792	678	964	250	236	2100	3570	170
2013–2014	184	134	133	171	168	148	2100	938	44.7
2014–2015	251	121	93	167	138	220	2100	990	47.1
2015–2016	459	641	882	464	270	280	2100	2996	142.7
2016–2017	394	409	159	203	147	193	2100	1505	71.7
2017–2018	409	191	155	174	221	261	2100	1411	67.2
2018–2019	52	62	88						

Year	October	November	December	January	February	March	Planned	Actual	%%
1992	428	3620	5480	6203	4830	2620	7000	23181	331.2
1993	664	1496	4371	3940	1482	1642	7000	13595	194.2
1994	1175	527	977	4607	4100	2604	7000	13990	199.9
1995	202	133	131	250	316	380	5000	1412	28.2
1996	227	319	623	1762	1067	873	5000	4871	97.4
1997	100	172	213	144	141	152	5000	922	18.4
1998	350	3430	5770	4719	4163	1745	3000	20177	672.6
1999	206	191	312	436	625	804	3000	2574	85.8
2000	195	141	137	62	42	37	3000	614	20.5
2001	31	19	18	20	15	23	2550	126	4.9
2002	13	31	1435	1686	450	658	2550	4273	167.6
2003	754	2034	2869	2750	306	421	2000	9134	456.7
2004	359	543	1704	1216	223	256	6600	4301	65.2
2005	1173	1034	1148	5922	1774	1223	6100	12274	201.2
2006	296	217	246	238	248	283	6100	1528	25
2007	120	107.2	165	285	204	169	2400	1050.2	43.8
2008	132	80.8	61	67.3	29	23	1890	393.1	20.8
2009	29	44	127.3	361	1389	699	2100	2649.3	126.2
2010	682	3323	2833	3874	4428	1969	2100	17109	814.7
2011	221	94	78	82	66	75	2100	616	29.3
2012	601	675	891	3342	754	923	2100	7186	342.2
2013	147	118	85	148	193	233	2100	924	44
2014	393	470	116	604	519	375	2100	2477	118
2015	361	226	146	1046	2469	1119	2100	5367	255.6
2016	243	114	173	361	273	240	2100	1404	66.9
2017	303	1045	2856	1808	2756	655	2100	9423	448.7
2018	125	85	64	72	58	57	2100	461	22.0

Table 2.3 Inflow to the Small Aral Sea measured at Karateren g/s, Mm^3

Year	October	Nov	December	January	February	March	Planned	Actual	%%
1991–1992	339.2	360.3	365.1	508.8	526.3	482	2983	2581.7	86.5
1992–1993	587.3	597.8	535.6	562.4	604.8	803.4	3588	3691.3	102.9
1993–1994	877.1	496.8	0	964.1	870.8	1098	3394	4306.8	126.9
1994–1995	1578.2	894.2	803.4	937.3	362.9	324	4722	4900	103.8
1995–1996	291.9	185.8	187.5	107.1	112.8	71	2412	956.1	39.6
1996–1997	405.9	699.8	723.1	603.1	507.8	695.5	3158	3635.2	115.1
1997–1998	295	246	187	402	484	723	2543	2337	91.9
1998–1999	758	829.4	857.1	696.4	616.9	948.2	4161	4706	113.1
1999–2000	255.3	290.3	310.4	308	275.6	217.6	4392	1657.2	37.7
2000–2001	54.6	359.2	674.1	643	460	562.5	2062.6	2753.4	133.5
2001–2002	69.6	171.1	174.1	246.4	239.5	291.9	2311	1192.6	51.6
2002–2003	732.8	591.7	638.3	776.7	774.1	624.1	6386	4137.7	64.8
2003–2004	823	948.9	1007.3	1071.7	952.1	1277	6100.6	6080	99.7
2004–2005	577.7	726.6	1364.4	1151.7	919.3	1366	5388.7	6105.7	113.3
2005–2006	950.3	1082.9	1167.8	964.2	895.1	1205.3	6719.3	6265.6	93.2
2006–2007	397.4	616.8	233	669.6	653.2	883.9	2252.6	3453.9	153.3
2007–2008	729	778.6	804	804	897	999	2823.7	5011.6	177.5
2008–2009	38	46	99	348	484	479	1914.3	1494	78
2009–2010	787	295	284	525	583	804	2351	3278	139.4
2010–2011	820	827	978	956	774	828	2603.4	5183	199.1
2011–2012	91	275	364	554	629	776	1961.9	2689	137.1
2012–2013	351	267	517	611	602	702	1964.5	3050	155.3
2013–2014	170	301	584	700	699	552	1906	3006	157.7
2014–2015	316	285	576	643	663	758	2489	3241	130.2
2015–2016	134	350	766	830	576	463	1991.55	3119	156.6
2016–2017	158	433	644	770	657	733	3317	3395	102.4
2017–2018	579	1089	945	760	585	693	3548	4651	131.1
2018–2019	170	388	605						

Year	October	Nov	December	January	February	March	Planned	Actual	%%
1992	318.6	238.3	246.1	46.9	129.3	362.3	1426	1341.5	94.1
1993	622.1	495.4	459	410.3	448.1	952	3286	3386.9	103.1
1994	867.5	336.5	677.4	42.5	35.3	1436	3145	3395.2	108
1995	124.2	53	58.1	69.6	85.4	127	1821	517.3	28.4
1996	93.8	128.5	75.2	69.8	194.6	365.7	1752	927.6	52.9
1997	648	0	0	0	0	0	1686	648	38.4
1998	699.8	581.2	497.7	455.3	629.4	671.3	996	3534.7	354.9
1999	927.9	720.5	210	219.6	115.2	225.5	1432	2418.7	168.9
2000	492.5	302.7	54.4	24.1	29.5	67.4	1264	970.6	76.8
2001	684.3	179.5	31.1	13.4	13.4	25.9	906	947.6	104.6
2002	676.6	708.8	551.7	432	549.8	703.9	3781	3622.8	95.8
2003	951.3	868.6	504	457.6	515.2	738.7	3145	4035.4	128.3
2004	1259	1377	469.5	423.3	404.9	460	7189	4393.7	61.1
2005	1257.7	1162.8	381.6	127.7	315.8	790.1	5721	4035.7	70.5
2006	1425	779	170	60.6	110.9	353.5	3473	2899	83.5
2007	888.2	870	162.8	58.3	283.4	333.2	1808	2595.9	143.6
2008	762	410	85	25	12	16	1806	1310	72.5
2009	340	429	283	163	283	845	1806	2343	129.7
2010	682	806	728	822	530	692	2444	4260	174.3
2011	928	335	139	68	50	53	1802.7	1573	87.3
2012	816	386	140	56	254	402	2894.2	2054	71.0
2013	570	404	167	64	52	217	2421.9	1474	60.9
2014	247	621	288	233	211	399	1900	1999	105.2
2015	461	268	120	59	78	245	2458.8	1231	50.1
2016	70	51	44	214	183	638	1804	1200	66.5
2017	1022	973	694	582	607	557	1363	4435	325.4
2018	569	203	87	30	39	222	1752	1150	65.6

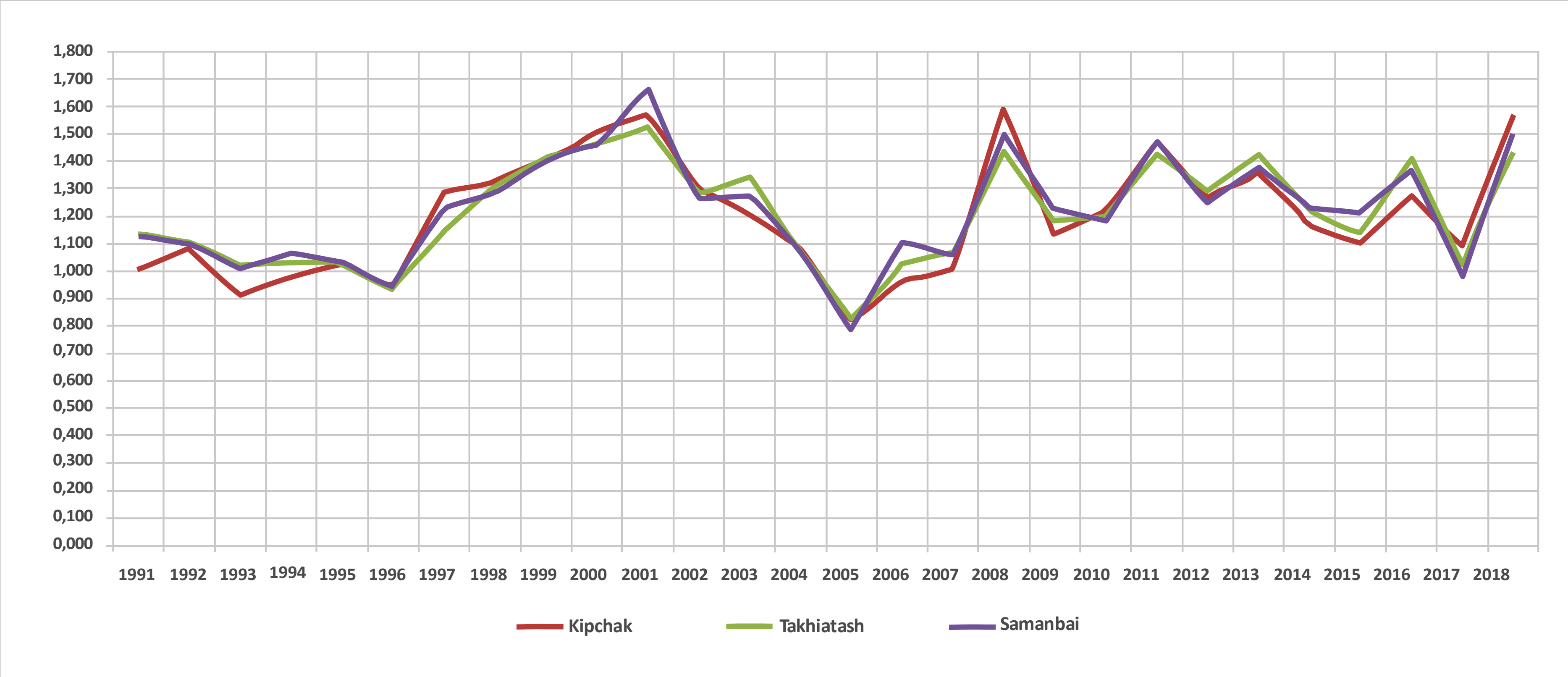


Figure 2.4 Average annual solid residue by gauging station along the Amu Darya River, g/l

Table 2.4 Dynamics of salinity in Eastern and Western parts of the Large Aral Sea

Year	Salinity, g/kg	
	Western basin	Eastern basin
1960	10*	10*
1970	12*	12*
1980	17*	17*
1990	32*	32*
1992	35*	35*
1995	42*	42*
1996	44*	44*
1997	51*	52*
1998	54*	58*
1999	56*	na
2000	63*	na
2001	68*	112*
2002	82**	160*
2003	86**	na
2004	92**	na
2005	98**	130**

The gypsum, which was formed directly from the seawater salinized to 35-45 g/l, was deposited in form of crystals in submillimeters in size (0.1 – 0.01 mm) and then, in time, either enlarged to larger grains (0.5 – 1 mm) or made up aggregates of coral shape (approx. 5 – 10 mm large). Thus, the accumulated gypsum, the layer of which is 0.2 to 0.5 m thick, covers mainly the central parts of bays.

Two zones are marked in terms of salt accumulation pattern: the Akpetkin archipelago and the rest of dried seabed. Salts were accumulated in the archipelago through evaporation of the seawater and the groundwater from the mainland. At present, salts are kept accumulated through both evaporation and seasonal discharge of highly saline groundwater into numerous small brine lakes. The salts include thenardite-mirabilite deposits (about 1 m thick), stratal halite with bloedite or halite-brine lakes. Thenardite-mirabilite and bloedite-halite deposits tend to cover deepest parts of dried bays and are found inside of earlier gypsum fields or outside them. Thenardite puffed solonchaks formed after dewatering of mirabilite are widely developed. Puffed solonchaks occupy about 250 km^2 of the dried seabed. The tenardite-mirabilite salt stock amounts to 80 million tons. Stratal halite, approx. 0.3-0.5 m thick, covers the bottom of many dry and brine lakes, salinity of which is 240-350 g/l. The halite stock is about 22 million tons. Tenardite puffed solonchak is the main source of salt in the atmosphere. Observations show that 1.5-2 cm of tenardite powder lime is deflated every year. Besides, the blown off powder lime is recovered and again removed by wind into the atmosphere.

The distribution of salts in depth of the Western body of the Aral Sea is of particular interest. Strongly saline water bodies usually have the salinity profiles that increase from the surface to the bottom. This can be expected for the Aral Sea as well, given that its ice regime triggers reduction of salinity through freezing from the surface of the lake. This phenomenon was attested by field and desk studies by A. Tutchin. However, according to Zavialov's findings that were reiterated by acad.

Vasiliev, the profile of salt distribution in depth of the Western Aral Sea is shaped as shown in Figure 2.5. This phenomenon can be explained only by a substantial inflow from groundwater into the deeper Western Aral Sea. We think that this is not without reason, taking into account alluvial deposits along the whole length of the Amu Darya, which eventually discharges into the Aral Sea, especially into its deeper Western part. The process needs to be clarified in terms of quantity and quality of groundwater inflow.

On the other hand, Russian researchers led by Zavialov in the course of CAWa Project studies in 2007 found the discharge of fresher water from the side of the delta and the Ustyurt Plateau. That time, against the background of the total salinity of more than 110 g/l in the Western Aral Sea, they found layers of discharging water that had salinity of 40 g/l (Fig. 2.6). This proves an intensive contribution from groundwater from the Ustyurt side to the Western Aral Sea.

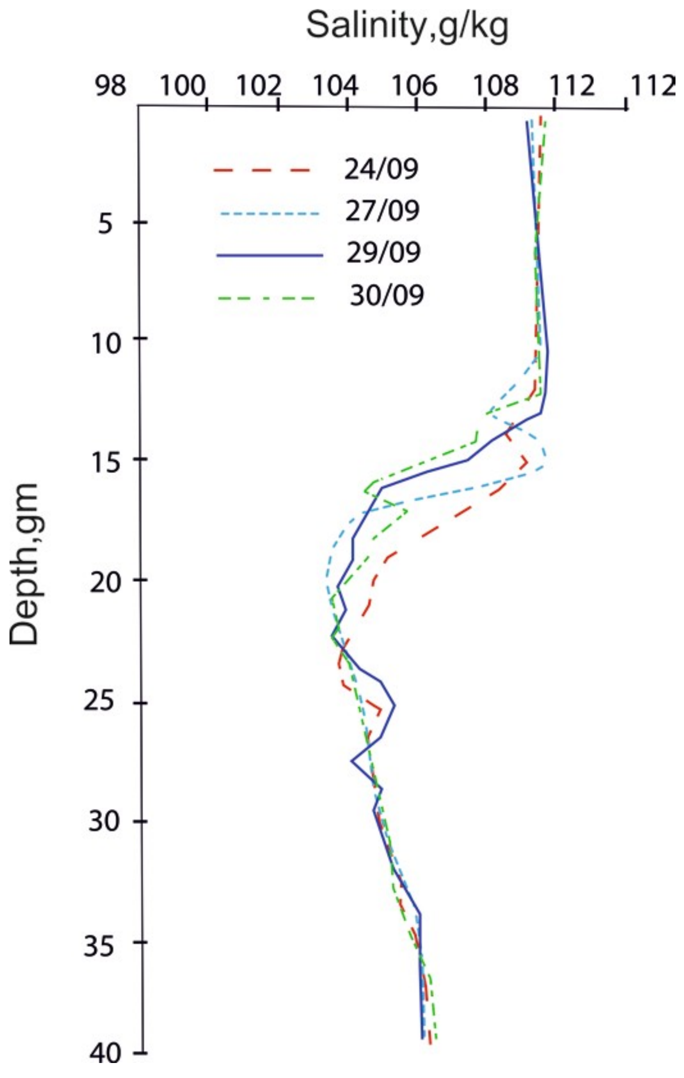


Figure 2.5 Profile of salt distribution in depth of the Western Aral Sea

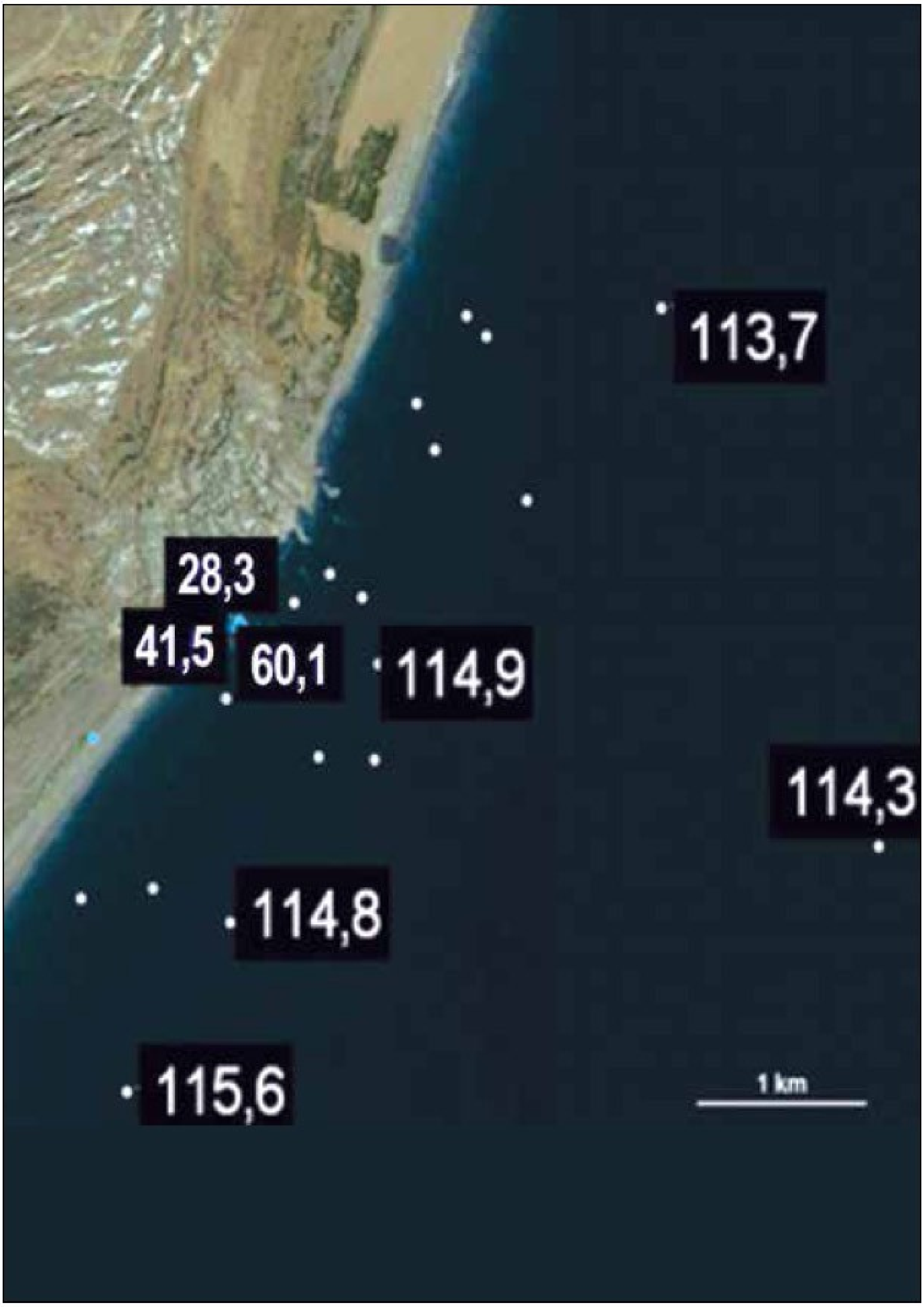


Figure 2.6 Effect of groundwater discharge in the western coast of the Western Aral Sea on seawater salinity (g/l)

Analysis of hydrological links between the Northern Aral Sea and two southern water bodies and assessment of the use of potential excess water from the North Aral Sea to feed Eastern and Western parts of the sea

Small (Northern) Aral Sea occurred in 1987 as a result of shrinkage of the Aral Sea. The Northern Aral took its current shape after construction of the Kokaral dam that prevented this part of the Aral Sea from drying up. The dam crosses the Bergh's Strait. The crest of the dam is 6 m high (45.5 m +BSL). The dam has a spillover, with nine weirs capable to pass 600 m^3/s, which is designed to protect the dam from breach by discharging excess water into the Southern Aral Sea (its Eastern part). The water level in the Northern Aral Sea is to be kept at 42-42.2 m +BSL, and the excess is to be discharged into the Large Aral Sea. The water is discharged mainly in January-August (see Table 2.4).

The hydrological link between the Northern Aral Sea and the Eastern part of the Large Aral Sea depends on flow capacity of the spillover at the Kokaral dam and the water level in the Northern Aral Sea. The direct link between the Northern and Large (Southern) Aral Sea (no inverse connection) is possible when the water level in the Northern Aral Sea is 41.75 m +BSL and higher.

The volume of water releases from the Northern Aral Sea into the Southern Aral Sea (its Eastern part) over a specific period of time depends on the water level in the Northern Sea at the beginning of the period and inflow from the Syr Darya over the period. Figure 2.10 shows the relationship between the inflow to the Northern Aral Sea and the discharge into the Large Aral Sea based on the Kazakh Hydromet's data over 2013-2018.

As part of the RSRMNA Project (Regulation of the Syr Darya River and Maintenance of the Northern Aral Sea), it is planned to augment the Kokaral dam's height by 6 meters from 42 to 48 m and remove the spillover into the Aral Sea from the Bergh's to Shevchenko Strait. The water volume in the Northern Aral Sea will be increased from 27 km^3 to 59 km^3, and this will make the sea deeper and allow the Small Aral Sea's water to approach the former Aralsk harbor within 1 km. Consequently, the hydraulic pattern of water discharge from the Northern to Large Aral Sea will change.

It may be expected that in the future, discharge of water from the Northern Aral Sea will be reduced and the existing hydrological link will be broken.

Table 2.5 Analysis of hydrological links between the Northern Aral Sea (NS) and two southern water bodies and assessment of the use of potential excess water from the Northern Aral Sea to feed Eastern and Western parts of the sea

Year	Indicator	Unit	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
2013	Karateren g/s	Mm^3	611	602	702	570	404	167	64	52	217	170	301	584	**4444**
	Water level NS	m+BS	41.75	41.8	41.95	42.06	42.06	42.18	42.04	41.95	41.85	41.6	41.7	41.87	**41.90**
	Volume NS	Mm^3	25470	25422	25516	25997	25740	25248	24619	24253	23974	24114	24336	24724	**24951**
	Discharge to LAS	Mm^3	754	689	705	11	33	49	35	3	0	0	0	145	**2424**
2014	Karateren g/s	Mm^3	700	699	552	247	621	288	233	211	399	316	285	576	**5127**
	Water level NS	m+BS	41.87	41.92	42.05	42.15	42.38	42.38	42.38	42.4	42.22	42.15	42.01	41.99	**42.16**
	Volume NS	Mm^3	25149	25508	26111	25440	26617	26124	25620	25022	24746	24820	24695	24833	**25390**
	Discharge to LAS	Mm^3	169	159	218	234	80	78	80	255	257	198.5	432	409.6	**2570**
2015	Karateren g/s	Mm^3	643	663	758	461	268	120	59	78	245	134	350	766	**4545**
	Water level NS	m+BS	42.06	42.16	42.15	42.34	42.29	42.24	42.06	41.98	41.94	41.77	41.76	41.87	**42.05**
	Volume NS	Mm^3	25307	25680	26125	26296	25922	25424	24775	24317	24193	24341	24556	25090	**25169**
	Discharge to LAS	Mm^3	413	392	464	382	60	47	32.7	4.3	0	55.47	257	332.8	**2440**
2016	Karateren g/s	Mm^3	830	576	463	70	51	44	214	183	638	158	433	644	**4304**
	Water level NS	m+BS	41.97	42.04	42.04	42.02	42.02	42.01	41.99	41.96	41.93	41.82	41.81	41.81	**41.95**
	Volume NS	Mm^3	25184	24924	24723	24830	24581	24214	23963	23871	21011	24111	24477	24882	**24231**
	Discharge to LAS	Mm^3	861.5	861.2	618	89.9	0.9	0	0	0	0	60	67	257	**2816**
2017	Karateren g/s	Mm^3	770	657	733	1022	973	694	582	607	557	579	1089	945	**9208**
	Water level NS	m+BS	41.86	41.86	41.9	42.28	42.2	42.13	42.05	42.05	42.02	41.83	42.04	42.13	**42.03**
	Volume NS	Mm^3	25322	25635	25977	26405	25901	25056	24200	24020	23938	24139	24733	24699	**25002**
	Discharge to LAS	Mm^3	327	342	387.76	493.43	1035	1052	835	184	166	396	481	962	**6661**
2018	Karateren g/s	Mm^3	760	585	693	569	203	87	30	39	222	170	388	605	**4351**
	Water level NS	m+BS	42.09	42.02	42.06	42.05	42.05	42.03	41.97	41.92	41.78	41.56	41.61	41.69	**41.90**
	Volume NS	Mm^3	24562	24400	24354	24019	23733	23239	22614	22021	21741	21880	22234	22771	**23131**
	Discharge to LAS	Mm^3	911	715	740	752	11	9	17	14	13	23	36	69	**3310**

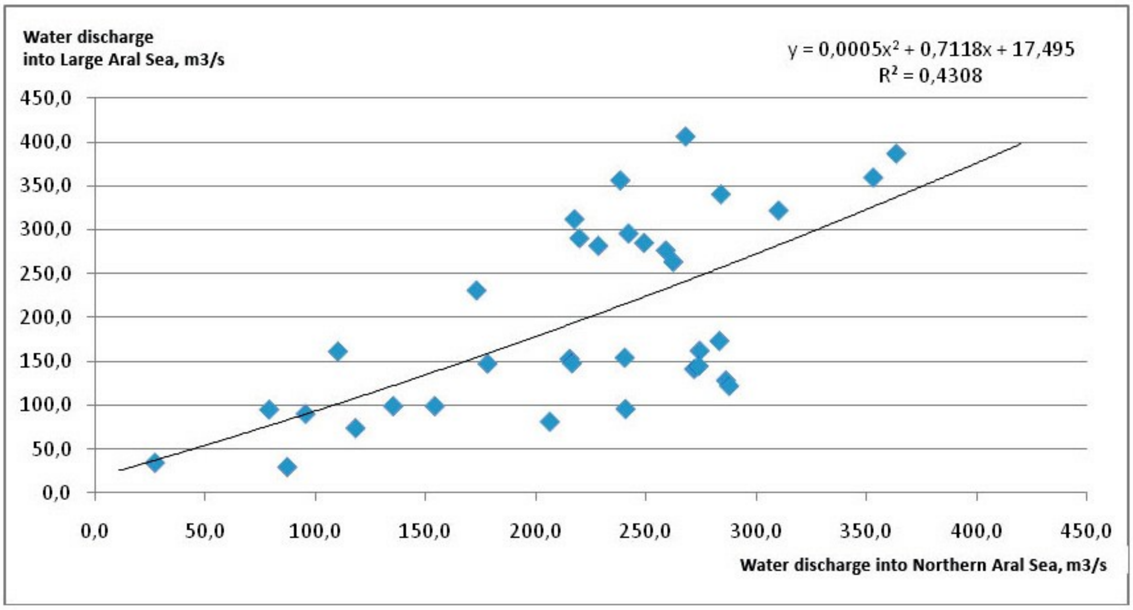


Figure 2.7 Discharge into Large Aral Sea from the Northern Aral Sea, 2013-2018

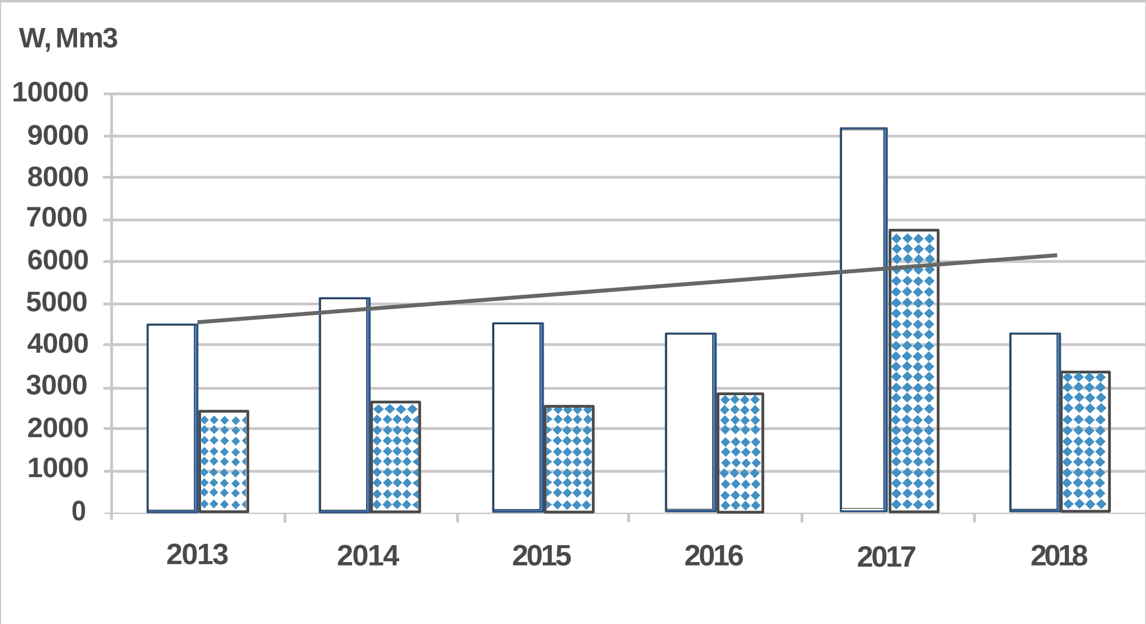


Figure 2.8 Annual inflow based on Karateren gauging station (g/s) and discharge into Large Aral Sea

Table 2.6 Change in water surface area of the Western and Eastern parts of the Aral Sea under the total inflow

n - period	Eastern sea	Western sea
1 year	y = 0.3753x - 4192.6	y = 0.0056x - 213.3
	R^2 = 0.6224	R^2 = 0.7985
2 years	y = 0.3041x - 6964.9	y = 0.0182x - 638.28
	R^2 = 0.6044	R^2 = 0.4598
3 years	y = 0.1793x - 5785.6	y = 0.0166x - 935.4
	R^2 = 0.4089	R^2 = 0.3815

Figure 2.9 Kokaral dam

Analysis of hydrological links between Eastern and Western parts of the Aral Sea and forecast of their status for the short-term future

In 1989, the Aral Sea separated into two isolated water bodies – the Northern (Small) and Southern (Large) Aral Sea. In 2003, the latter further broken into western and eastern parts. Currently, the hydrological link between Eastern and Western parts of the Large Aral Sea is maintained via a channel, as well as through filtration from the Eastern part to the Western part. Satellite images show (Fig. 2.12) that there is a cross-flow from the Eastern part to the Western part, depending on the water level and volume in the Eastern part and the difference in water levels in those parts of the sea (Fig. 2.13).

By processing the results of RS monitoring and analyzing the water surface areas of Western and Eastern parts, we had the possibility to assess the water balance in given territory. Relationships were found between the water surface areas of Eastern and Western parts and the total inflow (water from the Amu Darya, collector-drainage water, and discharge from the Northern Aral Sea) into the Large Aral Sea (Figures 2.10-2.11). These relationships were found from the analysis of n-periods (1 year, 2 years, and 3 years). The change in surface areas (dF) was determined as the difference between the water surface areas at the end and at the beginning of the estimation period.

An increase in the water surface area in the Eastern part of the Large Aral Sea is characteristic when the total inflow is more than 8 km^3 a year, while if the inflow to the sea is less than 6 km^3 a year, the water surface area decreases. Water flown into the Eastern part is accumulated partially in this bowl, partially flows into the Western part and is partly lost through evaporation and filtration.

As to the Western part, there is a downward trend of water level and surface area, depending on inflow to the sea and water volume in the Eastern part (the water level difference between Eastern and Western parts).

