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SOUTH PREARALIE – NEW PERSPECTIVES

Under the editorship of
Dr. Joop de Schutter and Prof. Victor A. Dukhovny

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INTRODUCTION

The tragedy of Aral Sea disappearance is one of the most convincing and vivid cases against unbalanced activities undertaken by the human society neglecting sustainable development, which are so numerous in the creative and simultaneously destructive latter half of the 20th century. During this period the humanity not only had the unprecedented achievements in engineering development, but also damaged the nature more than ever. Such a predatory outrage upon the planet was caused by the impetuous technological revolution, which at that time had been declared as a watershed of the human history, until the most advanced people found that very grave environmental consequences were hidden behind its frontage.

Almost all current global climatic, hydrological, and geological cataclysms (not only in the former socialistic countries) - the green-house effect, losses of rivers, lakes and wetlands, wide-spread desertification are caused by ambitious aspiration of people as if to provide their well-being, but in fact mainly for increasing property, domination and power, and followed by disregard of the fact that everything in the world is interdependent and has its own consequences in the form of large scale disturbance or transformations of natural processes. Some countries in the West recognized the necessity "to be respectful to the nature and to repay their debts to it" as early as the 1970s and 1980s, and in that time the community in the USSR just began thinking about ecological problems and has seen things clearly only when being on the verge of its collapse.

At present, the peoples and governments of such countries as Canada, the Netherlands, France, Switzerland, and Japan, which set an example for all mankind how to establish the interrelations with the nature, are worthy of gratitude and respect. They demonstrate how to integrate urbanization with preservation of fauna, flora, and landscapes on the basis of harmonizing interests of economic development and demographic growth with the environmental requirements and even raising a nature potential. In these countries, a partnership of people with the nature is based on profound respect and pride for natural resources belonging to their states, and worship of the nature which is inculcated from childhood.

The authors of this monograph managed to get to know remarkable and selfless concern, with which French, Swiss, and Dutch specialists, managers and representatives of public organizations assert rights of the nature and reasonable harmonization of nature protection with development requirements. Restoration of wetlands along the Rhone River in the Mediterranean Sea coastal zone, salmon population recovery and the Rhine River cleaning, existence of a great number of polders in the Netherlands, the protected Swiss landscapes in the outskirts of Zurich and и Lucerne are only some of inspiring examples, which all mankind should follow.

Drying up the Aral Sea that was a large water body with good quality water has reached such an extent that widespread nature degradation inside the dried area (at elevations less than 53 m + BSL) and outside its boundaries has resulted in the situation when this region is the natural disaster zone. The sea, which was the habitat of abundant flora and fauna and a natural regulator of climate in the adjacent irrigated area, degrades to such an extent that the desertification zone located between deserts Kyzylkum, Karakum and Usturt is formed. Vast areas of solonchaks and strongly saline lands, being sources of salt and dust transfer due to wind erosion, have occurred here.

In the coastal zone (above the elevation of 53 m + BSL) the ecosystem of the delta and a coastal zone, which was formed during many centuries was completely damaged; the lakes dried up, salinity of water increased; solonchaks appeared at the sites of the dried marshes; catch of fish and furry animal significantly diminished; migratory birds disappeared; flora and fauna degrade; and the local climate undergoes a change.

The five independent states located in the Aral Sea basin - Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan - have properly evaluated the necessity of tackling the problem of the Aral Sea and Prearalie (a dried coastal zone). The Heads of these states approved the Concept, in which the proposal to establish a new sustainable anthropogenic-natural complex in the South Prearalie in order to rehabilitate the productivity of this territory as much as possible was formulated. However, due to economic decline after disintegration of the USSR, implementation of this program faces difficulties.

The existing ecological situation is of great concern for all peoples living both inside and outside the Aral Sea basin. As a result, there have appeared many plans and proposals in order to solve, to a greater or lesser extent, the following issues:

- protecting the population from adverse impacts of desertification;
- restoring fauna and flora diversity to a maximally possible extent;
- creating workplaces for the local population by means of rehabilitation of fishery, muskrat breeding, cattle breeding, processing sectors, etc.;
- creating appropriate social and economic conditions necessary for improving the local standard of living by means of introducing high-yielding technologies in the field of water and land resources use;
- preventing further degradation of the environment, and rehabilitation the environmental balance in the South Prearalie.

Formerly, these issues had been addressed in two interrelated sustainable ecological zones (the Aral Sea and Prearalie) based on a certain hydrological regime of the Amu Darya and Syr Darya rivers. Social-economic activity in the vicinity of the sea and in deltas had been tightly related to the water regime of these zones and their peculiarities and not intervened significantly in natural conditions. At present, it is necessary to rehabilitate the former situation as much as possible and to direct developing negative trends conversely. Numerous donors tried to assist the "disaster epicenter", but they were not based on the integrated approach. Real actions were undertaken under support of the International Fund for the Aral Sea (IFAS) and the GEF, which initiated the projects for rehabilitating wetlands (the Sudoche Lake Rehabilitation Project) and some water bodies.

The invaluable assistance has been provided in this connection by the NATO Scientific Council that agreed to allocate resources at the expense of the "Science for Peace" Program for the research and development of the South Prearalie Environmental Protection and Water Infrastructure Project. The works within the framework of this Project have been carried out by the consortium consisting of the Dutch "Resource Analysis" company and the SIC ICWC jointly with the VEP SANIIRI enterprise, the NGO "Eco Prearalie" and "Aralconsult". The project was supported by the Ministry of Agriculture and Water Resources of Uzbekistan (A.A. Djalalov, M. Mirkhadjiyev), the Government of Karakalpakstan (T. Kamalov, A.K. Tadjiyev, and B. Bekturdiyev) and other governmental agencies and public organizations.

Dr. J. de Schutter (Netherlands) and Prof. V.A. Dukhovny (ICWC) have provided the scientific supervision of the project activities in consultation with Prof. P. Chevallier (France).

The Project activities were started in accordance with the decision of the NATO dated May 29, 2000, by which the SFP 974357 grant was awarded for implementing the project titled "Integrated Water Resources Management in the Aral Sea Basin for South Prearalie's Wetlands Rehabilitation". Implementation of relevant activities was carried out in concordance with the approved schedule over the period of 2000-2002, with their completion in June 2003.

The significant assistance in fulfilling the works was provided by the management of the "NATO for Peace" Program, the Assistant Secretary General of NATO Mr. I. Sillard, the Program Manager Mr. C. de Wispelaere, and their staff, without whom it would be impossible to implement this project.

This work is the outcome of joint efforts made by the team of leading specialists working in the SIC ICWC, VEP SANIIRI, "Eco Prearalie" and "Aral Consult" including Prof. V.A. Dukhovny, A.I. Tuchin, Prof. M. Tashmukhamedov, Dr. E. Kurbanbayev, Dr. K.B. Gromyko, A.G. Sorokin, O.G. Kobylin, E.M. Roshchenko, and R.I. Kadyrova. Young specialists D. Sorokin, E. Korshak, A. Beloglazov and many others took part in the project activities.

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J. de Schutter V.A. Dukhovny

Tashkent, August 2003

I. THE ARAL SEA AND SOUTH PREARALIE

Despite the fact that since the beginning of the past millennium many scientific volumes were devoted to the Aral Sea, its chronology remains contradictory and unclear. Since the second half of the nineteenth century the Aral Sea has become an object of numerous field studies conducted by the Russian Geographical Society and different scientific organizations of Russia. In 1908, the results of these studies were summarized by L. Berg in his great work "The Aral Sea Chronology Studies", where he stated that none of Greek or Roman authors had directly or indirectly mentioned the Aral Sea, however, most of them had told about Oksa (Amu Darya) and Aksart (Syr Darya), at the same time, it remains unclear which water bodies they emptied into. According to the famous scientist Al Beruni from Khorezm, who died in 1048, the inhabitants of Khorezm, keeping their chronology since 1292 B.C., attested the existence of the Aral Sea. L. Berg has referred to the Holy Book of Avesta, in which it was mentioned that the Vakhsh or the present Amu Darya River flowed into Lake Varakhsha, which some people had in mind as the Aral Sea. The first more or less reliable sources regarding the existence of the Aral Sea pertain to Arabic scripts, which recorded evidences of the conquerors of Khorezm in 712 A.D. These reports that were well described by V.V. Bartold confirm that the Aral Sea has already existed in the eighth century and was located not far from Khorezm, as its description fully coincides with features of the eastern coast of the Aral Sea. Other evidences belong to Massudi ibn Nurusti, Al Balkhi and many other Arabic writers and investigators-geographers.

Geological surveys carried out at the end of the nineteenth century and the beginning of the twentieth century (A.M. Konshin, P.M. Lessor, and V. Obruchev), have proved that in the *post-Pliocene epoch* the part of the Karakum Desert between cliffs of the Usturt Plateau in the north and the mouths of the Murgab and Tedjen rivers in the south, and the Kopetdag Mountain foot in the west had been flooded by the Big Aral Sea. The eastern half of the united Caspian-Aral Sea had, in their opinion, a cliff of the Unguz shoreline as the border of the former Karakum Bay. This united sea had covered a wide strip of the present pre-Caspian area right up to a foot of the western Kopetdag ridges, and linked with Karakum and Chilmetkum bays by two straits - the Bolshoy Balkhskiy and Maliy Balkhskiy. At that time the Aral part of the united sea flooded entirely the Sarykamysh depression and formed the bay stretched out to the Pitnyak, which is now occupied by the present-day delta of the Amu Darya and the Khiva oasis (as well, this explains the presence of salts deposit at the Pitnyak). The Uzboy Strait had linked both water areas, but it is obvious that its form with steep slopes arose due to separation of the Caspian Sea from the Aral Sea and increase in their water surface elevations. During the subsequent geological epoch and to our time, division of the united Aral-Caspian into its component parts and its gradual reduction up to the current boundaries took place. At first, the watershed between the Aral-Sarykamysh and the Caspian Sea at Balla Ishem on the Usturt Plateau formed, and then the Uzboy river channel gradually developed. The sequence of desiccation is confirmed by layers of transition deposits from the latest Caspian mollusks burials (along the former Uzboy river, in the sands of the Chilmetkul, and along the south-eastern shoreline of the Caspian Sea) covered by incoherent sands with sparse and young vegetation to ancient formations in the Central Karakum Desert, which have transformed into sors (deposits of super-salty water bodies under drying up), takyrs, compacted sand hills overgrown with woody vegetation. Sors, being the lowest places of the sea bottom and fed by saltish artesian water, kept the pattern of ancient coastal lakes.

Since the ancient times, all the researchers and historians were describing transformations of the Aral and Caspian seas depending on water availability and irrigation development in their united drainage basin. They have confirmed the fact of complete desiccation of the Sarykamysh Lake by the end of the sixteenth century, when inflow of the Amu Darya River into the Sarykamysh Lake via the Kunya-Darya, Daudan and Uzboy rivers had stopped. At the section from the Caspian Sea to the Bally Item watershed, the Uzboy channel is lifting by 40 m at a distance of more than 200 km. According to V. Obruchev, the existence of the Sarykamysh Lake took place during the period since the VII century

B.C. till the XVI century A.D. On the way to Khiva, in 1559, Jenkinson has observed the presence of the Sarykamysh Lake, which he recognized as the inflow of the Oksus into the Caspian Sea. He also relied on the similar evidences of Abdulghazi-Khan, Ghamdudla and other chroniclers of Khorezm.

The Aral-Caspian lowland was sketched out in many maps thoroughly analyzed by Rene Letal and Monica Mainglo in their excellent monograph "Aral"*. All trends of the Aral Sea migration are tracked in succession of maps drawn in accordance with human perception starting with the "Geography" by Ptolemy (the 2^{nd} century A.D.), on which the Caspian Sea was depicted in all its greatness and without any reference to the Aral Sea (Figure 1-1), then on the layout of Al Idrisi (1132 A.D.), (Figure 1-2) and "Catalan Atlas" (1352 A.D.) (Figure 1-3), where the Aral Sea is sketched out, and ending with the map drawn by Butakov, on which the Aral Sea was already shown in the well-known form (Figure 1-4).

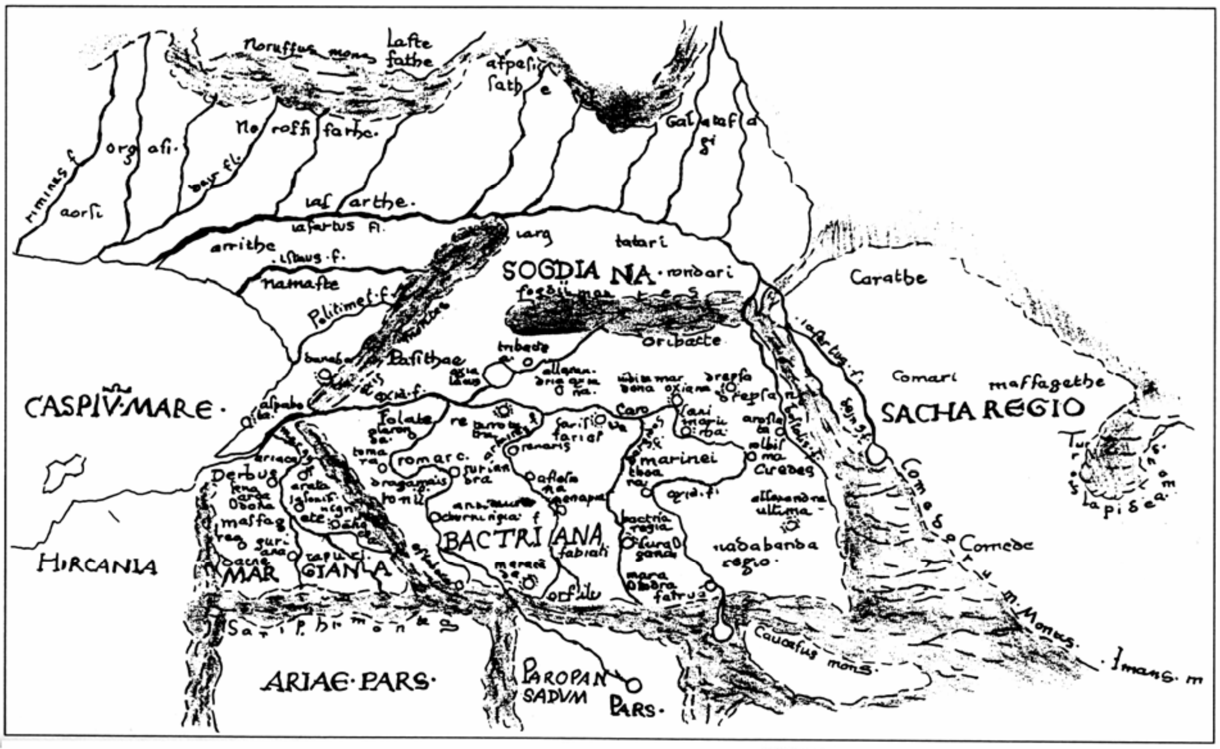
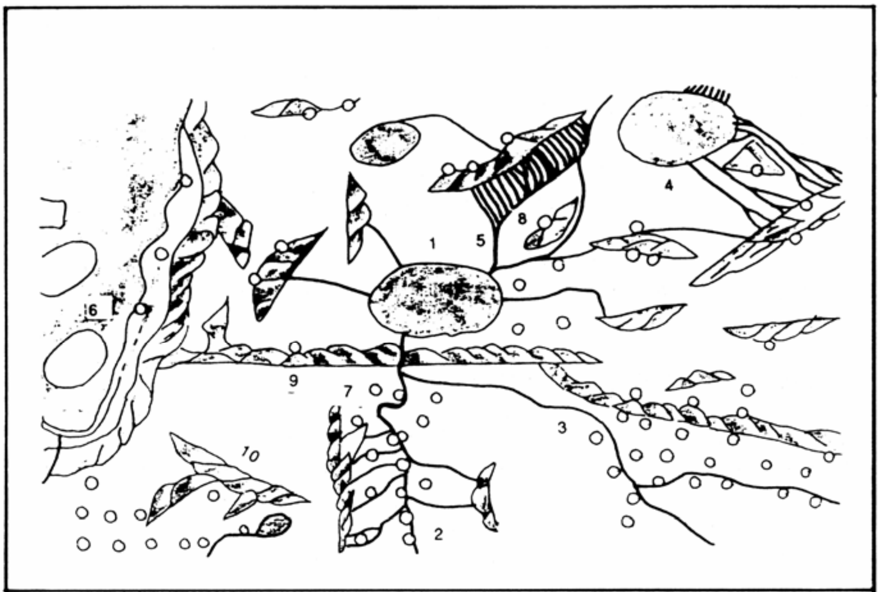


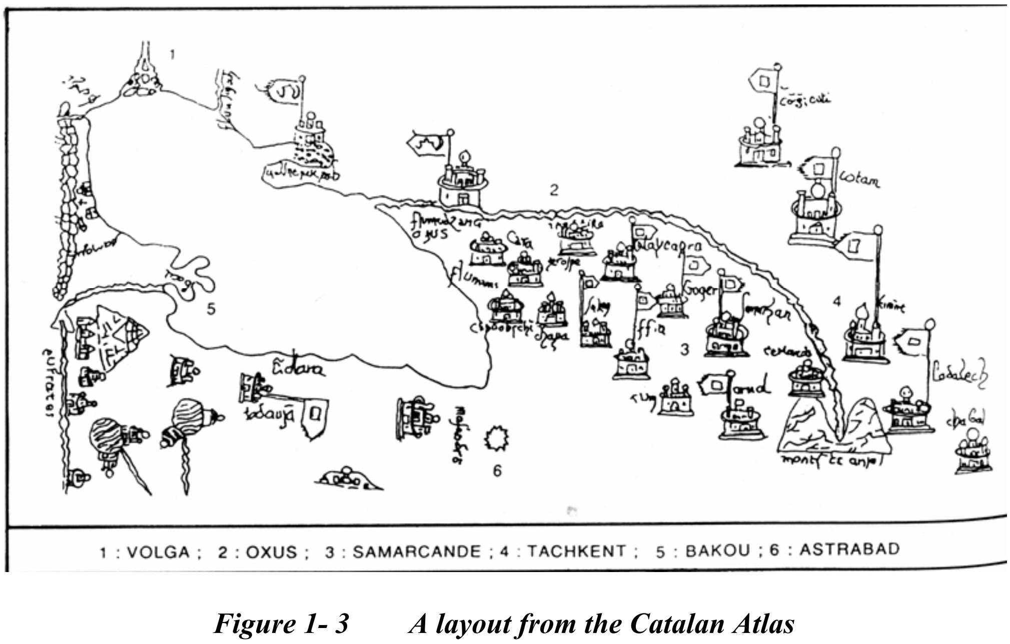
Figure 1-1   A Map from Ptolemy's "Geography"

* Springler – Verlag France, Paris, 1993



1 : ARAL ; 2 : AMOU-DARIA ; 3 : ZERAFZHAN ; 4 : Lac BALKACH ; 5 : SYR-DARIA ; 6 : CASPIENNE ; 7 : KHOREZM ; 8 : Région de TACHKENT ; 9 : le "TCHINK" ; 10 : KHOPET-DAG

Figure 1-2 A Layout by Al Idrisi



1 : VOLGA ; 2 : OXUS ; 3 : SAMARCANDE ; 4 : TACHKENT ; 5 : BAKOU ; 6 : ASTRABAD

Figure 1- 3 A layout from the Catalan Atlas

Figure 1-4 Butakov's Map

Below Table 1-1 developed on the basis of numerous historical sources and the latest papers, shows the supposed interaction between the rivers, the Aral Sea and the Uzboy Channel.