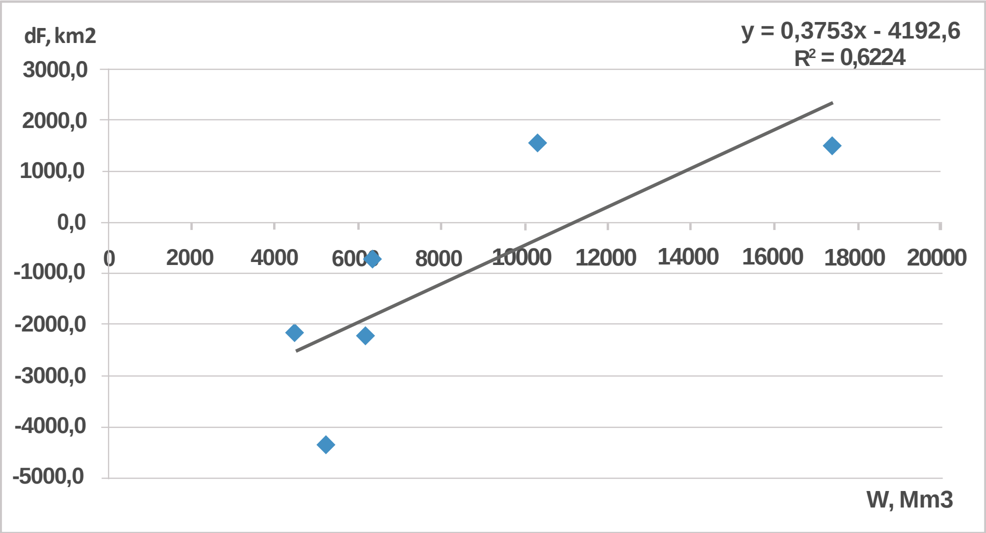


Figure 2.10 Changes in the surface area of the Eastern Sea (F) depending on the total annual inflow from the Amu Darya and the Syr Darya (W)

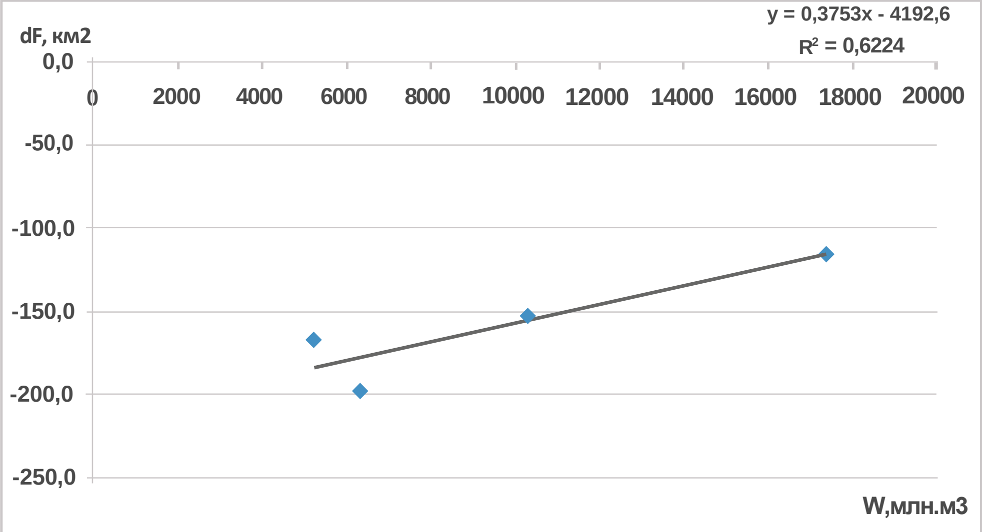


Figure 2.11 Changes in the surface area of the Western Sea (F) depending on the total annual inflow from the Amu Darya and the Syr Darya (W)

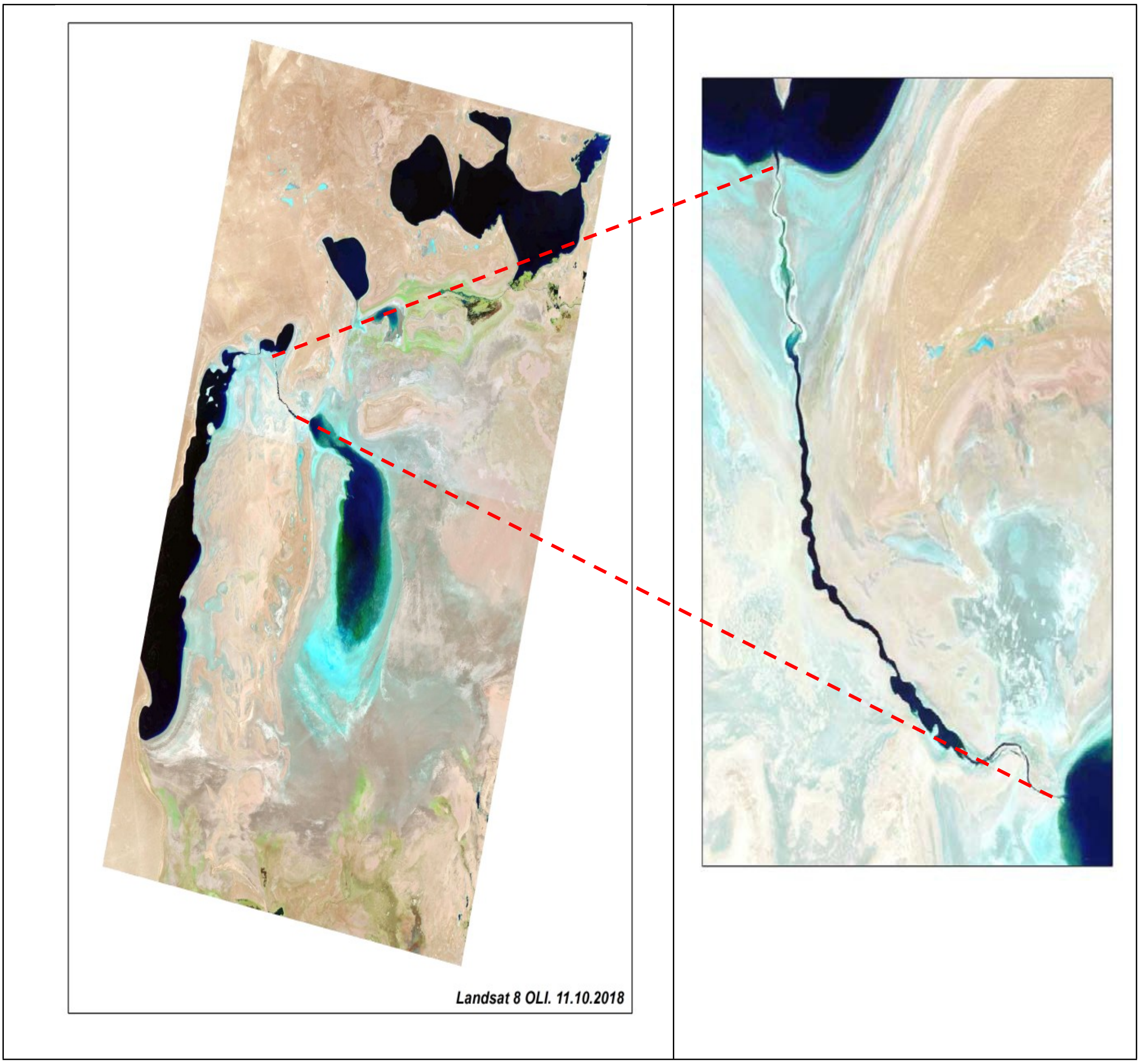


Figure 2.12 Crossflow from Eastern to Wester part of the Large Aral Sea

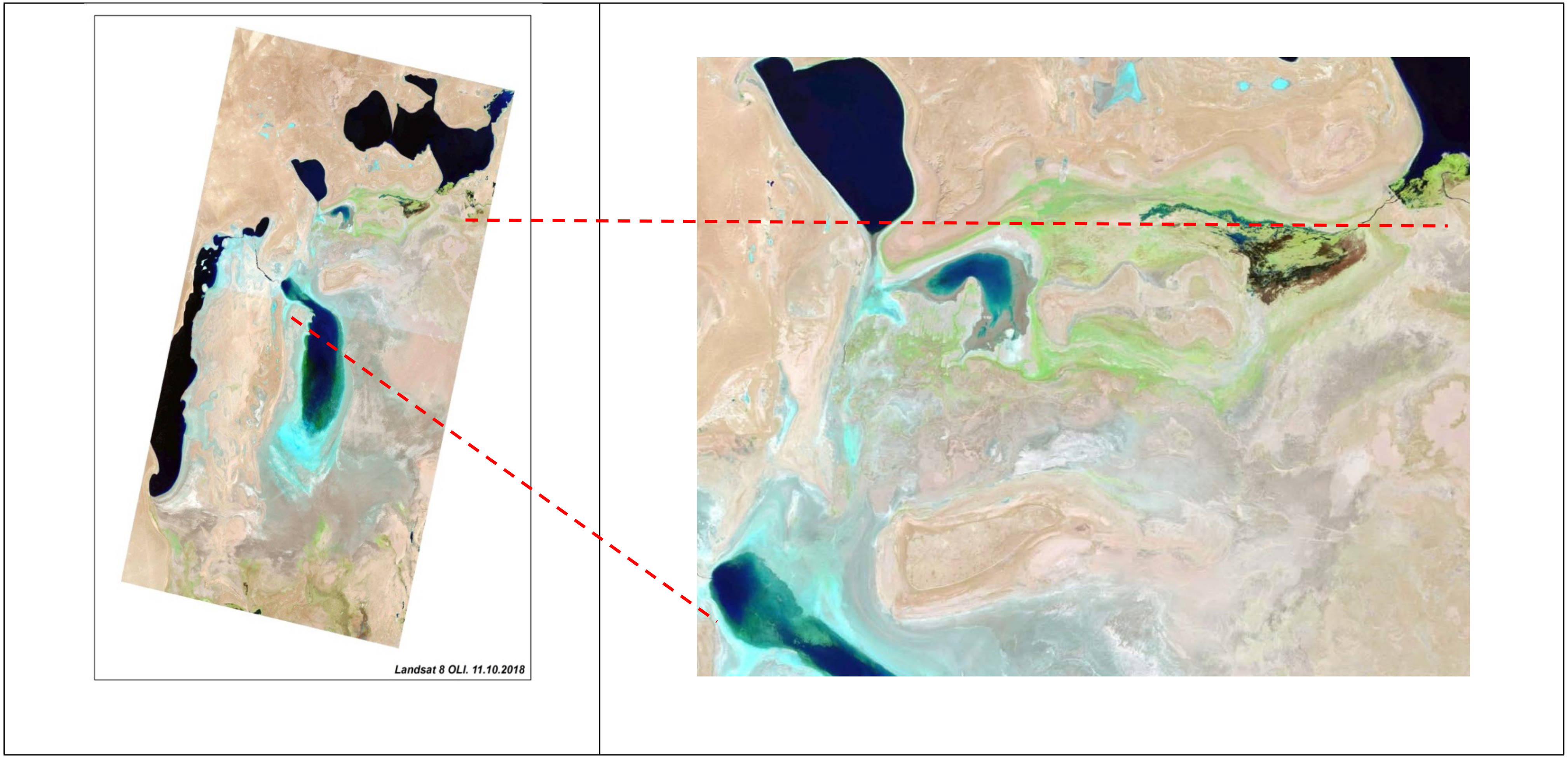


Figure 2.13 The zone of cross-flow from the Northern Aral Sea to Eastern part of the Large Aral Sea

Table 2.5 Analysis of hydrological links between the Northern Aral Sea (NS) and two southern water bodies and assessment of the use of potential excess water from the Northern Aral Sea to feed Eastern and Western parts of the sea

Year	Indicator	Unit	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
2013	Karateren g/s	Mm^3	611	602	702	570	404	167	64	52	217	170	301	584	**4444**
	Water level NS	m+BS	41.75	41.8	41.95	42.06	42.06	42.18	42.04	41.95	41.85	41.6	41.7	41.87	**41.90**
	Volume NS	Mm^3	25470	25422	25516	25997	25740	25248	24619	24253	23974	24114	24336	24724	**24951**
	Discharge to LAS	Mm^3	754	689	705	11	33	49	35	3	0	0	0	145	**2424**
2014	Karateren g/s	Mm^3	700	699	552	247	621	288	233	211	399	316	285	576	**5127**
	Water level NS	m+BS	41.87	41.92	42.05	42.15	42.38	42.38	42.38	42.4	42.22	42.15	42.01	41.99	**42.16**
	Volume NS	Mm^3	25149	25508	26111	25440	26617	26124	25620	25022	24746	24820	24695	24833	**25390**
	Discharge to LAS	Mm^3	169	159	218	234	80	78	80	255	257	198.5	432	409.6	**2570**
2015	Karateren g/s	Mm^3	643	663	758	461	268	120	59	78	245	134	350	766	**4545**
	Water level NS	m+BS	42.06	42.16	42.15	42.34	42.29	42.24	42.06	41.98	41.94	41.77	41.76	41.87	**42.05**
	Volume NS	Mm^3	25307	25680	26125	26296	25922	25424	24775	24317	24193	24341	24556	25090	**25169**
	Discharge to LAS	Mm^3	413	392	464	382	60	47	32.7	4.3	0	55.47	257	332.8	**2440**
2016	Karateren g/s	Mm^3	830	576	463	70	51	44	214	183	638	158	433	644	**4304**
	Water level NS	m+BS	41.97	42.04	42.04	42.02	42.02	42.01	41.99	41.96	41.93	41.82	41.81	41.81	**41.95**
	Volume NS	Mm^3	25184	24924	24723	24830	24581	24214	23963	23871	21011	24111	24477	24882	**24231**
	Discharge to LAS	Mm^3	861.5	861.2	618	89.9	0.9	0	0	0	0	60	67	257	**2816**
2017	Karateren g/s	Mm^3	770	657	733	1022	973	694	582	607	557	579	1089	945	**9208**
	Water level NS	m+BS	41.86	41.86	41.9	42.28	42.2	42.13	42.05	42.05	42.02	41.83	42.04	42.13	**42.03**
	Volume NS	Mm^3	25322	25635	25977	26405	25901	25056	24200	24020	23938	24139	24733	24699	**25002**
	Discharge to LAS	Mm^3	327	342	387.76	493.43	1035	1052	835	184	166	396	481	962	**6661**
2018	Karateren g/s	Mm^3	760	585	693	569	203	87	30	39	222	170	388	605	**4351**
	Water level NS	m+BS	42.09	42.02	42.06	42.05	42.05	42.03	41.97	41.92	41.78	41.56	41.61	41.69	**41.90**
	Volume NS	Mm^3	24562	24400	24354	24019	23733	23239	22614	22021	21741	21880	22234	22771	**23131**
	Discharge to LAS	Mm^3	911	715	740	752	11	9	17	14	13	23	36	69	**3310**

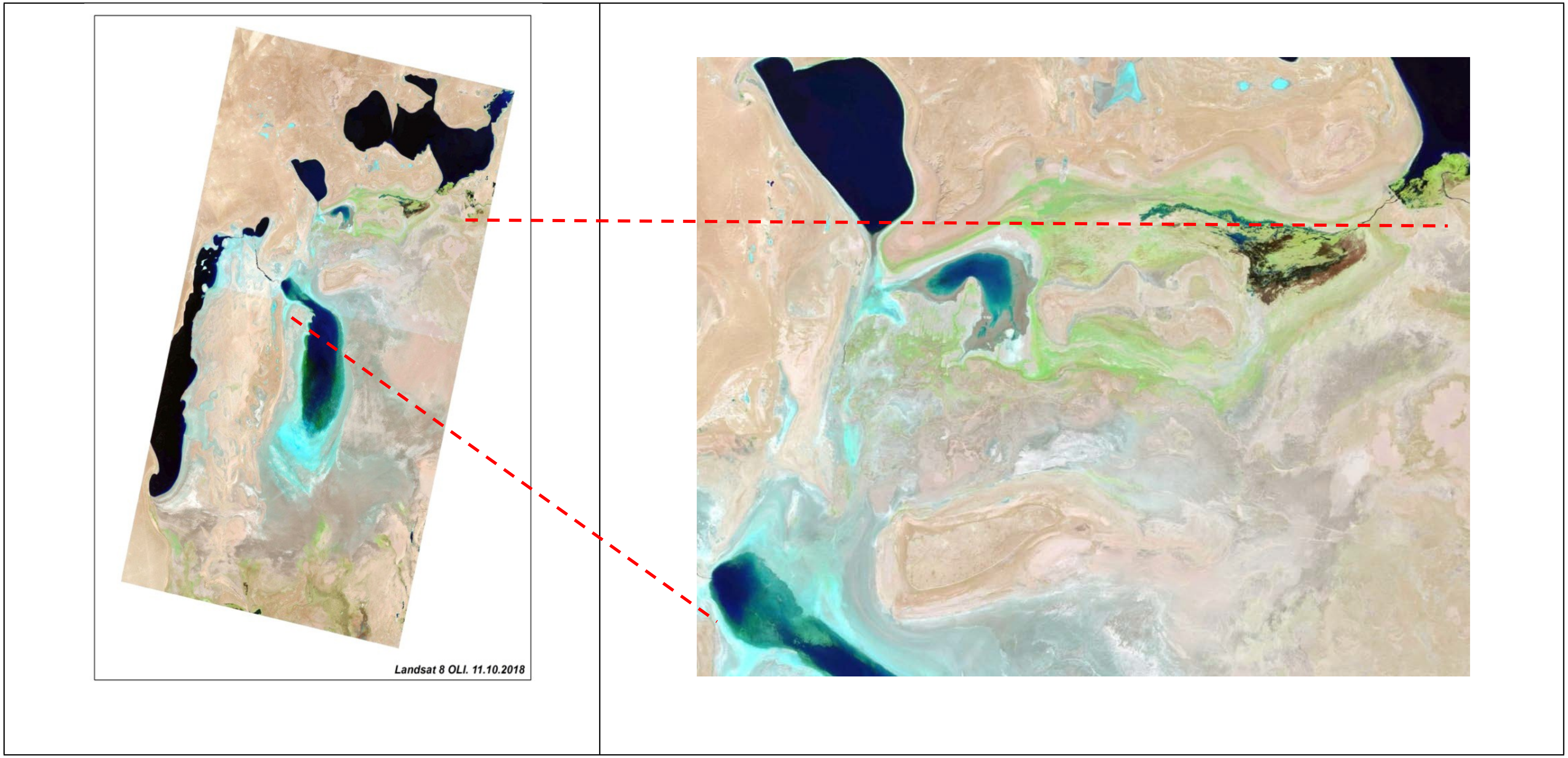


Figure 2.13 The zone of cross-flow from the Northern Aral Sea to Eastern part of the Large Aral Sea

3. SOCIO-ECONOMIC AND ENVIRONMENTAL CONSEQUENCES OF WATER DEVELOPMENT VIS-A-VIS DRYING UP OF THE ARAL SEA

In 1999-2000, a project was implemented in the Uzbek territory of the Aral Sea by SIC ICWC together with Mountain Unlimited, SIBICO International, Gosecomeliovod, and DHV Consultants BV. The National ecological society of the Republic of Kazakhstan (NES RK) also took part in this project from the Kazakh side.

While assessing and analyzing the causes of nature degradation in Prearalye, such as

- reduction of inflow to the delta and the sea;
- lowering of groundwater level;
- development of autonomous groundwater regime;
- increase in groundwater salinity;
- desertification, with development of aeolian processes, salt- and dust transport,

the researchers studied:

- soil-natural systems (soil maps of Prearalye),
- vegetation in Prearalye (riparian woodland (tugai));
- productivity of artificial and natural landscapes;
- bird population;
- productivity of fish.

As a result, the social, economic, and environmental damage categories and direct and indirect damage were determined. Additionally, the consequent losses were evaluated.

Thanks to the INTAS Programme, the participants of this joint project have made major efforts to analyze and generalize available data and assess the socio-economic damage caused to South Prearalye due to the shrinkage of the Aral Sea.

One may call in question the accuracy of the data collected and methodological approaches applied; however, the finding that the sacrifice of the Aral Sea to regional development causes an annual damage of more than $100 million in South Prearalye is true.

The research results allow making the following conclusions. As defined in the “Concept of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan on the solution of the Aral Sea and Prearalye problem through the lens of socio-economic development in the region”[6] (1993), the zone of major negative impact of the dried up Aral Sea comprises four districts of Karakalpakstan (Muynak, Bozatau, Kungrad, and Takhtakupyr) in Uzbekistan and two districts of Kzylorda province (Aralsk and Kzylorda) in Kazakhstan.

The Aral Sea Basin is an inland catchment, which has no connection with an ocean, and therefore, any transformations in natural runoffs and an increase in water consumption in the catchment area and the adjacent territory inevitably were meant to lead to the reduction of inflow into the Aral Sea and, consequently, to degradation of the sea. First ideologists of irrigation development in Russia at the beginning of XX century well understood this and voiced this idea as

[6] http://www.cawater-info.net/library/rus/gov8.pdf

early as in 1908 by Voyekov and later in 1913 by the head of the water sector of the tsarist Russia V. Masalsky. He saw the ultimate aim as the "use of all water resources in this krai and creation of a new Turkistan by developing tens of million hectares of new land and meeting the demand of Russian industry for cotton" [9].

Since 1960, the intensive development of irrigated agriculture and water connected with rapid population growth and industrial development undoubtedly has had a positive effect for social development in the Aral Sea region, although, at the same time, has caused an abrupt increase in intake from rivers and the following reduction of inflow to the Sea. Table 3.1 lists the main parameters of water use in the Aral Sea Basin. They indicate that since the beginning of lowering the water level in the sea, the water intake has increased 1.96 times, but, at the same time, the population has grown 2.7 times, the irrigated area has extended 1.7 times, the agricultural production has increased threefold, and the gross national product has risen as much as almost 5 times by 1990.

Table 3.1 Dynamics of water use since 1940

Parameter	Unit	1940	1960	1970	1980	1990	2000	2003	2005	2010	2012	2015	2017
Population	10^6	10.6	14.1	20.0	26.8	33.6	41.5	43.8	44.0	48.5	50.0	51.5	53.3
Irrigated area	10^3ha	3800.0	4510.0	5150.0	6920.0	7600.0	7890.0	7900.0	8434.0	8244.5	8241.6	7757.4	8093.1
Total water intake	km^3/year	52.3	60.6	94.6	120.7	116.3	100.9	118.0	116.3	109.9	102.7	107.2	103.2
incl., for irrigation	km^3/year	48.6	56.2	86.8	106.8	106.4	90.3	109.6	91.4	92.3	84.9	93.6	95.4
	m^3/ha	13763.2	13439.0	18361.2	17440.8	15298.7	12784.5	14936.7	13794.2	13325.2	12466.0	12059.4	11781.7
Water use	m^3/pers/yr	4934.0	4298.6	4728.0	4503.4	3460.4	2430.6	2695.3	2645.9	2267.3	2056.8	2082.0	1935.2
GDP	\$$10^6$	12.2	16.1	32.4	48.1	74.0	54.0	34.4	29.5	78.2	111.3	138.4	124.3

In the recent three decades, since 1960 to 1990, the irrigated agriculture and associated sectors, including manufacturing industry for agriculture, processing industry, hydropower, construction and operation sectors produced over 50% of the gross total product in the region. Moreover, it provided the larger proportion of employment for rural population in the region, with the latter accounting for 60% on average of the total population. The annual gross product in the sectors related to water use grew almost by $30 billion a year under the former Soviet economic system in these thirty years. However, even now, given a sharp drop in agricultural product prices, this growth in the absolute values is more than $10 billion a year as compared to 1960. At the same time, the proportion of the product of water use, including agriculture, hydropower and associated sectors, has decreased to 18-24% in different countries of the region by 2000 [10]. Undoubtedly, an abrupt decline in production in the region as a whole, an increase in the share of mineral stock, particularly of fuel mining and processing, and the decreased attention to the water sector have affected efficiency of water use. Characteristically, the observed deterioration of water uses in terms of their effect on environmental indicators turned to be well lower that the rates of declines in many industries.

To be fair, the GDP and the agricultural production volume should have been well higher with the development of water if two potential directions for improvement of multipurpose water use had been taken into account in the Soviet period:

- rapid adoption of water-saving technologies as was the case in new irrigation systems of the Golodnaya, Karshi and Kyzylkum steppes, where the system performance achieved 0.75 against the average 0.56-0.60 and where water productivity was 0.2-0.3 $\$/m^3$ against the basin average of 0.11-0.13 $\$/m^3$ [11];
- improvement of product processing in irrigated agriculture in the region instead of prevailing orientation to meeting the metropolitan demands for raw materials and wider employment of population in the production of final product. Currently, Kazakhstan, Turkmenistan and Uzbekistan follow this direction; however, time was lost.

As calculations demonstrate, if the above-mentioned directions had been taken into account in the Soviet period, the total water diversions could have been limited at 86 – 95 km^3/year so that to maintain the water level in the Aral Sea at 35 m +BSL.

The drying up of the Aral Sea has had the following consequences:

- intensive desertification in the area of Prearalye;
- drastic reduction in lakes and their areas due to abrupt decrease of the runoff of the Amu Darya and discontinuance of flood and watering in the river floodplain. There are about 10 lakes there at present. Their total water surface area widely varies by year and season, not exceeding 75,000 ha. Natural lakes occupy approx. 5,000 ha only but they are also recharged through return water;
- progressive soil salinization. In 1975, 43% of irrigated land was saline in Karakalpakstan. This indicator increased to 80% in 1985 and was as high as 94% in 1997. Development of Aeolian processes and salt and dust transport from the dried seabed and surrounding deserts is the strongest factor of desertification; it is characteristic, that, first, the intensity of salt and dust transport gradually grew and reached its maximum in 1986-1988 and then decreased and the process has stabilized;
- intensive degradation of the soil natural system. Generally over the Prearalye zone, the takyr and solonchak soil area increased by 91,000 ha, solonchak and sand extended by 43,000 ha, fixed and loose sand with spots of desert and sandy soil and solonchak expanded by 130,000 ha. The change in the takyr solonchak soil with the spots of sandy soil and solonchak and in

the grey-brown solonchak soil was insignificant. The area of the meadow-marshy solonchak and non-saline soil decreased by 266,600 ha;

- vegetation changes consistently with landscapes; the area of riparian woodland and reed bushes was reduced several fold. Meadow and riparian woodland landscapes have been replaced gradually with solonchak, takyr and sandy plain landscapes;
- local climate patterns have changed considerably. Microclimate varies within tens of kilometers from the water boundary of the former sea at the level of 1960. On average, summer air temperatures grew by 0.1°-0.4°C and spring temperatures increased by 0.5°-0.7°C. Winter and autumn temperatures decreased by 0.2°-0.6°C and 0.5°-1.3°C, respectively. The daily range of temperatures in the coastal area became wider, while the relative humidity decreased, especially in warm seasons;
- thanks to the construction of a system of artificial lakes, the population of migratory birds has been preserved, especially in the Karajar, Sudochie, and Mezhdurechie systems. It will be possible to keep such a good productivity of bird populations if a planned regulation system for deltaic lakes is implemented. In this context, the most prospective lakes are Sudochie, Mezhdurechie, Djiltirbas, and Karajar;
- fish population in the adjacent lake systems has been reduced more than 20 times.

Because of accelerated recession of the sea, recreation activities have turned to be impossible in the coastal area; the flow of tourists who came for fishing and hunting also has diminished.

As estimated, direct losses in the area of South Prearalye amount to (on a year-on-year basis), in $ million:

- 6.55 in irrigated agriculture;
- 28.57 in fish farming and fishing;
- 4.0 in muskrat catch;
- 8.4 in the livestock sector;
- 11.16 in recreation and tourism.

The total in agriculture is 58.68.

- 9.0 in fish industry;
- 18.0 in fur processing;
- 12.6 in reed processing;
- 1.0 in vehicles.

The total losses in industry are 40.6.
Overall in production – 99.28.

- Indirect losses – 16.74;
- Social losses – 28.81.

Thus, the cumulative direct and indirect socio-economic losses from the environmental disaster in Prearalye were estimated at $144.83 million.

Past and newly developed projects allow estimating preliminary the total cost of hydrotechnical constructions that will ensure more or less stable water supply and watering of Prearalye. Approximately $91 million are needed for permanent and temporary lakes, and the cost of maintenance of the Western Sea is about $140-160 million. More detailed estimations will show which part of ecosystem can be recovered and which damage can be reduced. However, even now it becomes evident that the size of annual damage to South Prearalye is virtually the same as a value of necessary investments.

Evaluation of socio-economic and environmental damage in North Prearalye at the level of the year 2002 by SIC ICWC [12] has provided the following figures:

Direct losses on a year-on-year basis amount to (in $ million):

- 13 in irrigated agriculture;
- 2.6 in fish farming and fishing;
- 0.3 in muskrat catch;
- 8.2 in the livestock sector;
- 4.3 in recreation and tourism.

The total in agriculture is 28.4.

- 0.8 in fish industry;
- 2.2 in fur processing;
- 2.6 in in reed processing;
- 0.3 in vehicles.

The total losses in industry are 5.9

Overall in production – 34.3.

Indirect and social losses – 13.66

Thus, the cumulative direct and indirect socio-economic losses from the environmental disaster in North Prearalye amounted to $47.96 million.

State of socio-economic affairs in Prearalye

The years 2000-2001 that were baseline for estimation of damage in Prearalye have closed the period of economic free fall in this region and in Uzbekistan as a whole. Since then, the population in Prearalye has increased by 155,400 or 16.3% by 2018. Nevertheless, people keep migrating from some areas of Prearalye. As of January 1, 2018, the number of migrants (thousand) was: 3.6 in the city of Nukus; 1.3 in Chimbay district; 1.2 in Khojeili district; 1.1 in Kegeily district; and, 0.9 in Takhiatash district[7]. This is caused by a range of socio-economic circumstances and the unstable environmental situation in Prearalye.

In 2001, the total area of unused irrigated land was 227,600 ha in Karakalpakstan, including 156,000 ha in Prearalye, whereas in 2011, this area was estimated at 183,600 ha and 138,000 ha, respectively, i.e. the bulk of unused land in Karakalpakstan was in Prearalye.

[7] http://www.qrstat.uz/images/PRESSRELIZLER/2017/Demografiya/yanvar-dekabr_ru.pdf

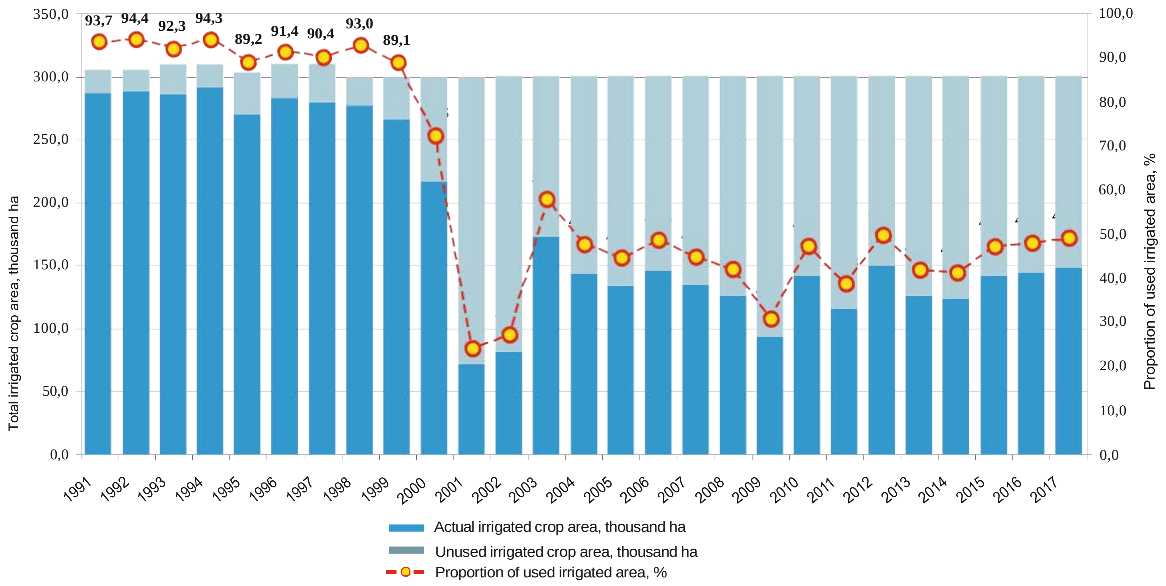


Figure 3.1 Dynamics of irrigated cropland use in Prearalye

Land productivity in Prearalye and in Uzbekistan in general widely varied from 1995 to 2002. However, a tendency towards rapid growth of these indicators has been observed since 2002. The critical level of these indicators is observed in dry years (1998, 2000-2002).

Additionally, land productivity is well lower in Prearalye than in Uzbekistan as a whole. Land productivity averaged 250.3 $/ha in Prearalye or this was 2.2 times lower that the average of 559.8 $/ha in the republic in 1995, whereas this indicator was 691.3 $/ha or almost 4 times lower than the average of 2 483.2 $/ha in the republic in 2017. This can be explained by different reasons: cropping patterns (more than 55% in Prearalye is under cotton and wheat, while in other provinces of the republic the proportion of cash crops is well higher); soil salinity, crop production technology (crop growing under film is widespread in the Andizhan province); and, labor resources (labor deficit is especially observed in Karakalpakstan).

In the period from 1991 to 2017, wheat acreage has substantially increased (11.2 times) and reached 44,200 ha in Prearalye. Slight increase was observed in crop acreage of potato (by 1,600 ha), vegetables (by 2,500 ha), and grapes (by 0,700 ha). Such increase has become possible through the reduction of crop acreage under fodder crops (10 times – 90,300 ha), rice (2.6 times – 49,900 ha), cotton (almost twofold – 36,800 ha), and corn (3.6 times – 4,500 ha) (Table 3.2).

Table 3.2 Dynamics of changes in cropping patterns in Prearalye

	1991	1995	2000	2005	2010	2015	2017	Change in 2017 against 1991, thousand ha
Wheat	3.9	15.1	25.9	44.8	46.2	44.4	44.2	40.3
Corn	6.2	6.4	6.4	0.4	0.7	1.5	1.7	-4.5
Rice	81.7	87.1	51.0	13.8	27.9	27.9	31.8	-49.9
Cotton	78.4	73.7	67.0	46.5	42.7	43.0	41.6	-36.8
Potato	0.5	0.7	0.4	0.5	3.7	1.9	2.1	1.6
Vegetables	4.1	4.7	4.5	3.4	3.6	6.2	6.7	2.5
Cucurbits	9.0	4.2	4.9	2.7	3.6	6.1	8.0	-1.0
Fruits and berries	2.8	2.8	2.2	1.2	1.6	1.9	2.0	-0.8
Grapes	0.1	0.2	0.2	0.2	0.3	0.4	0.8	0.7
Fodder crops	100.3	76.3	55.2	21.2	12.8	9.6	9.9	-90.3
Total crop acreage	**287.0**	**271.2**	**217.6**	**134.7**	**142.9**	**143.0**	**148.9**	**-138.2**

Source: author's calculations using the data from the Uzbek Statistical Agency.

Moreover, as mentioned above, due to shortage of water, the crop acreage in Prearalye was reduced by 138,200 ha as compared to 1991 and totaled 148,900 ha in 2017. An abrupt drop in acreage of the main crops was observed in dry years. By contrast, a moderate growth in the acreage of potato, fruits, vegetables, cucurbits and grapes has been observed since 2005.

As Figure 3.2 shows, given the land and water status and natural-climatic conditions in Prearalye, the positive changes in the shares of crops grown have not been observed.

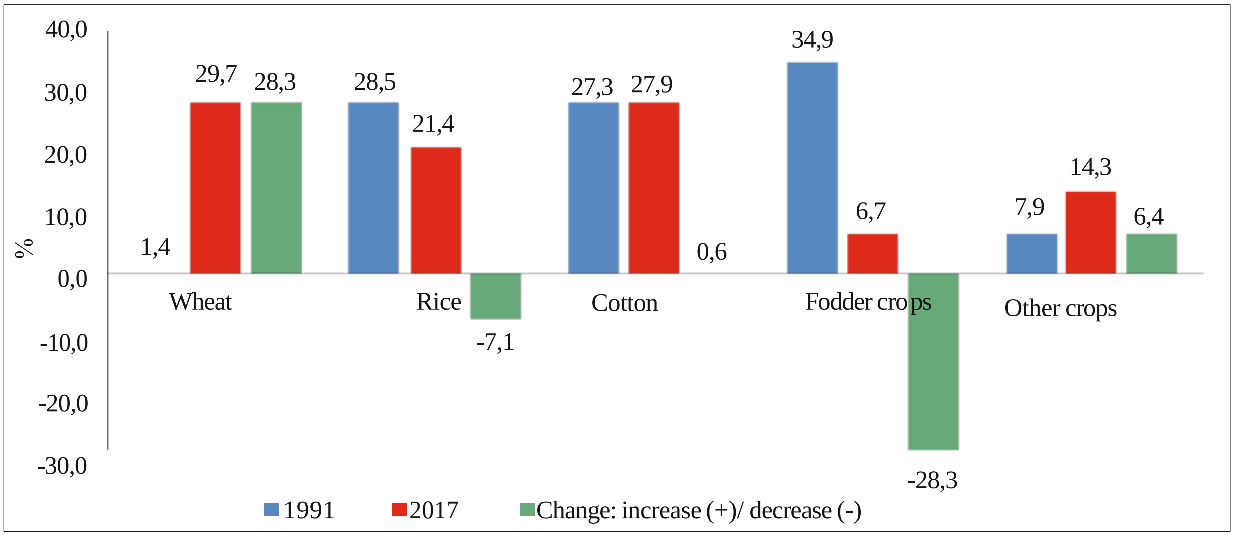


Figure 3.2 Dynamics in shares of crops grown in Prearalye

Source: author's calculations using the data from the Uzbek Statistical Agency

Thus, in 1991 in the Prearalye zone the shares of crops were like: wheat – 1.4%; rice – 28.5%; cotton – 27.3%; fodder crops – 34.9%; and, other crops – 7.9%; whereas in 2017, we observed the following picture: wheat – 29.7%; rice – 21.4%; cotton – 27.9%; fodder crops– 6.7%; other crops – 14.3%.

The high growth rate of production of the next crops have been observed in Prearalye over the analyzed period of time: wheat – 27.7 times or 86,400 t higher as compared to 1991 (the growth factors are the increased acreage and yields); grapes –35.7 times or 2,700 t higher (mainly, because of increased yields and partially through acreage); potato –23.9 times or 23,900 t higher (the growth factors are the same as for grapes).

However, production of vegetables, fruits, berries, and cucurbits showed the moderate rise as compared to 1991 (vegetables – 3.1 times or 75,900 t higher; fruits and berries - 2.3 times or 7,200 t higher; and cucurbits – 1.1 times or 6,200 t higher (Table 3.3).

Table 3.3 Dynamics of changes in crop production in Prearalye

	1991	1995	2000	2005	2010	2015	2017	Change in 2017 against 1991, thousand ha
Wheat	3.2	21.8	52.2	104.9	113.8	89.3	89.7	86.4
Corn	11.5	4.7	0.7	0.6	1.8	4.6	4.2	-7.3
Rice	273.1	120.8	6.6	25.6	60.2	49.1	74.2	-198.9
Raw cotton	127.6	136.8	53.5	91.6	78.1	80.3	82.6	-45.0
Potato	1.0	1.5	0.6	2.9	15.4	21.0	25.0	23.9
Vegetables	36.1	34.1	7.8	16.3	66.6	128.8	112.0	75.9
Cucurbits	70.2	24.5	8.2	14.8	40.7	70.2	76.4	6.2
Fruits and berries	5.5	4.5	2.7	2.2	8.8	13.4	12.7	7.2
Grapes	0.1	0.3	0.6	0.7	1.4	2.3	2.8	2.7

Source: author's calculations using the data from the Uzbek Statistical Agency.

In the meantime, production of some agricultural crops (e.g. rice, raw cotton and corn) has decreased substantially through the reduction of acreage and yields. For instance, production of rice has decreased 3.7 times or by 198,900 t as compared to 1991. Production of raw cotton has dropped 1.5 times or by 45,000 t and that of corn has lowered 2.8 times or by 7,300 t. Production of all crops, except for wheat and grapes, has decreased dramatically in dry years (2001-2002 and, consequently, 2003). Despite the rapid growth in production of the main types of agricultural crops per capita, the current consumption of such crops remains low (except for vegetables and cucurbits) as compared to recommended physical standards (Table 3.4).

Table 3.4 Dynamics of production of the main types of agricultural crops per capita in Prearalye, kg/year

Year	Potato	Vegetables and melons	Fruits and berries	Grapes
2000	0.7	16.8	2.8	0,6
2005	2.9	31.7	2.2	0,7
2010	15.0	104.1	8.5	1,4
2015	19.4	184.0	12.4	2,2
2017	22.5	170.0	11.5	2,5
Recommended norm[8], kg/year	**54.6**	**119.4**	**65.9**	

Source: author's calculations using the data from the Uzbek Statistical Agency.

All crops, except for rice, have demonstrated growing average yields over the analyzed period in Prearalye. However, the crop yields vary depending on available water resources in the year (Table 3.5).

Table 3.5 Dynamics of average crop yields in Prearalye

	1991	1995	2000	2005	2010	2015	2017	Change in 2017 against 1991, centner/ha
Wheat	7.0	13.5	16.6	23.8	32.3	16.8	23.1	16.2
Corn	17.3	6.9	7.7	14.8	28.8	25.2	24.7	7.4
Rice	23.3	10.9	11.4	15.8	16.7	15.3	22.2	-1.1
Cotton	10.4	12.9	6.7	14.8	12.1	14.1	16.9	6.5
Potato	17.1	18.2	34.2	45.3	67.6	78.9	105.4	88.3
Vegetables	64.0	50.2	47.8	63.4	133.5	144.9	161.3	97.2
Cucurbits	59.6	48.2	44.4	51.5	104.3	94.7	104.3	44.6
Fruits and berries	30.9	31.6	17.6	27.5	64.9	85.4	84.9	54.0
Grapes	17.8	17.3	21.6	33.4	17.3	60.3	83.5	65.7

Source: author's calculations using the data from the Uzbek Statistical Agency.

[8]Reference intake recommended by the Uzbek Ministry of Health.

Despite this growth, the average yields of main types of crops in Prearalya remain low as compared to south of Karakalpakstan and the Republic of Uzbekistan as a whole. At present, the average wheat yield in Prearalye is 38.2% lower than in south areas of Karakalpakstan and almost half the republican average (Figure 3.3).

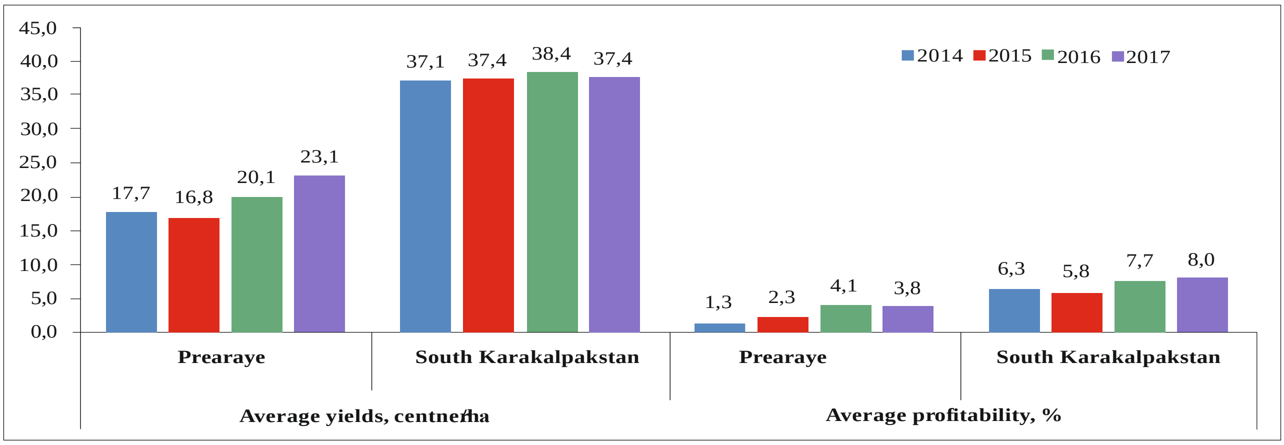


Figure 3.3 Comparative assessments of average wheat yield and profitability dynamics in Prearalye

Source: author's calculations using the data from the Karakalpak Ministry of Agriculture and the Uzbek Statistical Agency

Moreover, in 2017, given the growth of average wheat yield (from 20.1 centner/ha to 23.1 centner/ha), the average profitability of wheat decreased (from 4.1% to 3.8%) as compared to the last years, while in south areas of Karakalpakstan, in contrary, the wheat yield decreased, while profitability slightly increased.

Similar trend is observed for average yield and profitability of raw cotton. For instance, given the growth of average cotton yield in Prearalye by 1.9 centner/ha since the last year, the average profitability of cotton was 0.4% lower. In the south of Karakalpakstan, the growth of average yield of cotton was 0.3 centner/ha, while the average profitability of this crop decreased by 8.9% (Fig. 3.4).

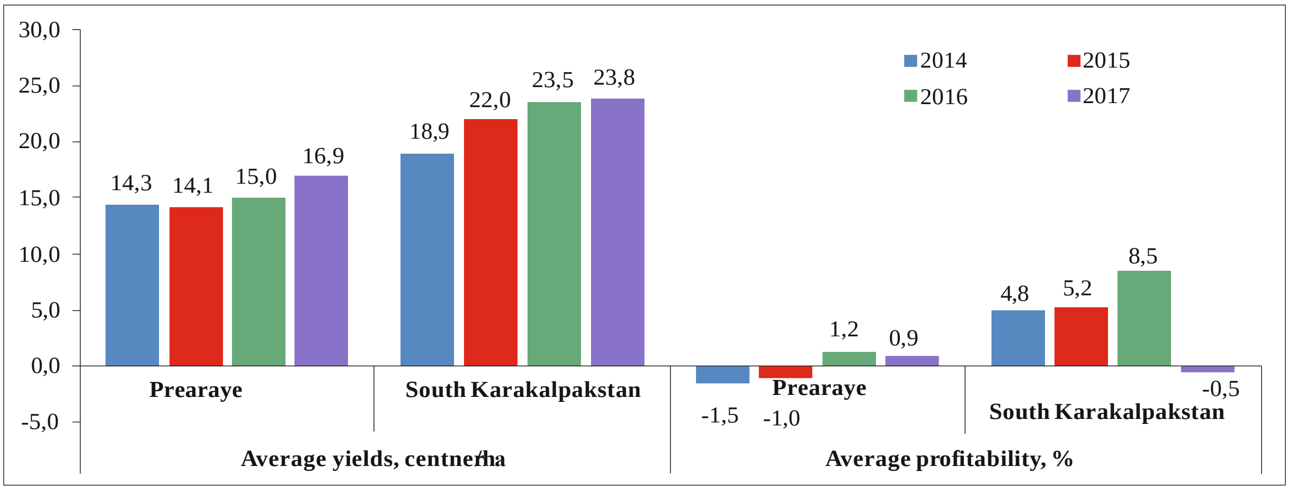


Figure 3.4 Comparative assessments of average cotton yield and profitability dynamics in Prearalye

Source: author's calculations using the data from the Karakalpak Ministry of Agriculture and the Uzbek Statistical Agency

As is clear from the above analysis, there is no definite relationship between the yield and the profitability of wheat and cotton production. This can be explained by absence of relationship between production costs and purchasing prices of wheat and cotton, i.e. by disparity between agricultural and industrial output that means unequal cost exchange in terms of expenses and generated income.

During the transition period, this process has become more pronounced since the growth rates of agricultural output prices lag behind the growth rates of prices of industrial inputs for agriculture. Eventually, the unequal cost exchange between these sectors causes that possibilities for accumulation of money in agriculture for its further growth have become more limited[9].

The livestock sector plays the important role in economy of Prearalye. The sector accounted for more than 40.2% of gross agricultural production in this zone in 2017. It is characteristic that most of livestock output is produced by small dehkan (peasant) farms possessing 1 cow and cultivating 0.2 hectares on average. Livestock production in those farms is of social importance as it is the important source of income and food for rural families. Nevertheless, the small size of many livestock farms makes it difficult to adopt up-to-date technologies and causes potential losses in economies of scale that, for example, leads to small milk yields[10].

Development of the livestock sector in Prearalye is restrained by the shortage of fodder resources for breeding healthful animals and the lack of quality service infrastructure for livestock farmers. The above analysis of crop acreage showed that the area under fodder crops has been reduced by 90,300 ha over the analyzed period in Prearalye.

One of the key factors that influence gross livestock production is the herd expansion. However, the expansion of animal population was not accompanied by appropriate increase in production of fodder crops for animals. For instance, as compared to 1991, in 2017, the cattle population in Prearalye increased 2.3 times or by 297,600 heads, of which cows – 1.9 times or by 75,200 heads, sheep and goats increased 1.7 times or by 245,600 thousand heads, and poultry population become 1.8 times or by 0.7 million heads more (Table 3.6).

Table 3.6 Dynamics of population of livestock in Prearalye

	1991	1995	2000	2005	2010	2015	2017	Changes in 2017 as compared to 1991
Cattle, thousand heads	232.4	227.3	207.9	239.7	377.4	451.3	530.0	297.6
of which: cows, thousand heads	86.1	92.2	87.0	98.3	128.1	146.8	161.3	75.2
Sheep and goats, thousand heads	367.5	314.8	278.0	338.6	445.4	550.3	613.1	245.6
Poultry, million heads	0.9	0.4	0.4	0.4	0.7	1.3	1.7	0.7

Source: author's calculations using the data from the Uzbek Statistical Agency.

9 http://www.cer.uz/upload/iblock/4ed/2012_04_xmwhxvwygtcpqp%20bkgdrywulhsjjalewhid%20yqboaf%20 whcomqrucmrmleottoiety%20lwpfwjbrbwjeawfcenvgnkxzno.pdf

10 http://www.uz.undp.org/content/dam/uzbekistan/docs/Publications/UN-Publications/Pb_Livestock/un_uzb_PB_ Livestock_rus.pdf

The main livestock products in Prearalye include cattle and poultry meat, milk, and eggs. Over the analyzed period of time, production of meat increased 25.5% or by 6,000 tons, production of milk rose by 85.5% or 77,400 tons, and that of eggs increased 67.1% or by 47.3 million (Table 3.7).

Table 3.7 Dynamics of livestock production in Prearalye

	1991	1995	2000	2005	2010	2015	2017	Change in 2017 as compared to 1991
Meat, thousand t of slaughter weight	23.6	13.6	11.6	12.0	16.5	25.9	29.6	6.0
Milk, thousand t	90.5	78.0	55.4	55.1	74.8	161.1	167.8	77.4
Eggs, million	70.4	21.2	10.8	13.4	20.5	98.5	117.7	47.3

Source: author's calculations using the data from the Uzbek Statistical Agency.

The current volume of livestock production, including meat, milk, and eggs does not meet the requirements of balanced nutrition. As is seen from Table 3.8, per capita production of meat, despite an upward trend, is 26.8 kg/pers/year, i.e. almost less than half the recommended consumption norm. Per capita production of milk is 151.5 kg/pers/year or 3.2% lower than recommended, while production of eggs is 106.3 kg/pers/year or threefold lower than the norm.

Table 3.8 Dynamics of per capita livestock production in Prearalye

Year	Meat	Milk	Eggs
2000	12.1	58.2	11.4
2005	12.2	56.2	13.7
2010	16.1	72.7	19.9
2015	23.9	149.0	91.1
2017	26.8	151.5	106.3
Recommended norm[11], kg	**46.1**	**156.3**	**295.0**

Source: author's calculations using the data from the Uzbek Statistical Agency.

It should be noted that Prearalye has gained industrial orientation by present. According to expert opinion, in near future, industrial growth in Karakalpakstan will be related to the development of hydrocarbon deposits on the Ustyurt Plateau in Muynak and Kungrad districts. Production of metals on the base of Tebinbulak and Zinelbulak deposits, of cement and vermiculite in Karauzyak district and other kinds of construction materials seems to be promising almost in all districts of Karakalpakstan[12].

Hence, the above analysis can be considered as a follow-up of the INTAS Project's analysis, and the project results and recommendations can still be relevant for socio-economic development in Prearalye.

The project INTAS ARAL-2000-1059 was implemented in the Kazakh territory of the Aral Sea by SIC ICWC in cooperation with Mountain Unlimited, National Environmental Society of the Republic of Kazakhstan (NES RK), SIBICO International, and DHV Consultants BV in 2001-2004. In contrast to South Prearalye, the Syr Darya delta has quite different morphology and hydrology. The detailed research of the delta has been completed by Cand. Sc. (Geography) Budnikova, Cand. Sc. (Engineering) Ruziev, Eng. Bensman, and economist Prikhodko.

[11] Consumption norm recommended by the Uzbek Ministry of Health.

[12] http://www.uz.undp.org/content/dam/uzbekistan/docs/Publications/economicgovernance/Investment_Guide/un_uzb_Invest_in_Karakalpakstan_rus.pdf

The deltaic system of the Syr Darya, unlike the Amu Darya delta, has the central regulator in the shape of Mezhdurechie reservoir and ends in the Northern Aral Sea, which accumulates the river runoff after the latter passes the delta (Dukhovniy 2017).

By project evaluations, the socio-economic development in the Kazakh territory of Prearalye is characterized by very low production and consumption of material goods. In 2000, the gross product in this region accounted for 2.4% in the national gross domestic product (GDP) and was the lowest one among provinces in Kazakhstan. Kzylorda province's GDP has increased its value 2.7 times since 1995 and reached 56,450.5 million tenghe in 2000. In 2017, the gross product of Kzylorda province amounted to 1.3 trillion tenghe.

In wet years, the sediment budget in the estuary of the Syr Darya becomes negative because of intensive inflow (including solids also) via the Kokaral Dam. Proximity of the Syr Darya estuary and the spillway of the dam make the estuarial geomorphological system highly sensitive to any changes in flow and water level in the sea.

Based on Malkovskiy's report (NATO SFP 980986 Project, 2004 … 2007), the Kazakh branch of SIC ICWC determined the area of delta watering in 2005 at 97,600 ha, given the current design estimation of 105,700 ha and the actual water input for watering of 1.12 km^3, although, in their opinion, the design demand is net 1.2 km^3/year or gross 1.8 km^3/year. Thus, the research estimates the total (average annual) water demand of the Syr Darya delta at 1.7 km^3 a year, including 1.3 km^3 for dry year and 2.7 km^3 for wet year.

According to Kipshakbayev's data (Kazakh branch of SIC ICWC), before the intensive development of irrigation, 4-5 km^3 a year has flown into the delta of the Syr Darya River. The natural-economic system comprised of lakes, hayfields, tugai (riparian woodland), wetlands, etc. developed sustainably. However, later on, watering of the delta was reduced drastically.

For the construction period of the Kokaral Dam, the delta area was estimated only for those years, when the water level in the North Aral Sea corresponded to modern one - 1985 and 1998. In other cases it was impossible to get reliable estimation of the delta's boundaries as the water level varied widely. The delta area extended from 2,025 ha in 1998 to 3,905 ha in 2017. Changes in runoff of the Syr Darya and consequent variations of the water level during 2006-2017 have undoubtedly influenced the accuracy of area estimations. Nevertheless, the expansion of delta area is visual [13].

Analysis of delta area dynamics shows that given the general upward trend, this process is not regular. In 2009-2011, after the wet year 2010 the delta area slightly decreased in 2011 as compared to 2009. Similar picture was observed in 2016-2017.

The Syr Darya delta downstream of Kazalinsk comprises several independent lake systems that disconnect from the river channel and are fed by river runoff, mainly, during floods that have shifted to winter by present. The current water-related conditions of the Syr Darya delta are shaped by changed inflow to upper delta (Kazalinsk gauging station), flow dynamics, and the state of hydrotechnical constructions.

Because of drop in water level of the Aral Sea in 1987, the water body was divided into two bowls: Small (Northern) Aral Sea and Large (Southern) Aral Sea. The Northern Aral Sea had the positive water balance and the excess of flow was discharge into the Southern Sea. Due to growing difference between water levels in northern and southern bodies of the Aral Sea, the bed of sill has gradually eroded. This has led to lowering in water level of the Northern Sea and could cause its degradation. Finally, it was decided to construct a dam between those two bodies of the sea. The first attempts were made in the 1990s.

In 1993, the Kazgiprovodkhoz Institute developed a feasibility study for construction of the Kokaral barrier to regulate the water level and regime in the northern shallow basin of the Aral Sea and in the Syr Darya delta. The project was completed. However, due to winter water releases from the Toktogul reservoir in 1993-1994, water overflew through the barrier crest and caused break of the barrier. After construction of a sandy barrage in 1999, the water level in the Northern Aral Sea rose to 42 m +BS; however, storm surges destroyed the barrage and the water level dropped to record low 36.8 m +BS that year (Dukhovniy 2017; Kipshakbayev et al. 2010).

The Syr Darya Control and Delta Development Project was implemented by Italconsult and Electroconsult as part of the Aral Sea Basin Program supported by the World Bank in 1996. The project aim was to improve ecological and socio-economic conditions in Prearalye through restoration and preservation of the Northern Aral Sea and rehabilitation of ecosystems in the Syr Darya delta. The project consisted in a preliminary feasibility study. Based on this study, the CEG/SOGREAH/Kazgiprovodkhoz has developed the project "Syr Darya Control and Northern Aral Sea". The project in the Kazakh territory of Prearalye offered:

1. Construction of the Northern Aral Sea (NAS) dam

The dam across the Bergh's Strait together with the Kokaral structure was constructed following the Kazgiprovodkhoz's design from 2002 to 2005 and the Kokaral dam was put into operation on the 8th of August 2005. As early as in spring 2006, the water level in NAS rose to the design elevation of 42 m +BS (Dukhovniy 2017).

Figure 3.5 Dam of the Northern Aral Sea

Results:

1. The risk of full disappearance of the northern part of the Aral Sea avoided;

2. The water level in the Northern Aral Sea rose by 4 meters (from 38 to 42 m +BS);

3. The water volume in the sea augmented by 9 km^3 (from 18 to 27 km^3) and the water surface area extended to 634 km^2;

4. Water salinity decreased from 23 to 17 g/l (0-5 g/l in estuary of the Syr Darya);

5. Commercial harvesting of fish increased from 400 kg to 8,000 t/year;

6. Flow capacity of the Aklak structure rose from 60 to 400 m^3/s;

7. Inflow to the Syr Darya delta and the Northern Aral Sea increased;

8. Lake systems started to be fed regularly, and their area extended to 6,250 ha, and the area of hayfields increased to 7,000 ha;

9. Wetlands in Prearalye recovered.

The NAS dam is to maintain the water level in the sea at 42 m +BS. In the years of average water inflow, the upstream water management will ensure sufficient inflow to NAS to maintain its level, without the need for spills. In dry years, even in case of reduced intakes in the delta and upstream, the water level will lower. In wet years, when all system needs can be met, the flow of the Syr Darya River may exceed NAS capacities, and water will be passed through a spillway into the Large Aral Sea (LAS). These spills will reduce salinity of water in NAS. This is supported by the data provided by M. Narbayev, Deputy Director of the Executive Board of the IFAS Republic of Kazakhstan ("Experience and Prospects of Projects and Programs in the Kazakh Territory of Prearalye") as shown in Table 3.9.

Table 3.9 Implementation of SYNAS-1 Project in the Kazakh territory of the Aral Sea basin as part of ASBP-1 and -2

Year	Level, m +BS	Volume, km^3 (LAS/NAS)	Area, km^2 (LAS/NAS)	Salinity, g/l (LAS/NAS)	Inflow from the Syr Darya River (million m^3)		
					Total	to LAS	to NAS
1990	38.3	335	35200	32/32	2400	-	-
1995	36.1	250	28200	42/42	1600	-	-
2000	33.6	169/21.6	22200/2900	63/17	3865	-	-
2005	30.3	22.1	2940	98/10.3	9888	4318	5570
2015	41.9	25.1	3246	100/11	5538	3090	2448
2018	42.05	---/25.2	---/3306	130/11	5943	2814	3129

2. Reconstruction of Kzylorda barrage

The barrage was put into operation more than 50 years ago and has had no major repairs over this period of time. By present, an offtake regulator has been in critical condition and needed to be reconstructed. Therefore, the project aim was to ensure safety of this structure and sustainable water supply to 63,200 ha of irrigated land and about 250,000 ha of pastures and hayfields.

3. Construction of Aitek structure

Figure 3.6 Complex of structures "Aitek"

Results:

1. The carrying capacity of the Syr Darya River increased from 300 to 760 m^3/s;
2. Available water supply improved for 15,300 ha of irrigated land;
3. Releases of water increased into the Aral Sea;
4. Syr Darya River channel stabilized and flooding of the Kzylorda city reduced.

4. Reconstruction of Kazalinsk barrage

Figure 3.7 Kazalinsk barrage

5. Construction of deltaic hydraulic structures, including:

a) Raim structure with water distributors for lake systems;

b) Aklak structure with water distributors for lake systems;

c) feeder of Aksai-Kuvandarya lake system.

6. Construction of Terenozek bridge

7. Construction of flood protection dikes along the Syr Darya River

Further steps for the improvement of socio-economic and environmental conditions in North Prearalye (Executive Board of the International Fund for saving the Aral Sea in the Republic of Kazakhstan):

1. **Reconstruction of offtake regulator of left-bank main canal (LMC) at Kzylorda barrage**

2.

Figure 3.8 Reconstruction of LMC offtake regulator at Kzylorda barrage

2. **Syr Darya River bed straightening**

1. Protection of Tan, Aksu and Zhalagash settlements with population of more than 10 thousand people from flooding and erosion of river banks during releases of high water discharges in winter;

2. Protection of motor roads, irrigated land, irrigation and collector-drainage networks from flooding.

3. Flood protection dikes

Protection from periodic winter high water releases from the Shardara reservoir, not regulated by the Koksarai counter-regulator in rare return years, as well as under ice jam in the river bed. The settlements to be protected include Bekarystanbi, Tuktibaev and Urkendeu in Kazalinsk district and Zhanajol and Akjar in Karmakchi district.

Protection of railroad and motor-road sections, irrigated land, and irrigation and collector-drainage networks.

4. Bridge near Birlik settlement in Kazalinsk district

Project purpose:

1. Improvement of carrying capacity of the Syr Darya River bed by destructing the pontoon ferry;

2. Provision of year-round reliable motor transport communication for economic entities and population situated on both banks of the the Syr Darya River;

3. Creation of favorable conditions for transit motor transport.

5. Kamyshlybash and Akshatau lake systems

1. Rehabilitation of Kamyshlybash and Akshatau lake systems in the lower reaches of the Syr Darya River;

2. Provision of water supply to wetlands on the total area of 40,450 ha, including lakes– 33,979 ha and swamps – 6,480 ha;

3. Improvement of social-economic and sanitary-epidemiological conditions in the region.

6. Extension of fishery ponds at Tastak site of Kamyshlybash fish hatchery in Aralsk district

1. Accelerated recovery of fish productivity in NAS, delta lakes and the Syr Darya River;

2. Creation of opportunities for fish breeding;

3. Creation of new jobs for the local population.

Green Belt Project – Protection from salt and dust transportation from the dried bed of the Aral Sea

To mitigate the direct impact of salt and dust transportation from the dried seabed and protect population, settlements, agricultural land and flora and fauna in Prearalye, it is planned to create a multilayered “Green Belt”. The design extension of the Belt is to be about 70 km and the width will be 200-1000 meters. The Belt is to serve as a special ‘environmental protective screen’ for the project territory. The plants in the Belt will be irrigated by drainage water from the Kazalinsk lef-bank irrigation scheme, excess water from Aksai and Kuandarya lake systems, and eventual water releases from the Syr Darya River.

The project economic benefits consist in reclaimed diversion of wastewater from irrigation schemes, with following improvement of water management, and in improvement of water-salt regime of irrigated fields.

Greening of Zhanakurylas settlement in Aralsk district – 7.5 ha

The Project provides for planting trees and shrubs in a park on an area of 4.5 ha located in central part of the settlement, as well as in the zone of new secondary school. It is planned to plant elm tree, poplar, osier and maple there.

The Executive Board of IFAS in Kazakhstan together with partners pushes the idea of a geo-park on the base of Barsakelmes nature reserve. The first geo-park in Kazakhstan is proposed under the name of the «Aral Sea Geo-park». The proposed geo-park meets most of relevant UNESCO's criteria, including availability of historical monuments, geological heritage, paleontological features, eco-tourism routes, NGO for partnership, etc.

Establishment of a Prearalye Center for wildlife adaptation to climate change. The project objective is to preserve and restore populations of rare and red-listed hoofed animals (saiga, Persian gazelle, kulan, Mongolian wild horse) by breeding them in semi-captivity and then reintroducing them in wildlife.

Establishment of a scientific-touristic center "Aral" at Kamystybas Lake to coordinate research in the Kazakh territory of Prearalye and develop infrastructure for educational tourism. This analytical center is expected to maintain a single regional monitoring system for environment and nature resources in Prearalye.

Creation of a network of hydro-meteorological and agro-climatic stations (Barsa-Kelmes, Akbasty, Shokusy) within Prearalye (Fig. 3.9) to arrange relevant monitoring in the depression of the Aral Sea.

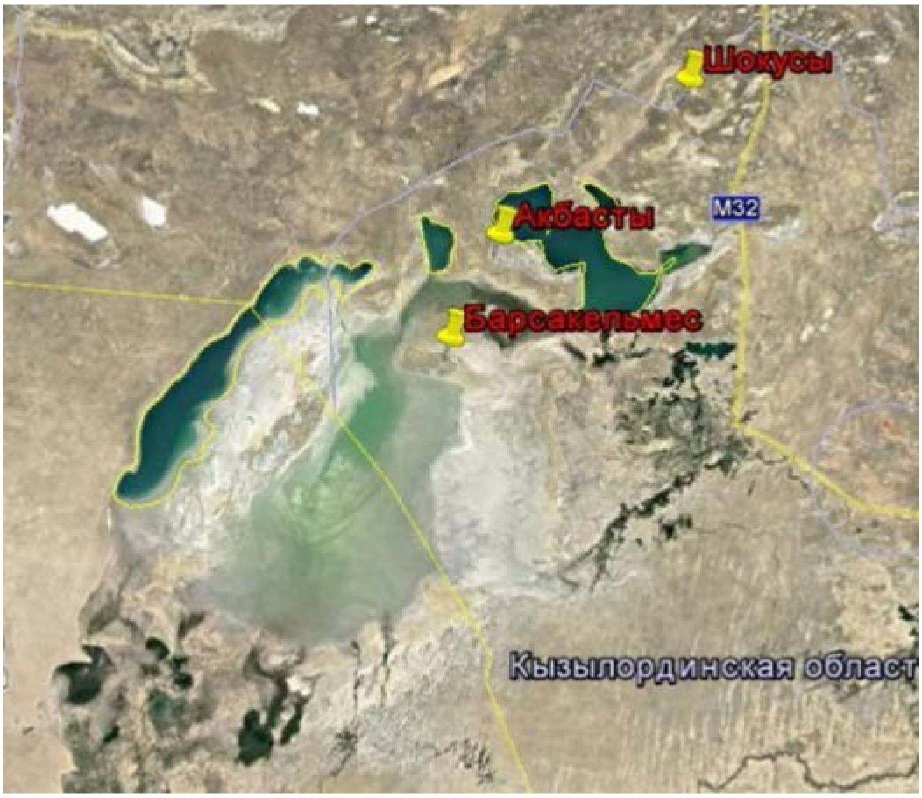


Figure 3.9 Meteorological and agro-meteorological stations Barsa-Kelmes, Akbasty and Shokusy

Automation of water record-keeping system at hydraulic structures of the Syr Darya River. The aim is to improve water management by equipping hydraulic structures with modern water metering facilities.

Restoration of Akkol Lake for fishery and irrigation of the Syr Darya delta front. As a result of the project, it is expected to have: monitoring of flow rates along canals and water levels in Akkol Lake on a real-time basis; the software for on-line computation of flow rates in canals to ensure planned water supply to the lake; improved agricultural production.

Construction of recreation centers around hydrothermal water wells in Kulandy, Akespe, Akbasty, Zhanakurlys settlements in the Aral District of Kzylorda province to improve living conditions and health in rural area.

Joint successful activities of the Executive Board of IFAS in Kazakhstan with the Government of Kazakhstan, international and regional organizations, financing institutions and donors can be measured directly by the following indicators (www.kazaral.org):

- preserved Northern part of the Aral Sea;

- increased carrying capacity of the Syr Darya River;

- reduced risks of water-related emergency;

- restored 19 lakes, including 8 lakes important for fisheries;

- wetlands and some area of the Northern Aral Sea (330,000 ha) included into the Ramsar Convention's list;

- rehabilitated traditional fisheries sector, with production of about 8,000 tons a year, including 2,000 tons exported to the European Union;

- restored pastures on approx. 50,000 ha;

- afforested nearly 300,000 ha on the dried bed of the Aral Sea;

- provided access to clean drinking water through construction of new water pipes and reconstruction of existing ones and by water carriers.

Generally, over the last 5 years the Kzylorda province demonstrated:

-14% higher birth rates, increased employment and decreased migration;

- downward trends of: maternal mortality – by 75 %; child mortality – by 22%; and tuberculosis incidence – by 23 %.

The Executive Board of IFAS in Kazakhstan implemented more than 70 projects at the total cost of about 760 million tenghe in the Kazakh territory of Prearalye from 1993 to 2017.

Those projects were aimed to:

-ensure clean water supply to population through the construction of new water pipes and reconstruction of existing ones, desalination of local saline groundwater, provision of regular water carriers, drilling of new water wells (over 1994-2016, settlements were provided with water purifiers, electrodialysis demineralizer and reconstructed water pipes for a total amount of 47.72 million tenghe, 27 water carriers were bought for an amount of more than 47 million tenghe to supply remote settlements in the Kzylroda province with water);

- recharge the dried lakes in the Syr Darya delta and water the pastures and hayfields by constructing new canals and waterworks facilities and reconstruct existing ones;

- address social issues by installing mini-boiler stations and reconstructing autonomous heating systems in schools and kindergartens.

The Eco-monitoring of wetlands and the Northern Aral Sea and their inclusion into the Ramsar Convention can be considered among important environmental projects. In 2012, 330,000 ha became protected under the Ramsar Convention on Wetlands.

The Syr Darya Control and Northern Aral Sea Project, Phase 2 provides for such an option of water delivery and diversion, where a flowing-water two-level body, i.e. the Northern Aral Sea with the water level of 42 m +BS in the existing sea area and 50 m +BS in the Saryshyganak bay is created.

Given the general downward water trend, inflow is set within 5.85 km^3 into the Syr Darya delta (Kazalinsk gauging station) and 4.45 km^3 directly into the sea. With this two-level option, water in NAS is to be divided in the following proportion: 3.15 km^3/year through the Syr Darya River channel into NAS; and, 1.3 km^3/year through a proposed delivery canal to the Saryshyganak bay.

The Saryshyganak bay with the normal headwater elevation of 50 m has quite large dimensions: length – about 50 km; mean width - 16 km; and, mean depth – 5 m (max depth – 11 m). Such dimensions and depth of the water body exclude the eutrophication process. The maximum salinity will be 5 g/l, with the following reduction of salinity to 1.5-2 g/l. Variation of water level in the bay will not be more than 0.8 m, and flooding of the bay will take 5-7 years.

4. MONITORING OF PREARALYE AND THE DRIED SEABED

Monitoring of the dried Aral Sea bed was carried out in two projects in 2004-2011:

1. "Stabilization and Use of the dried bed of the Aral Sea" - PN 04.2037.2-001.01

The project implemented by GTZ and SIC ICWC

2. Regional Research Network "Central Asian Water" - CAWa

The project was implemented by SIC ICWC and GFZ (German Geoscience Research Centre, Potsdam, Germany) and included one component of "Dynamics of Surface Water and Groundwater Change in the Amu Darya River Delta and the Dried Bed of the Aral Sea".

The objectives of work were to carry out monitoring within the dried bed of the Aral Sea to determine dynamics of ongoing processes, estimate the environmental risk of desertification, produce maps of land cover, and draft recommendations for stabilization of processes.

The research methodology was comprised of field observations to study in details reference landscape sites and then compare the ground-truth data with the data derived from satellite images for classification of landscapes and following production of GIS maps.

Over the two projects' period, nine expeditions to the dried seabed and the adjacent area were organized with the following team members: ecologist, soil scientist, geobotanist and botanist. More than 800 test sites were described and over 300 soil sections were arranged (Fig. 4.1).

The field studies addressed the following areas:

- Hydrogeology: groundwater level and salinity.
- Soil: genetic description, texture, humus, carbonates and gypsum contents, salinization, salt composition, soil types.
- Vegetation: composition, conditions, foliage cover.
- Ecology: landscape stability, risk.
- Classification using satellite images.

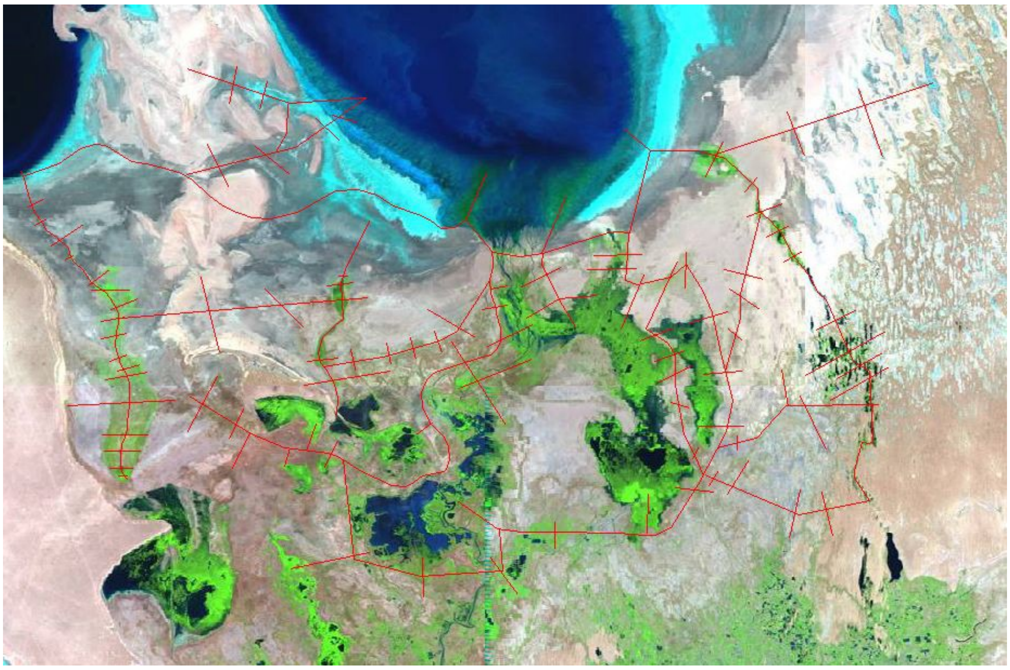


Figure 4.1 Schematic presentation of field studies on the dried bed of the Aral Sea

For the investigations on the desiccated Aral Sea bed, two types of satellite images were used: IRS LISS and Landsat (acquired by GTZ). Spatial (geometric) data resolution, which is characterized by minimum size of objects distinguishable on images, is 23.5 m for IRS and 28 m for Landsat. The software product “ERDAS Imagine 8.4” is used for work with satellite images in SIC ICWC. (ERDAS Imagine is a leading product in processing of satellite images like Arc/Info in GIS).