Table 1-1 Historical sources regarding water systems in Central Asian

Dates	Source	Conditions of the Aral Sea	Conditions of the Uzboy channel	Level of the Caspian Sea with respect to that of 1990, m + BSL	Note
5th century B.C.	Herodotus	the sea exists	Uzboy = Amu Darya		
3rd century B.C.	Patrocle	filled up with water	dry		The Amu Darya and Syr Darya flow into the Aral Sea
1st century B.C.	Strabon	the Amu Darya and Syr Darya rivers flow in, but the latter not to full extent	Amu Darya	+ 25	
891 A.D.	Al Balkhi	the sea exists	along the Uzboy Channel to the Caspian Sea	+ 9.8	
10th century	Idrisi	the sea exists		- 4.2	
1211	Jiveni Murkhand	almost dry	with flow		Descendants of Genhgis Khan diverted the Amu Darya from Khiva
1320	Marino Sanuto	mean level	Flow through the Uzboy channel from the Sarykamysh Lake into which the Amu Darya empties		The Small Aral is identical to a small lake (Sarykamysh)
1375	Catalonia	the sea exists	with flow	+ 5.64	The Syr Darya flows into the Aral Sea and Amu Darya flows into the Sarykamysh Lake
	Sanuto	the sea exists	with flow		
1400	Merashi	low level			
1575	Abul Ghazi	high level	dry		
1638	Olirey	low level	with 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	alternates	+ 4.03	
1826	Kolodkin	high level	not shown	+ 3.12	
1858	Ivanichev	high level	dried	+ 0.99	

Based on geological and historical investigations, most researchers (B.V. Andrianov, A.S.Kes, P.V. Fedorov, V.A. Fedorovich, Y.G. Maev, I.V. Rubanov, A.L. Yanshin and others) have came to the almost unanimous conclusion, which was well formulated by N.V. Aladin: “in prehistoric times, changes in the Aral Sea level and salinity took place due to natural climatic changes”. During the humid climatic phase the Syr Darya and Amu Darya rivers were abounding in water, and the lake reached the maximum level of 72 to 73 m +BSL (Figure 1-5).

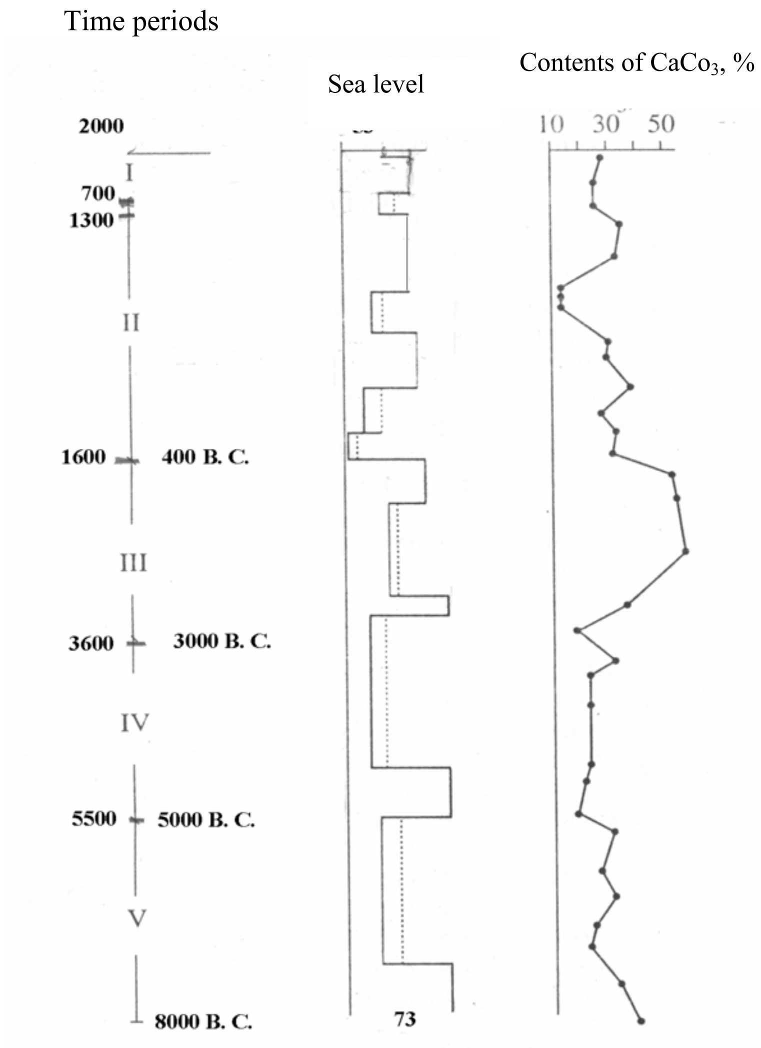


Figure 1-5

In contrast to that, in arid climatic phases both rivers became containing little water, the Aral Sea level also dropped, and the salinity level increased. In historical times, during the existence of the ancient Khorezm, the changes in the water level depended to some extent on climate change, but mainly on irrigation activity in the basins of two rivers. In the periods of intensive development of the countries adjacent to the Aral Sea, the increase in irrigated areas resulted in withdrawal of most of water for this purpose, and the sea level had immediately dropped. Unfavorable periods (wars, revolutions, etc.) in the region were followed by reduction of irrigated lands, and the rivers filled up again.

Geological and hydrological surveys, carried out by A.P. Kes and a number of the prominent geographers in the 1980s, showed that the Amu Darya and Syr Darya rivers changing regularly their flow direction and migrating throughout Central Asian in the historic period have not often reached the Aral Sea, and as a result the sea has dried up and a desert zone has formed on its territory. At the same time, as the sea was drying up, water salinity was considerably increasing and promoting precipitation of salts, which were found by the geologists at the bottom of the Aral Sea. Thick layers of mirabilite precipitations are especially impressive. The migration of both the Amu Darya and Syr Darya deltas has established a very peculiar downstream area, where the depressions filled with boggy deposits alternating with deserted, fine-silty, and sandy deposits that formed the delta and the most part of the Amu Darya River bed itself and its branches. On the other hand, the field studies carried out by zoologists, in particular, by Polishchuk and Aladin from the Zoological Institute under the Academy of Sciences of USSR in 1990 have shown that the Aral Sea itself is characterized by very poor original fauna and the absence of many species that are in the Caspian Sea which is similar according to its origin. At the same time, endemic species were found in the Aral Sea indicating that salinization of the Aral Sea, which took place from time to time affected these large-scale transformations.

The analysis carried out by zoologists has shown that a small number of marine and oceanic species remained in the Aral Sea; however communities of brackish water species including the Caspian-estuary fauna have been destroyed here. All the rivers emptying into the Aral Sea have not retained marine fish species or, at least, remains of this fauna. It means that water of the Amu Darya and other rivers, in one way or another, has penetrated both into the Aral Sea depression and through the Uzboy valley into the Caspian Sea. At the same time, it is necessary to note very developed deltas of the Syr Darya and Amu Darya rivers, which occupy sufficiently large areas. According to data of N.M. Novikova, during the period of sustainable water inflow (approximately 41 cu km/year), the total area of flooded lands exceeded 3,800 sq km, the area of lakes amounted to 820 sq km, only in the Amu Darya delta. The delta of the Syr Darya was also significantly developed. At the same time, a highly intensive vegetative background was widely spread in the delta. The periodically flooded delta was characterized by large areas of fructiferous reeds, tugai, hayfields and pastures. In particular, till 1970 only in the Amu Darya delta the area of reed thickets amounted to 700,000 ha, tugai – 1,300.000 ha, hayfields – 420,000 ha, and pastures – 728,000 ha. Appropriate areas in the Syr Darya delta were also occupied by deltaic and other vegetation.

A.S. Kes has her somewhat different opinion. Agreeing with opinions regarding several periods of the Aral depression flooding starting from the late Pliocene, at first by waters of the Akchagyl Sea and later the Apsheron Sea, she does consider that the existence of the united Aral-Caspian Sea has not been proved and insists on the absence of a link between the Aral and Caspian seas, though she supports the opinion that the highest elevation of the early-Apsheron lake were 80 m +BSL reducing to zero at the tail part of the Apsheron sea. The Akchagyl period was marked, in her opinion, by the partial existence of the Aral Sea with water level lower than the modern one (about 40 m + BSL).

In the late Stone Age, the Amu Darya River, having filled up the Khorezm depression with alluvium, has burst into the Sarykamysh depression and formed the big Audan Lake here and in the Assaka depression; about 20 percent of water of this lake (it was restricted by hydraulic parameters of the Uzboy channel) have released through the Uzboy channel into the Caspian Sea. This inflow continued during the 4^{th} and 3^{rd} millennium B.C., periodically occurred in the 2^{nd} and early 1^{st} millennium B.C. At that time, the Syr Darya River flowed into the Aral Sea. Though A.L. Yanshin tried to prove the presence of transgression in this period, the subsequent studies by L.G. Kiryukhin, Kravchuk and P.V. Fedorova (1966) as well as the most recent studies carried out by I.V. Rubanov (1982), Y.G. Mayev, Y.A. Kornichev (1999) have refuted his arguments.

At present, it is clear to a certain extent that (according to the recent radiocarbon measurements of bottom sediments) the Aral Sea has undergone five or seven transgressions, out of which the strongest ones formed the highest terraces (elevations of 72 to 73 m + BSL), pertaining obviously to the early Pliocene (A.V. Shitikov) or to the Akchagyl period (Figure 1-5).

The source of such high flooding is not clear. This might be either consequences of melting of northern ice masses, as V.A. Kovda and V.V. Yegorov have supposed in their work “Behavior of salt accumulation in the Aral-Caspian lowland” (the Academy of Sciences of the USSR, 1956), or water inflow of the Great Amu Darya, which was mentioned in the Avesta (supposedly, this river has united not only waters of all the Great Amu Darya tributaries including the Zeravshan, Tedjen, Murghab but also the Syr Darya and Chu till damming the Buam isthmus).

In this context, the results of revising the investigations of P.I. Chalov and others (1966) carried out by A.S. Kes are of interest. The first stage of the Aral depression flooding began in the late Pliocene. At that time, western plains in Central Asia were flooded at first by water of the large Akchagyl Sea, and then by the Apsheron Sea. Their eastern border was not determined, but fauna, terraces and beach ridges dated by this age are found in the Sarykamysh and Assaka-Audan, Aral Sea depressions, and in some depressions of the Kyzylkum desert.

The modern period of the Aral depression flooding began in the 1st millennium B.C., when the Amu Darya having formed the pre-Sarykamysh and Akchadarya deltas moved towards the Aral depression and together with the Syr Darya, which flowed through the Janadarya and Kuvandarya channels, started filling it up and formed the modern sea.

At the beginning of the 19th century the Aral Sea level was low. In 1845 and after the 1860s some increases in the level were observed. At the early 1880s the level became unusually low; the researchers of that time came to the conclusion that progressive reduction of water resources in Central Asia was taking place.

However, in the 1880s the Aral Sea level began rising, at first rather slowly, then more quickly. That continued till 1906. The level stopped changing in 1907, and then it increased again in 1908 and lowered in 1909. The rise was registered once again in the period since 1910 till 1912, and then the level slowly changed till 1917. The decrease began after the year 1917, which is known by the high level of aridity in Central Asia. By 1921 the level of the sea had reduced by 1.3 m in comparing with 1915. However, the observations in 1924 showed new increase (a little less than by 0.5 m).

The range of fluctuations during the period since the end of the 19th century till the beginning of the 20th century was about 3 m.

Natural water resources of the Amu Darya River (without inland basins of the Tedjen, Murghab and other rivers) amount to 75 cu km per year in the runoff formation zone, and those of the Syr Darya River – 37 cu km per year (in total - 112 km^3 a year). The fluctuations in availability of annual Amu Darya and Syr Darya water resources are significant enough (coefficients of variation C_v for the both rivers are 0.15 and 0.21 accordingly) and are characterized by high synchronism (a correlation coefficient is 0.83) that makes difficult water supply of the main water users in dry years.

The Amu Darya and Syr Darya basins are regions of an ancient irrigation that affected natural flow of these rivers during a long time. Prior to the early 1950s volumes of irreversible water withdrawals fluctuated insignificantly both in each of the river basins and over the entire Aral Sea basin, and amounted to 29 to 33 cu km per year. The increase in water withdrawal from the rivers in the 1950s to 35 to 42 cu km per year, caused by extension of irrigated lands area and water-related activities (construction of reservoirs on the Syr Darya River, water diversion from the Amu Darya into the Karakum Canal), was compensated by some reduction in streamflow losses, and also by natural high humidity in this decade (total water resources exceeded the norm by approximately 9 percent). As a result, inflow into the sea and its regime were kept relatively stable till the early 1960s.

The period since the beginning of systematic instrumental measurements of the water level and other regime characteristics of this water body (1911) till the 1960s may be defined as conditionally natural. An approximate equality of inflow and outflow components of the water balance of the sea (Table 1-2) determined little fluctuations in the sea level approximately at the elevation of 53 m + BSL, which was assumed as the mean annual level. The average water surface area at the elevation of 53 m + BSL amounted to 66,100 sq km, and the water volume reached 1,064 cu km.

Table 1-2 Mean annual water balance values of the Aral Sea for different periods

Periods (years)	Inflow				Outflow (evaporation)		Water balance		Actual increment		Odds	
	River runoff		Precipita-tion						In volume	In level		
	km^3	cm	km^3	cm	km^3	cm	km^3	cm	km^3	cm	km^3	cm
1911-1960	56.0	84.,7	9.1	13.8	66.1	100.0	-1.0	-1.5	0.1	0.1	-1.1	-1.6
1961-1980	30.0	48.9	7.1	11.8	59.7	99.4	-22.6	-38.7	-22.8	-39.1	0.2	0.4
1971-1980	16.7	29.3	6.2	11.0	53.7	95.4	-30.8	55.1	-32.3	-57.1	1.5	2.2
1981-1990	3.45	8.04	7.1	16.5	40.4	94.1	-29.8	-69.5	-30.4	-73.2	1.6	3.7
1991-1999	7.55	26.5	5.8	20.4	28.1	98.6	-14.8	-51.9	-17.5	-41.8	2.2	10.1

According to its dimensions, the Aral Sea was ranked as the fourth lake all over the world after the Caspian, the Great Lakes in North America and Lake Chad. The area of the Aral Sea constituted 64,490 km^2 (with islands); a maximum length - 428 km, a maximum width - 284 km.

The lake was relatively shallow: a maximum depth was 68 m, and an average depth was only 16 m. The deepest places were located along the western shore in the form of a narrow strip; the area of parts of the sea deeper than 30 m amounted to only about 4 percent of the entire area of the lake.

Thus, the ancient Aral Sea that had undergone 5 or 6 transgressions - increases and consecutive desic-cations - has once again come up to the threshold of a new shrinkage.

II. DEGRADATION OF THE ARAL SEA AND SOUTH PREARALIE

Though the Aral Sea desiccation is attributed to the Soviet State as the main initiator of this natural-anthropogenic disaster, the concept of sacrificing the Aral Sea for the sake of irrigation and agriculture development actually belonged to scientists of the pre-Soviet period. In particular, A.I. Voyejkov (1908) insisted that under effective agricultural practice in the region the Aral Sea existence is absolutely not justified, since economic effect of its existence (fishery and navigation), in his opinion, is much less than the effect of economic development, especially, irrigated agriculture.

The same idea emerged in 1913 in the mind of another person, not a scientist, but the head of the water sector in the former tsarist Russia, the Director of the Land Improvement Department, Prince V.I. Masalsky. He considered that a final goal was "use of all water resources of the region and creation of new Turkestan…, developing million hectares of new lands and providing cotton demanded for Russian industry… ".

In Soviet times, irrigation development initiated by the Russian Government progressed greatly. However, till 1960 water diversion for irrigation was accompanied by development of drainage networks and, naturally, by increase of return water released into rivers that exerted little impact on river deltas and the sea.

Quasi-equilibrium of water and salt balances of the sea is typical for the period of 1911 to 1960. About 25.5 million metric tons of salts annually entered the sea; the basic part of this salt discharge underwent sedimentation with mixing of marine and river waters due to over-saturation of the Aral Sea water by calcium carbonate and was precipitated at shallow waters in bays, bights, and infiltration lakes situated along northern, eastern, and southern coastlines. Due to freezing and melting of the sea, a mean salinity in that period varied over the range of 9.6 to 10.3 percent. Relatively high annual river discharge (approximately 1/19 of the sea water volume) gave a peculiar salt composition of the Aral Sea water with a high concentration of carbonate and sulfuric salts, which differed from salt composition of other inland seas.

The modern period of the Aral Sea, since 1961, may be described as the period of active anthropogenic impacts on its regime. Drastic increase of irretrievable river water withdrawal (which amounts to 70-75 km^3/year in recent years), exhaustion of compensating abilities of the rivers, and natural aridity in 1960 to 1980 (92 percent) resulted in disequilibrium of water and salt balances. The considerable exceeding of evaporation over the sum of all inflow constituents[1] was typical for the period of 1961 to 2002. The river water inflow into the sea has decreased in 1965 up to 30.0 km^3/year; in 1971-1980, it amounted to 16.7 km^3/year, on average, or 30 percent of 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 percent of the mean annual runoff. During some dry years, runoff of the Amu Darya and Syr Darya rivers has not actually reached the sea.

River water quality has also changed owing to increase of share of highly saline waste and drainage water that resulted in a significant increase of salinity and deterioration of river sanitary conditions. During dry years, the mean annual salinity of the Amu Darya water entering into the sea reaches 0.8-1.6 g/l, and salinity in the Syr Darya amounts to 1.5-2.0 g/l. In some seasons, higher salinity levels are observed. As a result, in spite of decrease of annual river runoff by 46 percent over the period of 1961 to 1980, the annual salts entry has decreased only by 4 million metric tons or by 18 percent for the same period. Other constituents of the salt balance have also substantially changed. Due to decrease of carbonates content in the river inflow, sedimentation of salts under mixing of river and marine waters was reduced by two times.

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

As a result, since 1961 the sea water level has steadily dropped. The total sea level drop, in comparison with the average annual value (prior to 1961) has reached 12.5 m by the beginning of 1985. The average annual rate of the sea level dropping was about 0.5 m, reaching 0.6-0.8 m/year in dry years. The annual sea level fluctuations were also changed. At present, the annual sea level rise is practically not observed, at best, it does not change in winter, and in summer an abrupt drop takes place.

The gradual drop in the sea water level has considerably exceeded predicted rates. Modeling carried out by the State Institute of Oceanology (Dr. V.N. Bortnik) in 1983 has predicted that by 1990 the sea water level would reach 41 to 42.5 m + BSL at probability of 90 percent, and by 2000 - 35.5 to 38.5 m + BSL. In fact, as Table 1-2 shows, by 1990 the sea water surface elevation was 38.24 m +BSL, and by 2000 – about 34 m +BSL. Similarly, seawater salinity has increased at higher rates - by 1990 it was 32 percent instead of predicted 26 percent, and by 2000 it was 40 percent instead of predicted 38 percent.

It was established that saturation of the Aral Sea water with calcium sulfate and precipitation of gypsum occur at the salinity level exceeding 25 to 26 percent. However, the most intensive precipitation of gypsum takes place at the salinity level higher than 34 to 36 percent. Under these conditions, in the winter period in parallel with precipitation of gypsum, precipitation of mirabilite occurs, the latter being of the greatest risk for the Prearalie environment. Dehydrated ammonium sulfate is exposed to wind erosion and can be easily transferred far apart.

The sea level drop and water salinization have resulted in an increase in the amplitude of annual temperature over an all water column and in some 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). This is one of the main factors restricting implementation of acclimatization measures and hindering rehabilitation of fishery in the sea in the nearest future. Lowering the sea level may result in rather noticeable modification of ice conditions, and even in moderate cold winters, ice cover of the entire sea water area with a maximum thickness of 0.8 to 0.9 m may be expected. Cooling and freezing of the sea will occur approximately during the same periods of time; however, reduction of its total heat storage will cause more rapid ice spreading. Increase in a mass of ice per unit area will lead to a more prolonged period of ice melting.

Extremely low specific values of biogenic substances inflow into the sea predetermine their low concentrations in seawater, further constraint for development of photosynthetic processes in the sea, and its low biological productivity. Deteriorating of the oxygen regime of the sea in summer owing to decrease in photosynthetic production and intensive oxygen consumption for oxidation of an organic substance causes formation of oxygen deficit zones and kill phenomena.

Further salinity increase causes both reduction of species of phyto- and zooplankton, phyto- and zoo benthos, and appropriate reduction of their biomass resulting in further degradation of food resources for aquatic life. The existence of endemic fauna is impossible owing to increase in the Aral Sea water salinity.

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

Major consequences 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 with the area of almost 3.6 million ha on the exposed seabed. As a result, a huge bitter-saline lake and a vast saline desert located at the interfaces between three sand deserts have replaced the unique freshwater water body.

In 1985-1986, the Small Aral Sea completely separated from the Large Aral Sea at the sea water level of 41 m + BSL. This resulted in formation of a new desert area of 6,000 sq km with a salt storage in the top layer up to 1 billion metric tons. Currently, precipitation of gypsum from the saturated marine water is under way. At the sea level of 30 m + BSL (total drop is 23 m) the western part of the deep-water Large Aral Sea will be separated from the eastern shallow part by islands.

After separation of the Small Aral Sea from the Large Aral Sea, their regimes started developing according to different scenarios. Since the Syr Darya River inflow has been higher than the Amu Darya river inflow, the Small Aral Sea level started rising and water salinity decreasing. A break in the Small Aral Sea temporary dam 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 developed project of an engineered dam, with a regulated spillway in the Berg's Strait, will provide the possibility of establishing 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 separated water bodies each with its own water-salt balance and own future depending on what policy will be selected by five countries that are economic entities of these river basins (Figure 2-1).

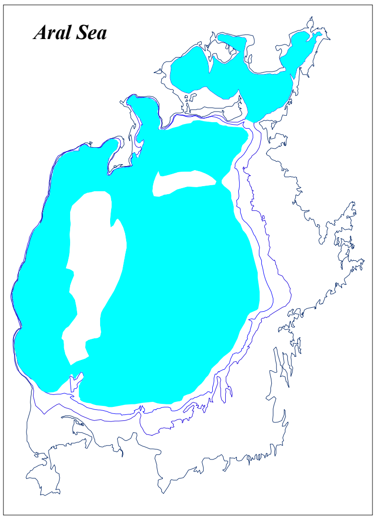


Figure 2-1

Characteristics of Prearalie habitat degradation under impacts of the sea desiccation are presented in the paper "Assessment of Socio-Economic Effects in Result of Ecological Disaster – Aral Sea Desiccation" prepared within the framework the INTAS/RFBR-1733 Project (August 2001), and published by the SIC ICWC (Tashkent). Summary of the basic degradation effects are given below:

- decrease of lakes' area in the Amu Darya delta from 400,000 ha in 1960 to 26,000 ha;
- groundwater table lowering up to 8 m depending on the distance from the sea coast,;
- erosion of river channels and their beds incision up to 10 m;
- development of salt and dust transfer within the belt of 500 km wide with load capacity of 0.1-2.0 t/ha;

- top-soil changes: an hydromorphous soil area reduced from 630,000 to 80,000 ha;
- the area covered by solonchak increased from 85,000 to 273,000 ha;
- the reed growth area reduced from 600,000 to 30,000 ha;
- the tugai forest area reduced from 1,300,000 to 50,000 ha;
- climatic changes in the zone of 150 to 200 km from the sea;
- fish catch decreased from 40,000 to 2,000 metric tons per year.

All these affects have resulted in economic losses amounting to US$115 million and social losses estimated in the amount of US$28.8 million annually.

It should be noted that ecological changes related to the sea desiccation have been accompanied by water inflow reduction and, consequently, deterioration of potable water supply (increase in salinity and decrease in groundwater inflow). This fact, in turn, has caused a growth of sickness rate of the population. It was clearly demonstrated by Dr. O. Ataniyazova and others (Nukus, 2001) in their paper "The Aral Crisis and Medical-Social Problems of Karakalpakstan" (Figures 2-2 and 2-3).

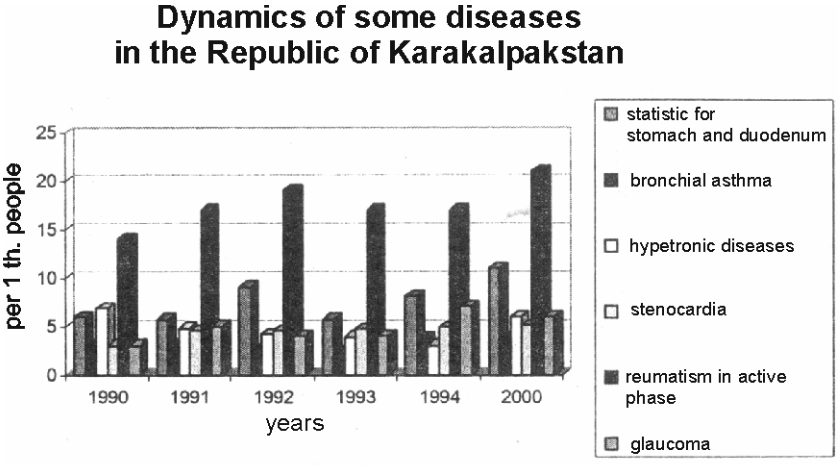


Figure 2-2

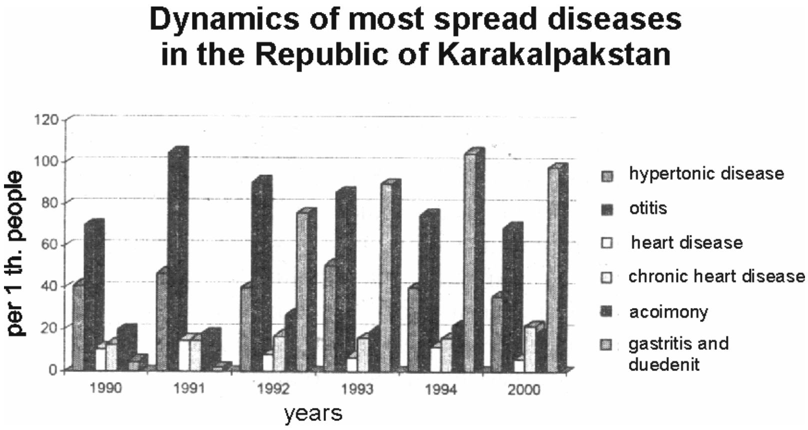


Figure 2-3

In the early 1970s, when the Aral Sea started rapidly shrinking, the Public of the former USSR arrived at an understanding of the need to undertake some reclamation measures. At that time several governmental commissions were established. They have concluded that it is necessary to undertake urgent measures if not on cessation of the sea level lowering, then at least, on mitigation of negative socio-economic and ecological impacts related to this disaster. Transfer of Siberian rivers' water in the amount of 18-20 km^3 annually was proposed to improve water supply and concurrently environmental conditions in the Prearalie. The government of the USSR rejected this proposal in 1986 and submitted a range of alternative measures approved by the Resolution No 1110 of 1986. Eventually, two BWOs "Amu Darya" and "Syr Darya", a special organization "Aralvodstroy", and the coordinator of the program - the Consortium "Aral" were established. During the period of 1987 to 1990, a certain scope of works related to water conservation improving in the South Prearalie, the Right Bank Drain, and completion of the Tuyamuyun Reservoir Project was implemented.

After the collapse of the USSR in late 1991 all these efforts were stopped until the Heads of five Central Asian States have established an International Fund for the Aral Sea in 1993 and on January 11, 1994 they approved the Aral Sea Programme, which includes measures on improving the situation in the South Prearalie. In particular, it was decided "to develop the feasibility study for establishing artificially-inundated landscape ecosystems in the Amu Darya and Syr Darya deltas and areas adjacent to the dried-up Aral Sea bed as well as implementing proper reclamation measures to rehabilitate the natural conditions in this area". At the same time, the basic provisions of the Concept of Improving Socio-Economic and Ecological Situation in the Prearalie" were approved. These provisions distinctly stated that rehabilitation of the Aral Sea to its original state is impossible, and the main efforts should be placed on construction of necessary water infrastructure and measures related to creation of a new sustainable ecological profile of the South Prearalie by means of proper water supply, afforestation, and other reclamation activities.

This document was actually based on our proposals, which had been published in the "Vestnik Pustyni" magazine No. 3 (1984), to preserve the South Prearalie by creating on its territory the ecologically sustainable zones that will perform those functions, which the two former ecosystems were jointly performing. For this purpose, the South Prearalie, including the delta and the sea itself, is subdivided into ecological zones different according to the forming principles (e.g. fresh, brackish and mixed water supply, etc.). This concept is analyzed in the following chapters.

III. HYDROLOGY AND HYDRO-GEOLOGY OF THE 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 Sudoche, Karateren, Kokchiel, Akchakul, Zapadnoe), have represented lakes of the coastal-deltaic plain occasionally flooded by river and sea waters and linked with the Adjibay 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.

The river runoff has become controlled to a certain (78 to 81 percent) extent due to effect of water reservoirs constructed on the Vakhsh and Amu Darya rivers (the Nurek, Baypaza, and Tuyamuyun Dams) and several intra-system reservoirs of the Amubukhara, Karakum and Karshy irrigation schemes, and that has substantially transformed the hydrological regime at lower reaches of the river.

Development of irrigation in the Amu Darya River basin, and, as consequence, increase of irretrievable water withdrawal, has resulted in drastic reduction of water inflow to the delta. Due to insufficient maintenance of water and salts exchange in these lakes, water quality started deteriorating and as a result, the ecological situation has worsened as a whole.

The Aral Sea shrinkage and loss of a natural linkage with its bays resulted to ceasing of water resources replenishment with sea water, and the delta has become completely dependent from the regime of river water inflow. As a result of permanent reduction of river inflow that started in the early 1960s, the lakes began functioning as a natural evaporators followed by drastic reduction of water volumes and increase in salinity.

The key factor determining the hydrological conditions within the delta is the Amu Darya river inflow. Another factor being of less importance but still significant is drainage water supplied through main drains, which feed some of the lakes, sometimes under mixing with fresh water.

The river hydrograph at Samanbay (the end gauging station at the current delta outlet) characterizes the river runoff variability, which had been fluctuating for the 20-year period from 330 million m^3/year (1982) to 24, 272 million m^3/year in 1992 (Figure 3-1).

The surface area of water bodies and their biological and economic productivity have accordingly changed.

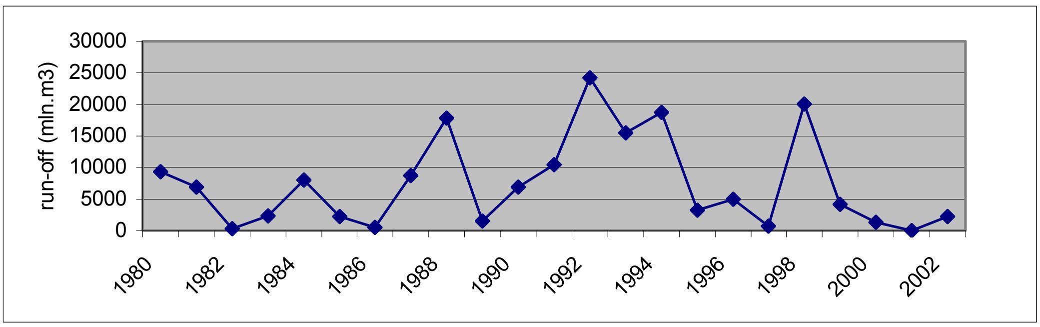


Figure 3-1 Diagram of the Annual Runoff Variability at Samanbay, 1980-2002

At present, all water bodies existing within the Amu Darya delta may be divided into two groups according to their water regime (Figure 3-2):

a) The lakes fed by drainage water (Sudoche, Western Karateren, Akushpa, Eastern Karateren, a part of Djiltirbas Lake and others);
b) The lakes fed by the Amu Darya river water (lakes Mezdureche, Dautkul, Ribache, Muynak, Dumalak and others).

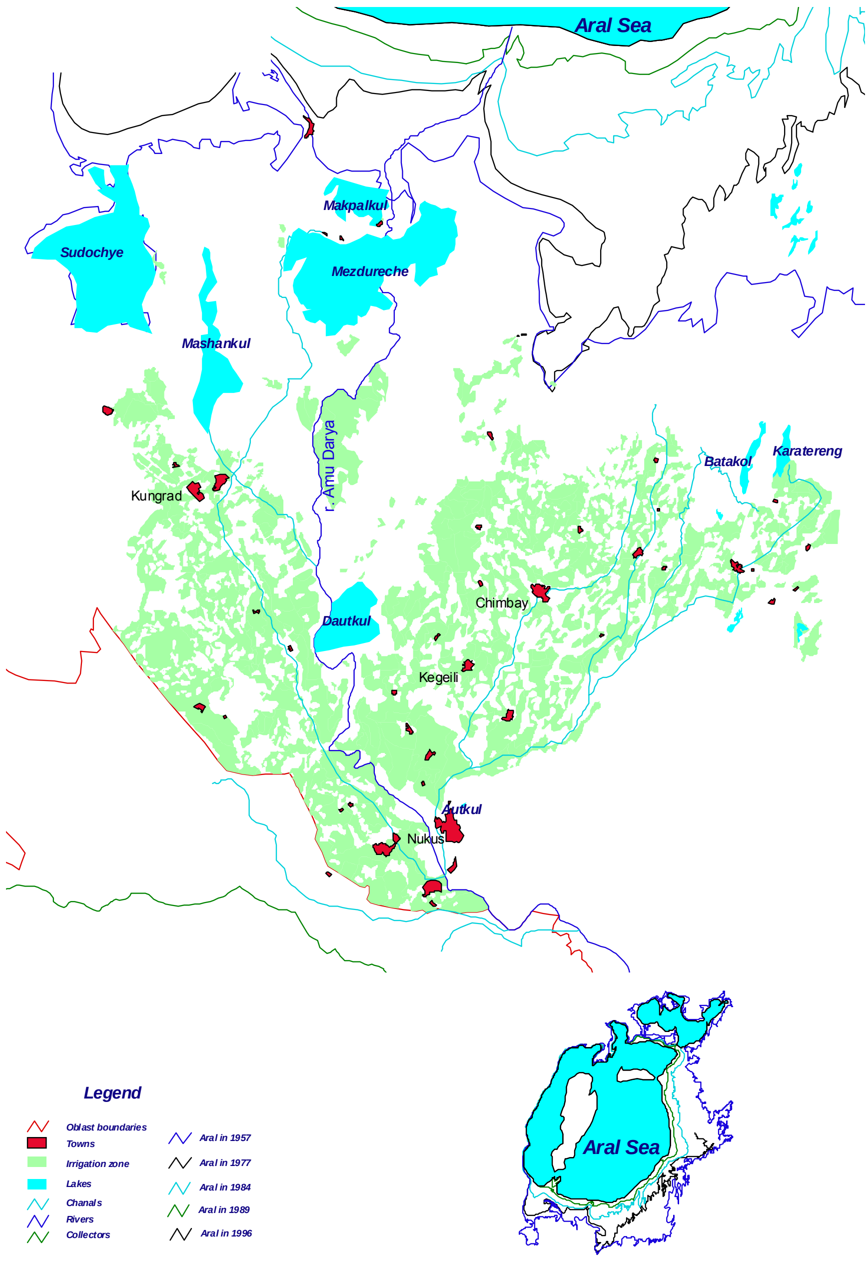


Figure 3-2 Schematic Map of Amu Darya Delta

During many decades such lakes as the Karateren, Akchakul, Sudoche, and Kokchiel have been used as receiver-evaporators for irrigation waste and drainage water discharged from irrigated lands. In the nearest future, these lakes would be impossible to use for both fishery and reed harvest needed for cattle-breeding if fresh water supply is not rehabilitated.

The volumes of drainage water supply through main drains situated in the left and right bank areas of the Amu Darya River depend mainly on annual water availability and the amount of water delivered for irrigation within the command area of the Suenly and Kyzketkent canals. Table 3-1, containing records of annual discharge through the drainage canals in the left bank area - the KKC and Usturt Main Drains, shows that the range of fluctuations in water volumes exceeds 50 percent. During catastrophic droughts of 2000-2001 drainage discharge has practically stopped. In line with hydrograph fluctuations, salinity levels in drains have changed over the range from 1.8 g/l (in wet years) to 6 g/l (in dry years) at the average salinity level of 2.2 g/l in the Usturt Main Drain and 3.8 g/l in the KKC Main Drain.

Table 3-1 Annual Runoff of the KKC and Usturt Main Drains

Year	KKC Main Drain	Usturt Main Drain
1980	645.91	200.08
1981	583.05	59.72
1982	413.68	12.22
1983	607.26	0
1984	769.35	182.77
1985	639.54	93.3
1986	406.33	531.03
1987	546.13	340.52
1988	559.76	290.12
1989	418.37	367.3
1990	548.8	106.59
1991	595. 73	134.02
1992	748.66	196.48
1993	739.37	248.7
1994	655.94	249.57
1995	525.94	85.93
1996	583.63	204.83
1997	469.11	85.69
1998	597.4	291.9
1999	78.3	61.25
2000	83.1	58.28
2001	47.34	0
2002	27.95	0.67

According to the pattern of water supply and quality of water, the territory of the Amu Darya delta may be divided into three zones:

1. *The Left Bank Zone* is the command area of the Raushan canal and Main Drains KKC and GK. The main water bodies are lakes of the Sudoche wetland – the Akushpa, Taily, Karateren, Big Sudoche, and Begdulla-Aidyn and lakes of the Karadjar system – the Mashankol, Hojakol, and Ilmenkol.

2. *The Central Zone* is located along the main channel of the Amu Darya, within the command areas of the Glavmyaso and Marinkinuzyak canals. The main water bodies are the Mezdureche Reservoir, Ribache and Muynak Bays, and the Makpakpol Lake.

3. *The Right Bank Zone* is located along the Kazahdarya channel, within the command areas of Main Drains KC-1, KC-3, and KC-4. The main water body is the Djiltyrbas Bay.

According to a water exchange pattern, water bodies of the South Prearalie are divided into: flow-through water bodies – the Mezdureche Reservoir and the Makpalkol Lake; water bodies with low (periodical) flow-through – lakes Karateren, Big Sudoche, Begdulla-Aidyn, Mashankol, Hojakol and Ilmenkol, bays Ribache, Myna, Djiltyrbas; and closed drainage water sinks – lakes Akushpa and Tayli.

At present, the first zone, where lakes are fed with drainage water (Main Drains KKS and Usturt) is unfavorable from the point of view of further development due to low water availability. In future, water delivery to this zone through the Raushan Canal will be practically impossible due to reduction of water availability in the Amu Darya River downstream of the Takhiatash Barrage. The key issue in this zone is preservation of the Sudoche Lake as a natural water body, the Karateren Lake and the chain of lakes of the Kyvsyr system*.

The Amu Darya Zone is the most promising for further development. Providing guaranteed discharges from the Takhiatash Barrage, the more or less favorable ecological and hydrological conditions would be created along the river channel at the stretch from the Takhiatash Barrage to the Aral Sea. A large regulating water body is needed here that will allow restoring productive fishery, muskrat breeding and distant-pasturing. This will be depending on the regime of water supply from the Takhiatash Barrage to the delta.

The situation in the third zone depends on water supply through the Kyzketken Canal. There are numerous lakes of the local significance in this zone fed by both fresh and drainage waters (lakes Djiltyrbas, Kokchiel, Karateren, Dautkul, Atakul, Mautkul, and others).