Besides combined ground-based and RS investigations on the desiccated Aral Sea bed, SIC ICWC introduced GIS technology based on Landsat 8 OLI satellite images in the water sector. The derived RS-based data for 2010–2018 allowed assessing actual changes in the area of wetlands and open water surfaces of Western and Eastern bowls of the Aral Sea (Table 4.1)

Table 4.1 Comparison of open water surface and wetland areas within the Large Aral Sea (2010-2018), thousand ha

	2010 Aug	**2011 Aug**	**2012 Oct**	**2013 Aug**	**2014 Aug**	**2015 Aug**	**2016 Aug**	**2017 Aug**	**2018 Apr**
Western part of the Aral Sea, thousand ha									
Wetland	182.34	165.86	161.25	224.78	186.99	264.65	265.54	283.15	290.31
Water surface	379.59	396.08	369.66	360.69	337.52	315.78	295.81	278.2	271.04
Eastern part of the Aral Sea, thousand ha									
Wetland	964.14	1243.9	1214.53	1155.3	1019.59	1183.95	1340.79	1036.02	1152.53
Water urface	532.68	252.94	215.99	184.31	103.22	149.19	156.04	460.81	344.3

The results of monitoring show that due to irregular water inflow, the area of water surfaces in Western and Eastern parts of the Aral Sea dramatically varied and depended on annual water availability. As compared to the wet year 2010, the water surface area in the Western part has decreased by 108,000 ha by 2018. Similar situation is observed for the Eastern part, where the water surface area decreased by 188,400 ha over the same period of time, and, consequently, the water level in the Eastern part has lowered by 2.9 m. This means that water level variation is 1.5–2.9 m there (Table 2.1). The gradual lowering of the water level in the Western part is also within 2.9 m.

As a result of shrinkage of water surface area, the wetland area has expanded. By 2018, the wetland area in Western part of the sea has increased by 108,000 ha and that in Eastern part of the sea has extended by 188,000 ha as compared to 2010.

4.1. Monitoring results

<u>Geomorphology</u>

The geomorphological processes on the dried seabed are complex. First of all, they are determined by the type of dried coast, including its exposed area width, slope, lithology, micro-relief, salinity, etc. (Gryaznova 1979, 1982, 1986; Gorodetskaya 1978; Geldiyeva & Budnikova 1985; Pinkhasov, Oteyev et al. 1999; Pinkhasov 1984; Rubanov 1994; Rafikov 1982).

The following key points define the structure of the exposed seabed:

1. Before the sea level decrease, the coastal area was characterized by a complex structure and highly indented shoreline due to structural and geomorphological features of Prearalye. The dried areas inherit the basic characteristics of the adjacent land.

2. During a long time period, the areas that have emerged from under the sea were subjected to coastal processes under sea level fluctuations around +53 m BSL. Furthermore, for the last one hundred fifty years, the sea level lowered twice to +50 m (in the 1820s and 1880s). In this context, a wide variety of coastal formations was generated in the given territory (Gryaznova 1982).

3. According to the principles of coastal-marine sedimentation, the dried territory developed under littoral conditions is mostly composed of sands, interchanged with siltstones and silt in meso- and micro-depressions. The lithology of the zones formed under influence of native shores depends on the structural features of the latter.

The dried territory represents a sloping coastal strip of recent sea desiccation bordered by a marine terrace, referred to as the terrace of the 1960s, from the side of the mainland along all the coast zones, except live deltas (Gryaznova 1986) (Fig. 4.2).

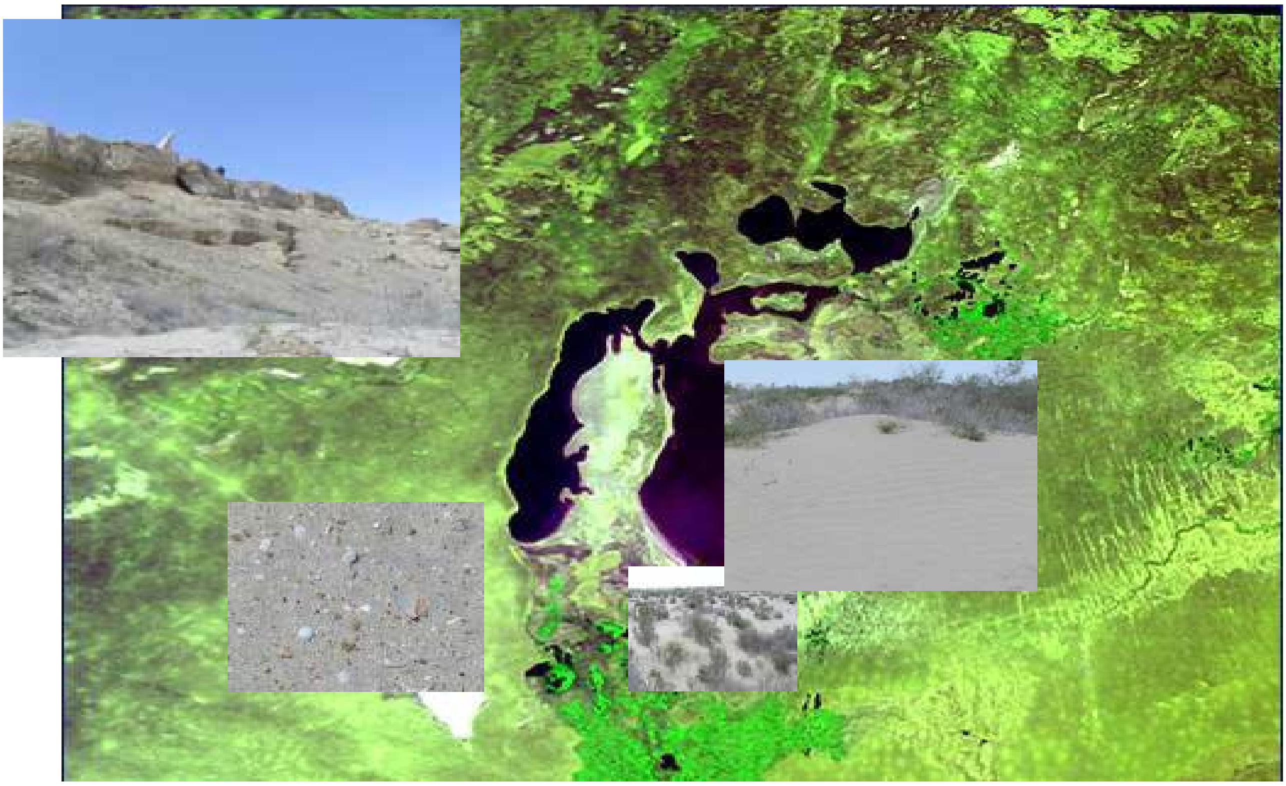


Figure 4.2 Dried coast types

Hydrogeology

Upper Cretaceous confined aquifers extend through the whole desiccated seabed and in the South Prearalye artesian basin feed 378 artesian wells with the total discharge of 19 615 thousand m^3 a day (1-10 l/sec). Additional 156 wells, with the total discharge of 1.44 thousand m^3 a day exist in the Ustyurt hydrogeological zone [14].

The dried bed of the Aral Sea within the surveyed sites is situated in the zone of artesian groundwater impacted by the Aral Sea level lowering and, to lesser degree, by polder and river systems situated in the south. Groundwater table varied from 0.57 up to 4.7 m and decreased with a distance from the shoreline (Fig. 4.3) and salinity averaged 26.0 g/l to 67.8 g/l on the dried seabed. The aquifers and water-bearing complexes of alluvial-lacustrine and pleistocene sediments respond faster to the sea level lowering than the upper horizons of alluvial marine and underwater-deltaic sediments of the Aral complex.

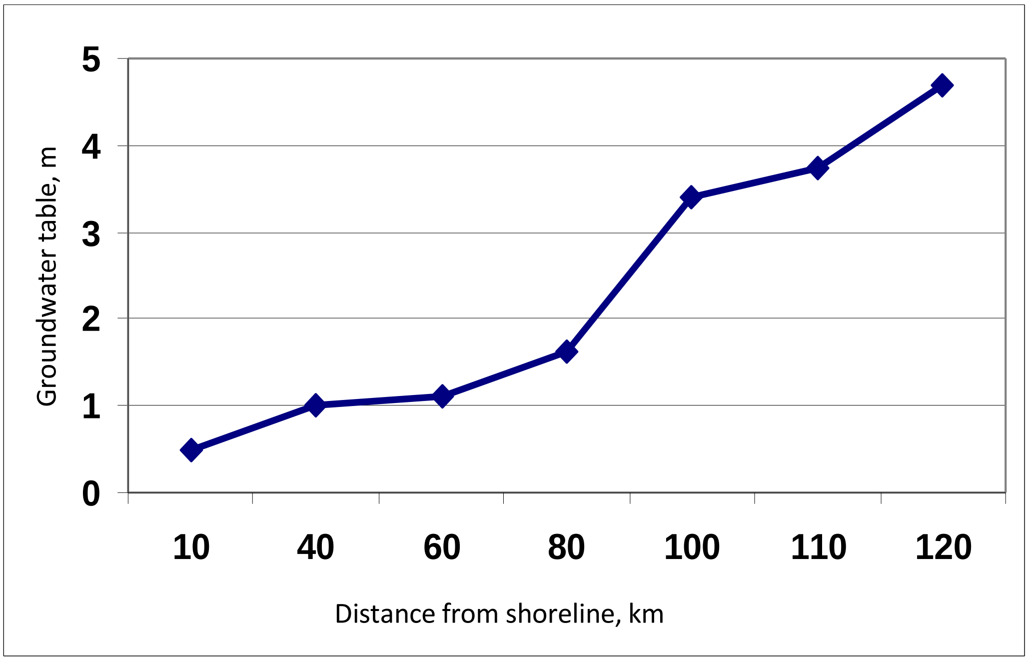


Figure 4.3 Relationship between groundwater table and a distance from the current shoreline

This relates mainly to the geological and lithological composition and the filtration parameters of water-bearing strata. As groundwater level drops and the sea's level lowers, the capillary edge detaches from seabed surface on the exposed bed, which refers to earlier period of sea drying. At the same time, soil salinization advances from the surface to the deeper layers, thus reducing the possibility of salt transportation into the atmosphere.

4.2. Soil

The processes of the Aral Sea desiccation led to new soil cover formation on the dried seabed. Studying newly emerging dry land is very important, as it is a source of dust storms and salts transported over great distances (Sektimenko 1991; Stulina & Sektimenko 2004).

At present, the dried belt of the Large Aral Sea is from 1-2 km along the cliff and western coast of the Western bowl to 150-200 km from the southern coast. It represents limnic, riverine and mixed deposits. The ongoing soil formation process on the exposed ground radically differs from zonal soil in specific features. These peculiarities enable the soil cover on the dried bed of the Aral Sea to pass a usually century-lasting development cycle over a short time.

The initial stage of soil cover formation on all types of the Aral Sea coast is the same. It is related to the intensive salinization of grounds emerging from under water as well as to the formation of marshy and coastal solonchak, with chloride, sulfate-chloride and chloride-sulfate salinization type in the active beach zone. The equal salt distribution along the profile gives place to intensive salt accumulation in the upper horizons under continental conditions by the end of the first year of young soil formation (Sektimenko 1991; Stulina, Sektimenko 2004).

Later, the soil formation process differentiates depending on lithological and morphological structure of former underwater slope.

Under the influence of changing hydro-geological conditions and arid climate, the soil is transformed progressively from a hydromorphic into an automorphic type. In case of light lithological composition, soil development usually ends with the formation of aeolian erosiveaccumulative relief. In case of heavy texture, mature desert soils of solonchak type appear, which can further become takyr soils, while shor solonchak is usually developed in closed sinks and lagoons.

Under these conditions, the soil evolution will follow the same scheme as it takes at present: excessively hydromorphic soils (marsh) → moderate hydromorphic solonchak → semi-hydromorphic solonchak → semi-automorphic solonchak → automorphic solonchak.

During the last stages of the soil evolution, solonchak processes caused by hydromorphic conditions fade out, and the influence of arid-zonal factor increases many times, thus making further soil development run as desert type process.

The periodical washing regime changes into an exudative one, while the initial chloride type of salinization changes into chloride-sulfate and sulfate-chloride types, with solid residue being as much as 15%. The transformation of marshy solonchak into coastal solonchak lasts about 3-4 years, and is related to a salt distribution pattern change in the soil profile and to salt accumulation in the upper 1 m layer. At the same time, the groundwater level decreases from 0.5 to 1.5 m. Automorphic and semi-automorphic soils, especially their crust-puffed types, become a source of dust and salt.

Under the conditions of insufficient watering, the hydromorphic delta soils degrade and change into deserted types, the swamp-boggy soils are transformed completely and the drying types of meadow-boggy and alluvial-meadow soils with very high salinity prevail, and the areas of takyr soil, sand and solonchak increases. The intensity of this process is determined by features of meso- and macro-relief and regional ecological conditions. During the period of flow regulation, almost all hydromorphic soils became highly saline. This process is especially typical for initial stages of soil desertification.

Sulfate and chloride-sulfate types of salinization changed into sulfate-chloride and chloride types. This tendency poses a risk of secondary salinization in hydromorphic soils. This process is particularly characteristic for initial stages of soil desertification.

The degradation of hydromorphic soils is becoming apparent in a decrease in productivity of range lands. All the territory is characterized by a high degree of desertification covering more than 50% of the area, loss of biological diversity, and almost irreversible transformations of landscape morphological structure.

Over 15 years since production of the last soil map by the Institute of Soil (Sektimenko 1991) (Fig. 4.9), significant changes have taken place. As a result of our nine expeditions in the dried seabed and the Amu Darya delta, 300 soil sections were arranged and a new soil map was generated (Fig. 4.10).

While studying the soil cover on the exposed bed of the Aral Sea, we distinguished and described the following types of seaside soils: semi-hydromorphic solonchaks, hydromorphic solonchaks, semi-automorphic solonchaks, automorphic solonchaks, desert-sandy soils, alluvial-meadow deltaic soils subjected to desertification, and fixed sands. Soils are often found in combinations and complexes, reflecting the heterogeneity of soil cover on the dried seabed.

Depending on geomorphological and soil conditions, the dried seabed is clearly divided into an eastern part related to Akpetki island system and a western plain part between the Ustyurt Plateau and the Kokdarya (Muynak part), including specific area between the Ustyurt Plateau and the Adjibai bay.

4.3. Landscapes

In terms of formal description methods, given task refers to that of pattern classification, where GIS plays the role of classification algorithms and satellite images and field observations serve as providers of input and training information, respectively.

As a result of the analysis of the thematic maps and field observations, also considering the relationships between major natural components such as relief, soil, and vegetation, the following basic landscape types of natural-territorial systems were selected:

1. Arid-denudation plateaus and isolated hills
2. Plains of deposition
2.1. Landscapes of marine plains
2.1.1. Landscapes of the exposed seabed
2.1.2. Landscape of lacustrine-alluvial plains
2.2. Landscapes of alluvial-delta plains
2.2.1. Emerging delta landscapes on the exposed seabed
2.2.2. Fore-delta (advancement deltas) of 70s-80s
2.2.3. Modern drying alluvial-deltaic plain
3. Holocene delta (former islands, straits and bays of the Akeptkin archipelago).

System analysis of the RS data, the landscapes of the desiccated bed of the Aral Sea and the field observations allowed experts from GTZ, TERRA and SIC ICWC to shorten the list of the thematic land cover classes. This cutback enables an assessment of the erosion risk degree and track desertification dynamics.

By grouping spectrally similar items, 17 classes were selected (Table 4.2).

Table 4.2 Classes of soil and vegetation cover

NN	*Name of class*
1	WATER
1.1.	Water surface
1.2.	Shallow water, sometimes with reed
2	SOLONCHAK
2.1.	Marsh soil, without vegetation or with Saltwort community
2.2.	Wet-coastal, with cockle-shell, spots of Saltwort and Sarsazan
2.3.	Desert crust-puffed and crust soil, without vegetation, spots of bushes (Karabarak, Tamarisk)
2.4.	Solonchak with blown sand cover, sparse Orach and Selin communities
2.5.	Shor solonchak of closed sinks, without vegetation, sometimes in Sarsazan setting
3	SANDS
3.1.	Plain (with shell rock), without vegetation or sparse bushes (Saxaul, Tamarisk)
3.2.	Dune, without vegetation
3.3.	Pit-and-mount (poor fixed) with sparse wormwood, bush communities and Selin plantings
3.4.	Hilly, hilly-ridge, without vegetation and poor fixed
3.5.	Hilly, hilly-ridge, poor-fixed with ephemeral-wormwood-bush communities
4.	PLAINS DELTAIC AND OF DEPOSITION
4.1.	meadow on alluvial plains (reedy, forb-Gramineae) on alluvial-meadow, bog-meadow and meadow-bog soils
4.2.	Subjected to desertification, hydromorphic Gramineae -halophyte-forb, with bushes
4.3.	shrubs (halophyte: Tamarisk Karabarak)
4.4.	subjected to desertification, shrub
4.5.	shrub-Saxaul (desert forest/artificial plantations)

Spectral profiles of all classes are shown in “Comprehensive Remote Sensing and Ground-based Studies of the dried Aral Sea Bed” [2].

Figure 4.4 demonstrates the classification results in form of a thematic map. The thematic map is the result of image interpretation, which is based on ground-truth data. The identified list of classes for the dried bed corresponded to the above project goals and objectives, i.e. determination of erosion hazard areas and the territory for future phyto-reclamation (afforestation) measures.

For the formulation and planning of environmental counteract measures against the ecologic disaster at Aral Sea, it is very important to analyze the landscapes of the dried seabed from the position of plausible development and their potential for deflation and dust-salt transport. Such assessment should be based on a landscape classification in connection with soil cover, vegetation state and other factors.

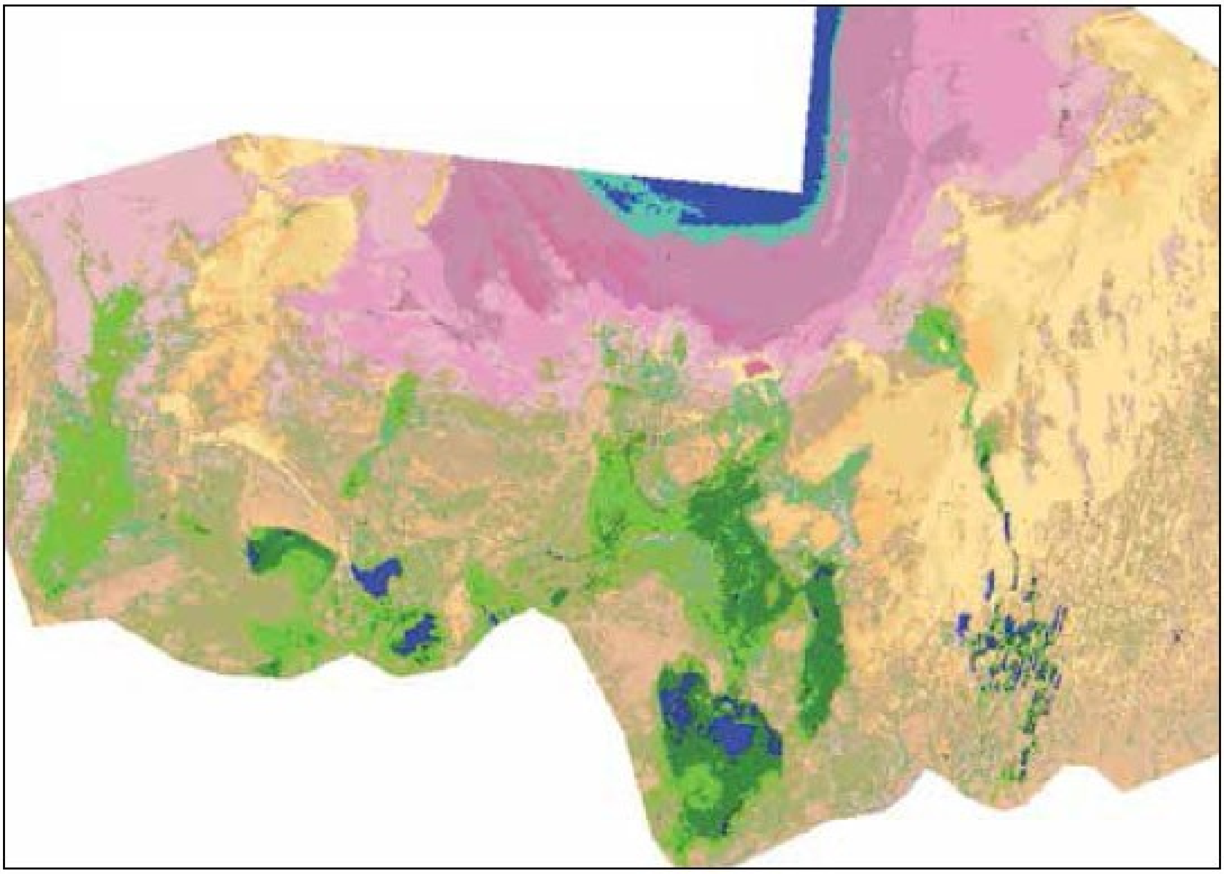


Figure 4.4 Results of supervised classification of the delta

Landscape is inherently a highly disbalanced dynamic system, for which daily, annual and multi-annual rhythms are characteristic. We regard the current transformation of the natural environment in Prearalye on a regional scale as anthropogenic-induced aridization. The particular feature of this process is that man acted as a trigger. Since given processes take place under desert zonal conditions, the leading factor of dynamics is moisture reduction, and the landscape evolves towards the forms corresponding to desert systems. This process is referred to as “desertification”.

As was mentioned before, ecological hazard is regarded in terms of landscape aggressiveness to human life and economic activity. Ecological hazard implies not only the momentary state of landscapes but also an impact on dynamics of their formation since landscapes of the desiccated bed are very unsustainable (unstable) at present. Thus, the assessment of ecological hazard takes into account dynamics of ongoing processes in given territory, according to the scheme shown above (map of erosion risk, Figure 4.5).

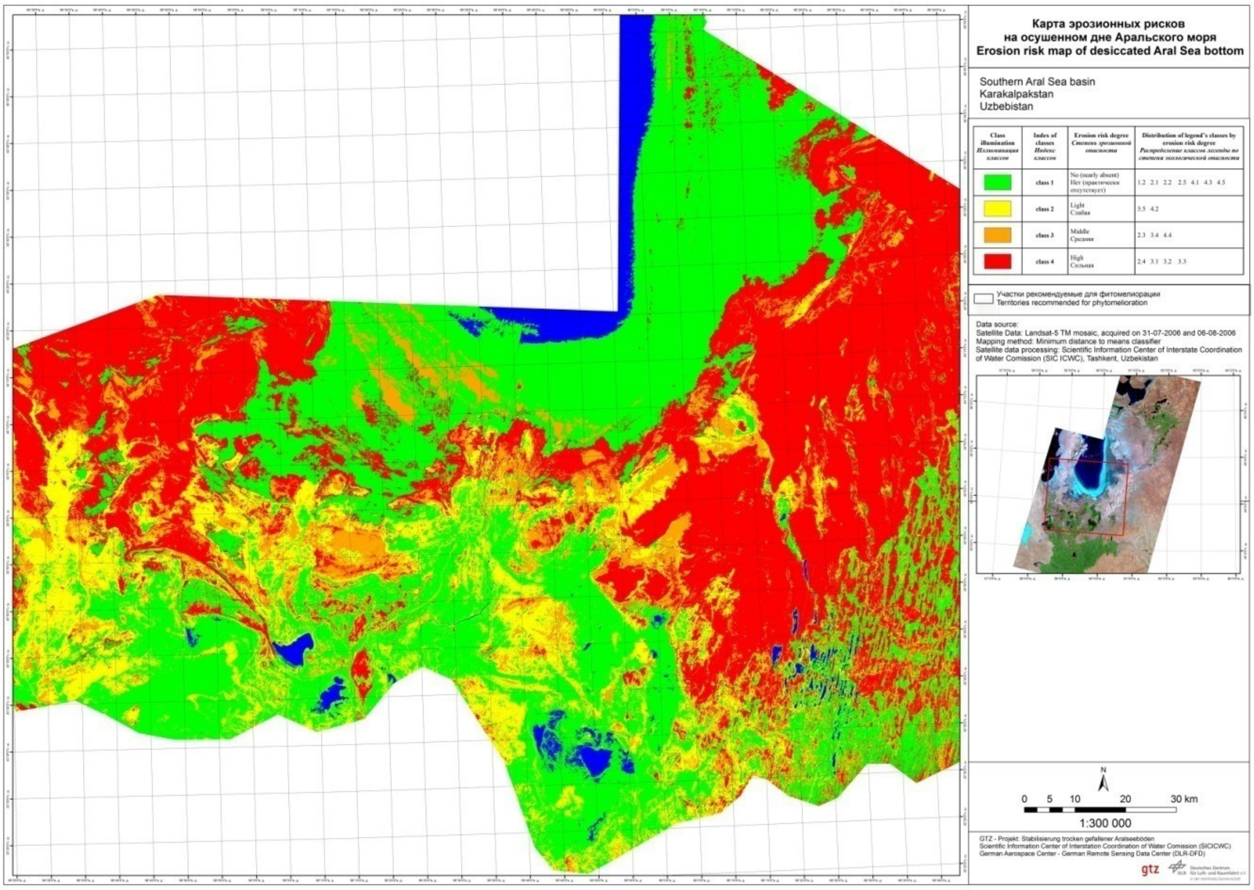


Figure 4.5 Map of erosion risk

The rating scale of ecological hazard was determined according to the assignment of the destructive exogenic processes (Table 4.3):

Table 4.3 Rating scale of ecological hazard for classification results

Degrees of ecological risk	Code	Land cover classes assigned (description below)
No (practically absent)	1	1.3 1.4 2.1 2.2 2.5 4.1 4.3 4.5
Low	2	1.1 1.2 3.5 4.2
Moderate	3	2.3 3.4 4.4
High	4	2.4 3.1 3.2 3.3

1. No risk (practically absent), given to the following classes:

- Marsh solonchaks without vegetation or with saltwort communities;
- Wet coastal solonchaks without vegetation, with rare isolated specimens of saltwort and sarsazan;
- Shor solonchaks of closed depressions;

In the first years after exposition (3-6 years), the coastal and shor solonchaks don't present a hazard, as the groundwater table depth varies from 0.1 to 1.5 m, and a thin salty crust of 1-3 cm is formed on the surface which both protects the surface from aeolian erosion. Over a time span of approximately 10 years, this protection can be considered as stable. Shor solonchaks can be regarded as stable, since they underlie the hydromorphic regime during the major part of a year.

- Meadows on alluvial plains (reed, herbs, cereals) on alluvial-meadow, bog-meadow and meadow-bog soils;
- Shrubs (halophytic vegetation: tamarisk, karabarak);
- Shrubby-haloxylon (desert forest/artificial plantations);

The landscapes belonging to palustrine plains, periodically or permanently flooded by river and collector-drainage water, do not represent a hazard because they also belong to the hydromorphic regime. Moreover, vegetation is one of the main stabilizing factors in dynamic landscapes. Meadows on alluvial plains have a sufficiently high projective cover, and shrubs contribute to fixing of otherwise unfixed sands.

2. Low ecological risk:

- Water surface in the delta;
- Shallow water areas, sometimes with reed;

The existence of the classes assigned to low ecological risk depends on water supply to the delta, i.e. on available river runoff during a year. When the water surface area decreases substantially in low water years, lake beds are being exposed, reed stands dry out.

- Fixed hilly, hilly-ridgy sands, with ephemeral-wormwood-shrub communities;
- Hydromorphic soils subjected to desertification, with cereal-halophytic herb communities and shrubs.

3. Moderate ecological hazard:

- Crust-puffed and crust solonchaks without vegetation, with rare isolated specimens of shrubs (Karabarak, Tamarisk);
- Poorly fixed hilly and hilly-ridgy sands, without vegetation;
- Soils subjected to desertification, covered with shrub vegetation.

Crust-puffed solonchaks are considered as one of the main source of salt and dust transport into atmosphere in saline desert environments. The soil subjected to desertification and covered with shrub vegetation represents a hazard in the view of vegetation cover degradation. This can lead, in turn, to intensive development of aeolian erosion processes. Hilly and hilly-ridgy sands not fixed with vegetation occupy vast territories on the dried bed of the Aral Sea and their thickness increases by 3-5 cm every year. The low vegetation cover (20% to 40%) increases the potential of aeolian processes. Therefore, inter-barkhan depressions are the main sources of salt and dust erosion.

4. High ecological hazard:

- Solonchaks with blown sandy cover and sparse communities of Orach and Selin;
- Plain sands (with shell) without vegetation or with sparse shrubs (Saxaul, Tamarisk);

- Dune sands without vegetation;
- Pit-and-mound sands (poorly fixed) with sparse communities of wormwood, shrubs and Selin plantings.

These classes represent territories with intensive development of exogenic (aeolian) processes and the highest ecological hazard due to the formation of salt and dust sources. Most part of the area belongs to the automorphic regime.

Based on the scale of ecological hazard and agreed class recoding, the results of the supervised classification were transformed into a map showing the ecological hazard degree, i.e. the thematic map of erosion risk. Based on this map, an area calculation of each ecological hazard class was done (respective class color on the map is shown in brackets) for the Uzbek territory of Prearalye.

- No (practically absent) - **858 621.4 ha** (green);
- Low - **311 353.0 ha** (yellow);
- Moderate - **280 842.0 ha (**orange);
- High - **785 035.0 ha** (red).

About 40% of the exposed seabed (within the Uzbek territory) can be regarded as safe (no risk), 25% represent low and moderate ecological hazard, and 35% are characterized as highly hazardous.

4.4. Dynamics of desertification processes

We have received interesting data after comparison of the data derived in the course of the research in 2006 with the "South Prearalye Landscape Map" of 1990 (A. Chernyshev, SANIIRI, digitized by SIC ICWC) as shown in Table 4.4.

Table 4.4 Change of aggregate indicators by comparing landscape assessments for 1990-2006, thousand ha / %

Risk degree	Areas by risk degree		Total vegetation covered area	
	1990	2006	1990	2006
1	199.4 24.2	760.2 42.9		
2	178.5 22.8	384.0 21.7	54100 6.5	512071 28.9
3	193.6 23.5	23.2 1.3		
4	243.4 29.5	605.0 34.1		

Thus, the percentages of the risk classes in the study territory have changed. Areas with no ecological hazard increased by 18.7% as a result of a considerable increase in the area of wet coastal solonchaks. These don't represent ecological hazard during the first 3-6 years after exposition by the receding water. Furthermore, high-projective cover (mainly shrubs, Black Saxaul) has extended. The high risk areas have increased by almost 5% due to the expansion of crust-puffed solonchaks. The areas with moderate ecological hazard have considerably decreased by 20% as compared to 1990 which can be explained by natural overgrowing processes observed on the dried seabed.

For example, after the construction of a dam on Lake Sudochie, shrub areas within the former Adjibai bay expanded noticeably. According to the “South Prearalye Landscape Map”, as of 1990, the vegetation-covered area in the former Adjibai bay amounted to 3,700 ha, while in 2006 it reached 29,700 ha, i.e. the overgrown area increased by the factor of 8. In absolute values, the areas extended by 950,000 ha through the recession of the sea; and, the areas of particularly high risk increased by 362,000 ha or 149%.

The comparison of the “Map of lithological structure of overlying strata (Quaternary) layers on the dried bed of the Aral Sea” with the data from 2006 (Table 4.2) shows that given the total increase in the exposed seabed area of about 600,000 ha, the change in ecological hazard degree looks as follows:

- No (practically absent) - **increased by 560,800 ha;**
- Low - **increased by 196,500 ha;**
- Moderate - **decreased by 170,400 ha**;
- High - **increased by 361,600 ha.**

In other words, from 1990 to 2006 the zones with high ecological hazard enlarged by more than twofold.

The current estimate of the projective vegetation cover is 30.5% in 2006 against 21.6% in 1996. This once again confirms the occurrence of self-overgrowing processes, which evidently have intensified over the last years.

4.5. Dynamics of processes on the exposed seabed. Risk assessment

Both, desertification and natural soil formation processes can be observed on the exposed seabed. These processes are determined by a complicated combination of changes in groundwater levels, formation of new landscape, wind transport, formation of new soils and vegetation cover. All of these processes are interrelated. It is obvious that the main indicators of those processes are surface characteristics, first of all, soil cover characteristics.

The soil cover is the main determinant of ecological stability and ecological hazard (risk), as the state and dynamics of the soil cover practically determine trends of processes in the biologically active layer.

Figure 4.7.1 shows the main effective forces inducing a change in the soil and landscape and their effect on the landscape classes determined above. Listed in a temporal order, these are: desiccation of the sea, subsequent development of deflation processes, desiccation of lakes and depressions in island and other systems, desertification (or inundation) of the delta, self-overgrowing and man-made plantations to fight deflation-eolian processes, deflation processes in affected and poor-overgrown barchans and dunes, and development of self-overgrowing in the area of artificial plantations.

The initial drying of the seashore is accompanied by the formation of hydromorphic marsh solonchaks, which have no vegetation, and their sustainability and stability is determined by moisture and content of sand or loam-clay particles.

By now, the groundwater level in the most part of the investigated territory has lowered below 3 m, with a very high salinity of up to 50 g/l. This leads to the transformation of hydromorphic and semi-hydromorphic solonchaks into semi-automorphic and automorphic ones. The zone of newly formed hydromorphic soils follows the receding sea shoreline.

Automorphic coastal solonchaks are represented by crust, crust-puffed types, becoming takyr-like in some places. The automorphic solonchak profile is very high, with overall salinity which peaks in the crust and sub-crust (powdery-puffed solonchak) horizons (Fig. 4.6). Their salt content varies from 3-5 to 15-25%. Down the profile, the salt content decreases and changes depending on the texture of the layers. In the lower horizons, the secondary salt maximum is reached often due to the presence of the highly saline groundwater.

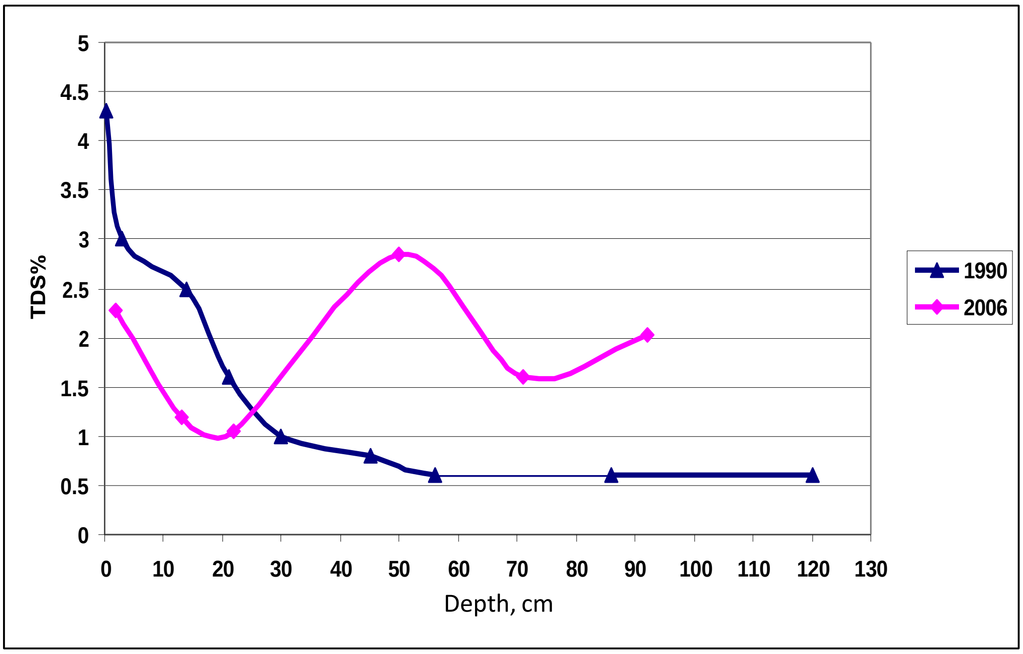


Figure 4.6 Salt distribution in hydromorphic soil and in automorphic soil generated from it

The salinity of surface solonchak horizons by anions is sulphate-chloride and chloride-sulphate. Down the profile, the sulphate-chloride type predominates over other salinity types. The uniform salt distribution gives place to a salt concentration in the middle part of the profile due to several processes: groundwater level lowering, upper layer desalinization and overlaying by sandy cover.

The soil drying up is accompanied by deflation processes. Although sandy solonchaks contain less salt than loamy-clayey ones, they become a strong source of salt-dust transport because they are more easily and deeply processed by the wind. Initially, such transformation and erosion processes resulted in aeolian relief formation along the relic seashore. In the course of time, this phenomenon also extended deep into the former sea water area (Fig. 4.7).

Further activation of deflation-accumulation processes leads to directed soil desalinization and the formation of sandy soil of the zonal range with slight salinity, and a sparse psammophyte vegetation cover. The transformation of coastal solonchaks into sandy soils takes approximately 8-10 years (Fig. 4.7.1).

Figure 4.7 Dry channel of the Amu Darya River

	class			
Sea desiccation	**1**	**2**	**3**	**4**
Artificial plantations and self-overgrowing	**class**			**3.1**
	2.1			
	2.2 3-4 years		**2.3** 5-7 years on heavy soils 4-5 years on light soils	
				2.4
Sea desiccation with subsequent deflation processes	**2.5**			
Lakes desiccation in island system	**4.1**	**4.2** 10-12years on light soils 14-16years on heavy soils		
	4.3		**4.4** 10-12years (depending on water supply to delta)	
Delta desertification		**3.5**	**3.4**	
Self-overgrowing, artificial plantations **Deflation - eolation processes**				**3.2**
				3.3
Deflation - eolation processes	**4.5**			

Figure 4.7.1 The desiccating sea surface classes transformation trends

regulated process development ________ possible process development ------------

Figure 4.8 Delta desertification, dried Asiatic poplar trees (Populus pruinosa)

Under reduced river water inflow into the delta, alluvial deltaic soils degrade, the groundwater level goes down, and salinity increases.

The latter process is particularly characteristic for the initial stages of soil desertification. The transformation period of hydromorphic soils into deserted ones is 10-15 years.

The soil cover degradation becomes apparent through a decrease of forage land productivity, loss of organic matters, and reduction of fertility elements. Of course, all of those processes cause severe damage to natural fertility of the soil cover. Moreover, biodiversity declines considerably and the typical deltaic vegetation disappears (Fig.4.9).

In order to identify the general trend of processes, we used the results of soil studies conducted by the Soil Institute at the Academy of Sciences of Uzbekistan and the detailed soil map of the dried seabed of 1990 generated by Sektimenko (Fig. 4.9) and compared them with the current status reflected in the soil map for 2005 (Fig. 4.10).

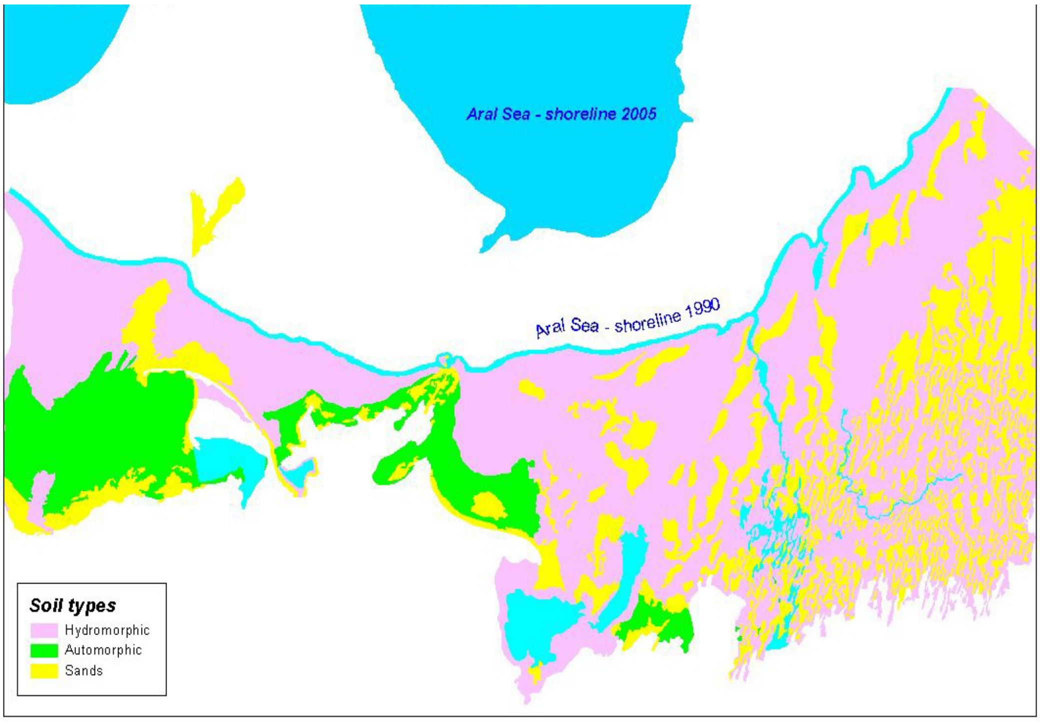


Figure 4.9 Soil map as of 1990

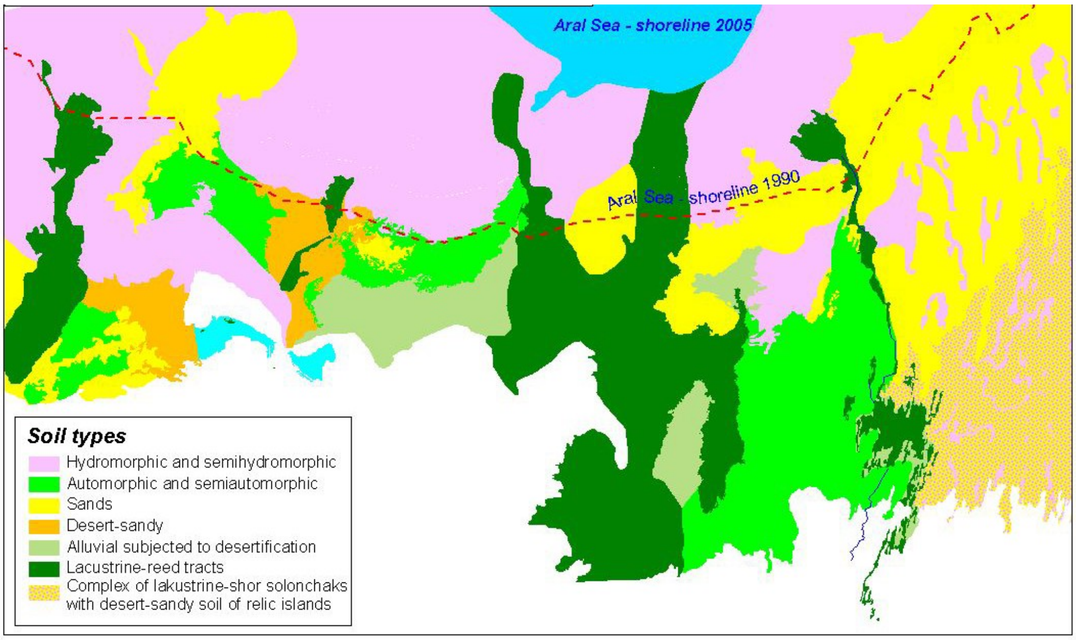


Figure 4.10 Soil map as of 2005

The results of the comparison of areas, which were covered by the survey of Sektimenko in 1990 and formed in the drying zone by 2006, are given below (Table 4.5).

Table 4.5 Comparative analysis of soil cover change (thousand ha), as compared to 1990

Landscape class	Soil groups	1990	2005	
			Zone covered by the survey 1990	Drying zone from 1990 to 2005
2.1, 2.2, 2.5, 4.1	Hydromorphic and semi-hydromorphic	763204	276340	372568
2.3, 2.4, 2.5, 4.3	Automorphic and semi-automorphic	114443	165834	8304
4.5	Desert-sandy		233460	4381
3.1-3.5	Sand	172348	321745	81888
4.2, 4.4	Deserted meadow		52616	45
Total		1049995	1049995	467186

The comparison was made by overlaying the soil maps. Thus, since 1990, automorphic solonchaks increased by more than 50,000 ha due to groundwater table lowering and transformation of hydromorphic soils into automorphic ones. Moreover, 233500 ha of desert-sandy soil were formed, which is regarded as a positive sign. However, the sand area considerably increased from 172000 ha to 322000 ha which indicates to intensification of erosion processes on the dried seabed.

From the position of ecological stability, the whole area of the dried seabed is unstable, because gradual surface change processes constantly take place, caused by the shoreline recession and beach desiccation from both the sea-side and the former delta. However, through regular artificial inundation of the surroundings of the former delta or periodical releases into the former closed depressions and lakes, the landscape and soil-formation conditions can be stabilized to a certain extent.

If it would be possible to maintain a stable water level in the Sea, or a level periodically fluctuating within 1-1.5 m, as it was in 2003-2005, then the hydromorphic and semi-hydromorphic regime of the zones near the shoreline would keep stable moistening and the gradual development of Saltwort and sometimes Sarsazan would be possible. Under abrupt drops in the sea level, solonchaks immediately transform into automorphic soil of the respective landscape classes. While transformation from one hydromorphic soil class to another one keeps a minimum degree of ecological risk, the transformation into automorphic soils immediately put the respective landscapes to next higher risk classes 3 and even 4.

4.6. Measures for the stabilization of the exposed seabed

As established, by the end of 2006, the total area with the high risk was 785000 ha of the dried seabed within the boundaries of Uzbekistan. According to the forecast, the total area of the dried bed will increase by additional 500 thousand ha (half of the dried area in territory of Uzbekistan) under a pessimistic scenario.

Undoubtedly, neither the country itself nor the assistance of international donors can protect more that 1.2 million hectares. In this context, it is necessary to seek out ways for optimized selection of areas to be protected.

The conducted research demonstrates that along with the negative consequences, positive trends such as self-overgrowing and the stabilization of certain landscape types can be observed on the dried seabed. Some measures are planned and shall stabilize the delta in its present status and even increase periodical inflows into temporal non-regulated old channels on the exposed bed, where the current fauna and flora need to be sustained through water releases in specific time intervals.

In the humid year 2005, wet zones occurred around outlet channels of Djiltirbas and Adjibai and covered substantial areas on the exposed bed. The total wet area increased by 55000 ha, compared to normal (drier) years.

Thus, by defining more exactly the areas of landscapes to be stabilized and organizing permanent monitoring of these zones, the high-risk zones can be prevented from extending.

Not the whole “high-risk” zone should be considered as presenting the same degree of hazard to human society. Therefore, within the limits of this zone, we should select the **territories of intensive development of negative processes**, where sources of stress may arise as a result of aeolian and hydrochemical processes under arid conditions and as a result of anthropogenic changes in moisture regime. These sources are represented by:

- barchans and blown sands. The expeditions found a number of such zones; moreover, the rate of their movement was about 4 km a year (2 km per half year);
- massifs of sandy unfixed landscapes, with light texture, that can be easily transformed into moving barchans;
- increased content of readily soluble salts in the soil, thus threatening growth of plants, especially lignose;
- development of sites of intensive salt and dust transport, including removal and accumulation of the light fractions of surface deposits (dust and silty sand) and their further transportation;
- intermittent or temporal waterways or wells that feed water bodies in desert and serve as a source of life.

In addition to fixation and monitoring of those “degradation centers”, a zone of their potential impact must be identified. Earlier SANIIRI’s observations (Razakov 1987, 1998) over those processes (INTAS-RFBR 1733) showed that the intensive salt and dust transport threatening human health and agricultural productivity extended to 50 km far from the intensive source of aeolian phenomena. Outside this zone, aeolian deposition of salt and dust decreases to a few tens of kilograms per hectare a year and obviously is not hazardous (Tolkachyeva 1998).

Present observations by GTZ (P. Navrateel) at five wind stations located eastward from Djiltirbas indicate the maximum value of salt and dust transport at 1914 kg/ha per year. Thus, the intensity of salt and dust transport has decreased as compared to the 1980s. Table 4.6 and Figure 4.11 show the zones to be protected.

Thus, there are 57,600 ha which should be prioritized for protection and 60,000 ha in the dried delta zone out of the total area of more than half a million hectares. This is an area of distribution between the first-priority afforestation and watering.

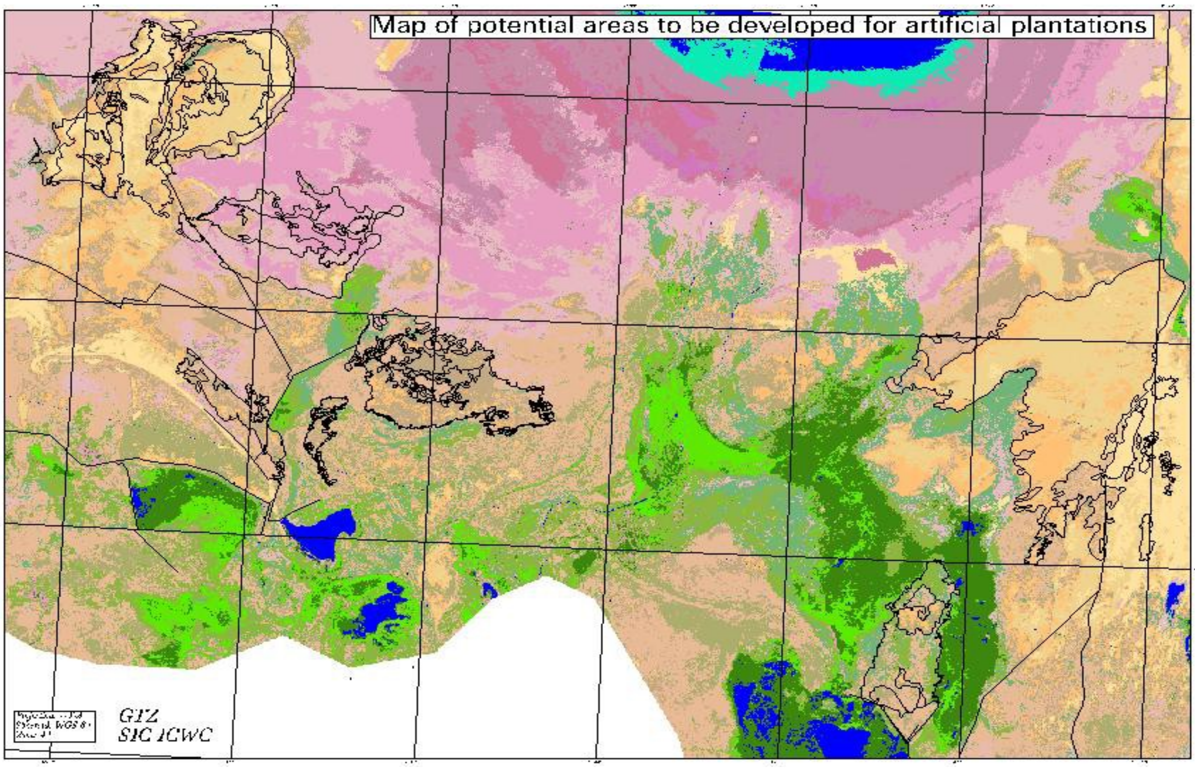


Figure 4.11 Zones suggested for development and afforestation

Table 4.6 Areas of potential negative impact and areas to be protected, ha

Degree (stage) of environmental hazard	Color	Areas of potential negative impact	Areas to be protected
No (practically absent)	green	293926.7	
Low	yellow	136674.6	
Moderate	orange	168717.6	
High	red	466915.3	57576.7

Based on the results of the expeditions and the image processing, the following zones are proposed as priority zones:

a) a zone northward of Muynak between the waterway of Rybachie bay and the delta, solonchaks with blown sands and some barchans posing a risk of salt and dust transfer to Muynak;
b) the area between Kokdarya and Djiltirbas, northward of the new GTZ's camp, where barchans advanced to 2 km in the last year, covered the road, and now move toward the new plantings of GTZ;
c) a zone of poorly fixed sand hills together with sand sinks in the southern exposed bed within Adjibai bay;
d) a zone in north sand spit (Bakhyt well), where plantings are already underway but their state is ambiguous.

In the investigated area, 30% of the present afforestation sites show bad plant establishment. It is recommended to study these areas in detail (soil-hydrogeological and botanical surveys), in order to find the reasons for the bad establishment and estimate the possibility of self-overgrowing. It is necessary to discuss, as a number of researchers propose (Wucherer, Gintzburger), a possibility of stimulating self-overgrowing though diffusion of Selin seeds (*Aristida karelini*).

Besides, a zone located above the elevation of 53 m a.s.l. in the delta part which genetically does not belong to the dried seabed area but where intensive desertification takes place should also be considered for priority protection and needs additional surveys. Here, additional sub-classes need to be included in the remote sensing assessment since the delta is characterized by additional plant associations (Asiatic poplar, riparian woodland) and soil conditions (meadow, meadow-bog, takyrs, and soils subjected to desertification). Those zones may be protected by watering combined with phyto-reclamation.

During the expedition, some factors likely leading to a bad plant establishment could already be identified. This leads to a need for developing a set of selection rules and preparation strategies for planting zones in order to improve the plant establishment rates. Poor quality seeds or dead (by the time of planting) seedlings, as well as the initial soil and hydro-geological conditions that do not meet the requirements can cause poor establishment rates. Besides, barchans are expanding, and this requires the assessment of their need for fixation by cane. Additionally, the identification of sites with degrading Saxaul or drying of Tamarisks is necessary, and multiple disturbance of plants by geological and oil explorations and by transport needs to be taken into account.

According to the GEF IFAS Agency’s data, by present day, afforestation efforts have been taken on an area of 740,000 ha in the Aral crisis zone, including 350,700 ha on the exposed seabed. Phyto-reclamation was financed by national budget on 321,800 ha, by GIZ (Germany) on 16,400 ha, by NGO “COFUTIS” (France) on 1,500 ha, and by IFAS on 11,000 ha.

Nine expeditions organized by SIC ICWC with the support of the German Government over 2005-2011 have found that all those efforts contributed to self-overgrowing processes on the exposed seabed on about 200,000 ha additionally.

At present, an action plan has been initiated for afforestation of 500,000 ha on the dried bed of the Aral Sea. In line with the initiative of the President of Uzbekistan voiced during the Summit of the Heads of State-Founders of the International Fund for Saving the Aral Sea on 24 August 2018 in Turkmenbashi city (Turkmenistan), a list of priority national programs and projects was adopted for organization of comprehensive afforestation efforts on the dried seabed to fix blown sand and prevent salt and dust storms.

5. MONITORING OF THE AMU DARYA RIVER DELTA

The Amu Darya delta has developed under the influence of long-term natural fluctuations of the river runoff. Eventually, under the influence of various interrelated processes caused by the sea, river and erosion dynamics, the landscape of delta and its hydrological and hydro-geological profiles with numerous water bodies were formed. These water bodies, when the Aral Sea level was 53 m +BSL (lakes Sudochie, Karateren, Kokchiel, Akchakul, Zapadnoe), have represented lakes of the coastal-deltaic plain occasionally flooded by river and sea waters and linked with the Adjibai and Djiltirbas bays. During wet years, lakes were completely desalinated with plentiful river waters and have obtained features of water bodies with good flow-through. When inflow of fresh water has decreased during dry years, these lakes were partly flooded with sea water, and that has resulted in abrupt change in physical and chemical properties of water with subsequent modification of their flora and fauna and their biological productivity. In recent years, due to inflow of polluted water into Sudochie Lake and a number of other lakes, they have lost their productivity and many fish species and muskrat, and reeds and near-water vegetation has become suppressed.

Thus, one of the key environmental and social objectives in Prearalye is to preserve biodiversity and improve natural productivity of bio-resources, where lakes and wetlands as the natural habitats of local and global fauna play the crucial role.

The largest deltaic lake of Sudochie is the nesting place for numerous migratory birds. In this context, a package of documents was prepared for inclusion of Sudochie Lake into the sites under the Ramsar Convention, the mission of which is "the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world."

The Uzbek Government has taken huge efforts to create infrastructure of Sudochie Lake in western part of the Amu Darya delta and construct a range of structures to flood the delta and improve water supply to small lakes in the delta. As a result, by the beginning of 2000, lake systems have covered an area of 116,700 ha in the delta. It was very important to avoid the loss of existing deltaic vegetation through the ongoing desertification process.

In 2000–2003, SIC ICWC together with the Dutch company "Resource Analysis" developed the Amu Darya delta's aquatic system scheme and feasibility study for an amount of slightly higher than US$ 90 million. SIC ICWC did work on determination of water volume required to maintain rivers and deltas, especially their lake systems. Particularly, they estimated that the water volume required for maintenance of environmentally sustainable profile in the Amu Darya delta and recharge of lake systems is 8 km^3 in wet years, 4.6 km^3 in normal year, and, at least, 3.5 km^3 in dry years.

Geographically and by source of water, water bodies in the Amu Darya delta are grouped into three zones: Western, Central, and Eastern. In terms of Amu Darya river water management and use, the most important water bodies in the Central zone are the Mezhdurechie reservoir and related bodies of Muynak, Makpalkol lake, Rybachie reservoir (bay), and Maipost lake. Water flown into the reservoir is distributed between Muynak and Makpalkol lake, which feeds the Rybachie bay with water. Besides, Mezhdurechie, Muynak and Rybachie are used as the sources of drinking and household water for Muynak city and other settlements located around those water bodies. During flood period, when water level in the Mezhdurechie reservoir rises above 57 m, water is discharged towards the Aral Sea.

Generally, water bodies in those zones are differentiated by source of water – the Central zone receives river water of the Amu Darya in contrast to Western zone (Sudochie and Mashankul-Karadjar lake system) and Eastern zone (Djiltirbas Lake, etc.).

Dynamics of water surfaces in the Amu Darya delta (Table 5.1, processing of RS-data) showed that over 2009-2018 the water surface of lakes was very unstable and depended mainly on available river runoff during a year. The projected area of water bodies at 194,100 ha has been never achieved. Maximum water surface of 115,200 ha was achieved in 2010, and 10% of projected water surface area of lakes was maintained in 2011, 2013 and 2014. The reason is that the designed set of structures in the delta has been constructed partially only and the planned regulating capacity of the Mezhdurechie reservoir has not been achieved. Moreover, because of siltation, the reservoir's capacity even decreased. In addition, the Lower Amu Darya Basin Authority virtually does not ensure any control and regulation of water supply in the delta.

Figure 5.1 shows that in August 2018 the Mezhdurechie reservoir dried up completely due to low water. Moreover, the whole water volume in the reservoir is taken fully by the mid of season.

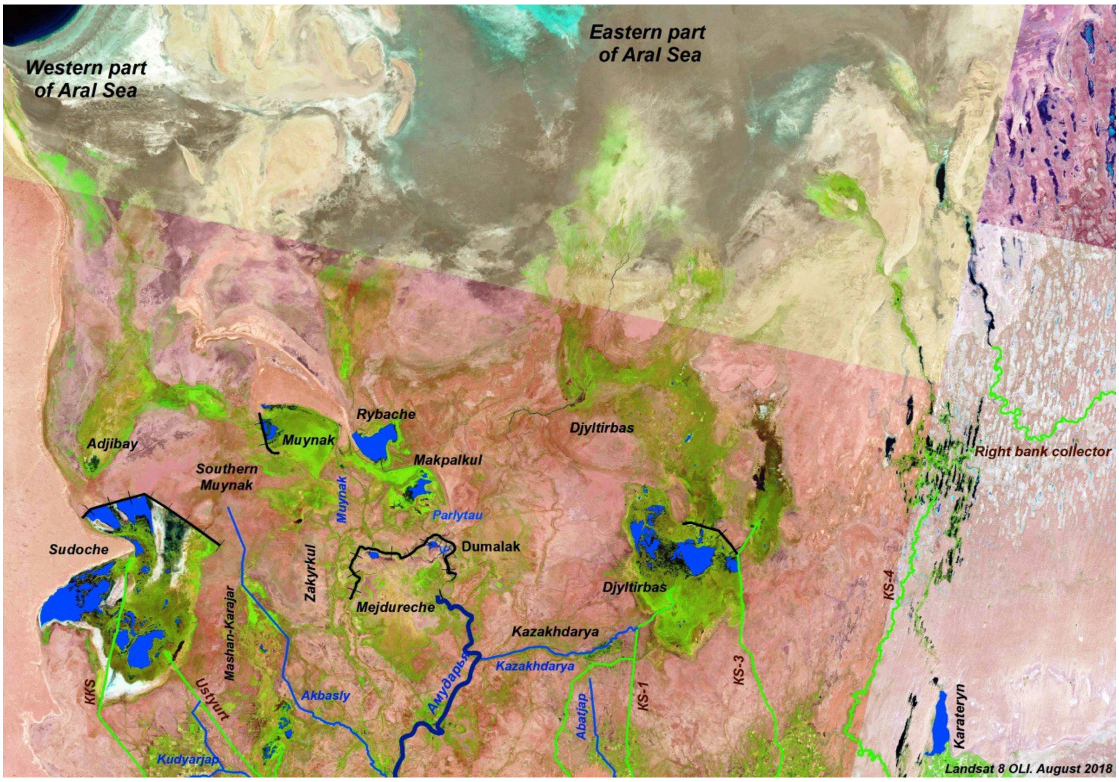


Figure 5.1 Satellite images of local water bodies in the Amu Darya Delta (Landsat 8 OLI, August 2018)

The Sudochie lake system, which is fed mainly by collector-drainage water, lost 61% of the water surface area in the dry year 2018. Similar situation was observed in other water bodies, like Muynak, Rybachie, and Djiltirbas, and even Dumalak and Zakirkol lakes dried up.

The results of monitoring over dynamics of water surface area and wetlands in South Prearalye in 2018 indicate to ongoing intensive desertification in Prearalye due to low-water conditions and the lack of control over provision of water for environmental needs in South Prearalye. Additionally, statistical analysis of the total annual inflow to the Aral Sea and the Amu Darya delta indicates to variability of river runoff. Moreover, catastrophically dry years have increased since 2000, and the annual inflow to the delta varied from 0.403 km^3 in 2001 to 20.3 km^3 in 2010.

Therefore, the results of monitoring carried out by SIC ICWC in the Amu Darya delta (Tables 5.1 and 5.2) demonstrate high variations and instability of open water surface and wetland areas in the delta over 2009-2018. Besides, the monthly dynamics of water surfaces in lake systems is also variable and unsteady.

The last two years show entirely different conditions in the Amu Darya river delta. In 2017, inflow into the Aral Sea and the delta amounted to 10.7 km^3, and the total open water surface area in lake systems extended to 86421.7 ha in June. However, in 2018, the minimum required inflow was not provided, and the delta actually received 1.319 km^3, which is only 37 % of the minimum required water. Consequently, the total area of open water surface of the lakes systems decreased to 21565 ha, i.e. diminished by 64857 ha in one hydrological year.

Monitoring of changes in water surface areas in the delta indicates to complex hydrological process, which fully depends on inflows of water. The maximum area of wetlands and lake water surface (Table 5.2) was reached in 2005 (347,120 ha) and in 2010 (326,009 ha). The water area decreased to 79,500-122,000 ha in other years.

The delta receives water not only from the river but also from collectors, such as KC-1, KC-3, KC-4, Akchadarya (right-bank), KKC and Ustyurt. The Ustyurt collector also discharges water into Mashankul lake (from Raushan canal to Sudochie lake via the Ustyurt collector). The right-bank collector system takes start from the Beruny collector and through the Main South Karakalpak collector (GUKK) ends in the Akchadarya collector. The collector water flows into the Eastern part of the Large Aral Sea via Zhanadarya. In the second half of XX century, since the lower reaches of the Amu Darya were transformed into a rice growing zone, there was a need to construct large collecting drains (collectors) like KKC, KC-1, KC-2, KC-3, KC-4 and a number of other collectors to divert return water outside the irrigated fields. Moreover, many existing freshwater lakes, like Sudochie, Karateren, Djiltirbas and many others have become the receivers of waste collector water, and the operation of these lakes in non-circulating water mode has led to an increase in water salinity in these lakes and the loss of their productivity. For example, as of 2010, salt concentration in Akushpa lake reached 60-65%. As a result, all aquatic and semi-aquatic organisms (fish, muskrat, plankton, and fodder vegetation) have disappeared. Reeds serving as forage for cattle and as the stuff for local construction have been lost in coastal zones as well.

The loss of habitats, especially of preferred types like reed thickets, tugai (riparian woodland) and shallow water grounds leads to reduction of bio-diversity and population. Tugais have shrunk to as low as 5% of their former area in the delta of the Amu Darya. There are one sanctuary (Baday-Tugai) and one nature reserve Sudochie that are formally recognized in the delta. The latter was formed as an ornithological reserve. Out of 282 bird species found in the delta in the 1950s, 30 species have disappeared and 88 species are rare, including 22 endangered species in the Red Book of Uzbekistan. Generally, bird populations have been decreasing considerably. The delta as an oasis between the vast deserts is very important for migratory birds. Only 57 bird species found in the delta live there permanently. Historical analysis shows that more than 400,000 waterfowl dwelled there during autumn flights of birds. More than 35 bird species, including 11 nesting species are found in Sudochie.

Table 5.1 Comparison of open water surface areas in the Amu Darya delta (2010-2018), ha

№	Water body	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	Sudochie	31228	6185,61	9083	14178	9704	12476,5	22318	20501	14144
2	Mezhdurechie	10307	501,69	9144	2423	1671	19642,5	8263	9072,7	402,0
3	Rybachie	5552	3069,57	4807	3105	1462	4115,1	3243,5	3435,2	2987,6
4	Muynak	4060	1543,02	1372	1146	508	902,6	1307,5	1142,6	566,9
5	Djiltirbas*	42263.25	5060,18	23420	6176	5774,05	10185,07	6814,97	6945,9	5779,6
6	Former Adjibai bay		-							
7	Dumalak	3773,57	-	326,7	21	9	6679,4	150,9	879,8	-
8	Adjibai 2**		-	-	-					
9	Makpalkol	2061	950	1723,7	1442	8,51	2706,19	1289,62	1032,5	763,2
10	Mashan-Karadjar	7566,20	215,70	1009,7	638	507,54	421,4	596,7	495,8	503,5
11	Water south of Muinak	3937,60	-	-	-	-	398,5	-	-	-
12	Water of Kazakhdarya	3616,17	-	1854	-	-	912,9	6,09	268,9	-
13	Zakirkol lake	819,02	-	70	10	-	1520,5	328,5	376	-
Total area		**72920,56**	**17525,77**	**52810**	**29139**	**19644**	**59960,6**	**44318,8**	**44150,4**	**25146,8**

[*] Djiltirbas – together with former right and left channels.

[**] Adjibai 2 – artificial structure to the north of Rybache and Muynak reservoirs.

Table 5.2 Comparison of wetland areas in the Amu Darya delta (2010-2018), ha

№	Water body	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	Sudochie	49372,0	38915,36	31080,1	56981	53292	57480,7	50379	55327	61550
2	Mezhdurechie	33593,6	22465,0	20131,5	33195	32934	15393,3	29521	28718,9	36008
3	Rybachie	5585,1	5531,1	6837,4	8426	8161	7870,5	8249,5	8380,2	8514
4	Muynak	12049,5	9832,7	9572,2	13254	12409	12801,9	14856,5	15167,5	15618
5	Djiltirbas*	129968	150640,86	141156	151629	61869,35	96189,01	139633	138601	140794,8
6	Former Adjibai bay	12824,6	21023,1	17564	-	-	-	-	-	-
7	Dumalak	22809,1	15986,0	17061,4	17924	13247	15780,4	15899,6	15558,6	16051
8	Adjibai 2**	11738,26	10614,93	15269,1	-	-	-	-	-	-
9	Makpalkol	12599,7	5947,13	5998,9	7017	7454	5977,9	7394,5	7609,1	8171
10	Mashan-Karadjar	4999,9	14128,59	9710,3	27404	9932	27607,4	26604,7	26489,2	26698,5
11	Wetlands of Muynak	13058,6	15024,5	8335,1	9886	9585	9913,8	9605,2	9605,1	9577,7
12	Wetlands of Kazakhdarya	14618,3	16508,04	14753,4	2867	1978	4112,3	4745,5	4655,5	4751,5
13	Zakirkol lake	2882,5	3721,5	2506,2	1468	1577	1270,7	2462,7	2450,3	2791,2
Total area		**326099,2**	**330338,8**	**299975,6**	**330051**	**212438,4**	**254398**	**309351,2**	**312562,4**	**330525,7**

[*] Djiltirbas – together with former right and left channels.

[**] Adjibai 2 – artificial structure to the north of Rybache and Muynak reservoirs.

The watered delta of the Amu Darya is the main source of fish in Karakalpakstan and, despite heavy degradation the delta still has considerable potential. However, due to drastic reduction of river runoff from the Amu Darya into the Aral Sea and an increase in hydraulic gradient of the river, all deltaic lakes have been left with no water and have lost their fishery importance. In dry years, inflow into the delta decreases 6-7 times and the lake area shrinks to 20,000 ha. The reduction of volume of collector water is accompanied by drastic increase in salinity of water, having a very negative effect on water-salt regime of water bodies. Muynak and Rybachie bays preserve their reduced water area even in dry years. In recent years, for watering of deltaic lakes, fixed dams were constructed in the Amu Darya channel in the area of Sheghe, and river water has started to flood the dried zones of former lakes.

Watering of the delta supported fish catch in deltaic water bodies but failed to stabilize fish catch within 20,000-35,000 centner. Since 2004, all lakes located in Karakalpakstan and having an area of 72,000 ha have been leased by 80 farms. The dynamics of fish catch is shown in Table 5.3. Initial (2003) productivity of water bodies at 4 kg per hectare increased to 15 kg by 2008; however, this figure was well far from the projected 100 kg/ha. In the meantime, the best world's productivity of 1 ha of a water body is 1.0–1.5 t/year.

Table 5.3 Fish catch in natural lakes in Karakalpakstan

Year	Fish catch thous. centner	Year	Fish catch thous. centner	Year	Fish catch thous. centner
1960	**225.2**	**2001**	5.52	**2010**	5.84
1965	160.9	**2002**	2	**2011**	11.12
1970	70.6	**2003**	1.32	**2012**	18.96
1975	68.7	**2004**	3.29	**2013**	26.54
1980	35.1	**2005**	4.44	**2014**	26.58
1985	24.6	**2006**	6.06	**2015**	34.1
1990	20.9	**2007**	8.03	**2016**	45.15
1995	20.9	**2008**	13.9	**2017**	59.86
2000	11	**2009**	11.1		

Analysis of the current fishery status in the Amu Darya lower reaches shows that the key problem in fishery development is very unstable water regime and lack of water. Many lakes in Prearalye served as receivers of wastewater and drainage water from irrigated land during last decades. If no freshwater flows to those lakes in near future, it will be impossible to use them for fishery and production of fodder plants (reed).

At the same time, salinity of runoff in the lower reaches of the Amu Darya dramatically increases and water discharge for environmental purposes is reduced, especially in dry years. Combined with the lack of regulating capacities in the lower reaches, this may lead to complete drying of the deltaic water bodies and the loss of their fish productivity.