The retrospective review of the 1980-1999 period shows that the salinity level in flow-through water bodies was over the range of 0.8 to 1.9 g/l. At that time, these water bodies were an oligogenic or slightly mesogenic lakes. The salinity level in water bodies with low flow-through has reached 3.5 to 9.6 g/l. According to the salinity level they belonged to brackish or highly mesogenic water bodies. The salinity level in closed water bodies amounted to 17.2 to 30.5 g/l. The salinity in drainage canals varied over the range of 2.1 to 4.5 g/l – slightly and moderate mesogenic waters.

Preserving these lakes and improving ecological and economic conditions in this region depend on water availability and quality, mainly on runoff of the Amu Darya River. In wet years (1991, 1992, 1993, and 1994) as a result of abundant water inflow to the Amu Darya delta through the river channel and tail sections of irrigation canals, the conditions of these lakes had significantly improved (especially in the Amu Darya River Zone), and even their water areas have enlarged.

Precipitation and evaporation are very important components of the hydrological regime in the Prearalie. According to data of three weather-stations located in the Prearalie, average annual precipitation amounts to 75 to 110 mm. At the same time, an evaporation rate from the water surface calculated by V.L. Shults amounts to 1600 mm per year, on average. Taking into account that ice phenomena in the South Prearalie comes to the end in March, the average values of evaporation according to measurements at three weather-stations are given in Figure 3-3 for the period since April till November (the ice-period in the South Prearalie makes up, on average, 119 days), and Figure 3-4 demonstrates evaporation rates at the Kungrad weather-station.

* The Sudoche Lake Improvement Project, implemented within the framework of the GEF WEMP project, Component E, is described in Section VIII.

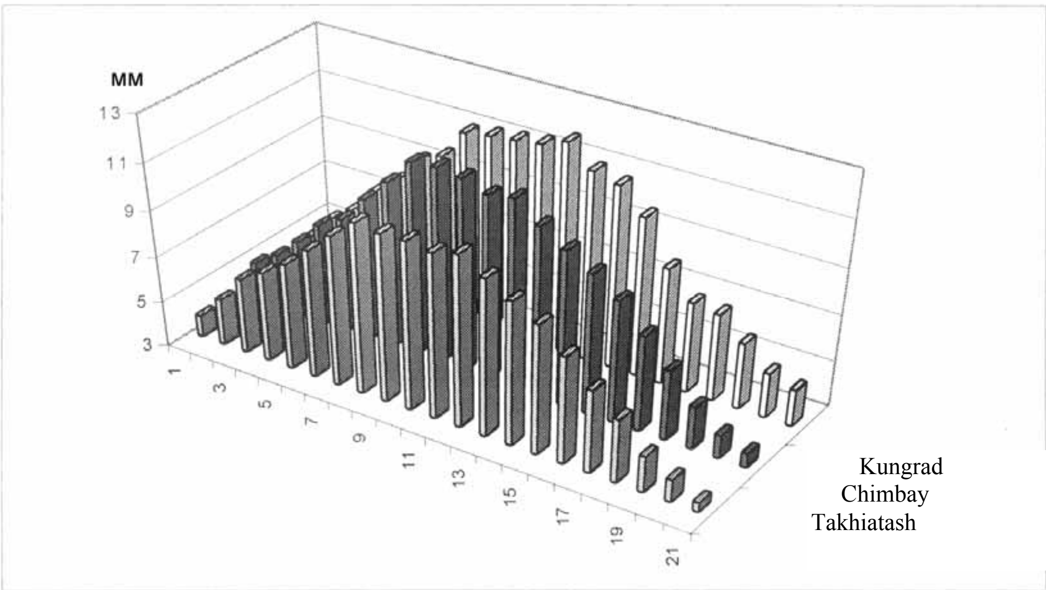


Figure 3-3 Intra-seasonal evaporation rates from a water surface at three weather-stations in the South Prearalie (since April)

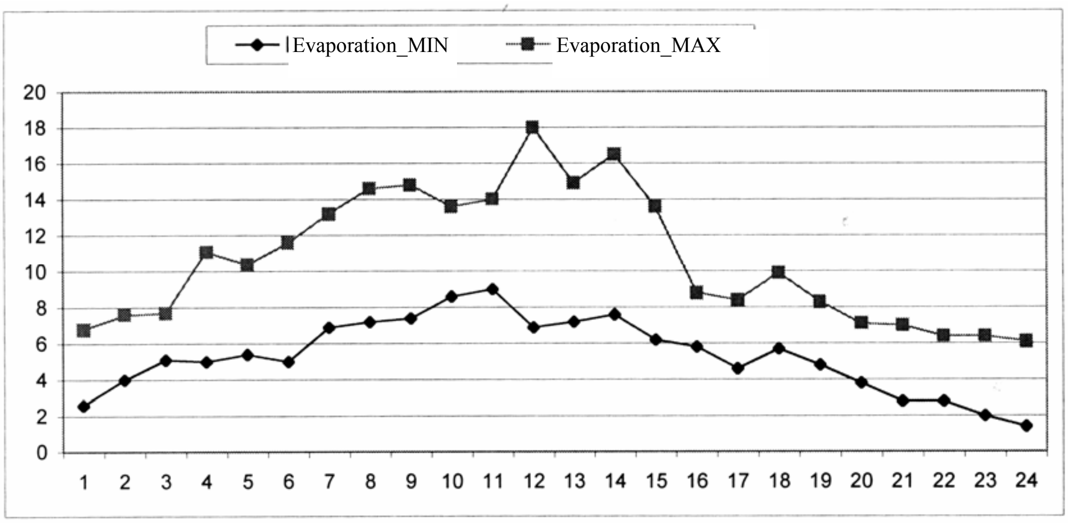


Figure 3-4 Maximum and minimum evaporation rates since April till November (with a 10-days interval)

Evapotranspiration of reed is a very important indicator (Table 3-2).

Table 3-2

Month	IV	V	VI	VII	VIII	IX	X	For the season
mm	29	119	321	394	218	103	34	1,298
%	2.3	9.2	24.8	30.3	22.9	7.9	2.6	100

The Decision adopted by the Heads of State of the five Central Asian Republics of January 11, 1994 concerning the Concept for improvement of socio-economic and ecological conditions in the South Prearalie stipulates that the Aral Sea disaster impacts must be mitigated by establishing the system of artificially regulated water bodies at the location of former coastal and intra-delta lakes and sea bays along with appropriate afforestation and land reclamation measures.

Preservation of these lakes and maintenance of their appropriate hydrological and hydro-chemical conditions entirely depends on inflow of river water i.e. on the availability of water in the Amu Darya River at the Takhiatash hydroscheme site. In wet and average years favorable conditions for preservation of these lakes will be ensured under inflow of the Amu Darya water into these lakes at the rate of 3.0 to 4.5 billion m^3 per year.

Problems may occur during dry years and also in the future under reducing the availability of river and return water.

As shown in Table 3-3, the water supply at the rate of 5.2 billion m^3 per year (the net water supply) is needed to maintain the optimal water level of coastal and intra-delta lakes.

Table 3-3 Estimated River Flow Rates (m^3/sec) and Runoff (million m^3) to Maintain Coastal and Intra-Delta Lakes (the tentative assessment)

Location	Water surface area of water bodies (000' ha)	Mean annual flow rate (m3/sec)	Runoff (km^3)
Left Bank Zone	96.0	35.0	1.1
Amu Darya Central Zone	122.0	99.3	3.14
Right Bank Zone	64.7	32.4	1.03
Total	282.7	166.7	5.27

Subsurface geology and, first of all, the Quaternary deposits determine hydrogeology of the Prearalie. The geological section of the territory bounded by the Usturt Plateau in the west, the Kyzylkum Desert in the east, and the latitude of Kungrad City in the south is presented by the modern Quaternary and Upper Neogene deposits 30 to 50 m thick. The upper part of the geological section 10-20 m deep is formed by alternating loams, loamy sands, and clays of the alluvial-lacustrine genesis. Silt, sand loam, and loam fractions predominate here. The morphology of the modern Quaternary deposits is represented by the following genetic types:

- deluvium-proluvium deposits at the foot of the Usturt plateau cliff;
- lacustrine-boggy deposits of the dried-up delta of Amu Darya River and the Sudoche Lake;
- marine deposits of a beach ridge;
- alluvial deposits of the Amu Darya River;
- wind-borne deposits.

Deluvium-proluvium deposits have developed in the form of a narrow strip (150 to 200 m wide) along the foot of the Usturt Plateau cliff. They were formed by detrital rocks consisting of limestone and marl aggregated by sand loam with thickness of 2 to 3 m. Lacustrine-boggy deposits form the dried-up delta of the Amu Darya River and the Sudoche Lake's bed. The humus horizon consists of a black reed peat 0.05 to 0.25 m thick and is underlain by lacustrine-boggy loam 0.5 to 1 m thick. Marine deposits are formed by fine and silty sands with a thickness reaching 1 m. Wind-borne sands form dunes (barkhans) of a height ranging from 0.3 to 1.5 m.

Lacustrine-boggy deposits of the delta are underlain by a bedding of lacustrine-alluvial deposits, which are represented by brown fine-grained sands and brown loams, sometimes by fluvial sands. The geological section in vicinity of the Otsechnaya Dam is formed by the following deposits:

- lacustrine-boggy deposits of the delta;
- lacustrine-alluvial deposits of the Amu Darya River.

Lacustrine-boggy deposits (a thickness of 0.5 m) are represented by reed peat, black sand loams and loams with the high level of humus content. They are overlain by sediments of the Amu Darya River represented by grey fine-grained sands and brown loams with interlayer of clay. Their thickness is 1.5 m. A hydraulic conductivity of different deposits is as follows: the Quaternary alluvial sands - 1.69 to 9.0 m/day; sand loam – 1.0 to 3.0 m/day; loam - 0.03 to 0.05 m/day; Upper Neogene sands – 2.0 to 8.1 m/day; sandstone - 0.78 to 2.8 m/day. An average transmissivity is 1.1 to 7 $^{*}10^{3}$ m^{2}/day.

The regional groundwater flow is mainly directed towards the North to the base level of drainage (the Aral Sea). The groundwater gradients correspond to the surface slopes and amounts to 0.00025 to 0.00032. The groundwater table fluctuates over seasons depending on the availability of water ranging from 0.0 m (rice fields in the Raushan Farm during water application) to 5.0 to 10.0 m deep.

Groundwater is fed due to seepage losses on rice fields, from drainage canals and lakes (at high water levels in them), discharged in the form of the regional runoff and drained by drainage canals at low water levels. An average regional groundwater runoff rate is low and amounts to 30 m3 per day per km. Water is brackish with the salinity level over the range of 15 to 50 g/l, with prevailing of ions of chlorine, sulphate, and sodium in its chemical composition.

During the recent decade, the groundwater regime of the desert zone has stabilized regarding a water table depth and a salinity level. The long-term monitoring at the Muynak and Akkala transects shows that the zone of the Aral Sea influence on the groundwater table has extended as far as 15-25 km from the initial shoreline. The stabilization of a groundwater table depth during recent years indicates that there is not interrelationship between the existing sea and groundwater in the delta.

The monitoring network operating on the given territory consists of two regional south-north (the Akkala and Muynak) transects of observation wells crossing the delta towards the former Aral Sea shoreline, two local transects of observation wells (The Akbulak and Adjibay) located in the desert zone, and some single observation wells scattered throughout the region, mainly in the irrigated area.

Monitoring of the groundwater table and salinity dynamics has been carried out since the early 1960s. During the recent decade some additional monitoring points have been established; however, many points were abandoned due to the lack of funding, therefore, the ten-year series of monitoring data are available no for each observation well. So, well clusters for hydro-chemical monitoring (WC HCM) No 207 and 209 at the Muynak transect were liquidated in 1996, and monitoring was stopped at the WC HCMs No 1 and No 2 during the period of 1992-1998 due to their flooding by irrigation waste water. WC HCMs at the Akkala transect are under monitoring since 1986, and only the WC HCM No 112 since 1992. At the Adjibay transect, monitoring of WC HCMs No. 803, 804, 805, 806, 807 and 811 were started in 1992, and WC HCMs No. 819 and 820 since 1996. WC HCMs of the Akbulak transect started to be monitored since 1989.

Well clusters for hydro-chemical monitoring at the above mentioned transects consist of, as a rule, the three-level piezometers with depths of 12, 20, 30 and 50 m; single monitoring points consist of a single well. The total number of monitoring points in the study area exceeds 40. The frequency of collecting data on a groundwater table depends on a type of monitoring and a season; and it varies from 1 to 3 times a month. Sampling for a general chemical analysis is carried out twice a year: in a growing season (July-August) and a dormant season (January-February) in the irrigated area, and once in desert territories.

IV. BASIC APPOACHES TO SELECTING ALTERNATIVE SOLUTIONS OF PROBLEMS IN THE SOUTH PREARALIE

The inevitability of the Aral Sea desiccation became evident in the early 1980s, and along with appeals to stop irrigation (it was absolutely unreal) or to proceed to drip and sprinkler irrigation (it was economically impossible due to large-scale irrigation on about 7.0 million ha) a search of alternative solutions for saving, at least, a part of the sea has been begun. At that time, scientists from the Central Asian Irrigation Research Institute (SANIIRI) has proposed to embank the southern part of the sea by an extensive dam, thus creating a so-called fore-delta pool with water levels of 53 m +BSL, in order to rehabilitate, at least, partly a natural ecological profile. This proposal was published in the journal "Desert Bulletin" (Issue 3, 1983) and repeatedly presented at high-level conferences and meetings in water-management organizations and the Secretariat of the Central Committee of the CPSU. The proposal has incurred a severe criticism of both the Aral Sea's defenders who claimed that this would be a "surrogate" of the sea and the irrigation development supporters who believed that such a proposal would divert considerable funds (about Ruble 1.2 billion, i.e. approximately US$ 2 billion) and water resources (12 to 15 cu km of water would be required for creation of the fore-delta pool and extra 5 cu km of water to meet demands of the delta itself, thus 20 km^3 of water in total on a routine basis). The authors are still sure that in case of a support of the Soviet Government, the USSR was capable to implement this proposal at that time, as even in years of decline of the Soviet Union, the Water Construction Consortium "Aral" had its annual turnover of about Ruble 1 billion over the period of 1987 to 1990. At the same time, this would have forced five Central Asian republics to apply water-saving technologies and to maintain the water demand level in the limits of 100 to 103 cu km that corresponds to the current level; but it could be implemented 20 years ago. However, the proposal to build a fore-delta pool was forgotten because a "mirage" of transferring Siberian rivers runoff to Central Asia has appeared on the scene.

The idea to build a fore-delta pool has arisen again when the project of transferring Siberian rivers runoff was stopped, and the competition for the best solution of the South Prearalie problem was announced. Under developing this idea in 1988-1989, the need to solve the problem of the Aral Sea and Prearalie differentially has resulted in selection of the following zones:

Zone 1 is the Amu Darya River delta itself stretching from the irrigated area in the south to the former Aral Sea shore line in the north.

Zone 2 is the dried seabed from the former Aral Sea shore line at the level of 53.0 m +BSL to locations with isobaths at the level of 29.0 to 30.0 m + BSL, where, as it is supposed, the sea level will be stabilized in the future.

Zone 3 is the Aral Sea itself.

Each of the above-mentioned zones is subdivided into several ecological sub-zones classified according to such factors as the presence of residential areas and their social conditions, water resources (river and/or drainage water) and their deficit, flora and fauna and their degradation, soils, ground waters, etc.

To solve problems in each of three zones it is needed to implement interrelated engineering and ecological measures with the following objectives:

Zone 1: to develop the Amu Darya River delta in order to rehabilitate as much as possible its natural environmental regime and to create reasonable living conditions for the population.

Zone 2: to develop the dried seabed to mitigate negative impacts of the exposed bed by means of creation of the areas with man-made water bodies and forest shelter belts.

Zone 3: to preserve the existing biological potential of the residuary parts of the sea and to mitigate negative impacts of drying up of the sea.

In addition, the SANIIRI has worked out "The Block Diagram of the Aral Sea and Prearalie Problems Solving" (Figure 4-1), where all possible options for single zones and their interaction are represented.

There are three different options with a set of sub-options regarding water levels, volumes, etc. for Zone 3: conservation of the Western Sea to the detriment of the Eastern Sea is Option 1.1; conservation of the Eastern Sea to the detriment of the Western Sea is Option 1.2; conservation of the uncontrollable residuary part of the sea is Option 1.3 (separating a number of smaller water bodies that are not linked with each other and depend on a way of water supply). At the same time, there are two basic options for the delta zone: rehabilitation of some parts of the delta (in eastern, western, and central zones) to the original conditions (II.1); and gradual development of a new type of the delta (II.2).

Protection of the dried seabed from wind erosion and prevention of salt and dust transfer would be provided either by creation of so-called “lagoon” and water bodies behind it or by flooding of some former bays establishing one or two lines of water bodies (closed and flow-through water bodies) along with afforestation and other measures. The simultaneous solution of the block "sea - delta - dried seabed" (Figure 4-1) would be possible only under combining Option 1.1 for the sea, Option II.1 for the delta, and Option IV.1 for the dried seabed, if the Small Sea could be conserved (or filled up to the level 53 m +BSL), and on this base to develop a new delta with conditions close to original ones. Taking into account unfeasibility of this option, the SANIIRI has studied issues of developing shallow water bodies (so-called anti-polders) on the dried seabed and elaborated the general approach based on subdividing the region into zones according to the ecological classification. In particular, the following zones were classified:

- The first ecological zone is presented by the delta and adjacent zones of distant-pasture livestock-breeding and grazing areas with the Mezdureche Reservoir as the major water body for water distribution and management within the delta;
- The second ecological zone is residential areas, such as Muynak, Porla-Tau, Shega, Kazakdarya, etc. (their development and improvement of social conditions). This zone includes such reservoirs as Muynak Bay, Ribache Bay, Maipost, and Dautkul;
- The third zone is a dried area adjacent to a contour line of 53 m +BSL, where the system of scalar-type water bodies fed with fresh water is proposed to be placed;
- The fourth ecological zone is natural and man-made water bodies fed with brackish or mixed waters (Sudoche, Adjibay, Djiltyrbars, Karadjar system, Vostochniy Karateren and others);
- The fifth ecological zone is the territory located between the current seashore and the proposed system of man-made lakes;
- The sixth zone is the Aral Sea itself or its parts: the Western Sea, the Eastern Sea, and the Small Sea.

Based on the tentative analysis of different options, the logical diagram for rehabilitating the delta was plotted (Figure 4-2).

Problems of desertification control in the Amu Darya delta and rehabilitation of the Priaralie ecosystems have been studied and summarized in proposals of specialised design and research institutes of Uzbekistan and other countries.

In 1989, the *Institute "Sredasgiprovodhlopok"* has developed the feasibility report on water infrastructure for regulating the level and flow regime of water bodies in the Amu Darya delta. The basic parameters of water bodies fed with drainage inflows and fresh water from the Amu Darya River in the former bays of the Aral Sea (Ribache, Muynak, Adjibay, and Djiltirbas) were specified, and the schematic layout of these water bodies was plotted (Figure 4-3).