According to data of OOO "Qaraqalpaqbaliqsanoat", currently there are 116 natural lakes, which cover 83277 ha in Karakalpakstan. The total fish catch was 5986 tons in 2017. In line with the Government approved forecast parameters, the total fish production and catch in natural lakes of Karakalpakstan should increase to 8000 tons in 2019.

In 2016, according to the Uzbek Government decree, the state unitary enterprise "Muynak Aqua Sanoat" was established to develop fishing industry in Prearalye and provide population with high-quality fish products. The territory adjacent to Djiltirbas, Sudochie and Rybachie lakes were transferred to the enterprise for organization of fish nurseries and fish farms. At present, the

Muynak Aqua Sanoat stocks these water bodies with fish to increase fish population to 2.5 million a year. It is expected to increase fish production to 3,500 tons a year.

The systematic monitoring of the delta has been conducted during three years as part of the **"CAWa" Project Phase – "Dynamics of Surface Water and Groundwater Change in the Amu Darya River Delta and the Dried Bed of the Aral Sea"** (from June 2009 to December 2011). The Project was jointly implemented by SIC ICWC, the German Geoscience Research Centre (GFZ) and the Institute «GIDROINGEO» at the State Geological Committee of the Republic of Uzbekistan. In 2009-2011, the objective of the Project was to conduct monitoring in the Amu Darya river delta (surface water and groundwater) and within the dried bed of the Aral Sea (changes in sea level and salinity, soil salt content, and groundwater as well). This work was a follow-up of the research carried out as part of the Project "Stabilization of the Dried Bed of the Aral Sea in Central Asia", the results of which showed critical dynamics of landscapes as the sea dried up and the new ground was formed.

The surface water monitoring was implemented in the three points (sections) along the Amu Darya River (Takhiatash, Samanbai, and Kyzyljar) and the Suenly, Kyzketken, Marinkin, Muynak, Raushan and Kazakhdarya canals. Gauging stations were installed in these points where flow rates and water salinity were measured every month. The wells were drilled in 44 points throughout the delta to monitor groundwater tables and salinity.

To improve the quality of monitoring in the delta and in Prearalye, 21 new gauging stations were constructed by the CAWa Project in early 2011. These new gauging stations have been transferred under responsibility of operating organizations and served for the observation of flow rates and levels along canals, collectors and lake systems in the Amu Darya river delta.

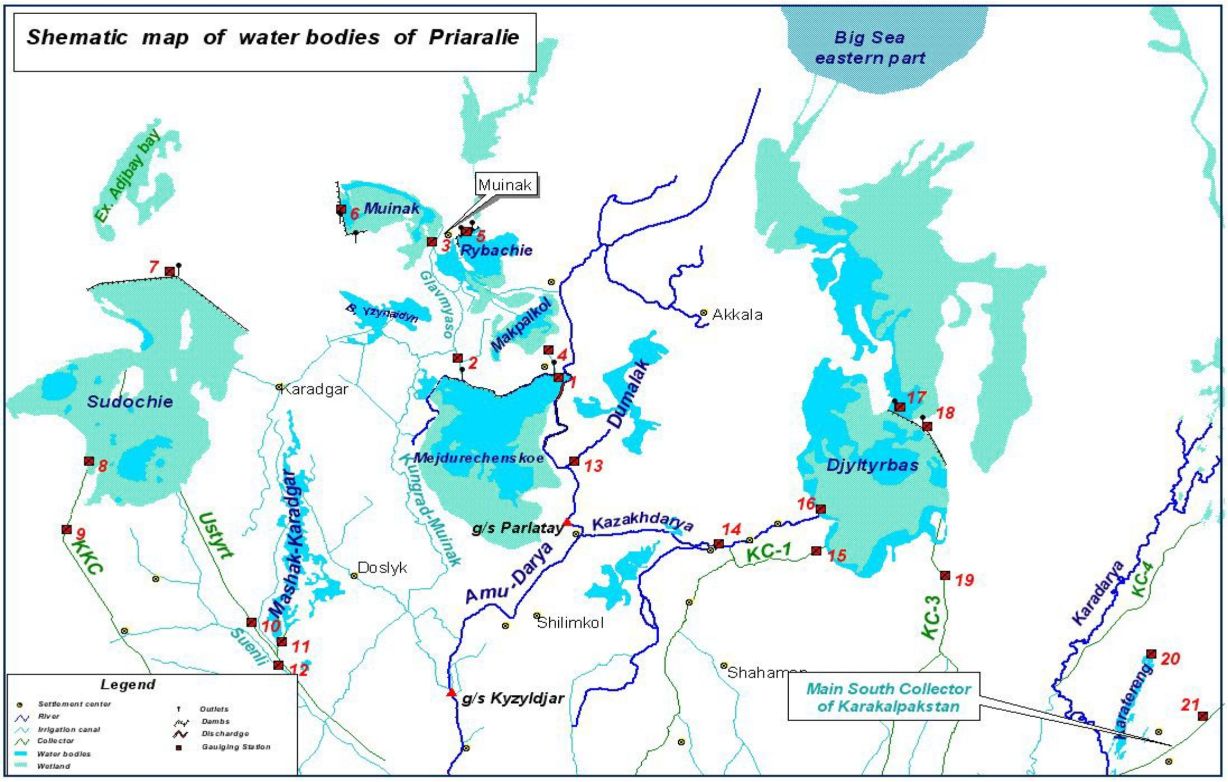


Figure 5.2 Schematic map showing location of gauging stations in Prearalye (2011)

In general, the study of hydrological changes in the Amu Darya delta reveals that the current hydrological situation in the delta is critical. The comparison of the open water surface areas in wet

(2010– 116,000 ha) and dry (2011 – 20,000 ha) periods of time demonstrates extreme unsustainability of lakes' water surfaces, variation of which is almost 100,000 ha.

SIC ICWC organized meetings with the Chairman of the Government of Karakalpakstan and the Head of the Basin Organization on the project results. Measures were proposed for the improvement of delta management and for the completion of hydraulic structures according to the feasibility study developed. Particular attention was paid to a need for regulation of water use through organization of a Water User Association. Based on these proposals, reports were drafted and submitted to the Government of the Republic of Uzbekistan and the Ministry of Agriculture and Water Resources. Unfortunately, those proposals have not been put into effect yet, though measures listed in the proposals were included in the list of projects to be presented to donors, according to decisions of the Urgench Conference on the Aral Sea crisis.

Based on available data on water resources and wetland areas in the deltas, experts of SIC ICWC made calculations showing that a huge amount of water was discharged into the delta from the Amu Darya River and collectors in 2010. This resulted in the increase of the wetland area to 356,000 ha in South Prearalye in October 2010 and certain environmental stabilization in the Amu Darya Delta. The total inflow into the delta and the Aral Sea amounted to 19.6 km^3 in 2010. This amount of water was used for watering of the delta on an area of 203,400 ha (4.5 km^3) and for transpiration and evaporation (4.95 km^3).

In 2009, in the Eastern Sea the water level was 26.3 m +BSL and the water volume was 0.66 km^3, while the water surface area reached 0.92 km^2. In 2010, the water surface area extended to 5.85 km^2. The water level in the Eastern Sea rose to 29.4 m +BSL. According to the data of SIC's GIS experts, the water volume in the sea was 9.8 km^3, i.e. water accumulation in the sea amounted to **9.14 km^3**.

In Western part of the Large Aral Sea, the water level was 27.5 m +BSL in November 2009 and 27.8 m +BSL by the end of 2010. Over 2010, the water level in the Western Sea increased by 0.30 m, and the water surface area was 3.94 km^2. The water volume accumulated over 2010 in the Western Sea amounted to about **1.10 km^3**. Based on the above calculation results and RS-data, one may draw a conclusion that the total amount of water accumulated in the Large Aral Sea over 2010 is **10.24 km^3**.

Those data show that the difference in balance is about 800 million m^3 of groundwater inflow in wet 2010 and 300-400 million m^3 in average and dry years.

The results of monitoring in late 2011 indicated to drying process in water bodies due to low flow conditions. The levels decreased in all water bodies of the Amu Darya river delta. The water level was higher than the design one in all water bodies but the Muynak Bay in 2010, whereas at the end of 2011 the water level dramatically decreased against the design one. Consequently, the water volume in the Eastern Sea halved to 4.46 km^3. The water level in the Western Sea remained within 28.8 m +BSL and the volume was 14.96 km^3.

By comparing the data of water balance of the Amu Darya delta and the Large Aral Sea with the RS-data (derived by SIC's GIS experts) one may see that such surplus was fully used for changes in water volumes in Eastern Sea and Western Sea. (Quarterly reports of the CAWa Project's monitoring are available on CAWater-Info: www.cawater-info.net).

Experts of SIC ICWC continued monitoring of dynamics of water surface areas in Eastern and Western parts of the Large Aral Sea and of lake systems in the Amu Darya delta in South Prearalye over 2012-2018, by using Landsat 8 OLI images. Based on the derived data, inputs and outputs of the water balance of lake systems in South Prearalye were determined for 2017 and 2018.

Water balance over 2017 (million m^3)

- Actual river water inflow, based on BWO Amu Darya's data at Samanbai gauging station, into Prearalye and the Aral Sea (including discharge of collector-drainage water) **– 10721.0**

- Rainfall (Kungrad and Chimbay weather stations – 142.2 mm) – **766.4**

- Groundwater inflow (Institute "GIDROINGEO") **– 0.26**

Total input (+) over 2017 – 11487.7

- Evaporation: Total water surface area of lakes in the Amu Darya delta - 53896 ha × 10000 m^3/ha – **539.0**

- Wetland (reedy) area 300705 ha ×12000m^3/ha – **3608.5**

- Groundwater outflow (Institute "GIDROINGEO") **– 0.26**

Total output (-) – 4147.8

Finally, we get the positive balance **(+) 7339.9** in 2017.

Water balance over 2018 (million m^3)

- Actual river water inflow, based on BWO Amu Darya's data at Samanbai gauging station, into Prearalye and the Aral Sea (including discharge of collector-drainage water) **– 1183.0**

- Rainfall (Kungrad and Chimbay weather stations – 156.8 mm) **– 535.3**

- Groundwater inflow (Institute "GIDROINGEO") **– 0.26**

Total input (+) over 2018 – 1718.6

- Evaporation: Total water surface area of lakes in the Amu Darya delta 34141 ha × 10000 m^3/ha **– 341.4**

- Wetland (reedy) area 317348.13 ha ×12000 m^3/ha **– 3808.2**

- Groundwater outflow (Institute "GIDROINGEO") **– 0.26**

Total output (-) – 4149.9

Finally, we get the negative balance **(-) 2431.3** in 2018.

The comparison of water balance of lake systems in South Prearalye over 2017 and 2018 shows the positive balance because of inflow of 10.721 km^3 into the Amu Darya delta. This has led to 1.10 m rise in the water level in Eastern part of the Large Aral Sea as compared to 2016 (Table 2.1). In 2018, the water balance was negative because of low water conditions. Since environmental demands of South Prearalye have not been met, the lakes systems started to dry and the water level in Eastern part of the Large Aral Sea has lowered by 1.10 m (as compared to 2017).

6. SOCIO-ECONOMIC AND ENVIRONMENTAL PROJECTS FOR THE AMU DARYA AND THE SYR DARYA DELTAS

First project aimed at socio-economic and environmental improvement in delta area was the NATO SFP 974357 Project **"Integrated Water Resources Management for Wetlands Restoration in the Aral Sea Basin"**[13] implemented by the Dutch "Resource Analysis" company and the SIC ICWC jointly with the VEP SANIIRI enterprise and two non-governmental organizations in 2000-

[13] http://www.cawater-info.net/library/rus/nato.pdf

2003. The project objective included summarizing hydrological, historical, water-management, and natural conditions in the delta of the Amu Darya River. In the course of the Project, the water management model of the Amu Darya delta was developed, the relevant hydrographic information system was created, the zones of maximal socio-economic damage were identified and the lake-wetland scheme was determined to mitigate the negative effects of delta drying. The project's schemes included both existing lakes systems that were not provided with sufficient infrastructure (Sudochie, Mezhdurechie, Rybachie, Muynak, Djiltirbas) and new additional water bodies, particularly in the area of former Adjibai bay and to the north of existing Djiltirbas lake. Three options were considered for location of water bodies and their operation was modeled. Particular attention was paid to Mezhdurechie reservoir and to selection of a water level, which was to be kept for accumulation of certain regulated water volume in the reservoir. Different options of reservoir capacity were analyzed: from 400 million m^3 to 1 billion m^3, with the normal storage level (NSL) in the Mezhdurechie reservoir from 56 to 58 m +BSL. As an optimal water level the project selected NSL at 57 m +BSL with 700 m^3/s of the carrying capacity of outlet-regulator. Besides, the calculated width of needed spillway was 440 m with elevation of the spillway at 57 m +BSL and the possible exceedance of maximum possible water level over NSL of 1.5 m. Thus, dam crest elevation was to set at 60 m, provided that sediments in the amount of 2.1 million m^3 in the Mezhdurechie reservoir were removed. The total cost of the selected option was US$ 96.2 million at 2002 values. The Feasibility Study included the reconstruction of the Mezhdurechie reservoir, the Glavmyaso canal, the Muynak and Djiltirbas reservoirs and of three additional water bodies, such as Djiltirbas-1, Djiltirbas-2 and Adjibai-1. The survey of Sudochie lake was completed also and recommendations for finalization of its reconstruction were drafted to reach environmental sustainability of the lake.

The survey of the lake after its reconstruction showed that the lack of efficient rules for management and watering of lake systems, even after reconstruction of Sudochie lake, could not prevent its deterioration. Given that 2000 and 2001 were very dry years, the lake, which produced from 36 to 60 kg of fish until 2000, has decreased its productivity twofold and lost muskrat population by 2002. Based on the results of work, the necessary volume of water supply to the delta was determined for maintenance of all water bodies there. The values of water supply were set at 8 km^3 for wet year, 4.6-4.9 km^3 for average year, and 3.2 km^3 for very dry year.

Unfortunately, despite an agreement of the World Bank to provide a loan for the projected infrastructure and the relevant resolution of the First Vice-Premier Minister of Uzbekistan, the whole complex in the Amu Darya delta was developed through country budget only. As a result, though more than $10 million in local currency were invested in some structures, virtually the whole water complex of the delta did not work properly, first of all, due to impossibility to regulate the Mezhdurechie reservoir since the latter was not completed like other huge efforts that were to be made for delivering water to water bodies (Fig. 6.1).

At the same time, one should note that in parallel to small water body projects, the Uzbek Government with the support of the World Bank has completed the construction of the Right-bank collector. Started as early as under the Soviet Government's Aral Sea Program and subjected to prolonged freeze, the Right-bank collector has finally got its way to the Eastern part of the sea through Akchadarya and the old channel of Djanadarya, with the carrying capacity of 25 m^3/s. As a result, drainage waters in the south of Karakalpakstan from Turtkul, Beruni and Elik-Kala districts are diverted by gravity from the Amu Darya channel. Moreover, now, the Eastern Sea has regular, though small inflow of drainage water.

NATO SFP 980986 Project "Integrated Water Resources Management for Wetland Restoration in the Aral Sea Basin (Northern part)[14]

Over 2004-2008, the comprehensive study of the Northern part of the Aral Sea was carried out in the following focus areas:

- hydrological regimes of the Syr Darya River, the Northern Part of the Aral Sea, and lake systems;
- biodiversity and desertification in given territory;
- water infrastructure;
- social conditions of population and economic status of Aralsk and Kazalinsk districts in the Kzylorda province;
- mathematical modeling of ongoing processes and determination of optimal parameters for recommended measures;
- processing of data in GIS and mapping.

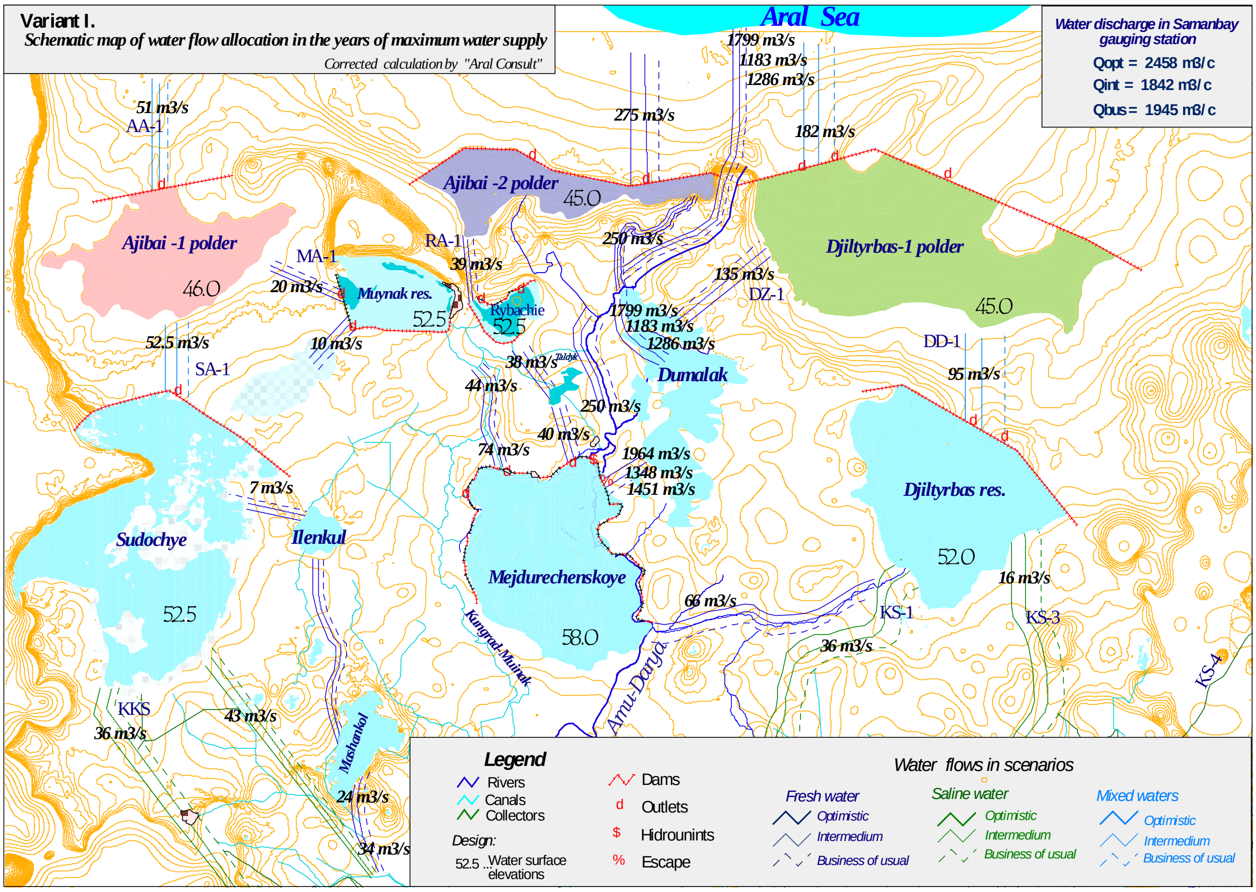


Figure 6.1 Schematic map of water allocation in the years of maximum water supply

Based on the conducted research, concrete actions were proposed for the improvement of the Syr Darya Delta through a complex of hydraulic structures that helped to achieve sustainable water

[14] http://www.cawater-info.net/library/rus/north_aral_ru.pdf

supply and preserve the most important lakes systems and wetlands, localize abandoned highly-saline water bodies, and improve usage of deltaic land. Construction of the Kokaral dam was proposed for environmental stabilization in the region and preservation of the Northern Aral Sea at the level of 42 m +BSL at the first stage.

For the first time, thematic e-maps were generated by applying GIS-technology and using sketching boards and satellite images. These maps included soil, vegetation, hydrology, and hydraulic structure maps and allowed tracing environmental conditions in the lower reaches of the Syr Darya River and in the Northern Aral Sea in subsequent years. Additionally, the need was justified for the construction of Koksarai counter-regulator, which improved water flow along the Syr Darya river in winter and reduced the risk of ice jams and, as a consequence, the risk of flooding of adjacent settlements and in-stream structures.

In contrast to the Amu Darya delta, which has the Mezhdurechie reservoir as the central regulator of water, the deltaic system of the Syr Darya ends in the Northern Aral Sea, which accumulates all discharge water from the Syr Darya River after this water passes through the delta. The dam in the Bergh's Strait together with Kokaral waterworks facility was constructed by the Kazgiprovodkhoz Institute's design from 2002 to 2005 and, as early as in spring 2006, the water level in the Northern Aral Sea reached its design value. This contributed much to the prevention of desertification processes in the Kazakh part of Prearalye and allowed starting work for the improvement of lake systems. The deltaic system of North Prearalye consists of six lake systems, such as Kuvandarya, Aksai, Kamystybas, Akshatau, Primorskaya Right-bank and Primorskaya Left-bank. Individual hydrological solutions were developed for each of the systems and have been implemented now (Fig. 6.2).

The Project modeled operation of the Kamystybas lake system and analyzed its supply in the following options: construction of Amanotkel waterworks facility at the Syr Darya River, with maximum rise of water level in the river to 57.6 m; second option – through the Raim waterworks facility, with maximum water rise in the river to 59.1 m, but in two sub-options of water supply via the Jasulan canal or only via the Sovetjarma canal. Finally, it was recommended to construct the Amanotkel dam for provision of needed water supply.

The total water needs in all lakes systems are estimated at 2.7 billion m^3/year. At present, the development of the delta is planned through a World Bank's project, phase II at the total cost of over $ 120 million.

Based on this work, the book "Restoration of Eco-System in the Syr Darya Delta and the North Aral Sea" [15] was published.

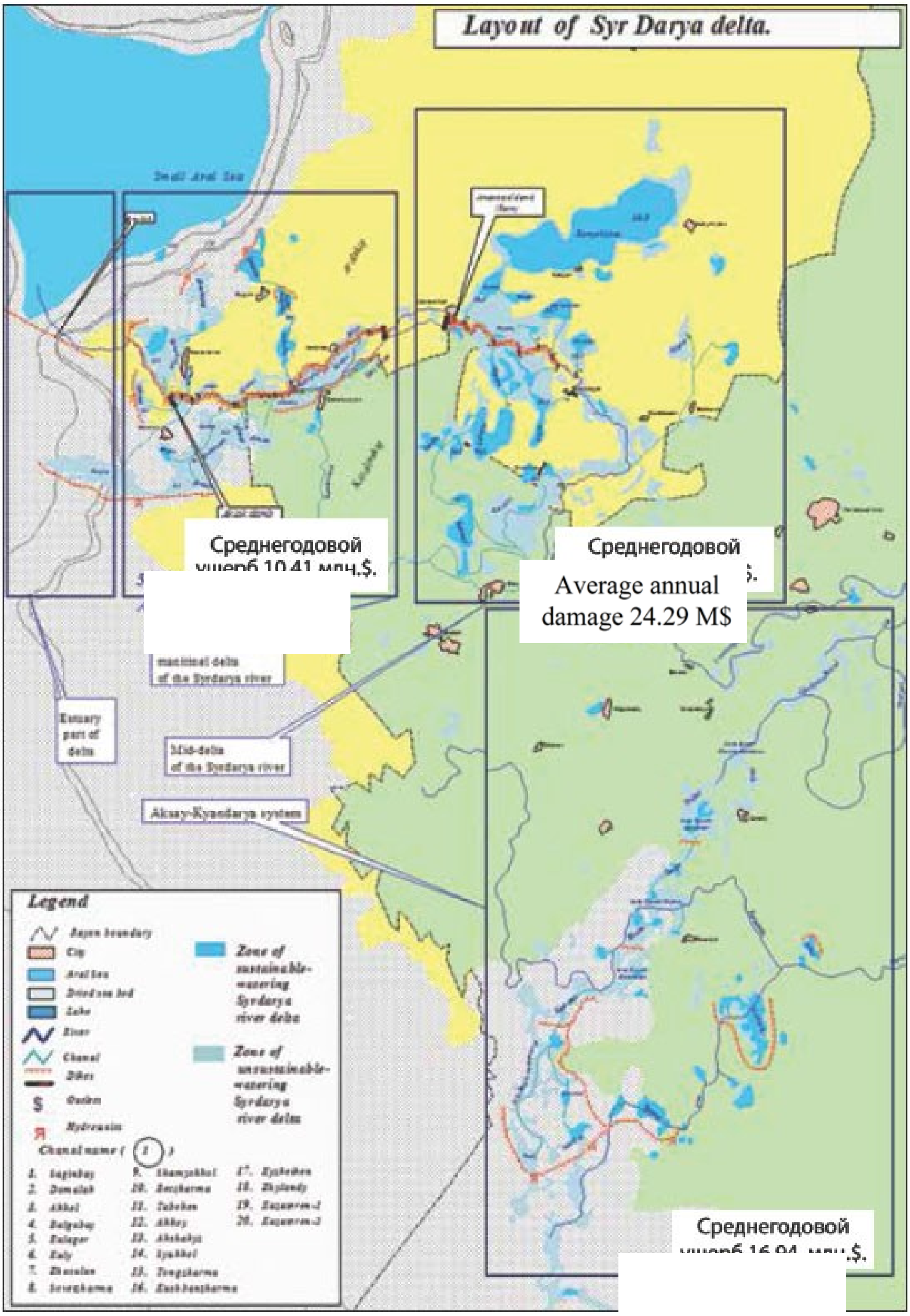


Figure 6.2 Scheme of lake systems in the Syr Darya delta

7. VEGETATION AND FOREST PLANTATIONS ON THE DRIED SEABED AND IN PREARALYE

7.1. Vegetation

The first pioneer in the zone of periodical floods is Saltwort (*Salicornia*). Saltwort abundance increases sharply at a distance of 60-80 m from the coastal line and Sea blite *(Suaeda: S. prostrata S. microphylla)* appears. These plants occupy mainly flat areas and interzones. Dense microstands of Saltwort and Sea blite are the most characteristic for the major part of active shore, while Saltwort is prevalent in the zone close to the sea and sea blite is in the more distant zone. The common reed is met along the border between hydromorphic solonchak and semi-hydromorphic one.

As the sea recedes and groundwater table drops, plant-growing conditions become worse since capillary groundwater rise accumulates salts in the upper horizons. This causes the disappearance of the Saltwort associations. Vegetation is practically absent on deposits of clayish and loamy texture. Vegetation appears when sand deposits on the surface as a result of aeolian process.

Sands fixed by vegetation on the dried seabed are met almost in the whole study territory. They are mainly developed on aeolian sediments, covering large and small areas of solonchak lowlands. Thin humus layers are formed on top of hilly and ridgy sand layers as a result of soil-formation processes and zoogenic factors. This initial soil formation stage coincides with the fixing of sand with psammophytes, which have particular features to stop movement of sands blown by wind. Those are mainly wormwood (*Artemisia L.*), Selin (*Aristida karelini*) etc.

Wind speed and direction, sand formations, available seed-base location, etc. impact plant growing processes on the sandy deposits prone to aeolian processes. The most striking example of self-overgrowing can be the sites of earlier deposited sands located along the eastern chink of the Ustyurt Plateau. At the present time, these sites are under Selin - Black Saxaul associations. Sites of hilly fine-sands to the north of the Tigrovy Khvost Bay are overgrown with Kandym (*Calligonum caput-medusae*). An impressive example of self-overgrowing is the Akpetki archipelago and its dried part from the sea side, where the ground surface is covered with vegetation on about 80 %. More salt-tolerant vegetation species grow in the depressions, while tree and shrub vegetation grows on the elevated zones.

The landscape background in the hilly-ridgy sand complex is formed by tree, shrub and herbaceous plants such as: *Haloxylon aphyllum* (Black Saxaul), Kandym types (*Calligonum caput-medusae, Calligonum eriopodum, Calligonum junceum*), *Ephedra strobilacea, Astregalus villosiassmus*, including *Artemisia terraealbae, Heliotropium lasiocarpum, Carex physodes, Corispeormum lehenanianum*, etc. The dominant components in the lowest layers of the above mentioned complex are: *Bromus tectorum, Eremopyrum orientale, Poa bulbosoae, Stipagrostis pennata, Jsatis minima, Strijosella scorpioides*, etc. *Haloxylon persicum* and *Ammodendron conollyi* are characteristic for loose sandy massifs and ridgy sand slopes, while *Artemisia terrae-albae, Corispeenum lehmanianum, and Eeremopyrum orientale* are typical for compacted sands. Ephemers and ephemeroids are the elements of rich and diverse herbaceous vegetation on sands: *Allium sabulosum, Tulipa sogdiana, Alyssum turkestanicum, Diptychocarpus strictus, Bromus tectorum*, etc.

We found Zhuzgun (Kandym) groups of *Callygonum caput-medusaue*, *C. junceum*, *C. microcarpum, C. murex* including Saxaul *Haloxylon aphyllum*, *Ephedra strobilaceae* and rare Saltwort shrubs *Salsola richteri* in psammophyte shrub associations in addition to the above mentioned species. Kyzylchar-Selin-Zhuzgun and Selin-Zhuzgun associations are met on fine-hilly and barchan sands as well as on slopes of large sandy ridges. Such associations in combination with grass-Zhuzgun and Soaka-Zhuzgun ones are found in some places. We described also Saltwort and Tamarisk associations in exposed clayish soil, with some solonchak spots.

Microrelief elements of biogenic origin are met along the eastern and the southern coast of the dried bed of the Aral Sea: vegetative hillocks, hummocks among disappearing reed beds (kupa laki) covered by sand. We disclosed sprouts of Saltwort, Sea blite, Tamarisk, etc. Coast vegetation of the receded sea is represented by a number of halophytes such as: *Atriplex dimirphostegia, Salicornia europea. Salsola micranthera, Suaeda, Tamarix hispida, T. laxa, T. Pentadra*, etc.

These hillocks serve as a transition to the more compacted small hillocks with abundant vegetation, where *Haloxylon persicum*, *Haloxylon aphyllum*, *Salsola arbuscula*, *Salsola richteri, Artemisia santolina, Artemisia diffusa* (spreading wormwood), *Artemisia terrae-albeae* (white land wormwood), *Ceratocarpus arenarius, Carex physodes*, etc. grow. Eroded solonchak shores like hollows with clay and crusted-salt covers were observed in hilly sands. We registered the following species here: *Haloxylon aphyllum, Tamarix elongata, Tamarix laxa, Halostachys belingeriana, Salicornia europea, Suaeda salsa*, etc.

The aim of phyto-reclamation on the exposed Aral Sea bed was to prevent negative ecological consequences of the Aral Sea disaster and form artificial desert range land (Novitskiy 1984; Koksharova 1985). Local and German foresters undertook forest reclamation in an area of 250,000 ha on the dried seabed of the Aral Sea over the last 15-20 years (Fig. 7.1-7.2).

Figure 7.1 Artificial plantations of Saxaul (age 10 years)

Figure 7.2 Artificial plantations of Saxaul (age 3-4 years)

One of particularly hazardous effects of desertification is the progression of aeolian processes and the following transport of salt and dust from the exposed seabed. The volumes of such transport can be reduced through afforestation of the dried bed of the Aral Sea. However, at present, it is not feasible to cover the exposed ground with afforestation because of limited funds allocated and the plant establishment rates under such conditions. ***In this context, it is important to identify sites on the exposed seabed that are more appropriate for afforestation at present.*** Given the limited availability of information and the complicated nature of field surveys on the dried bed of the Aral Sea, remote sensing methods using satellite images and GIS offer the more productive way out.

In the course of expeditions mentioned above, we studied the state of vegetation in certain types of landscape only. Forest plantations in a targeted study of plant establishment rates (to be described below) were addressed only by third, fourth and fifth expeditions.

According to data from the Karakalpak Forestry Authority, the area of artificial afforestation covered 225,500 ha as of 2006 on the dried seabed, including 212,500 ha planted by seeds and 13,000 ha by young plants. The average rate of seeding and planting was 12,000 ha a year. We investigated 14 sites on the total area of 80341 ha, of which 66-69.2 % showed good development. It is noteworthy that artificial afforestation is accompanied by natural succession everywhere.

During the expedition, some factors likely leading to a bad plant establishment could already be identified. This leads to a need for developing a set of selection rules and preparation strategies for planting zones in order to improve the plant establishment rates. Poor quality seeds or dead (by the time of planting) seedlings, as well as the initial soil and hydro-geological conditions that do not meet the requirements can cause poor establishment rates. Besides, barchans are expanding, and this requires the assessment of their need for fixation by cane. Additionally, the identification of sites with degrading Saxaul or drying of Tamarisks is necessary, and multiple disturbance of plants by geological and oil explorations and by transport needs to be taken into account.

It is interesting that the total vegetation covered area increased by about 471,000 ha. Taking into account that artificial plantations were made in an area of approximately 240,000 ha, it can be concluded that the ongoing self-overgrowing process has already covered an area of 230,000 ha.

While understanding that these estimates are very rough, nevertheless it is necessary to stress that these processes are on-going and require in-depth studies. According to the field observations, overgrowing is particularly enforced near and in the margin of artificial plantations, as well as especially on hydromorphic and semi-hydromorphic soils with Saltwort and ephemeral plants.

Vegetation coverage is well visible in an image (Fig. 7.3), where almost the whole area of Akpetkin archipelago is green.

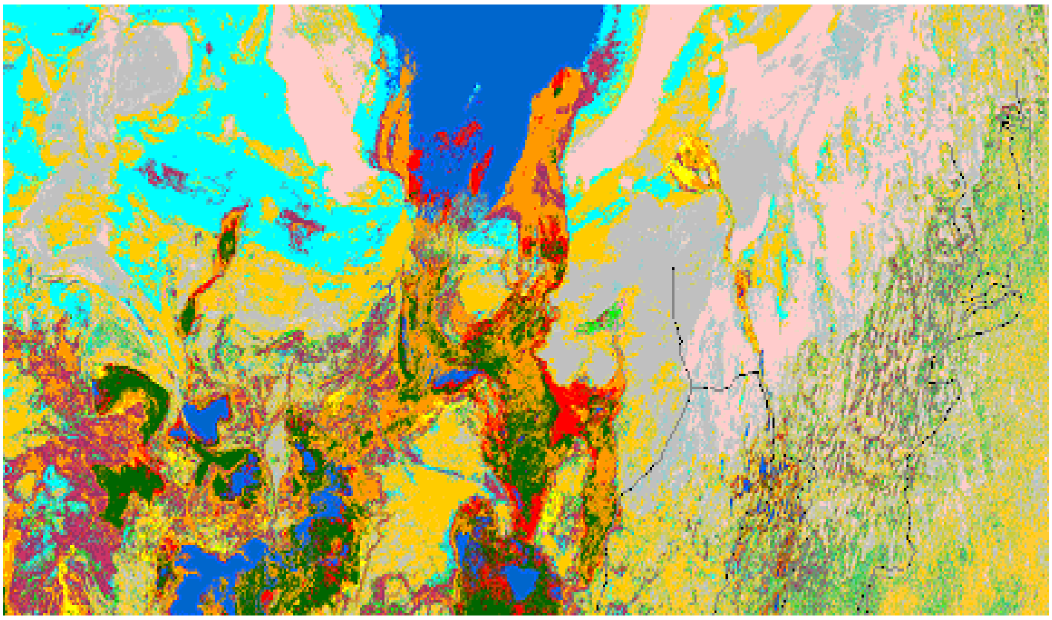


Figure 7.3 Vegetation cover map (generated by IRS-data)

Tugai forests covering the coastal area and, especially, the Amu Darya delta, have a special place in vegetation estimates. Earlier research under INTAS Project has found that the tugai area decreased dramatically over 1990–2000. Vegetation cover has changed alone with landscape changes.