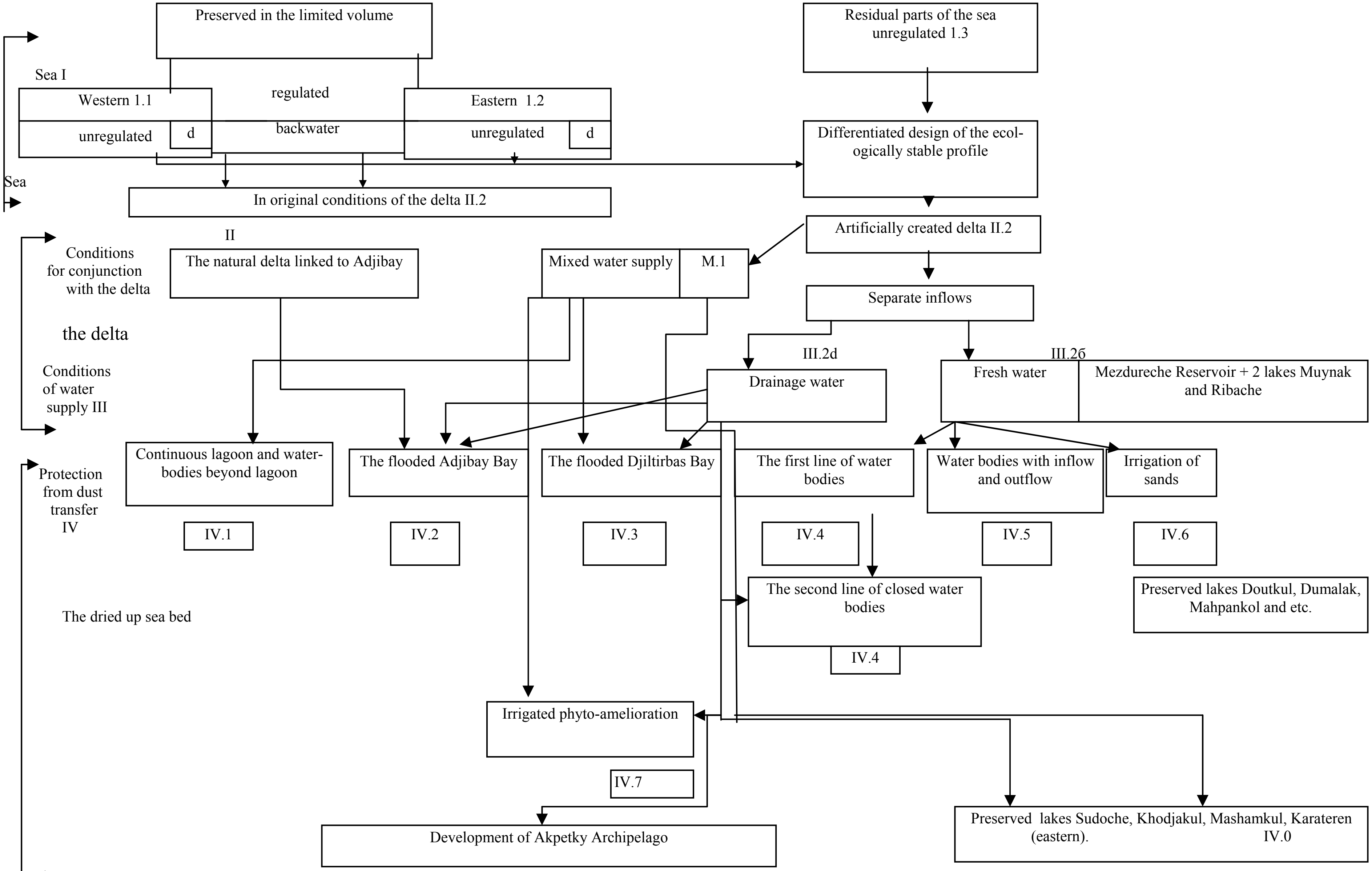


Figure 4-1 Block Diagram of the Aral Sea and Prearalie Problem Solving

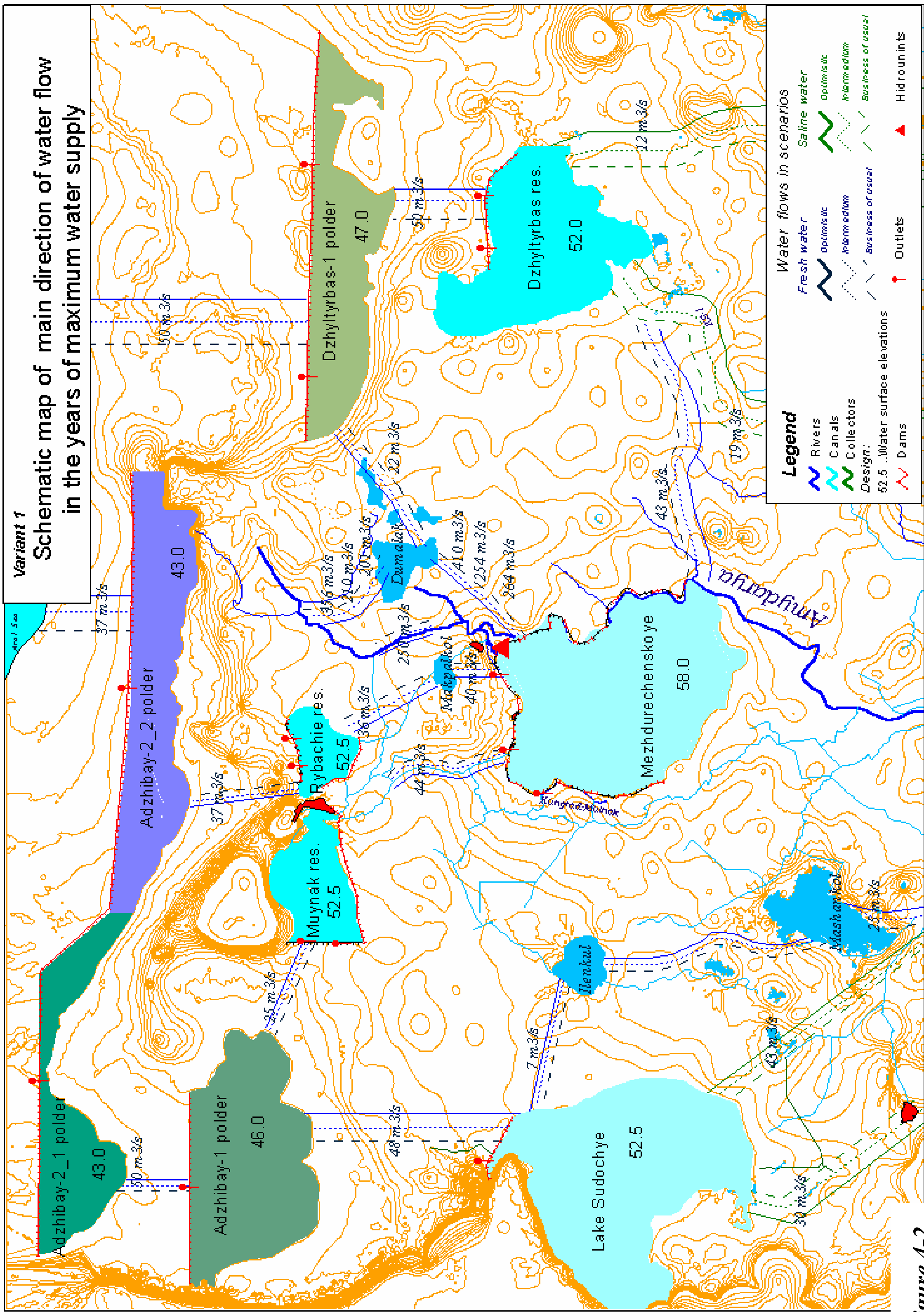

Variant 1
Schematic map of main direction of water flow in the years of maximum water supply
Adzhibay-2_2 polder
43.0
Adzhibay-2_1 polder
43.0
Adzhibay-1 polder
46.0
Dzhyltyrbas-1 polder
47.0
Dzhyltyrbas res.
52.0
Rybachie res.
52.5
Muynak res.
52.5
Mezhdurechenskoye
58.0
Lake Sudochye
52.5
Dumalak
Makpalkol
Mashankol
Ilenkul
Amudarya
Kungrad-Muinak
Aral Sea
Legend
Rivers
Canals
Collectors
Design:
52.5 ..Water surface elevations
Dams
Water flows in scenarios
Fresh water
Saline water
Optimistic
Intermedium
Business of usual
Outlets
Hidrounints

Figure 4-2

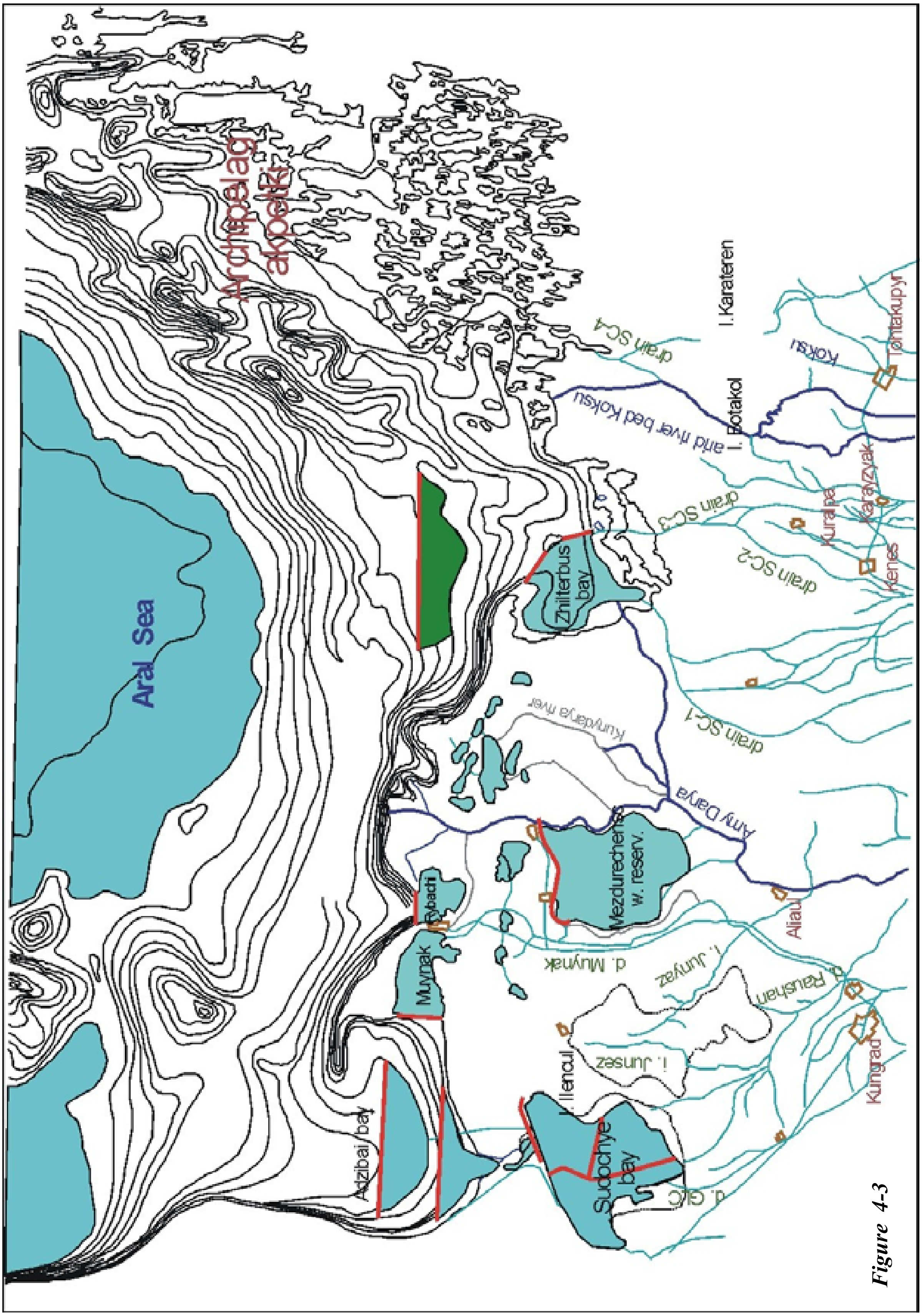

Aral Sea
Archipelag akpetki
I. Karateren
drain SC-4
I. Botakol
arid river bed Koksu
Koksu
drain SC-3
drain SC-2
Kuralpa
Kenes
Zhilterbus bay
drain SC-1
Amy Darya
Mezdurechens w. reserv.
Rybachi
Muynak
d. Muynak
l. Junyaz
Aliaul
d. Raushan
l. Junsez
Kungrad
Adzibai bay
Sudochye bay

Figure 4-3

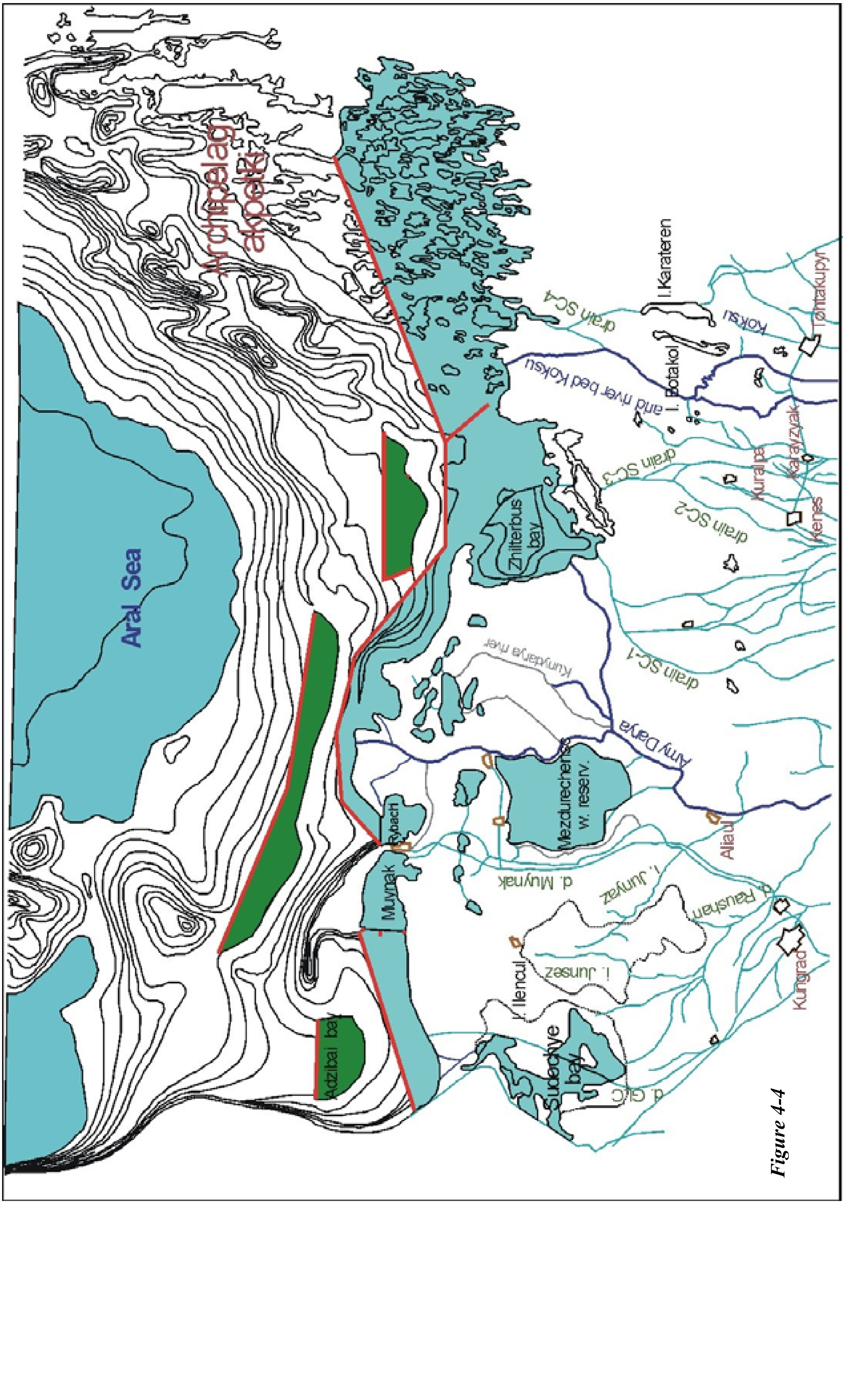

Aral Sea
Archipelag akpetki
Zhilterbus bay
Mezdurechensk w. reserv.
Amy Darya
Kunydarya river
drain SC-1
drain SC-2
drain SC-3
drain SC-4
old river bed Koksu
Koksu
l. Karateren
l. Botakol
Kuralpa
Kenes
Rybachi
Muynak
d. Muynak
Adzibai bay
Sudochye bay
l. Ilencul
l. Junsez
l. Junyaz
d. Raushan
Aliaul
Kungrad

Figure 4-4

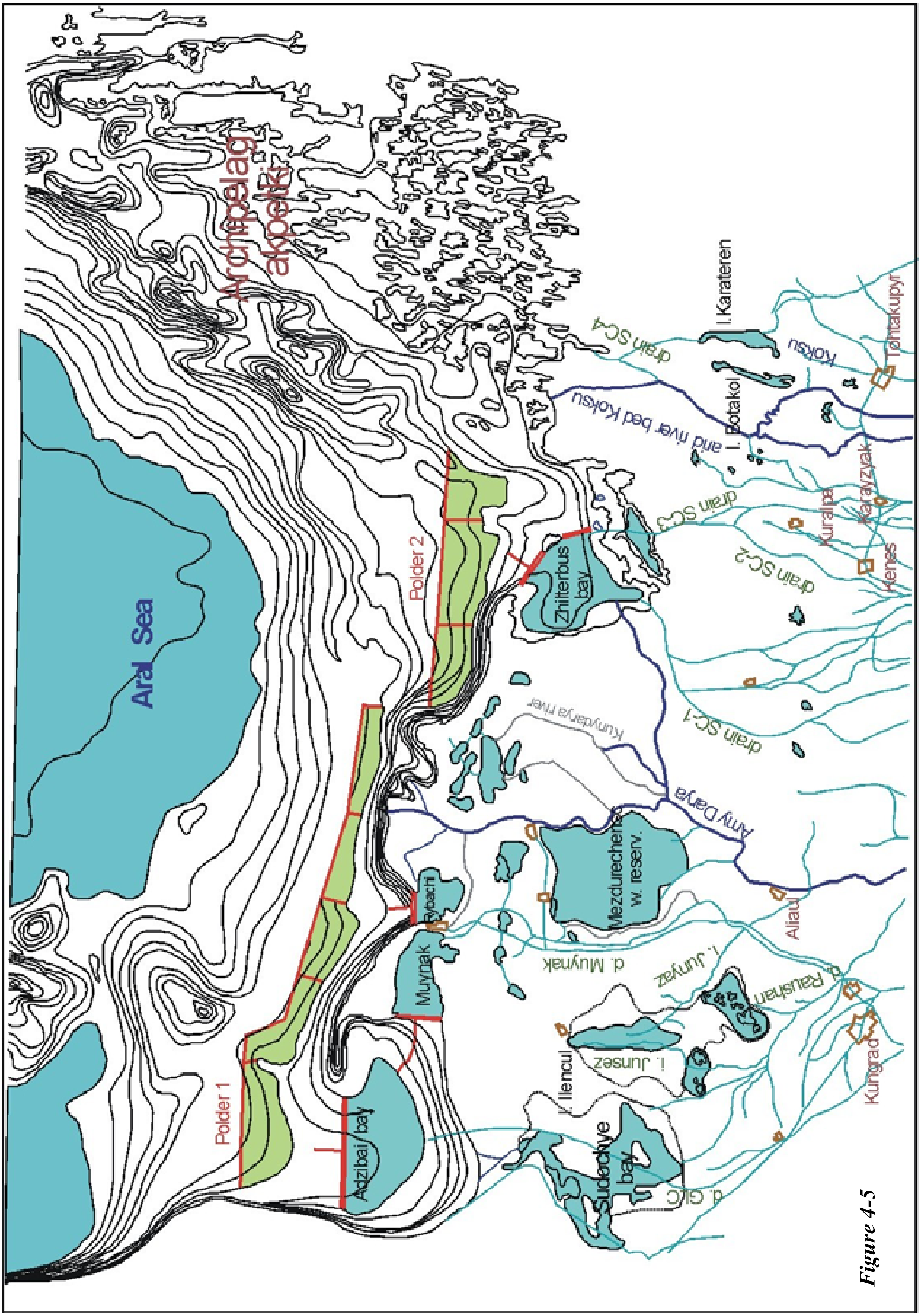

Aral Sea
Archipelag
akpetki
Polder 1
Polder 2
Adzibai bay
Muynak
Rybachi
Zhilterbus bay
w. reserv.
Sudochye bay
l. Ilencul
l. Junsez
l. Junyaz
d. Muynak
Amy Darya
Kunydarya river
drain SC-1
drain SC-2
drain SC-3
drain SC-4
arid river bed Koksu
l. Botakol
l. Karateren
Koksu
Kuralpa
Kenes
Aliaul
d. Raushan
Kungrad
d. GLC

Figure 4-5

To keep the flow-through regime and the design water level in the reservoirs Ribache, Muynak and Djiltirbas as well as in the system of natural lakes Dumalak, Maklapul etc. the parameters of the Mezdureche Reservoir have been identified for a seasonal regulation of the Amu Darya River flow. In 1990, the same institute has developed the feasibility study for construction of an artificially regulated water bodies in vicinity of Muynak, in which parameters, filling and operation regimes of water bodies Muynak and Ribache, and feasibility of their economic use were specified.