Most developed vegetation was confined to deltas' river arms forming vast tugai areas – unique woodland combining shrubs, herbs and trees specific for plains flooded periodically and silted. Gerasimov et al. describe the following picture of processes taking place in the 70s and their quantification: "Before, deltas were comprised of wet landscapes cut into and disharmonized with surrounding zonal desert landscapes. Alluvial-meadow and meadow-marshy soil along terraces, tugais, and reed thickets contributed to development of tugai vegetation".

Treshkin et al. [16] show a diagram of tugai shrinkage in the Amu Darya delta (Fig. 7.4), where the area of tugais was considerably smaller even at the level of the 1930s (300,000 ha) and decreased largely by 150,000 ha before lowering of the Aral Sea, i.e. before 1960. By the present level, the reduction of tugais was recorded by additional 120,000 ha.

Figure 7.4 Reduction of tugai forests in the Amu Darya delta

The authors characterize the reduction of tugais in terms of both area and productivity. Comparative measures of the yield of ligneous, bush and grass components of tugai forests have decreased over the 35-year period as follows:

Table 7.1 Dynamics of mass of tugai forests per unit area

Measure	Productivity	1960	1995	% reduction
Total phytomass	t/ha	170.1	128.9	24.2
Green phytomass	t/ha	29.1	19.2	34.0
Ligneous phytomass	t/ha	38.7	28.6	26.1
Roots	t/ha	102.3	81.1	20.5

By considering green and ligneous phytomass as a productive element of tugai vegetation, we see its average reduction from 67.8 t/ha to 37.8 t/ha or by 45 %!

According to Novikova [17], the degraded tugais were replaced by tamarisk and halophylic shrubs. Typical tugai group diminished from 42 % in 1960 to 18 % in 1993 (Fig. 7.6).

Reed thickets have played the important role in vegetation communities of the delta before its drying. Reeds covering shallow areas of lakes and floodplains have occupied about 600,000 ha before 1960. They represented major high-productive pastures and hayfields in the lower reaches of the Amu Darya. By present, the reed area has shrunk to 30,000-50,000 ha. Reed productivity decreased from 30-40 t/ha to 13-15 t/ha of air-dry weight. Some part of reeds confined to floodplain depressions is flood-irrigated to create favorable conditions for reed production. At present, the landscapes with reed thickets on meadow-marshy soil in the delta have been restored to a certain degree through watering of the delta in the last years. Whereas former spills of Akdarya and Kipchakdarya were partially restored, the inter-channel depressions in inner delta of the Kunyadarya have dried up completely. Similar landscapes in the left-bank of the delta occupy only flood plain areas within the Moshankul-Khojakul-Ilmenkul-Kipsyt lake system and the zone to the north of Sudochie Lake. Discharge water feed these landscapes.

The area of landscapes represented by tamarisk shrubs on meadow and meadow-marshy soil has expanded. Currently, such landscapes are prevalent in the north part of the delta and are typical for all lateral and flood plains.

The area of *Tamarix hispidula* and karabarak shrubs on heavily saline soil and solonchak also expands, including on lowland plains adjacent to Sudochie lake. Formation of these landscapes is also observed in inner delta of the Kunyadarya channel.

The landscapes of Black Saxaul on takyr soil and Saltwort on desert-sandy soil and sands have increased slightly. This process takes place mainly through desalinization of former irrigation land in the eastern part of the delta to the north from Turkmenkyrylgan sands.

As compared to the early 1960s, the irrigated area, especially in the seaside of the Amu Darya delta, has expanded slightly. This expansion is caused by development of small land masses in different parts of the delta.

Generally, the reduction of meadow and tugai landscapes and the gradual expansion of solonchak, takyr and sandy plain landscapes are notable in the delta.

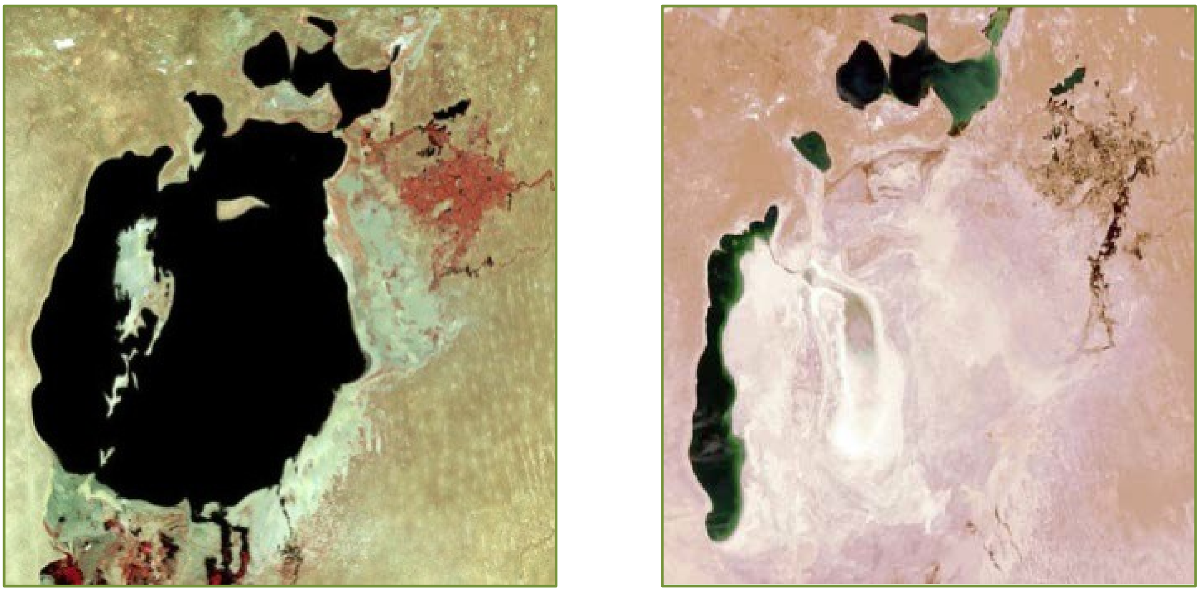
8. REMOTE SENSING BASED DYNAMICS OF THE ARAL SEA WATER AREA[15]

The Aral Sea - located on the border between Kazakhstan and Uzbekistan in the heart of the Central Asian deserts – was the fourth largest lake in the world till 1960. However, in the last 50 years the water area and volume of the sea have shrunk almost ten times, the seawater salinity has increased, and fish population has almost disappeared.

Until 1960, the Aral Sea has been in the steady-state condition. Over the observation period since 1850 to 1960, variations of the sea water level did not exceed three meters and were caused exclusively by natural cycles. In 1960, the area of the Aral Sea was 68,900 km², the water volume was 1083 km³, and the water level was 53.4 m +BSL.

[15] ArcReview - 3 (74) | 2015 (https://www.esri-cis.ru/news/arcreview/detail.php?ID=22433& SECTION_ID=1081)

Figure 8.1 Aral Sea Basin



1960 2016

Figure 8.2 Satellite images of the Aral Sea

By present, parameters of the sea have changed critically. The total area (*Large Aral Sea + Small Aral Sea)* shrank 9 times to 7,500 km² and the seawater volume was reduced 21 times to 50.1 km³. The water level also varies widely from 25 m in the Large Aral Sea to 42 m in the Small Aral Sea against 53.4 m in 1960.

Different opinions are voiced about causes of the Aral Sea disappearance. Some speak about erosion of the sea bottom and consequent water overflow to the Caspian Sea and adjacent lakes. Some argue that this disappearance of the sea is a natural process driven by the general climate change on the Earth. Others see the cause in degradation of glaciers feeding the Syr Darya and the Amu Darya (Fig. 8.3).

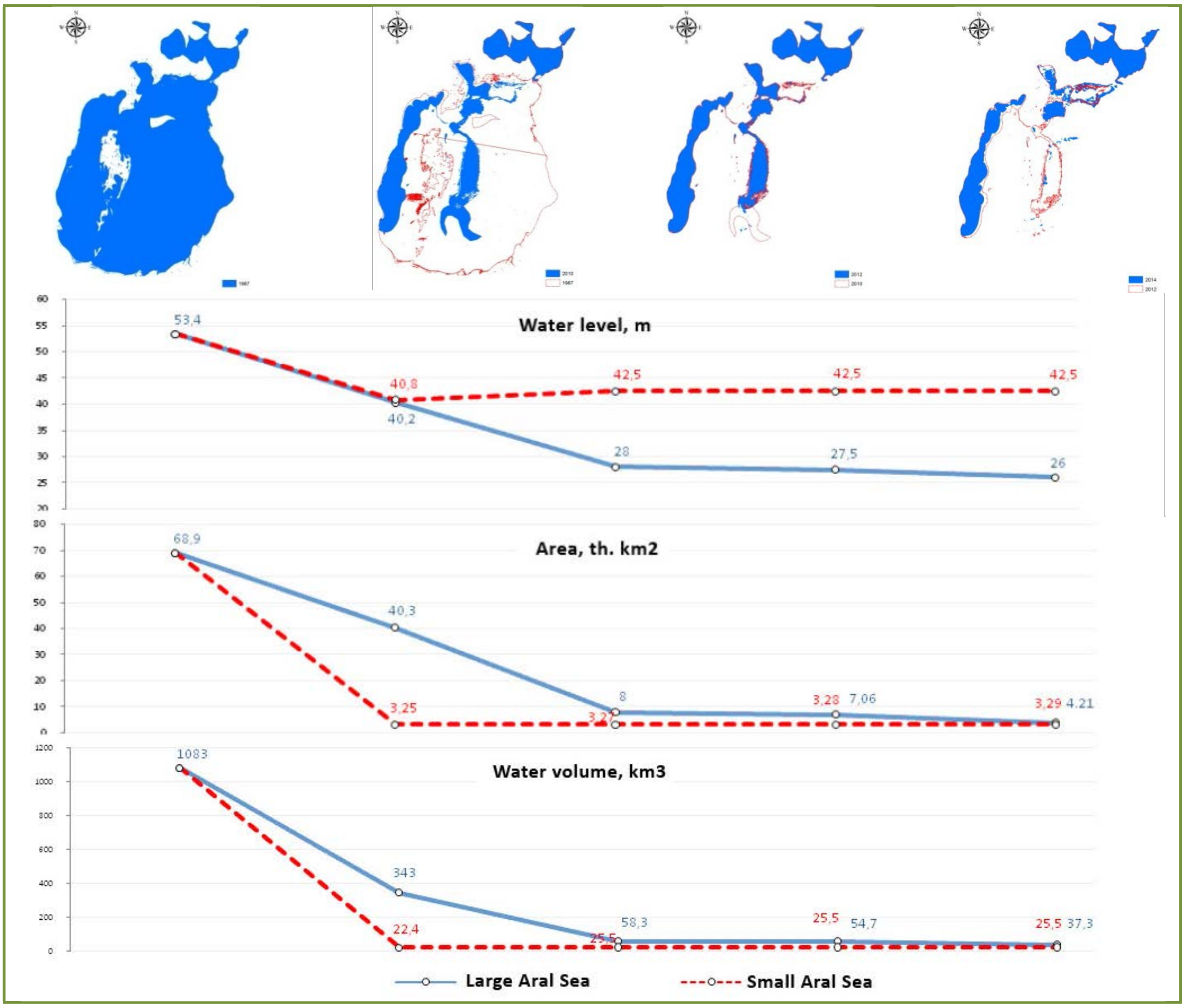


Figure 8.3 Dynamics of the Aral Sea parameters

Table 8.1 Dynamics of the Aral Sea parameters

Aral / Paramet er	Water level, m +BSL						Water area, thousand km²						Water volume, km³					
	0	7	2010	2012	2014	2016	0	1987	2010	2012	2014	2016	1960	198	2010	2012	2014	2016
Large Aral Sea:																		
Eastern part	53.4	40.2	28.5	27.5	26.5	25	68.9	40.3	4.13	3.19	0.97	1.25	1083	343	6.1	2.5	0.9	0.1
Western part			27.5		25.5	25			3.87	3.87	3.24	2.91			52.2	52.2	36.4	25
Small Aral Sea		40.8	42.5	42.5	42.5	42		3.25	3.27	3.28	3.29	3.29		22.4	25.5	25.5	25.5	25

Step 1. For the purposes of monitoring of the Aral Sea area and the coastal waters, GIS experts of SIC ICWC used products of MODIS *(Moderate Resolution Imaging Spectroradiometer)* TERRA 13A1 NDVI and Landsat TM *(satellite providing images of Earth)* over 1987, 2010, 2012, 2014 and 2016.

The MODIS instruments capture data in 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm and at varying spatial resolutions (2 bands at 250 m, 5 bands at 500 m and 29 bands at 1 km) (Fig. 8.4.1-8.4.2)

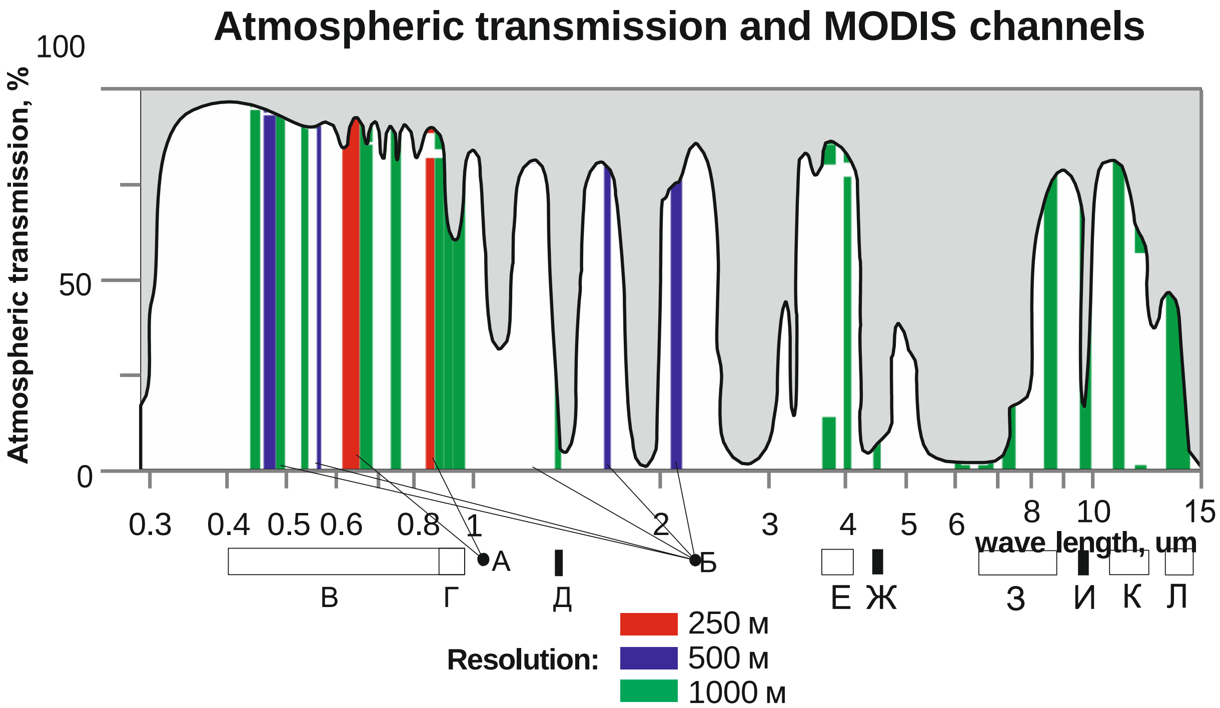


Figure 8.4.1 MODIS image bands

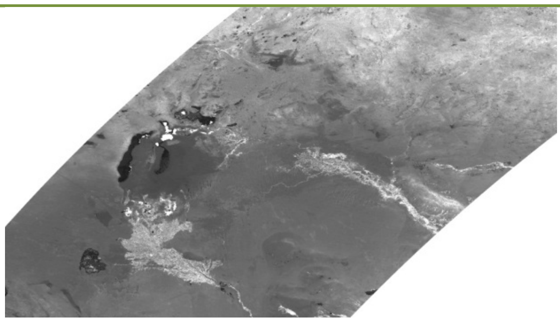


Figure 8.4.2 MODIS Terra 13A1 NDVI imagery

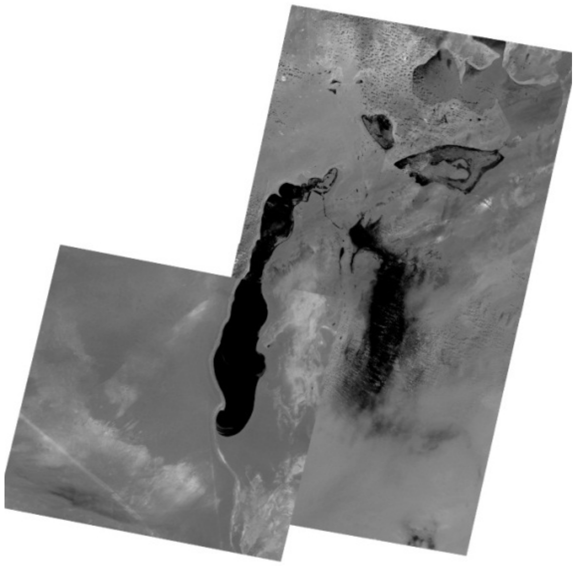


Figure 8.4.3 Landsat TM NDVI imagery

Landsat is the longest-running enterprise for acquisition of satellite imagery of Earth. The first satellite was launched in 1972, while the last Landsat 8 was launched on February 11, 2013.

The instruments on the Landsat satellites have acquired millions of images. The images, archived in the United States and at receiving stations around the world, are a unique resource for global change research and applications in agriculture, cartography, geology, forestry, surveillance, education, and national security.

For example, Landsat 7 data has eight spectral bands with spatial resolutions ranging from 15 to 60 meters; the temporal resolution is 16-18 days (Fig. 8.4.3).

Step 2. Geometric processing and radiometric correction of LandsatTM images were made using ERDASIMAGINE 9.1 software. A digital elevation model (DEM) was created and the following were modeled:

- FillDEM – filling gaps in pixels and smoothing *(geometric processing and radiometric correction)*;
- Flowaccumulation – calculation of water catchment area *(basin)*;
- Contour (*boundary)* of the sea basin using SRTMDEM imagery.

Step 3. Then NDVI was determined. The method for calculation of vegetation indices consists in identification of green vegetation using the simple arithmetic conversion. This is a fully automatic method, where user's input is limited to the last stage – identification of selected sites. The normalized difference vegetation index (NDVI) is a standard index showing vegetation and its status (relative biomass). NDVI is also used to monitor drought, **water surface**, forecast agricultural production and assist in forecasting desert offensive maps.

Clouds, water and snow are better reflected in visible region than in near infrared region, whereas the difference is almost zero for rocks and bare soil. Processing of NDVI creates a one-band set of data, which is mainly represented by vegetation. Water and/or snow give negative values, and rocks and bare soil produce positive values approaching 0. The NDVI is calculated as follows:

$$\mathbf{NDVI = ((NIR - R)/(IR + R))}$$

- NIR = the spectral reflectance measurements acquired in the near-infrared channel
- R = values of pixels from red channel

The index varies between -1.0 and +1.0, which mainly represent greens, where negative values indicate to water surface and snow (winter images). Very low values (0.1 and lower) of NDVI correspond to barren areas of rock, sand or snow. Moderate values (from 0.2 to 0.3) represent shrubs and grassland, while high values (from 0.6 to 0.8) indicate temperate and tropical rainforests. The NDVI calculation algorithm is embedded almost in all widespread RS-data processing software packages (ArcViewImageAnalysis, ERDAS Imagine, ENVI, Ermapper, Scanex MODIS Processor, ScanView, etc.).

Generally, the key advantage of NDVI is its simplicity: no additional data and methods are needed for calculation of this index, except for satellite imagery and related parameters.

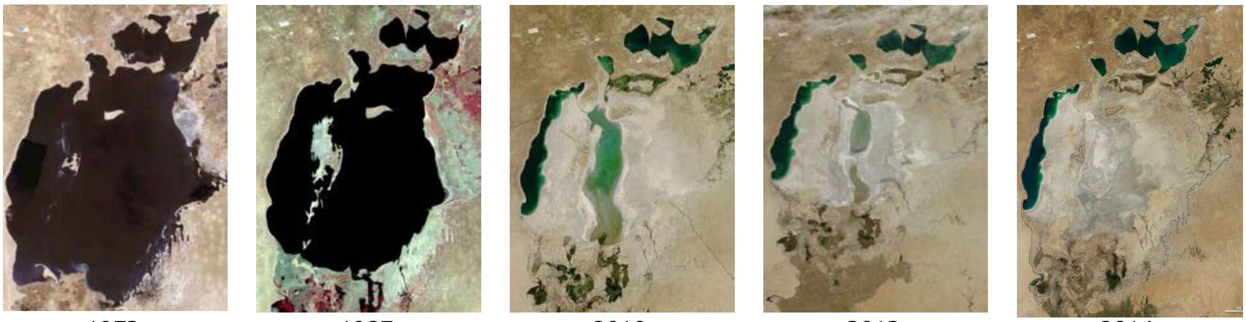


Figure 8.5 Satellite images of the Aral Sea in dynamics

Step 4. By using GoogleEarth and SASPlanet, we selected representative points for calculation of reflectance. Then, diagrams were plotted on the base of these points for classification and pixel values for water surface were determined. In this task we used the tool (*ZonalAttribute) of ArcGIS 9.3 software (Figures 8.6.1, 8.6.2).

Attributes of zstat7

OID	VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
0	1	7697	4,13057E+08	-0,3	-0,0362	0,2638	-0,1277	0,032064	-982,903
1	2	2972	1,59491E+08	-0,1259	-0,0351	0,0908	-0,0872967	0,0100032	-259,446
2	3	3183	1,70815E+08	-0,1988	-0,0615	0,1373	-0,146627	0,0184565	-466,714
3	4	4285	2,29953E+08	-0,2	0,0163	0,2163	-0,115838	0,0331832	-496,366
4	5	2329	1,24985E+08	-0,2	0,0266	0,2266	-0,148355	0,0339403	-345,518
5	6	2868	1,5391E+08	-0,2	-0,0315	0,1685	-0,0828406	0,0451257	-237,587

Record: 1 Show: All Selected Records (0 out of 6 Selected)

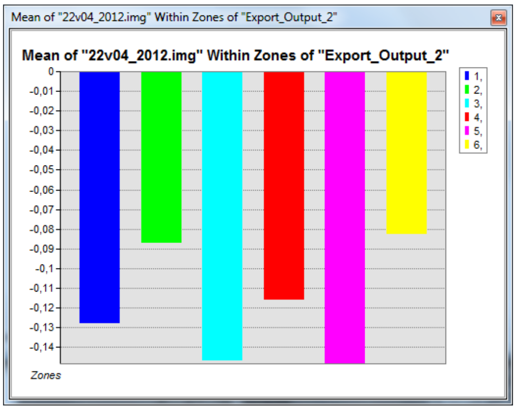


Figure 8.6.1 NDVI by LandsatTM

Attributes of zstat10

OID	VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
0	1	7697	4,13057E+08	-0,3	-0,0362	0,2638	-0,127575	0,0321084	-981,947
1	2	2972	1,59491E+08	-0,1259	-0,0351	0,0908	-0,0871116	9,86933E-03	-258,896
2	3	3183	1,70815E+08	-0,1988	-0,0615	0,1373	-0,146415	0,0184185	-466,039
3	4	4285	2,29953E+08	-0,2	0,0163	0,2163	-0,115225	0,0327134	-493,738
4	5	2329	1,24985E+08	-0,2	0,0266	0,2266	-0,149437	0,0324721	-348,038
5	6	2868	1,5391E+08	-0,2	-0,033	0,167	-0,0835817	0,0448573	-239,712

Record: 6 Show: All Selected Records (0 out of 6 Selected) Options

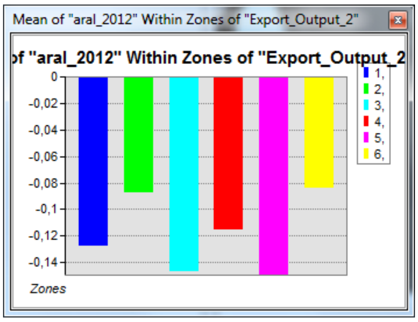


Figure 8.6.2 NDVI by MODISTerra

Step 5. Next, ArcGIS 9.3 calculated the area of water surface, which was derived from LandsatTM and MODIS imagery. Raster layers characterizing dynamics of water surface and bare soil (rock and degraded land) were modeled for the whole period of observations.

Then, the modeling results were validated. Having all necessary information, including downloaded images with resulting classification of land cover and the online analysis of land cover by GooglePlanet and SASPlanet, we drew tables showing the accuracy of modeling for more than 500 representative points.

Next, GIS layers were produced in ArcGIS 9.3 on the basis of modeling results and topographic maps. All layers are in format of *.shp files and make up a GIS-project. All components of a .shp file for one layer have the same name. A .shp file contains spatial data in binary code, and a .dbf file contains attributive data in dBASE format. A .shx file is a spatial index, which contains sketchy information about the structure of .shp file. In other words, the .shx file is a key to spatial data, which allows quick reading of .shp file and, consequently, all operations of search and selective display of objects (Fig. 8.7).

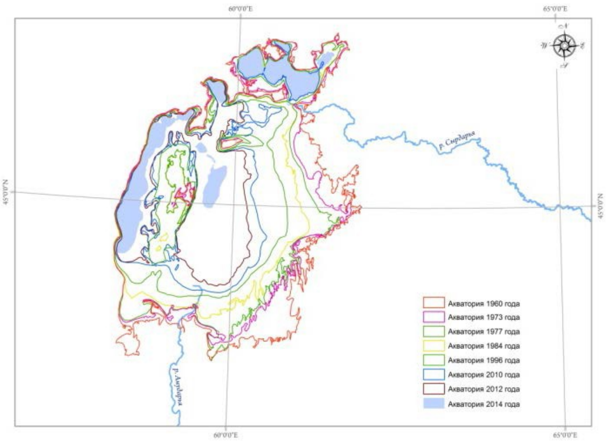


Figure 8.7. Dynamics of the Aral Sea water area, *.shp files (vector format)

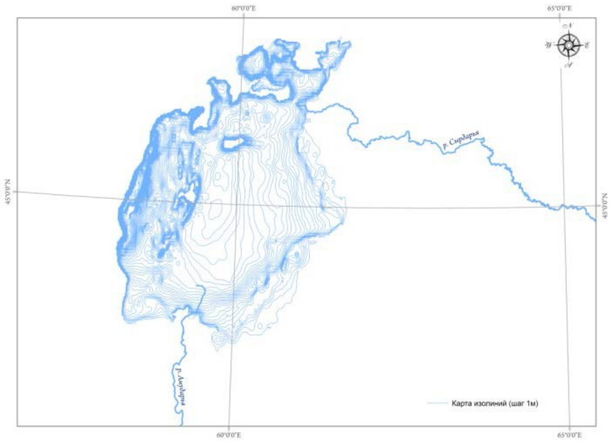


Figure 8.8 Sea bottom contour map, depth increment 1 m

Step 6. Then, by using DEM, we plotted contours for the whole territory of the Aral Sea, with 1 m depth increment.

The table showing relationship of the sea water volume on elevation, with 1 m increment, was prepared using the bathymetric curves produced under the INTAS-0511 REBASOWS Project in 2001 (Fig. 8.8).

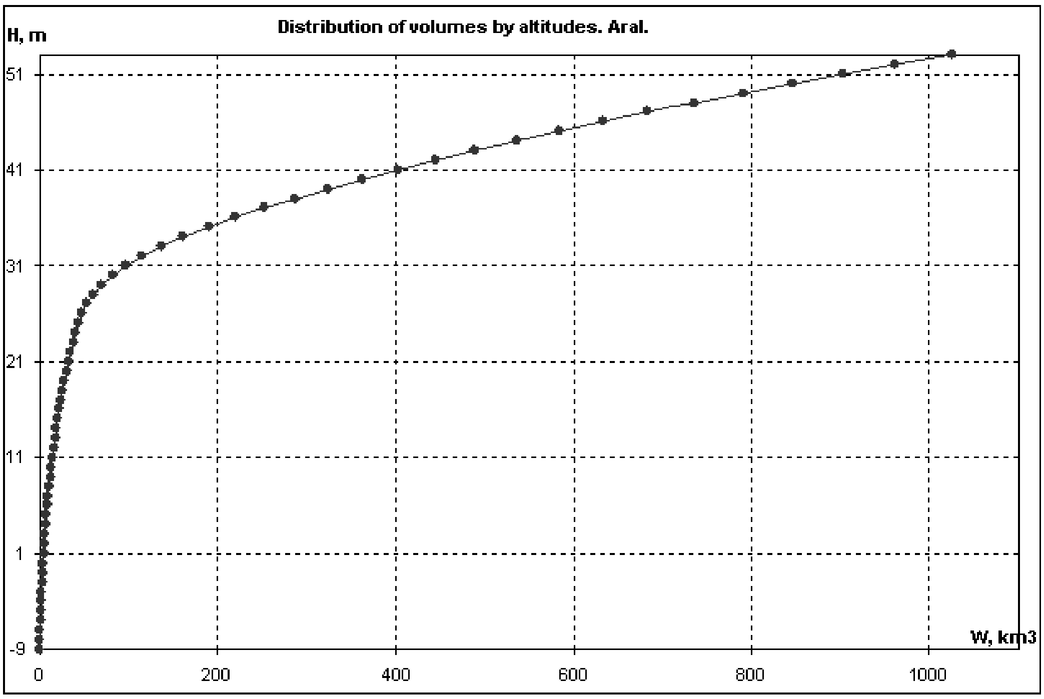


Figure 8.9.1 Changes in water volume with elevation. Aral Sea

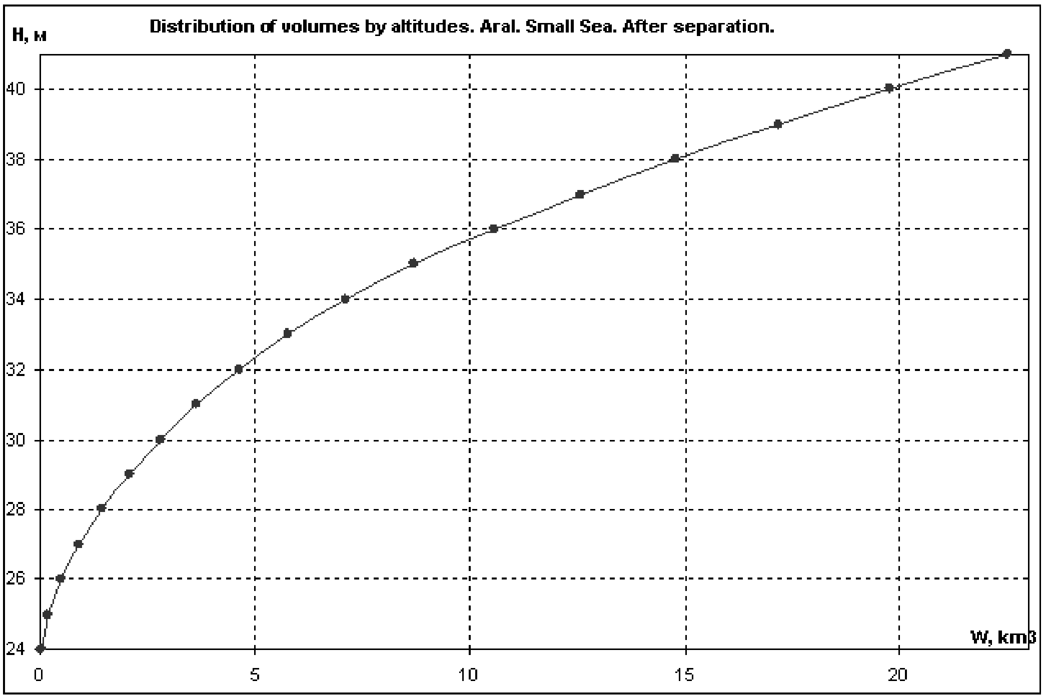


Figure 8.9.2 Changes in water volume with elevation. Aral Sea. Small Sea. After separation

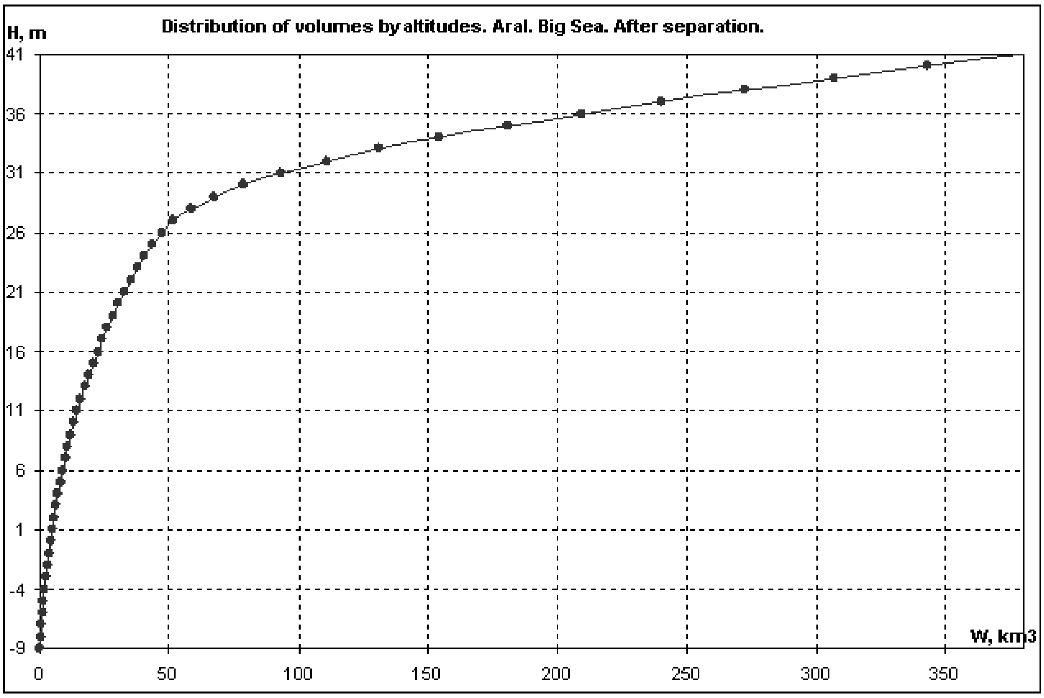


Figure 8.9.3 Changes in water volume with elevation. Aral Sea. Large Sea. After separation

Conclusions. Assessment of the water surface area of the Aral Sea using the GIS technology and modeling showed that Western part of the Large Aral Sea shrank less intensively than Eastern part. Calculations and analysis of RS-data has proven the hypothesis about an underground flow from Eastern to Western part of the Large Aral Sea. The calculation methodology of water balance of the Large Aral Sea was corrected accordingly.

For instance, calculations of water balance over October 2016 for Western part of the Large Aral Sea show that water losses through evaporation are about 0.74 km^3, while losses of the volume (with the area changing from 3.39 to 3.38 km^2) are estimated at 0.14 km^3 only; the difference refers to seepage of 0.6 km^3 per month (that time, surface water inflow to the Western part was not available). In September-December, with the reduction of water surface area in the Eastern part, seepage also decreases drastically to 0.10-0.15 km^3 a month.

9. FAUNA AND FLORA OF THE ARAL SEA

9.1. Fish

Initially, the ichthyofauna of the Aral Sea was relatively poor. The native fish fauna of the Aral Sea consisted of only 20 species from 7 families, including 10-12 commercial species, mainly: Aral barbell, bream, carp, asp, roach, pike, catfish, pike perch, etc. The fish catch of those species accounted for 80 to 85%.

At a later stage, as a result of introductions in the 1950s and 1960s, the number of fish in the sea increased to 30 species. Thanks to acclimatization, the ichthyofauna has become substantially richer. The acclimatization was started in 1927-1929 (Karpevich 1975) in order to enrich the fauna and increase the fish catch. Eventually, introduction of euryhaline species has become prevalent. Totally, 18 fish species from 8 families were introduced in the Aral Sea. All those species, except for ship sturgeon, i.e. 95% are new for the Aral. Out of planned introduction of 9 species, only 2 species – Baltic herring and flounder-gloss – got acclimatized. In contrast, all 9 accidentally introduced species got acclimatized. Those species came to the Aral Sea at the same time in the mid-50s during transportation of mullet from south-eastern part of the Caspian Sea. Most of them, being undemanding eurybiontic species, increased their populations over short periods of time. With growing salinity of water in the 1970s, most native species have disappeared. Fishing was stopped in the Aral Sea in 1981. In the 1980s, because of high water salinity, all native and most introduced species disappeared in the sea. By the 1990s, only 5 species remained in the Large Aral Sea: Baltic herring, flounder-gloss, Caspian sand smelt, Caucasian dwarf goby, and monkey goby. The source of food for flounder included mainly shrimps, crabs, nereis, mollusks, and gobies in the 1990s, whereas in the early 2000s the key food resource for this fish was brine shrimp (Artemia) (Mirabdullaev et al. 2001).

In 2002, only two fish species were found in the Aral Sea: sand smelt and flounder. Sand smelt juveniles were recorded in Western part of the sea in 2002, indicating to reproduction. Later one, probably, sand smelt could not tolerate cold winters in the Large Aral Sea. This is proven by the fact that sand smelt was found on the beach in winter season and this fish was recorded in the Uzbek territory of the Large Aral Sea only in the latter half of the year. Perhaps, the sand smelt population was reproduced in the sea as a result of spring migrations from the North Aral.

Dead flounder specimen was noted around Zhideli Bulak in 2002. Other researchers also recorded flounder in 2002 (Zavialov et al. 2003). However, later in 2003-2005, we did not observe fish species. Evidently, no fish remained in the Large Aral Sea.

9.2. Bioproductivity of the Aral Sea

Initially, the ecosystem of the Aral Sea was rather poor and low productive due to oligotrophic water. Nevertheless, before the 1960s, the sea was the largest fishery water body in Central Asia and produced annually 15,000-40,000 tons of fish (mainly carps and sturgeons). As a comparison, all water bodies in Uzbekistan (except for fish-rearing ponds) produce about 8,000 tons of fish every year. However, since 1980, the Large Aral Sea has lost completely its fishery function.

The key factor that critically changed the Aral Sea biota is the salinity of seawater, which grew up from 10 ppt to 100 ppt for less than 50 years. Therefore, in estimation of the adaptive capacities of local biota we analyzed adaptation to salinity. The derived data on salt tolerance of aquatic organisms allow forecasting the composition of the sea's biota for different degrees of salinity. Reduction of water salinity and consequent re-introduction would contribute to improvement of fish productivity. Fishing (of flounder and sturgeons mainly) in the Aral Sea is possible at a salinity range of 35-40 ppt. However, this will be feasible only with regular stocking of the water body with sturgeon baby fish and if the Aral Sea is used as a feeding body (the so called pasturable fish culture).

Any use of the Aral's bio-resources seems to be impossible at the salinity ranging within 40-75 ppt. However, with the salinity increasing higher than 75 ppt, a new type of bio-resource is formed in the Aral Sea – brine shrimp Artemia. The cysts of Artemia are widely used in aquaculture and have commercial value. Major factors restraining development of Artemia are food (phytoplankton in form of microalgae), competing organizms (zooplankton), and predators (fish). Production of phytoplankton depends on an amount of nutrients (N, P) in the sea. Presence of competing organisms and predators is determined by their salt tolerance. Fish dies at the salinity level of 70-80 ppt, and production of zooplankton decreases greatly. This makes the Artemia population dominant in the aquatic ecosystem. In turn, this creates opportunities for harvesting of Artemia cysts. Artemia population keeps its productivity to the salinity of 200-250 ppt. Artemia tolerates the higher salinity (to 300 ppt) also; however, productivity of the shrimp becomes very low for profitable business.

9.3. Refugiums for the Aral Sea biota

The Large Aral Sea has virtually lost its native and introduced biota. To find whether refugiums for the Aral Sea biota were preserved, a range of water bodies in South Prearalye was studied. The data on refugiums are needed for the development of measures for restoration of the Aral Sea ecosystem and for preservation of the unique biodiversity of the sea.

Identification of the remaining Aral fauna in lakes of South Prearalye is important in terms of national biodiversity preservation and for improvement of bioproductivity in local water bodies. Water used for irrigation purposes in Uzbekistan and riparian countries is then accumulated in tail water bodies, such as Aydarkul, Sarykamysh, Ully-Shurkul, Kara-Kyr and others. Most lakes in Uzbekistan are such brackish accumulators of collector-drainage waters (tail escapes of irrigation systems). Appearing brackish-water lakes usually have poor hydrofauna formed mainly on the base of river fauna. Mollusks and bottom-dwelling crustaceans serving as a food base for fish in water bodies with similar conditions (Aral, Caspian, and Azov seas) virtually are not found in those lakes. Consequently, the biomass of benthos forming the food base for most of commercial fishes, e.g. in Aydaro-Arnasay lake system, is tenfold less than in the above mentioned brackish-water seas. This leads to reduced bioproductivity and, eventually, to low fish productivity. In this context, the introduction of hydrobionts of the Aral Sea origin could be a useful source for better productivity in major fishery water bodies in Uzbekistan. Such measure could improve the biological productivity of lakes and fish productivity as well (Mirabdullaev et al. 2001).

In 2000-2004, the following lakes were studied in South Prearalye: Saikul, Ayazkul, Akshakul, Sarykamysh, Muynak bay, Mezhdurechie, Sudochie, Sarbas, Eastern Karateren, Atakul, Ully-Shorkul, and Kaladjik.

The studies found a number of components of the Aral Sea biota still remained in some lakes of South Prearalye, which thus represent refugiums for the biota. Major refugiums are Sudochie, Sarykamysh, and Eastern Karateren.

The richest community of aquatic animals of the Aral Sea origin is found in Sudochie lake. The conducted research identified a number of marine origin species in the lake's fauna: the marine infusorium *Folliculina*, Bryozoa, nereid, marine copepods and ostracods, Aral Amphipod, snails *Caspiohydrobia*, and sand smelt. The Aral mollusks *Cerastoderma* and *Theodoxus* and crustaceans *Podonevadnecamptonyx* and *Turkogammarusaralensis* are found in Sarykamysh Lake.

However, in order to benefit from the remaining fauna of the Aral Sea, first of all, we need to preserve these resources. A steady-state of lakes in Prearalye should be reached to this end. Moreover, both drying up of the water bodies (almost all Prearalye lakes are shallow) and their excessive desalination can be fatal for the remaining fauna. We draw a very important conclusion from the drought 2000-2001 that the ecosystems of most lakes in Prearalye (e.g. Sudochie, Sarbas, Shegekul, Khojakul, etc.) are utterly fragile in the context of water shortage, and this threatens with disappearance of a number of refugiums (Mirabdullaev et al. 2004).

The ecosystem fragility is linked to shallow depth (within 1-2 m) of those lakes and high rates of evaporation (over 1 m annually). Consequently, droughts cause drastic shrinkage in the lake area and increased salinity.

Other risk factors include the anthropogenic changes of hydrological regime and the growing pollution. For instance, diversion of considerable amounts of water from Ayazkul Lake has caused an increase in salinity and disappearance of most Aral species from the lake's plankton (Mirabdullaev, Herz 1996). It is equally important to note that heavy reduction of water salinity also threatens the Aral biota, besides drought. Most of the Aral fauna representing brackish-water hydrobionts do not tolerate fresh water.

9.4. Plant community

Because of high water transparency and the shallow pattern of the Aral Sea, most of organic matter was produced by phytobenthos rather than by phytoplankton. This made the ecosystem of this water body different from ecosystems of other inland seas. In general, the proportion of phytobenthos biomass was 90%, while phytoplankton, only 10% (Karpevich 1975). Stonewort comprised approx. 75% of phytobenthos biomass, and green alga, 13%. Other benthos algae included red alga (Karpevich 1975). All these types of plants disappeared in 1995. At present, the only remaining macroscopic algae in the Aral Sea are *Cladophorafracta* and *Vauscheriasp.*

Diatoms were dominating in phytoplankton of the Aral Sea in the 1950s-1960s (Zenkevich 1963). According to Aladin and Kotov (1989), most of brackish-water algae, including dominant blue-green algae and diatoms, disappeared in the Aral Sea in the period from 1972 to 1983. In the 1980s, at the salinity reaching 24 ppt, both brackish-water and marine euryhaline types of algae started to die in the Aral Sea (Yelmuratov, 1981).

159 species of algae in periphyton and 167 species in plankton were recorded in 1999-2002. This accounts for almost half of recorded phytoplankton diversity. Kiselev (1927) recorded 375 phytoplankton species of the Aral Sea in the 1920s, whereas Pichkily (1981) and Yelmuratov (1981) observed 306 and 278 species, respectively in the 1960s-1970s.

In 2002-2005, the diversity of phytoplankton was kept but at lower levels than in the previous period. 159 species of algae were recorded in the Aral Sea in 1999-2001, while only 81 species remained in 2002-2005. Moreover, less than 60 species were observed in any single year. Virtually, marine and halophilic types only have remained in the water body. Additionally, not all the recorded alga species refer to plankton. Since samples were taken from shallow water sites (2-4 m), major part of recorded alga species represented phytobenthos and periphyton.

10. FUTURE OF THE ARAL SEA

«Rehabilitation of the ecosystem and bio-productivity of the Aral Sea under conditions of water scarcity»

The project objective was to forecast the future of the Aral Sea and Prearalye through the modeling exercise undertaken by the IWHW-BOKU Institute for Water Management, Hydrology and Hydraulic Engineering (Austria), SIC ICWC, Resource Analysis, Institute for Water and Environmental Problems of the Russian Academy of Sciences and the environmental assessment by the Institute of Physiology and Biophysics & Institute of Zoology of the Academy of Sciences of the Republic of Uzbekistan. The forecast was developed for 25 years and comprised different options of inflow to the Amu Darya delta, socio-economic development, infrastructure in the delta, and cooperation between riparian countries. The ASBmm model was used as a modeling tool. The following seven future development scenarios were considered:

- Optimistic - close cooperation
- Optimistic – no cooperation
- Pessimistic – enhanced cooperation
- Pessimistic – no cooperation
- In-between the first optimistic scenario and BAU
- Business as usual (BAU)
- “Hypothetical”, under which all water resources flowing into two (Eastern and Western) parts of the Aral Sea from the Amu Darya and collectors are directed to deeper Western Sea.

Below we will show the results for two scenarios only – business as usual to compare with the actual situation in 2015; and, “hypothetical” to see whether it is possible to preserve the Western Sea. The both scenario options consider the current infrastructure in the Amu Darya delta. The proposed “hypothetical” option is described below and analyzed for feasibility of potential inflow.

The water-ecological balance in the region can be achieved while meeting the needs of industry, food, domestic sector, and energy for water if all the riparian countries aim at regular reduction of water consumption through water conservation and better water record keeping. The IWRM-Fergana Project demonstrated a real possibility to reduce water intakes from transboundary rivers by 20% that by 2035 would save 9 billion m^3 of water a year. Water conservation is not a simple endeavor; however, it is feasible to achieve 1% of water saving every year. In combination with genuine cooperation between the countries and organization of a program of water education on the Central Asia scale, future population, and particularly, young generation, will be more resilient to potential effects of water scarcity, based on customary respect and care for water.

Besides, the Amu Darya river basin has considerable resources of collector-drainage water (3.5 km^3 in Ozerniy collector system and 1.5 km^3 in Tashauz canals in Turkmenistan), which could be reduced by 20% through water saving, but nevertheless would amount to 4.0 km^3. Before independence, the “Soyuzgiprovodkhoz” Institute has developed a scheme for supply of this type of water to the Western Aral Sea via the route along Ustyurt through Sudochie lake and via former Adjibai bay. Since independence, the successor “Uzgiprovodkhoz” Institute developed a new scheme of drainage flow delivery: 150 m^3/s to the right bank of the Amu Darya or discharge of 3 km^3 a year into the river, and further feeding the Eastern part of the Aral Sea with this water. Given the shallow depth of the Eastern basin, it is advisable to recharge directly the Western Sea through Prearalye and Sudochie lake in order to increase water supply in Kazakh and Uzbek territories of Prearalye in case of available additional saved water and raise water level in the Western Sea. Additionally, the Western Sea can receive discharged water from the Northern Sea in wet years, as it was the case in 2010. The overflow from the Northern Aral amounted to 5 km^3, which, unfortunately, was wasted in north part of the Eastern Sea. If this shallow water body is cut as a transit East-West channel, the Western Sea can get additional volumes of water. Implementation of such measures will allow stabilization of landscapes through more sustainable functioning of lakes and wetlands on about 500,000 ha in the Uzbek territory.

Figure 10.1 Scheme of water supply to the Western Aral Sea

The Business as Usual option

In this option, since 2010, water level in the Eastern Sea varies within 28-30 m with the salinity ranging from 100 to 200 g/l. This corresponds to reality with the difference in water level of 1-2 meters. Moreover, the level in the Western Sea continues decreasing under low-water conditions and the current level corresponds to 26 m. Salinity in this water body goes up and reaches the current level of 130 g/l that corresponds to reality. Deviation of level variations in the Eastern body from the real conditions is caused by inaccuracy of some assumptions made in the Eastern Sea model.

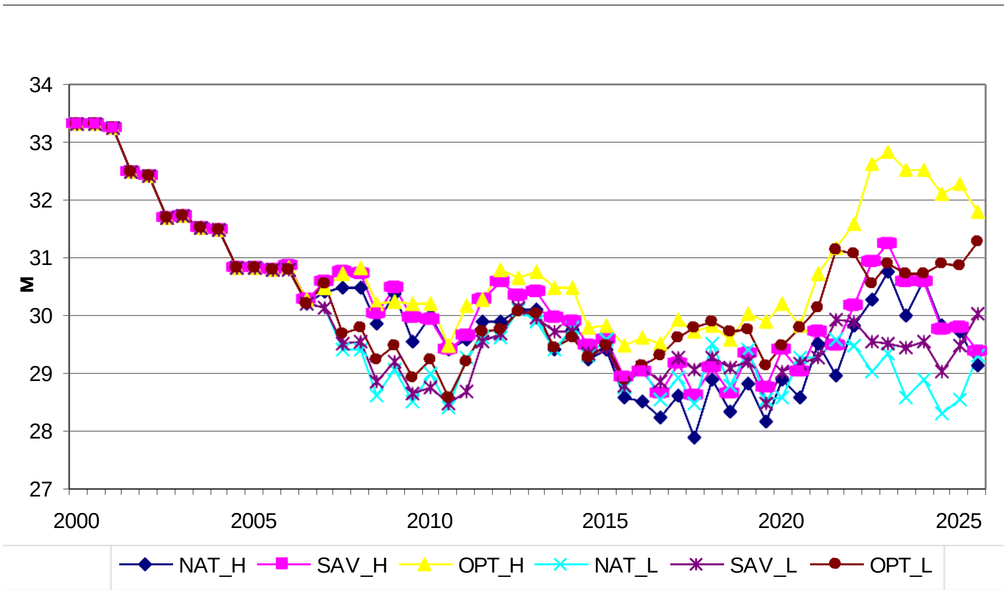


Figure 10.2 Water level in the Eastern Sea

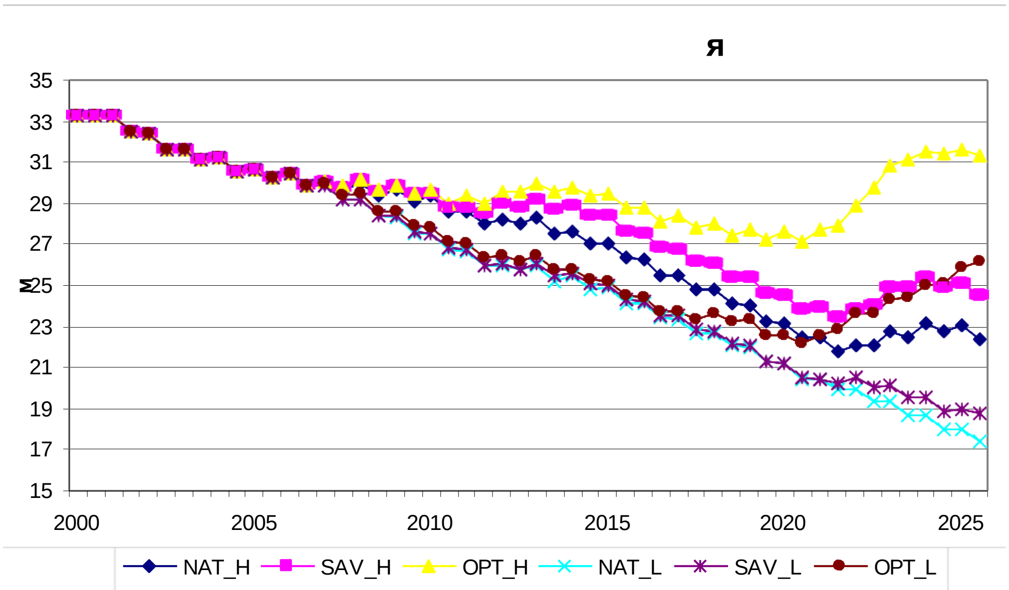


Figure 10.3 Water level in the Western Sea

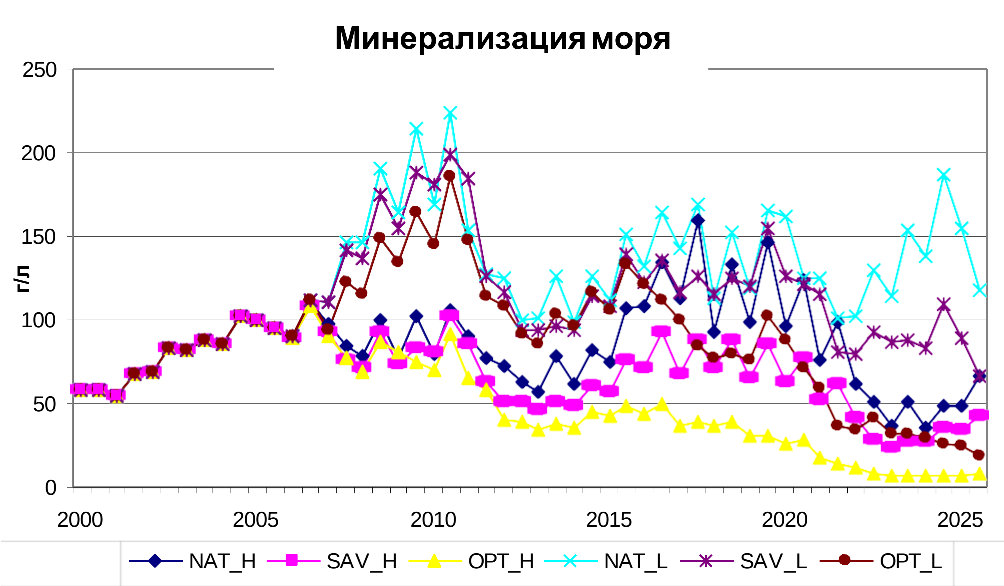


Figure 10.4 Water salinity in the Eastern Sea

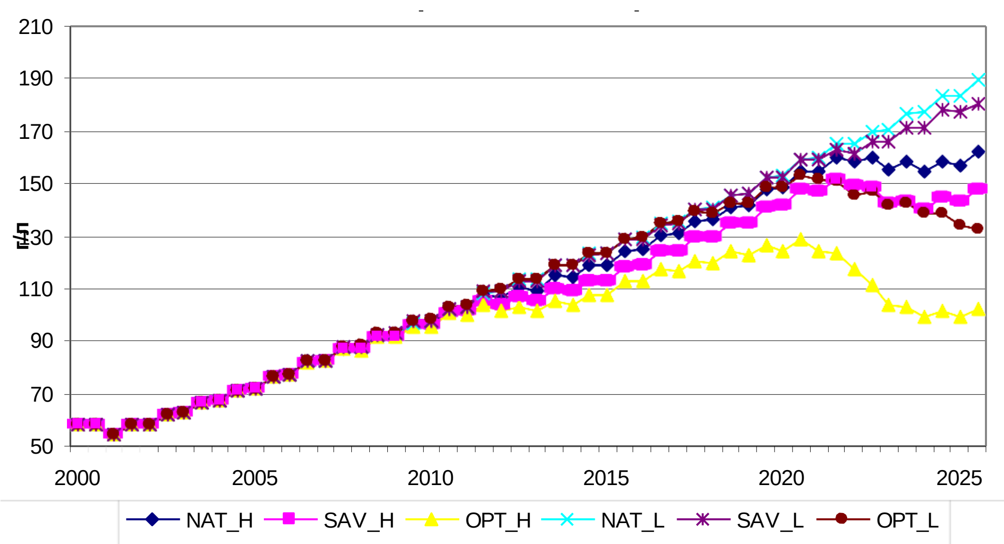


Figure 10.5 Water salinity in the Western Sea

Hypothetic inflow to the Western Aral Sea

It is quite difficult to implement this option; that is why we called it hypothetic. Nevertheless, this is the only option, which will allow preservation of the Aral Sea in a very reduced but active form, provided that all riparian countries, particularly, Kazakhstan, Turkmenistan, and Uzbekistan join their efforts. From the delta's right-bank, while by-passing the Mezhdurechie reservoir (where no more than 3.5 cubic kilometers of water should be reserved per year for deltaic water bodies), the whole remaining runoff of the Amu Darya at the Parlytau section or even upstream should be diverted via Adjibai (the former bay along Ustyurt), including water from the Right-bank collector to the Western Sea. What will we have finally?

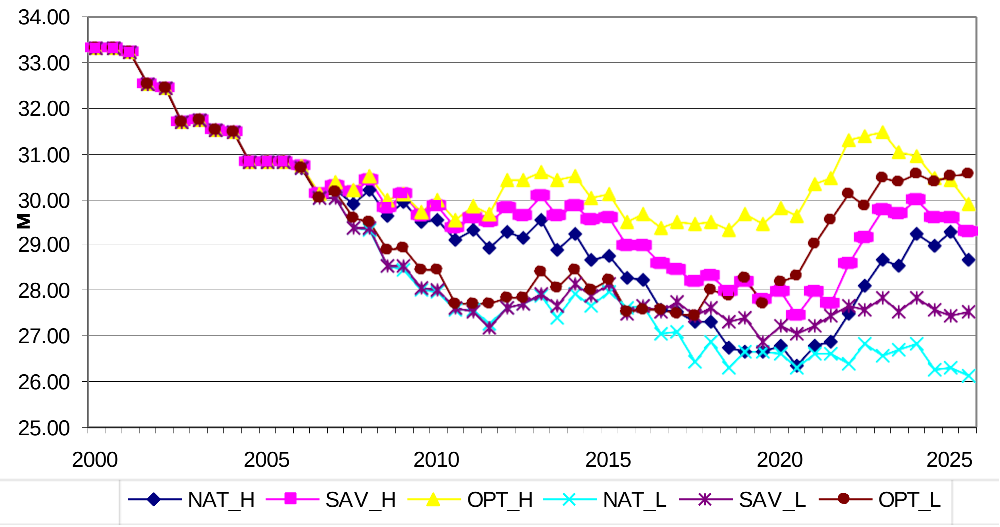


Figure 10.6 Water level in the Eastern Sea

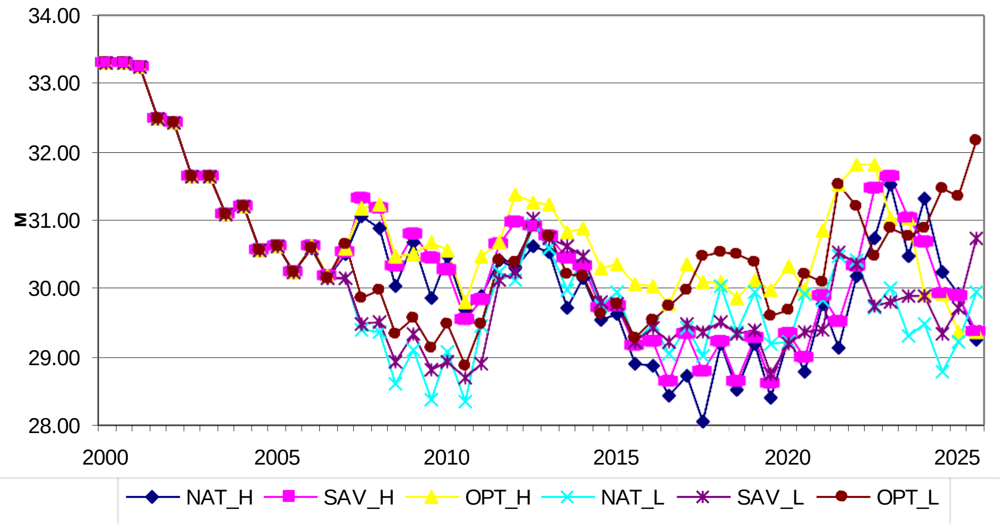


Figure 10.7 Water level in the Western Sea

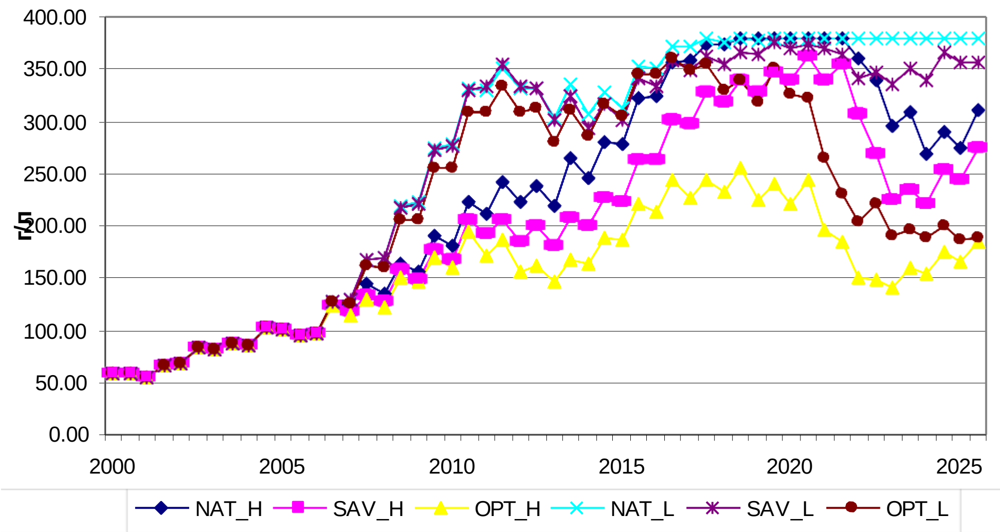


Figure 10.8 Water salinity in the Eastern Sea

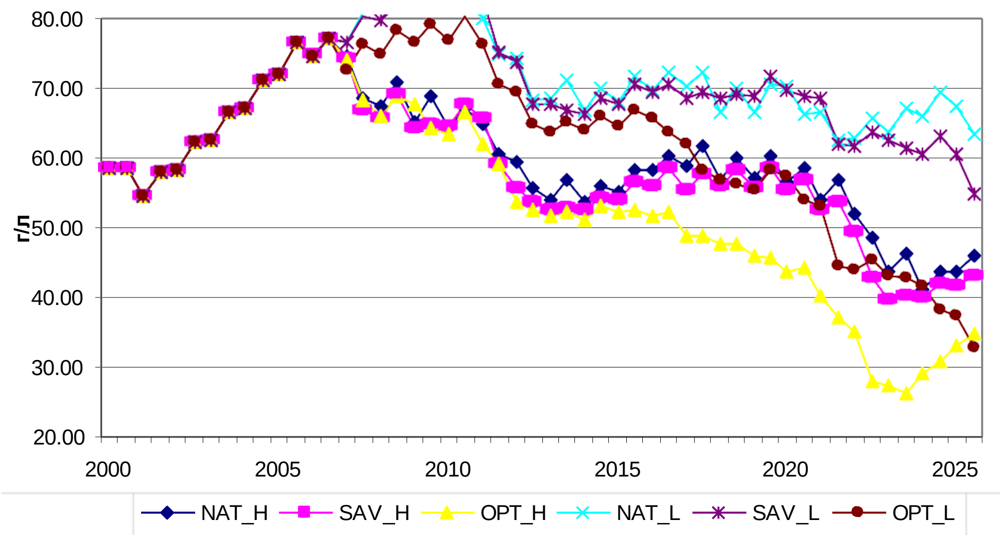


Figure 10.9 Water salinity in the Western Sea

It is supposed that water will be delivered to the Western Sea through the newly created waterways system Amu Darya-Sudochie-Adjibai. This system is fully oriented to the deeper water body. The Eastern Sea will become stabilized at 26-27 m. The increase of the water level to 30 m +BS as stipulated in the optimistic option should be considered as not feasible. Eventually, the Eastern Sea will be transformed into a saline wetland, which has salinity of 200-350 g/l and is fed by overflow from the Western Sea only. In all options, the water level in the Western Sea is set at 29-31 m, with the temporary minimum at 28 m and the maximum at 32.3 m. The supposed inflow will lead to steady trend of desalination in the Western Sea to 45 $\pm$ 16 g/l by 2025. In contrast, salinity in the Eastern Sea will grow to 380 g/l, though in this case the model assumptions become invalid and, accordingly, detailed hydrochemical modeling of highly saturated solution will be needed.

The bioproductivity team considers it doubtful and unfeasible to implement the hypothetic option of water supply to the Western Sea from the Amu Darya in such a scale so to ensure cost-effectiveness of the sea preservation under current environmental indicators, where the salinity is less than 30 g/l. For implementation of this option, it would be necessary to:

- follow the optimistic scenario of water use in the basin;
- have favorable natural flow conditions;
- have quick (in 5-6 years) filling of the Western Sea;
- have available stock of collector-drainage water from Ozerniy collector pumped into the Main Left-bank collector and then to Sudochie lake;
- attract investments in the amount of $1,500-1,800 million.

For such investments, there exists the only possibility to attract funds of gas and oil companies that work in Prearalye, given their interests in the development of gas and oil on the bottom of the Eastern Aral Sea.

CONCLUSIONS

By the present time, only about 6% of the water volume recorded in the mid-XX century has remained in the Aral Sea. Nevertheless, the lake is still a remarkable water body, stretching to 150 km and reaching more than 20 m in depth. Moreover, the lake continues having an impact on climate and atmospheric circulation on the regional scale.

The environmental disaster of the Aral Sea has led to considerable transformation of all ecosystem elements. First, hydro-physically, the radical changes took place transforming the lake from brackish into hypersaline, from mixed into heavily stratified, from well aerated into anoxia- and sulphurous-prone water body. However, one should note that until 2002 the water level in the Large Aral Sea was lowering on average by 1 meter a year, whereas, since the beginning of monitoring in 2002 till present, the level lowering has reached about 3 meters only. Analysis of sea’s water balance shows that the system is close to equilibrium state; and, if the remaining river runoff and groundwater flow are maintained at the level of recent years, one could expect stabilization of the seawater level and discontinuance of growth of the water salinity in the near future. However, even in this case, salinity will continue growing for a while in the Western part of the Sea. The chemistry of the Aral Sea is closely interrelated with the hydro-physical state of the sea. The ion-salt composition of seawater has changed significantly and still changes due to precipitation of carbonates and gypsum. Whereas in the so called conditionally natural period of existence the Aral Sea was a sulphate-type water body, now the sulphate ion content against chlorine has decreased substantially. Particularly drastic changes are observed in calcium content, which has been decreased almost 7 times. The depletion of calcium can become a factor restraining further precipitation of gypsum. If salinity continues growing, mirabilite will start to precipitate (especially at lower temperatures in winter) in the nearest future. In turn, this will lead to sodium depletion and further changes in composition of salts. Changes in ion trigger transformation of all major physical relationships, such as the relationship between the density and the salinity and temperature (equation of state), that between the freezing temperature and the salinity (the freezing temperature is about -5°C for the current Aral Sea), between the electric conductivity and the salinity, etc. Thus, it is important to study in details these reactions between hydrophysics and hydrochemistry of the Aral Sea.

The ongoing physical and chemical transformations in the Aral Sea have an effect on the current state of sea's biological systems. One should note that despite enormous biodiversity losses resulted from the environmental disaster, the modern biological communities of the Aral Sea cannot be considered as dead or endangered. The newly formed, very specific and quite dynamic ecosystem of the sea is comprised of plankton and benthos species that were able to adapt to huge salinity of the seawater. Their total biomass is quite substantial. There also attempts for commercial catch of the dominant zooplankton in the Large Aral Sea - Artemia shrimp. Thus, evolution of biological communities, which primarily will depend on physical and chemical changes of the sea, should be in the focus of further research.

A very important issue is to continue monitoring of the dried seabed and, particularly, of the Amu Darya and the Syr Darya deltas and to organize appropriate management of this complex natural-anthropogenic system. Critical environmental processes which usually occur over centuries have been accelerated on the dried seabed by now. With initiation of natural vegetation growing processes on the exposed seabed, which is called now as the Aralkum Desert, the nature tries to protect itself. Thus, the task of the both countries, to which the Aral Sea water area belongs, is to organize observations over this important process and maintain it. Unfortunately, despite a number of Uzbek and Kazakh government decisions, the above matters remain outside of priorities of the national investment policies.

It seems necessary to continue the ground-based monitoring of the Aral ecosystem in the next years. Such monitoring should be comprehensive and put the main focus on the relationships between hydrophysical, hydrochemical, meteorological, and biological elements of the ecosystem. The monitoring data will be used for ecosystem modeling and forecasting of environmental conditions in the region. The results of such comprehensive research will serve for solution of concrete socio-economic and environmental problems in Prearalye and can be useful in general context. The Aral Sea can be considered in some sense as a "model site" to study aquatic ecosystem response to anthropogenic impacts that are felt in many other regions all over the world. In this context, undoubtedly, the Aral Sea disaster is of global importance. On the other hand, at present, the Prearalye countries (Uzbekistan and Kazakhstan) hardly can undertake the required research and monitoring on their own. Therefore, involvement of the international research community is absolutely necessary.

The research of Prearalye and the Aral Sea itself should be multidisciplinary so that to study in details ecosystem elements (hydrogeology, soil, flora and fauna) and their relations, on the one hand, and address social aspects, i.e. people in this region, changes in their livelihoods since the recession of the sea and adaptation, on the other hand. This will allow assessing losses from environmental disequilibrium and finding ways to reverse the situation and improve system management for better lives of people in this region.

Finally, thanks to the initiative of the Uzbek President Shavkat Mirziyoyev voiced at the Summit of the Heads of Central Asian State on August 24, 2018 in the city of Turkmenbashi (Turkmenistan), the Aral Sea and Prearalye problem has re-gained visibility. Later on, the Government of Uzbekistan approved a Roadmap for the implementation of initiatives and proposals voiced by the Uzbek President at the Summit. One of key tasks set in the Roadmap is to transform the exposed bed of the Aral Sea and Prearalye into an area of environmental innovations and technology. To this end, it is decided to intensify efforts on afforestation on the exposed seabed by planting drought-tolerant trees, such as saxaul, saltwort and tamarisk on an area of 500,000 ha. Additionally, necessary conditions, such as water supply infrastructure, drainage, roads, atomic power plant and communications should be created.

A pioneer monitoring of the dried seabed is to be organized to update information on the status of this area for 2019 and a system of regular RS and ground-based monitoring over soil, vegetation, groundwater and water bodies is to be established. It is planned to develop fisheries, muskrat catch and livestock production, increase catch and organize processing of Artemia and licorice for medical applications, as well as organize a balneotherapy center on the base of mineral water and muds. Drawn from the experience of Israel and China, it is also intended to develop sun-powered greenhouse and hydroponic farms.

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THE UNESCO OFFICE IN UZBEKISTAN

ARAL SEA AND PREARALYE

Review of work undertaken by SIC ICWC
on monitoring and analysis of socio-economic
and environmental situation in the period from 1994 to 2018

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