The Association "Vodproekt" has proposed to construct a continuous fresh water lagoon (on the dried seabed along the former coast line) stretching from the Usturt Plateau to the Akpetky archipelago, with the length of 180 km and a water level of 53.0 m + BSL, which corresponds to the former sea level. The lagoon dam will block streams in the delta and create a backwater in their mouths. The lagoon should accumulate the river water that inflows into the delta periphery and distribute this water among channels and lakes to fill them up to a level of 53.0 m +BSL as well. To provide flow-through in the lagoon and to maintain the required water level it is planned to use the Mezdureche Reservoir of seasonal regulation with a control structure at Parlotau. Construction of a system of canals and regulators has been proposed to maintain the required flow-through in the natural lakes Sudoche, Mashankul, Ilenkul, Maklakul, Dumalak etc. (Figure 4-4).

In 1996, the consortium comprising *Euroconsult* (leading firm), *the Wetland Group* (The Netherlands), and the *Agricultural Centre* (Uzbekistan) has submitted to the Executive Committee of IFAS and the World Bank the project report “The Aral Sea Wetlands Restoration, Uzbekistan”.

In its project report, the Consortium has proposed four floodplain areas to be brought under new water management as the pilot project (Figure 4-5):

- The floodplains of the Mashankul, Zakirkol, Ilmenkol (MZI) system;
- The floodplains south of the Muynak Bay;
- The floodplains around lake Tuz, north of Karadjar;
- The floodplains of the Sudoche and Karateren lakes system.

Establishing a new sustainable natural and anthropogenic complex that will ensure better socio-economic and environmental conditions in the South Prearalie in line with the Concept approved by the Heads of States of five Central Asian republics, requires the careful forecast not only of hydrological and climatic conditions but also of socio-economic situation and after-effects of different trends and projects.

The logic diagram of interaction of factors determining an effectiveness of proposed measures and expected effects (Figure 4-6) shows clearly a variety of factors and a degree of uncertainty in the final results due to the process of development of numerous constituents. Indeed, natural runoff of the Amu Darya river that has been well enough studied is characterized by some recurrence, which, to a greater or a lesser extent, may be predicted on the basis of available or artificially constructed simulation data series; however, river runoff may change under influence of climatic (a greenhouse effect) conditions (forecasts of 2000). Recently, on the basis of the more detailed analysis of climatic series and flow characteristics, much smaller changes have been predicted, practically within the measurement accuracy till 2020 (+1 … -3).

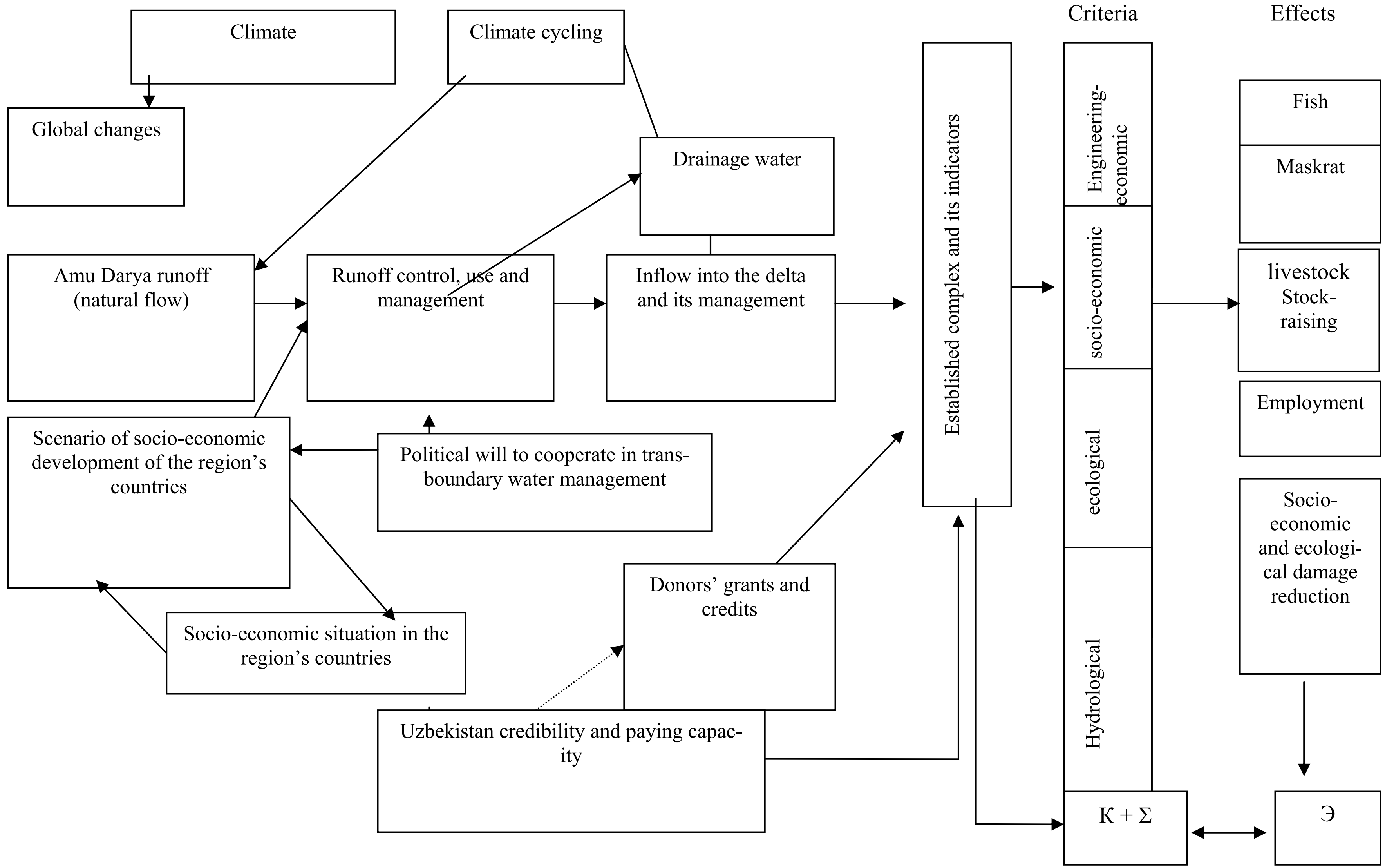


Figure 4-6 Logic Diagram of Options Selection for Supplying with Water to the Delta

Runoff that can be expected at Samanbay will depend considerably on socio-economic and political conditions in the Aral Sea basin, which are determinative both regarding water diverting from the Amu Darya Syr Darya rivers and conditions for implementing water saving measures, constructing water infrastructure in the delta and, above all, are critical for the development of mutually beneficial and well-organized joint management of transboundary waters. The political consent regarding these principles will allow involving donors in improvement of the situation in the basin as a whole and of the South Prearalie in particular.

Options of expected river and drainage water inflow into the delta are selected on the basis of simulating of the water-management situation in Central Asia under different development scenarios: optimistic, pessimistic, and “maintaining current development trends”*, developed in the ASB-MM model (the SIC ICWC and Resource Analysis).

At the same time, operational sustainability of the proposed complex will be tested for all development options and assessed on the basis of hydrological factors, i.e. inflow to the delta. In addition, the following requirements should be satisfied:

- hydrological;
- socio-economic;
- environmental; and
- technical-economic.

Hydrological requirements

- maximum control and use of the river flow, particularly the flood flow to maintain active reservoir operation;
- maximum control of existing wetland areas during the whole hydrological year, taking into account the peculiarities of their functioning depending on the zones mentioned above;
- maintaining environmentally acceptable salinity levels in water bodies;
- flood control without damaging the water infrastructure; and
- establishing the necessary winter regime in water bodies.

Socio-economic requirements

- maximum restoration of former productivity;
- maximum employment of the population in the delta;
- maximum area of wetlands covering socially adverse zones; and
- maximum mitigation of damage caused by desiccation of the Aral Sea.

Environmental requirements

Identification of environmental requirements for shallow water bodies under arid climatic conditions was a separated problem that was addressed by a number of experts: the academic-consultant B.O. Tashmukhamedov; members of the Steering Committee; experts and researchers of the Karakalpak Branch of the Academy of Sciences. The previous data collected by local experts and special monitoring carried out in the Sudoche wetlands in the south-western part of the South Prearalie was the basis for this identification. The design of a new profile of this lake and ecological monitoring were carried out by the participants of the GEF Project "Water Resources and Environment Management in the Aral Sea Basin" that has helped to formulate environmental requirements for the system of water bodies in the South Prearalie.

* The development scenarios are discussed in the model description, see www.icwc-aral.uz

The basic environmental requirements for the water bodies system in the Amu Darya delta were specified as follows:

- To ensure flow-through in water bodies, particularly in lakes, where drainage water is the only. It is especially important to maintain flow-through during the growing season.
- To ensure water salinity less than 5 g/l in lakes used for fish-breading. This is particularly important in spring and summer periods during spawning, fry stage and young fish growth (April-June).
- To maintain a water depth more than 1.5 m in lakes in winter. Such a depth will ensure wintering for fish and forage resources for muskrat.
- To prevent sudden drop in water levels during spawning and fry stages when this will result in drying of shallow water zones and death of young fish.
- To prevent a sharp rise in water levels during the winter period, as this will cause formation of ice mounds, deteriorating winter forage resources for muskrat and, in case of extreme changes, damaging their shelters and causing death of smaller animals.
- To ensure availability of shallow water zones providing conditions necessary for reed growing, which, in turn, provides shelters and food for water fowl and muskrat.
- To maintain the lakes' water areas that form the hydro-biological regime of water bodies, thus ensuring forage resources availability for fish and birds.

Technical-economic requirements

- Minimum cost;
- Maximum efficiency of desalination using such evaluation methods as Cost-Benefit Analysis, NPV, IRR.

In order to integrate and to assess all the factors providing the project effectiveness, and to examine the compliance of work results with the above-mentioned criteria, the Steering Committee has approved the following work procedures and schedule that have been taken as the basis for implementing works and monitoring their progress.

1. ***Assessment of available water resources for the delta system and the South Prearalie***. Taking into account previous modeling the Amu Darya river runoff, it was proposed to estimate water resources coming to the Amu Darya delta outlet for each year out of the 20-year series using a prospective hydrological series for each option and an expected hydrograph of drainage inflow into the Prearalie.

2. ***Identification of negative socio-economic and ecological impacts and mitigation measures included in different project options;*** evaluation of improvements. This includes a comparison of the relief dynamics maps plotted on the basis of field surveys of 2000 conducted by the group of A. Ptichnikov within the framework of the Project SFP No 974101 and by the NGO "ECO Prearalie" with the background map of 1992 developed by the SANIIRI. Data collected by the SIC ICWC were used as well. The GIS group transforms these data into the GIS format, and alternative schemes of the environmental complex are overlaid on these GIS themes.

3. ***Identification of preliminary water bodies and annual water demand***. The "Aralconsult" company carries out the initial assessment such parameters of water objects for each complex as a capacity and a water area of water bodies, dimensions of connecting canals, etc. Then, according to the assignment of the Modelling and Design Group, each of these water bodies is evaluated by the GIS group to plot the curves of $V = F(H)$ and $S = F(H)$ (where: V is capacity of a water body; S is a water area of a water body; and H is a depth of a water body), which are the database for large-scale hydrological models.

4. ***A possibility to meet water demand of different options determined on the basis of large-scale hydrological models***. Taking into account outcomes of previous studies of the Sudoche Lake, the Modelling and Design Group has to improve a low-accurate hydrological model and to calculate a time and

volume of filling planned water bodies with available water resources. These computations would be made for the annual runoff distribution. The results were supposed to be analyzed with respect to two water supply options:

- A secure water supply in years of any water availability level, at the minimum inflow (a probability of 95 percent) into the delta, and long-lived water bodies providing conservation and maintenance of their ecological sustainable development;
- For other years, the strategy of recurring filling and maintaining water bodies with the limited bioproductivity and biodiversity should be elaborated.

Concurrently, development of a modeling mechanism and training of specialists in modeling and application of the MIKE 11 software, which was purchased and used for detailed modeling of selected water body systems are provided.

5. ***Selection of basic infrastructure parameters*** for various options on the basis of modeling.

6. ***Estimation of required capital investments*** at the first phase on the basis of aggregative indicators. At the same time, expected socio-economic and ecological effects are assessed on the basis of the potential productivity of water bodies.

7. The most acceptable project options are selected on the basis of this preliminary assessment and above-mentioned criteria.
To specify ecological indicators the NGO “ECO Prearalie” monitors water quality in rivers and water bodies after the drought period. This allows assessing the current situation in the South Prearalie more exactly. Concurrently, water quality measuring instruments purchased at the expense of the NATO project funds are calibrated. Water samples are analyzed in the SANIIRI’s laboratory.

8. ***The detailed plan of field studies*** was drawn up for the selected project option in order to specify parameters of water infrastructure according to the requirements of the Design and Modeling Group. At the same time, the more detailed model of a water body was developed on the basis of the MIKE-11 software of the IHE (the Netherlands). This model is the basis for optimizing both engineering parameters of water bodies (discharges of canals and outlets, water depths in reservoirs or wetlands) and regimes of their filling and drawdown and for developing water body management methods in order to provide the sustainable natural-anthropogenic complex.

The new model, using the MIKE 11 software, enables the GIS and Design Group to receive the detailed description of operation regimes for the selected option in order to evaluate to what extent such regimes meet environmental requirements mentioned above. At the same time, it is important to receive the detailed hydrological background and GIS materials (at a scale of 1: 50,000), as well as to assess soil conditions. Based on these data and modeling all design parameters of the proposed infrastructure were specified.

9. Using data described in Item 8, the engineering solutions were developed at the stage of technical and economic calculation for the selected complex, as well as the feasibility study was prepared, including calculations of capital investments and effectiveness according to methods such as Cost-Benefit Analysis, NPV, etc. All this allowed developing the management plan for the natural complex.

10. ***Management of the natural complex*** in the South Prearalie involves the following aspects:

- The institutional framework for water and environment management in the Prearalie;
- Regulations for water distribution among water bodies in years of a different water availability;
- Regimes of water releases through the network of water bodies and wetlands under different water availability;
- Identification of water releases into the Aral Sea.

These activities were preceded by training in wetland management and DSS. The developed work schedule is the basic document to monitor a project implementation progress.

V. HYDROLOGICAL BACKGROUND

This chapter presents an evaluation of the predicted water inflow to the Amu Darya and Syr Darya deltas for next 20 years. Calculations have been performed using the *hydrological model* developed by the SIC ICWC for three assumed scenarios of development in the Central Asian countries: optimistic, intermediate, and "maintaining current development trends".

Natural river hydrographs (by analogy with the period of 1975/1976 to 1994/1995), data on the return flow into transboundary rivers due to economic activities, and on water demand in the riparian states were used as source information for the hydrological model. Water demand and the return flow were calculated for three development scenarios using the social-economic model (M. Ruziev, V. Prihodko), which along with the hydrological model is a component of the Aral Sea Basin Management Model (ASB-MM).

Hydrological calculations provide a quantitative assessment of the monthly river inflow to the Priaralie till 2020, as well as water salinity values under three development scenarios in the countries of this region and different options of river flow control using the water reservoirs.

The operation regime of reservoirs is selected based on the following conditions

$$W_{k,t} \qquad k = 1, R, \; t = 1, T \tag{5-1}$$

that meet planning objectives

$$F \rightarrow Extr \tag{5-2}$$

and set of constraints

$$G_{i,t} = 0, \quad i = 1, n \tag{5-3}$$

$$P_{i,t} > 0, \quad j = 1, m \tag{5-4}$$

where:

k, R	= index and number of reservoirs;
i, j, n, m	= indices and number of constraints, respectively;
t, T	= time step and base period;
W	= regulated flow;
F	= target function.

The system (5-3) is presented by the balance equations, the system (5-4) - by constraints for permissible filling and drawdown of a reservoir.

The balance equations are based on the laws of water and salt conservation, and on the process flowsheet of energy transformation at hydropower plants. Salts are presented as conservative admixture. The hydrological network is formalized in the form of the oriented graphs. The hydrological network is subdivided into such elements as designed sites and alignments, reservoirs, lakes, water intakes, spillways and power plants, which are simulated in the algorithm by a grid of arch-nodes. Balance equations are calculated for each node.

The hydrological model describes current processes, trends and constraints for formation, regulation (by reservoirs and hydropower plants) and use of transboundary water resources in the Aral Sea basin.

The model permits to simulate (at simulation and optimization modes) different development scenarios in order to determine conformity of water demands and available water resources, and alternatives of water resources management according to selected criteria and constraints, as well as to calculate water and salt balances for rivers and reservoirs. The modules of the Amu Darya and Syr Darya river basins are the main components of the hydrological model. The hydrological model was developed using the Graphic Access Method System (GAMS) with an information interrelationship with the social-economic model through an interface (developed in Access) and a set of programs-translators.

Within the project frameworks, the hydrological schemes of the Amu Darya and Syr Darya river basins (linear schemes, GAMS graphs) were specified as well as the basic module algorithms, which were modified to avoid duplications, and to establish links with wetland models. The software was adjusted to improve data export and import.

In the hydrological schemes, water resources are aggregated according to the following sources:

The Syr Darya basin: (1) the Naryn River – the total inflow to the Toktogul Reservoir, (2) the Karadarya River – the total inflow to the Andijan Reservoir, (3) the channel inflow to the rivers Naryn and Karadarya, (4) the channel inflow to the Syr Darya River (excepting the Chirchik River), (5) the Chirchik River – the total inflow to the Charvak Reservoir, (6) the Aris River.

The Amu Darya basin: (1) the Vahsh River – the total inflow to the Nurek Reservoir, (2) the channel inflow to the Vahsh River, (3) the Pandj River, (4) the channel inflow to the Amu Darya – the rivers Kaphirnigan, Surhandarya, Sherabad, and Kunduz.

The hydrological model was adjusted to optimize operation of the hydropower schemes by selecting target functions (criteria). Maximum net income in the irrigated agriculture and hydropower sectors has been selected as a criterion for management of reservoirs under the optimistic scenario; for the "maintaining current development trends" scenario - maximum net income in the irrigated agriculture sector (simulation of the irrigation-energy operation regime of two main reservoirs of the region - Toktogul and Nurek, and compensation of hydropower damages).

Table 5-1 Selected Development Scenarios for the Central Asian States for the Period of 20 Years

Scenarios	Brief characteristics
1- Optimistic scenario	This option provides a scenario for achieving 80 percent of potential land productivity, development of the agricultural sector, water savings, with minimum water losses, meeting ecological requirements, maximum investments, and considerable reduction of water diversion from transboundary rivers.
2 - Intermediate scenario (pessimistic)	This option implies less water savings, and land productivity increase, lack of certain necessary investments, and less decreases in water diversion from transboundary rivers.
3 - "Maintaining current development trends"	This option implies retaining the current trends of states' development, stabilization of productivity and water demand provided from transboundary rivers at the present level. Development is based on local water resources potential.

Calculations show that under the first scenario (optimistic) the inflow to the Priaralie will increase in comparison with the third scenario, by 9.6 km^3/year, including the Amu Darya - 6.4 km^3/year, the Syr Darya - 3.2 km^3/year.

Table 5-2 Average Annual Inflow through Rivers under Three Scenarios of Development (km3/year)

Scenarios	Amu Darya	Syr Darya	Total
1. Optimistic	15.2	7.8	23.0
2. Intermediate	11.4	5.5	16.9
3. "Maintaining current development trends"	8.8	4.6	13.4

Table 5-3 The Amu Darya (the Samanbay Gauging Station) - Mean Annual Discharges (Q) and Water Salinity (S)

Year	Scenario 1		Scenario 2		Scenario 3	
	Q, m^3/s	S, g/l	Q, m^3/s	S, g/l	Q, m^3/s	S, g/l
1	235	1.56	212	1.70	196	1.75
2	327	1.50	301	1.60	288	1.62
3	441	1.35	415	1.45	415	1.45
4	323	1.50	314	1.55	314	1.55
5	368	1.40	318	1.50	292	1.60
6	390	1.38	282	1.60	276	1.65
7	238	1.55	209	1.70	187	1.80
8	244	1.53	85	2.10	10	2.20
9	352	1.45	240	1.75	76	2.10
10	400	1.38	336	1.60	288	1.60
11	320	1.50	190	1.70	38	2.10
12	263	1.54	136	1.95	12	2.20
13	650	1.10	491	1.35	298	1.55
14	647	1.10	526	1.25	519	1.25
15	419	1.35	143	1.90	57	2.10
16	596	1.20	412	1.45	276	1.60
17	812	1.00	570	1.30	314	1.55
18	887	0.95	732	1.00	740	1.00
19	869	0.97	659	1.05	526	1.15
20	853	1.00	647	1.10	533	1.10
Mean	480	1.30	360	1.50	280	1.60

Figure 5-1 The Amu Darya River Runoff at the Samanbay Guaging Station for 20 years (km3/month)

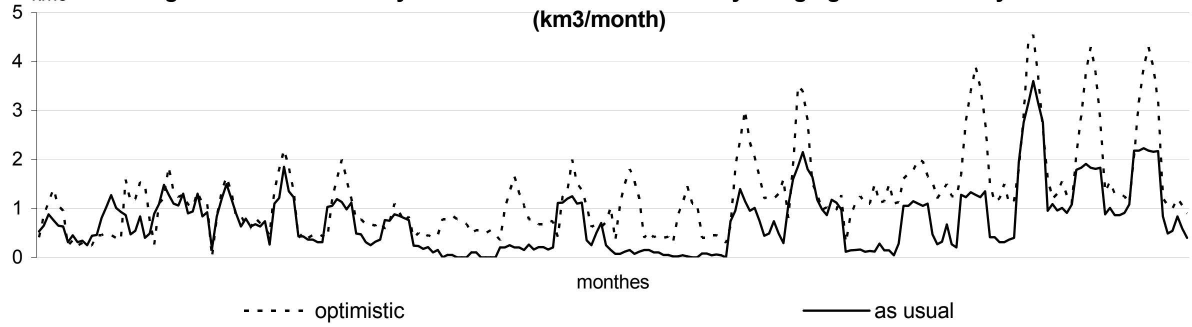


Table 5-4 Annual Water Balance of Transboundary Rivers - the Current Level (km³/year)

№	Indicator	Syr Darya	Amu Darya	Total
	Inflow			
1	Water resources	30.0	68.7	98.7
2	Return flow	7.5	7.0	14.5
	Total	37.5	75.7	113.2
	Outflow			
1	Water diversion	30.5	60.2	90.7
2	Water losses	3.0	7.0	10.0
3	Water Supply to the Priaralie	4.0	8.5	12.5
	Total	37.5	75.7	113.2

Table 5-5 Water Diversion from Transboundary Rivers according to the States (km³/year)

No	State	In the zone of management of the BWOs *)			Total
		Syr Darya	Amu Darya	Sum	
1	Kazakhstan	8.2	-	8.2	11.0
2	Kyrgyzstan	0.22	0.15	0.37	1.45
3	Tajikistan	2.0	8.3	10.3	10.7
4	Turkmenistan	-	22.15	22.15	22.15
5	Uzbekistan	11.15	22.65	33.8	45.5
	Total	21.57	53.25	74.82	90.7

*) BWOs allocate water to the Central Asian states according to the established limits (quotas).

Table 5-6 The Regional Water Resources (km³)

No	Years	Syr Darya Basin		Amu Darya Basin		Total
		Growing season	Dormant season	Growing season	Dormant season	
1	1975/1976	18.1	5.4	53.1	14.3	90.9
2	1976/1977	18.3	5.7	54.0	14.5	92.5
3	1977/1978	19.9	6.4	55.1	15.3	96.7
4	1978/1979	22.5	7.0	60.5	14.9	104.7
5	1979/1980	28.5	6.1	54.5	14.7	103.8
6	1980/1981	21.7	5.9	52.9	14.8	95.3
7	1981/1982	23.9	6.4	51.0	13.1	94.4
8	1982/1983	15.9	6.1	45.1	11.7	78.8
9	1983/1984	21.0	6.2	51.6	12.2	91.0
10	1984/1985	21.9	6.1	54.4	12.2	94.6
11	1985/1986	23.0	6.1	51.9	12.4	93.4
12	1986/1987	17.8	6.7	44.7	12.7	81.9
13	1987/1988	33.1	8.8	57.7	14.4	114.0
14	1988/1989	31.8	7.2	60.2	13.5	112.7
15	1989/1990	18.5	6.9	48.4	11.8	85.6
16	1990/1991	26.0	6.6	55.6	13.2	101.4
17	1991/1992	20.7	6.4	56.1	14.0	97.2
18	1992/1993	24.5	6.9	68.1	14.3	113.8
19	1993/1994	29.4	8.4	61.7	14.1	113.6
20	1994/1995	30.6	7.9	53.1	14.4	116.0
Mean	For all the period					98.7

The Amu Darya River: the predicted flow at the Samanbay gauging station for 20 years. Monthly, seasonal (a growing season, a dormant season), and annual water runoff (km^3).

Table 5-7 Option 1: the Optimistic Scenario

GS = 4th…9th months = since April till September; DS = 10th…3rd months = since October till March
IG = 3rd …4th months = since March till April 4/10 months = April/October, etc.

No	Months	4/10	5/11	6/12	7/1	8/2	9/3	GS/DS	IG
1	**4…9**	0.41	0.86	1.11	1.40	1.06	0.96	5.80	
	10…3	0.24	0.35	0.24	0.29	0.24	0.24	1.60	7.40
2	**4…9**	0.45	0.45	0.50	0.45	0.40	0.35	2.60	
	10…3	1.59	1.14	1.19	1.54	1.49	0.75	7.70	10.3
3	**4…9**	0.26	1.10	1.21	1.85	1.35	1.23	7.00	
	10…3	1.28	1.08	1.03	1.33	1.09	1.09	6.90	13.9
4	**4…9**	0.00	0.84	1.34	1.64	1.34	0.84	6.00	
	10…3	0.85	0.65	0.60	0.80	0.70	0.60	4.20	10.2
5	**4…9**	0.45	1.35	1.80	2.20	1.85	1.35	9.00	
	10…3	0.40	0.50	0.40	0.45	0.40	0.45	2.60	11.6
6	**4…9**	0.40	1.20	1.60	2.00	1.60	1.20	8.00	
	10…3	0.78	0.78	0.68	0.68	0.65	0.73	4.30	12.3
7	**4…9**	0.58	0.73	1.10	0.93	0.73	0.83	4.90	
	10…3	0.40	0.50	0.40	0.45	0.40	0.45	2.60	7.50
8	**4…9**	0.78	0.78	0.85	0.78	0.73	0.68	4.60	
	10…3	0.50	0.55	0.55	0.50	0.55	0.45	3.10	7.70
9	**4…9**	0.35	1.00	1.35	1.65	1.30	1.05	6.70	
	10…3	0.78	0.78	0.68	0.68	0.75	0.73	4.40	11.1
10	**4…9**	0.41	1.25	1.36	2.00	1.50	1.38	7.90	
	10…3	1.05	0.62	0.67	0.62	0.72	1.02	4.70	12.6
11	**4…9**	0.35	1.10	1.50	1.80	1.55	1.20	7.50	
	10…3	0.40	0.52	0.41	0.45	0.40	0.42	2.60	10.1
12	**4…9**	0.30	0.85	1.10	1.45	1.10	1.10	5.90	
	10…3	0.40	0.40	0.45	0.45	0.40	0.30	2.40	8.30
13	**4…9**	0.65	1.85	2.40	3.00	2.35	2.05	12.3	
	10…3	1.65	1.20	1.25	1.20	1.30	1.60	8.20	20.5
14	**4…9**	0.80	1.90	3.50	3.40	2.80	1.50	13.9	
	10…3	1.30	0.97	1.02	0.97	0.97	1.27	6.50	20.4
15	**4…9**	0.30	0.85	1.10	1.25	1.10	1.10	5.70	
	10…3	1.50	1.12	1.15	1.50	1.10	1.13	7.50	13.2
16	**4…9**	1.61	1.71	1.76	2.00	1.96	1.66	10.7	
	10…3	1.55	1.20	1.35	1.50	1.25	1.25	8.10	18.8
17	**4…9**	1.68	2.78	3.38	3.90	3.48	2.78	18.0	
	10…3	1.52	1.13	1.20	1.50	1.10	1.15	7.60	26.6
18	**4…9**	1.81	2.91	4.41	4.55	3.71	2.61	20.0	
	10…3	1.60	1.20	1.30	1.55	1.25	1.10	8.00	28.0
19	**4…9**	2.08	2.88	3.78	4.30	3.78	2.78	19.6	
	10…3	1.34	1.54	1.29	1.29	1.24	1.10	7.80	27.4
20	**4…9**	2.08	3.18	3.88	4.30	3.88	3.18	20.5	
	10…3	1.20	1.05	1.00	1.20	1.05	0.90	6.40	26.9
Av									15.2

The Amu Darya River - the predicted flow at the Samanbay gauging station for 20 years. Monthly, seasonal (a growing season, a dormant season), and annual water runoff (km^3).

Table 5-8 Option 2: the Intermediate (Pessimistic) Scenario

GS = 4th…9th months = since April till September; DS = 10th…3rd months = since October till March

IG = 3rd …4th months = since March till April 4/10 months = April/October, etc.

No	Months	4/10	5/11	6/12	7/1	8/2	9/3	GS/DS	IG
1	**4…9**	0.40	0.60	1.00	0.85	0.60	0.65	4.10	
	10…3	0.40	0.52	0.41	0.45	0.40	0.42	2.60	6.70
2	**4…9**	0.33	0.49	0.83	0.65	0.50	0.50	3.30	
	10…3	1.29	0.90	0.95	1.25	0.93	0.88	6.20	9.50
3	**4…9**	0.60	1.20	1.55	1.75	1.55	1.25	7.90	
	10…3	0.94	0.90	0.85	0.80	0.85	0.86	5.20	13.1
4	**4…9**	0.00	0.93	1.40	1.78	1.40	0.99	6.50	
	10…3	0.61	0.70	0.54	0.50	0.55	0.50	3.40	9.90
5	**4…9**	0.42	1.26	1.68	2.10	1.60	1.34	8.40	
	10…3	0.24	0.35	0.24	0.29	0.24	0.24	1.60	10.0
6	**4…9**	0.43	1.08	1.43	1.73	1.43	1.20	7.30	
	10…3	0.24	0.35	0.24	0.29	0.24	0.24	1.60	8.90
7	**4…9**	0.48	0.48	0.53	0.55	0.48	0.48	3.00	
	10…3	0.65	0.65	0.55	0.55	0.62	0.58	3.60	6.60
8	**4…9**	0.25	0.30	0.30	0.25	0.25	0.25	1.60	
	10…3	0.22	0.22	0.17	0.17	0.17	0.15	1.10	2.70
9	**4…9**	0.53	0.53	0.58	0.60	0.53	0.53	3.30	
	10…3	0.74	0.84	0.65	0.65	0.57	0.85	4.30	7.60
10	**4…9**	0.33	0.49	0.81	0.69	0.51	0.47	3.30	
	10…3	1.46	1.10	1.15	1.45	1.12	1.02	7.30	10.6
11	**4…9**	0.30	0.30	0.40	0.35	0.30	0.35	2.00	
	10…3	0.80	0.60	0.55	0.80	0.65	0.60	4.00	6.00
12	**4…9**	0.25	0.30	0.30	0.25	0.25	0.25	1.60	
	10…3	0.43	0.50	0.50	0.45	0.42	0.40	2.70	4.30
13	**4…9**	0.34	1.00	1.34	1.65	1.34	1.03	6.70	
	10…3	1.75	1.30	1.35	1.75	1.40	1.25	8.80	15.5
14	**4…9**	0.45	1.30	1.70	2.15	1.65	1.35	8.60	
	10…3	1.60	1.20	1.30	1.55	1.25	1.10	8.00	16.6
15	**4…9**	0.25	0.30	0.30	0.25	0.25	0.25	1.60	
	10…3	0.40	0.50	0.55	0.50	0.40	0.55	2.90	4.50
16	**4…9**	0.71	1.41	1.81	2.20	1.86	1.41	9.40	
	10…3	0.80	0.47	0.62	0.77	0.52	0.42	3.60	13.0
17	**4…9**	1.66	1.76	2.00	1.76	1.71	1.61	10.5	
	10…3	1.45	1.20	1.15	1.45	1.20	1.05	7.50	18.0
18	**4…9**	1.91	2.61	3.05	3.41	3.11	2.61	16.7	
	10…3	1.20	1.05	1.00	1.20	1.05	0.90	6.40	23.1
19	**4…9**	2.48	2.48	2.55	2.48	2.43	2.38	14.8	
	10…3	1.22	0.87	0.97	1.22	1.02	0.70	6.00	20.8
20	**4…9**	2.11	2.31	2.55	2.46	2.31	2.26	14.0	
	10…3	1.27	1.02	0.95	1.27	1.02	0.87	6.40	20.4
Av									11.4

The Amu Darya River - the predicted flow at the Samanbay gauging station for 20 years. Monthly, seasonal (a growing season, a dormant season), and annual water runoff (km^3).

Table 5-9 Option 3: the "Maintaining Current Development Trends" Scenario

GS = 4th…9th months = since April till September; DS = 10th…3rd months = since October till March
IG = 3rd …4th months = since March till April 4/10 months = April/October, etc.

No	Months	4/10	5/11	6/12	7/1	8/2	9/3	GS/DS	IG
1	**4…9**	0.53	0.65	0.88	0.76	0.65	0.63	4.10	
	10…3	0.31	0.45	0.31	0.34	0.25	0.44	2.10	6.10
2	**4…9**	0.46	0.80	1.03	1.27	1.01	0.93	5.50	
	10…3	0.86	0.47	0.54	0.84	0.40	0.49	3.60	9.10
3	**4…9**	0.89	1.09	1.48	1.28	1.10	1.06	6.90	
	10…3	1.30	0.90	0.94	1.30	0.84	0.92	6.20	13.1
4	**4…9**	0.17	0.84	1.20	1.50	1.20	0.89	5.80	
	10…3	0.63	0.79	0.63	0.68	0.63	0.74	4.10	9.90
5	**4…9**	0.26	1.10	1.21	1.85	1.35	1.23	7.00	
	10…3	0.43	0.43	0.36	0.36	0.31	0.31	2.20	9.20
6	**4…9**	1.03	1.05	1.19	1.13	0.98	1.12	6.50	
	10…3	0.49	0.47	0.31	0.25	0.32	0.36	2.20	8.70
7	**4…9**	0.76	0.75	0.88	0.85	0.80	0.76	4.80	
	10…3	0.24	0.23	0.17	0.21	0.10	0.15	1.10	5.90
8	**4…9**	0.00	0.05	0.05	0.00	0.00	0.00	0.10	
	10…3	0.10	0.10	0.00	0.00	0.00	0.00	0.20	0.30
9	**4…9**	0.20	0.20	0.25	0.20	0.20	0.15	1.20	
	10…3	0.26	0.16	0.21	0.21	0.16	0.20	1.20	2.40
10	**4…9**	1.11	1.12	1.20	1.25	1.10	1.12	6.90	
	10…3	0.35	0.25	0.50	0.70	0.25	0.15	2.20	9.10
11	**4…9**	0.07	0.07	0.12	0.15	0.07	0.12	0.60	
	10…3	0.15	0.15	0.10	0.10	0.05	0.05	0.60	1.20
12	**4…9**	0.02	0.02	0.04	0.02	0.00	0.00	0.10	
	10…3	0.08	0.08	0.04	0.06	0.04	0.00	0.30	0.40
13	**4…9**	0.74	0.95	1.40	1.15	0.95	1.01	6.20	
	10…3	0.75	0.44	0.49	0.74	0.49	0.29	3.20	9.40
14	**4…9**	1.06	1.60	1.85	2.15	1.80	1.64	10.1	
	10…3	1.18	0.98	0.86	1.18	1.12	0.98	6.30	16.4
15	**4…9**	0.11	0.14	0.15	0.16	0.11	0.13	0.80	
	10…3	0.12	0.28	0.14	0.14	0.04	0.28	1.00	1.80
16	**4…9**	1.05	1.05	1.15	1.10	1.05	1.10	6.50	
	10…3	0.47	0.27	0.32	0.67	0.27	0.20	2.20	8.70
17	**4…9**	1.28	1.23	1.33	1.28	1.23	1.35	7.70	
	10…3	0.41	0.41	0.31	0.31	0.36	0.40	2.20	9.90
18	**4…9**	1.96	2.76	3.16	3.60	3.16	2.76	17.4	
	10…3	0.95	1.09	0.96	1.01	0.91	1.08	6.00	23.4
19	**4…9**	1.79	1.83	1.91	1.83	1.81	1.83	11.0	
	10…3	0.88	1.01	0.86	0.86	0.91	1.08	5.60	16.6
20	**4…9**	2.18	2.18	2.23	2.18	2.16	2.17	13.1	
	10…3	0.84	0.49	0.54	0.84	0.59	0.40	3.70	16.8
Av									8.80

Drainage water within the Amu Darya delta (downstream the Takhiatash Barrage) is mainly disposed through drainage canals on the right riverbank: KC-1, KC-3, KC-4; and on the left riverbank – the KKC flowing into the Sudoche lake system. Current annual runoff through main drains is estimated as 0.5…1.3 km^3. Data on drainage runoff changes for the period of 1981-2000 is shown in Table 5-10.

Table 5-10 Mean Annual Runoffs through Main Drains in the Amu Darya Delta (mln. m^3)

Years	KKC	KC-1	KC-3	KC-4	Sum
1981-1985	592	361	218	174	1,345
1986-1990	509	334	132	170	1,145
1991-1995	647	378	220	211	1,456
1996-2000	408	336	153	98	995
Average	539	353	181	163	1,236

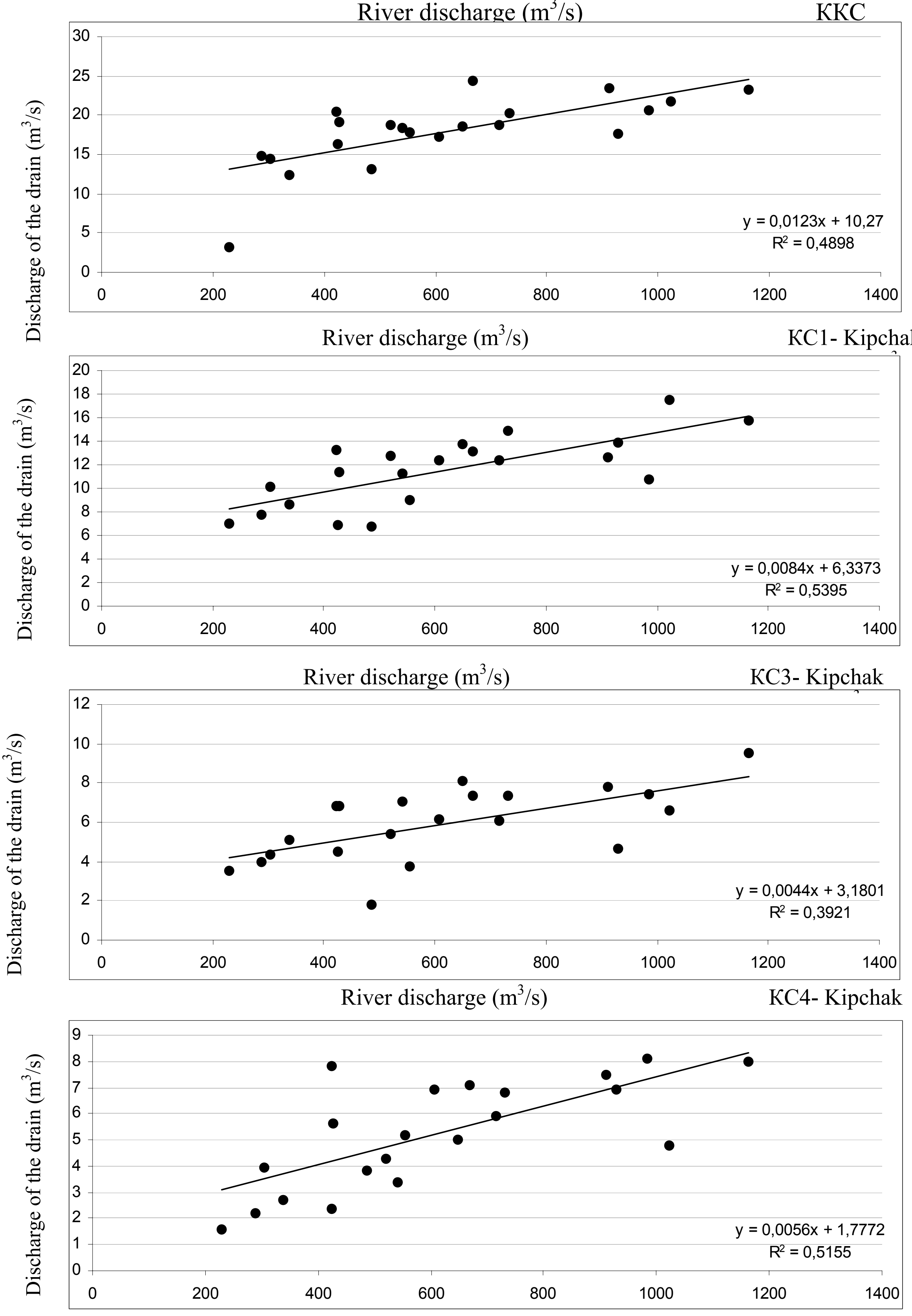
In 2000-2001, drainage outflow reduced to 0.4-0.3 km^3/year due to low river water availability and decline in rice production in Karakalpakstan. Nevertheless, after the 2-year drought, water releases downstream the Takhiatash Barrage were rehabilitated and discharges through the main drains have increased. Only since October 2002 till March 2003 drainage runoff amounted to about 387 million m^3. Maximum discharges were measured in June-August (exceeding the mean annual discharge 2 to 4 times), minimum discharges were found in February-March.

For forecasting drainage runoff in the Amu Darya delta, correlation between annual runoff of main drains KC-1, KC-3, KC-4, and KKC and river runoff has been specified. The closest correlation for the period of 1980-2000 was received for river flows monitored at the Kipchak gauging station (Figure 5-2).

The designed annual drainage runoff distribution for an average year (in percent): in October - 6, in November-January - 16, in February-March - 4, in April-May - 7, in June-August – 52, in September - 15.

A more accurate forecast of drainage runoff requires the integrated modeling of groundwater flows in interaction with seepage losses from irrigation canals and on irrigated fields, which is determined by a crop pattern, an irrigated area and irrigation requirements, a river water level (the river can be a source of groundwater recharge or a drain). Main natural drainage for groundwater in the delta downstream the Takhiatash Barrage is the Sudoche Lake on the left riverbank and the Karateren Lake on the right riverbank.

Figure 5-2 Average annual discharges through main drains KKC, KC-1, KC-3, KC-4 versus the Amu Darya discharges at Kipchak (data of 1980-2000)



VI. THEORETICAL FOUNDATIONS OF MODELING

The analysis of various options for water-supplying the Amu Darya river delta based on water bodies with the controlled regime and Sudoche lake's operation options developed by the project has identified a number of requirements for both the mathematical models that are used for a formal description of water-economic trends in the Aral Sea region and for input information for the numerical simulating. The basic requirement for mathematical models is, first of all, determined by natural-climatic changes in this region, where sustainable recurring periods are impossible to identify, and hence regressive models cannot be used in this case. Thus, the class of evolutionary models is employed that is guided by some conservation laws; in our case the law of conservation of mass for fluid is determinative. The next requirement - the need for optimization - derives from extensive options for water-supplying the Amu Darya river delta, each of which includes a complex water infrastructure and quite different schemes of water allocation between western and eastern parts of the Aral Sea. The solution of this management task is based on the mathematical model supported by the GAMS environment, which considers separately the existing and planned water bodies. Therefore, the computer language of the GAMS is also used for modeling the optimization problem in this project due to both quite high reliability of solutions found on its basis and availability of experts managing this programming language.

A set of three mathematical models including hydrological, hydro-dynamic, and environmental models that represent various aspects of the Aral Sea's behavior and development, has been adopted as a working hypothesis for modeling trends of Aral Sea development. Each model is used for the certain goal, and solves a specific range of problems in order to justify every rehabilitation options, as well as to develop recommendations on water management under operating of water bodies in the Amu Darya river delta. Though different spatial and temporal scales are employed in different models to describe processes, the models have the common topographic base by means of which all modeling data (data of two simulation models and one optimization model that are located at two hierarchical levels) is coordinated.

The goal of hydrological modeling is to determine permissible water elevations for the lake system and of the sea using data on current and projected water inflows, to forecast annual fluctuations of the water levels on the basis of flow probability of the Amu Darya and Syr Darya rivers and accepted water management policy.

Mathematical model selected for hydrological modeling is based on the system of ordinary differential equations describing structural relations within the system of water bodies and all components of the water balance taking into account water salinity.

Input data for the hydrological model consists of a lay-out of water bodies with indicated supplying and tail-race canals and drains, correlation curves for relationships of an open water surface area and water volumes versus water levels for each water body, time series of water inflows, reed and cattail coverage of water bodies, and temperature and rainfall plots.

Modeling outputs are the sets of water level curves in monthly and annual scales, amounts of evaporation and filtration, and an average salinity for each water body depending on inflow changes, and an adopted water allocation policy.

The goal of hydro-dynamic modeling is to determine the intensity of water mass mixing within each water body, the basic parameters of stream inflows and spatial and temporal salinity distribution taking into account hydraulic impediments due to overgrowing of various parts of the water surface area with reed and cattail.

Mathematical models selected for hydro-dynamic modeling are based on the system of partial differential equations, which follow the laws of conservation of mass and momentum for two-phase liquid under the assumption that the volume of solid phase (in this case, salt content) is quite small and forms only ecology of the medium, while momentum conservation equations are written as for homogenous liquid with variable density. Boundary conditions of these models are set on the basis of the solution of the first level problem and the physical and climatic characteristics of the year under consideration.

Input data of the hydro-dynamic model include: a topographic map; a layout of supplying and discharge canals and drains; time series of water inflow with data on salinity and temperature; reed and cattail coverage of water bodies; temperature and evaporation curves.

Modeling outputs are represented in form of datasheets comprising parameters of streams within water bodies, free-standing water surface elevations and salinity depending on the status of water bodies and water inflow.

The goal of environmental modeling is to determine acceptable depths, salinity, and active oxygen content within selected surface water areas of the Aral Sea based on environmental requirements for projected options of biological and water resources restoration. Bio-productivity growth will be estimated within selected parts of the Aral Sea using this data.

Mathematical model selected for the environmental simulation is based on the system of ordinary differential and algebraic equations describing the processes of bio-resource growth and loss depending on a water depth and salinity, dynamics of frost penetration, and the presence of active oxygen content in summer and winter periods.

Input data of the environmental model consists of: the parameters of water flows and their salinity derived from the hydraulic model simulation; time series of temperature and active oxygen content derived from the hydro-dynamic simulation; and, coefficients of biomass growth as a function of a depth, temperature, salinity, and active oxygen content derived from environmental studies.

Modeling outputs are given in the form of sets of maps representing modifications in volumes of vegetation mass and in bio-productivity for various periods of time (its own set of maps for each period), with indication of the most risky periods of time during the Aral Sea evolution.

Studies of evolution of any object by means of mathematical methods require that time series be selected and used to calibrate and to evaluate the adequacy of selected mathematical models and testing and forecast periods. Within the project, those periods are rationally distributed as follows:

- till the 1960s — the period of stationary state of the sea (in the long-term scale),
- 1961 to 2002 — the reference period of unsteady state of the sea,
- 2003 to . . . — the forecasting period,
- 2003 to 2004 — the testing period.

The first period is characterized by mean annual values of parameters (month by month) with reference to the project site coordinates.

The second period is represented by annual values in monthly profile with reference to coordinates of the objects selected at the project site. The first two periods form the basis for obtaining numerical values of phenomenological parameters for all groups of mathematical models.

The forecasting period is unlimited since at present one can quite definitely estimate a period of the Aral Sea stabilization according to the water factor, i.e. water surface elevations and a volume of the water body under different water inflows; however, time of stabilization of hydro-chemical and biological processes cannot be determined at the this stage.

The testing period within the framework of this project allows evaluating an accuracy of forecasts in the first approximation and, if necessary, specifying recommendations based on forecast results or rejecting such recommendations.

Thus, all groups of mathematical models should be tested for three modes:

- calibration of phenomenological parameters,
- short-term forecast,
- long-term forecast.

Formal Description of a Single Water Body

The formal description of processes determining water body evolution is based on a set of three ordinary differential equations, which reflect inflow and outflow of water resources, variation of salinity levels and overgrowing of water areas with reed. Selection of such a set of ecosystem components is conditioned by the importance of the analysis of assigned components, and by the possibility of carrying out an indirect assessment of other ecological parameters using these above-mentioned components. The most important component for a water balance is evaporation from free-standing water surface, which during the summer period in the Aral Sea region amounts to about 200 mm/month. Significantly more losses take place from water surfaces that are occupied by vegetation. Evapotranspiration from reed and cattail increases the evaporation by a factor of 1.6 to 1.7 and results in losses of approximately 340 mm/month with an average annual value of 1600 mm/year. Therefore, among the basic parameters that constitute water and environmental balances of lakes are those areas occupied by reeds and parameters such as water salinity. For definition of the mathematical model we consider an elementary volume, the geometry of which is described by two functions $F(z)$ and $L(z)$, where z is the water surface elevation, $F(z)$ is the free-standing water surface at the same z-elevation, and $L(z)$ is the contour encompassing the free-standing water surface $F(z)$ at the same z-elevation. Both functions are dependent on the topography of a particular locality where the water area is located. Hereinafter, under the term “elementary volume” we will understand this as a volume within which water can be considered to have a unified elevation $z(t)$, mean salinity $s(t)$ and a reed mass $m(t)$. The interaction of the elementary volume with an external environment (e.g. open air) takes place through the free-standing water surface F, in the form of evaporation and rainfall, through the bottom in the form of seepage, and through the contour L via conjunction with different canals, drains or other elementary volumes. Mass conservation equations for water and salts as applied to the elementary volume can be re-written as:

$$\frac{dW}{dt} = \int_L Q(l,z,t)dl + q^0(t) - q_f(t) - q^e(t); \quad (6\text{-}1)$$

$$\frac{dS}{dt} = \int_L (s(l,t) \times Q(l,z,t))dl - q_f^s(t); \quad (6\text{-}2)$$

$$W(z) = \int_0^z F(h)dh; \quad (6\text{-}3)$$

where:

$Q(l,z,t),\ \forall l \in L$ is water discharge determined by conditions of conjunction at the contour L,
$q^0(t)$ is precipitation,
$q_f(t)$ is filtration outflow;
$q^e(t)$ is evaporation from the free-standing water surface;
$q^s_f(t)$ is salt outflow at the boundary “water – bottom”.

The evaporation flux from the free-standing water surface $q^e(t)$ depends on the percentage of reed coverage; if we express through $e^{tr}(t)$ – reed evapotranspiration intensity, and through $e^0(t)$ - intensity of evaporation from the open water surface, we will receive the expression for $q^e(t)$:

$$q^e(t)= e^0(t)\times F^0 + e^{tr}(t)\times F^{tr} \qquad (6\text{-}4)$$

where

F^0 , F^{tr} are the open water area and the area occupied by reed, respectively; and,
$F^{tr}+F^0 = F$ is the free-standing water surface area.

The process of reed growth within the surface water area is predominantly conditioned by two parameters: water salinity – s and a water body depth - h. It has been experimentally proven that reed grows only at depths of less than one meter in the Sudoche Lake. On sites, where water levels increase more than one meter, reed growth gradually declines.

Assuming that such conditions of reed growth are contained within the Prearalie's water area, we consider the dynamics of these areas under reed growth. Assuming $F^{tr}(z)$ to be a part of the water area covered by reed growth, and $F^1(z)$ to be a section of water area with a depth of less than one meter, then:

$$F^1(z)= \{ F(z)- F(z-1) \text{ when } h>1;\ F(z) \text{ when } h\le 1\} \qquad (6\text{-}5)$$

Assuming that both expansion and reduction of reed growth are linearly dependent, gives the equation for $F^{tr}(z)$

$$\frac{dF^{tr}}{dt} = \lambda(T)\times(F^1 - F^{tr}) \qquad (6\text{-}6)$$

where: $\lambda(T)=\lambda^1(T)$, at $F^1 - F^{tr} >0$ and $\lambda(T)=\lambda^2(T)$, at $F^1 - F^{tr} \le 0$ are rates of expansion and reduction, respectively.

The functions $q^0(t)$, $q_f(t)$ are determined from the hydrological data, and in addition, values $W(0)$, $S(0)$, and $F^{tr}(0)$ are known. Therefore, in order to complete the set of equations (6-1) - (6-6) it is necessary to determine discharges along the contour of an elementary volume. The contour of an elementary volume should coincide either with typical areas of the relief, for which it is possible to use relationships as "Chezy Equation" or with hydraulic works, where discharges are determined using hydraulic formulas by means of known structures and flow parameters; the number of these formulas (equations) are equal to the number of conjunctions of elementary volumes.

Any water area may be practically arranged by a set of elementary volumes. For this purpose, the contours of prospective water areas, which cover the whole possible water area, are delineated on a topographic map. Then, using this topographic map for each elementary volume the functions $F(z)$ – an area of the free-standing water surface at the elevation z and $L(z)$ – a contour encompassing the area $F(z)$ at the same elevation (z) are calculated. This results in a set of bathymetric curves for all selected contours. By superposing those curves with the least bed elevation along the contour, an integral bathymetric curve is plotted for the whole water area, and will be used at the first stage of the study. The indicators of water area functioning consist of integral characteristics that represent an average weighted status of elements for various periods of time. These indicators are ranked according to their significance by the following way:

- a volume of a water area $W(t)$ and relative annual and long-term variations of the volume $\delta W(t)/W(t)$, measurable parameters: water-surface area - $F(t)$, $\forall t \in\{t\}$.
- water salinity within the water area – $s(t)$ and relative temporal and spatial variations of salinity $\delta s(t)/s(t)$ and $\delta s(X)/s(X)$, measurable parameters: salinity in different points of the water area for various time points: $s(X,t)$, $\forall s(X,t)$, $\forall t \in\{t\}; X \in\{F\}$.

- an area occupied by reeds – $F^{tr}(t)$, measurable parameters: a water-surface area under reed growth.

Equations (6-1), (6-2), and (6-6) correspond with these indicators. Numerical approximation of the mathematical model (6-1) – (6-6) is made on the basis of discrete temporal mesh using the finite-difference method. For this purpose, a time interval $\{t^0:t^K\}$ should be divided into equal intervals Δt in such a way that t can take on values from the set of $\{t^0, t^0+\Delta t, t^0+2\Delta t, \ldots, t^0+K\Delta t=t^K\}$. Besides, a partial-linear approximation of contour L should be made, as a result of which we obtain J conjunctions. For each conjunction a discharge direction Q is assigned and they are grouped on the basis of equal signs that gives J^+ and J^-, ($J= J^+ + J^-$), (if during the computation the sign of Q is negative, this implies an opposite flow direction). The values of elementary volume parameters should be attributed to points of time $t\in\{t^0, t^0+\Delta t, t^0+2\Delta t, \ldots, t^0+K\Delta t\}$, while parameter values in conjunctions will be attributed to points of time $t\in\{t^0+0.5\times\Delta t, t^0+1.5\times\Delta t, t^0+2.5\times\Delta t, \ldots, t^0+(K-0.5)\times\Delta t\}$. Then, instead of (6-1) and (6-3) we have:

$$W^{t+\Delta t} = W^t + \Delta t \times (\sum_{j\in J^+} Q_j^{t+\Delta t/2} - \sum_{j\in J^-} Q_j^{t+\Delta t/2} + q^{0,t} - q_f^t + q^{e,t}) \quad (6\text{-}7)$$

$$S^{t+\Delta t} = S^t + \Delta t \times (\sum_{j\in J^+} (s\times Q)_j^{t+\Delta t/2} - \sum_{j\in J^-} (s\times Q)_j^{t+\Delta t/2} + q_f^{s,t}) \quad (6\text{-}8)$$

$$F^{tr,t+1} = F^{tr,t} + \Delta t \times \lambda^t \times (F_{h<1}^t - F^{tr,t}) \quad (6\text{-}9)$$

$$F^{t+\Delta t} = F(W^{t+\Delta t});\ Q^{t+\Delta t/2} = Q(W^{tt}, W^{t+\Delta t}) \quad (6\text{-}10)$$

Other equations retain the same sense but are calculated in discrete points of time with averaging of Δt interval.

Formal Description of the System of Water Bodies

The system of water bodies is formalized in the form of the oriented graph **G**(J,I), where J = {0, 1, ..., j} is a set of nodes corresponding to volume objects, while I = {0, 1, ..., i} is a set of arcs reflecting links as to water distribution within the system. Each element $i\in I$ is characterized by such a pair (j, k) that ($\forall$(j, k), $j\in J$, $k\in J$, $k\neq j$), where j is the starting node and k is the end node of arc i. Thus, each node **G**(J,I) is associated with some object having a water volume, while each arc is associated with a structure generating water flow between nodes. Equations that describe functioning of individual water bodies are based on a system of ordinary differential equations reflecting inflow, outflow, and evaporation of water resources, salinity changes, and water areas overgrown by reed. The equations are associated with objects from the set of nodes J = {0, 1, ..., j}. The given section describes formalization of objects relating to the set of I = {0, 1, ..., i} - arcs, which determine conjunctions between reservoirs themselves and the outer boundary of the Aral Sea territory. The equations of water and salt conservation on the graph **G** (J, I) have the following form:

$$\frac{dW_j}{dt} = \sum_{(k,j)\in I_j^+} Q_{k,j} - \sum_{(j,k)\in I_j^-} Q_{j,k} + q_j \quad (6\text{-}11)$$

$$\frac{dS_j}{dt} = \sum_{(k,j)\in I_j^+} (s\times Q)_{k,j} - s_j \times \sum_{(j,k)\in I_j^-} Q_{j,k} + q_j^s \quad (6\text{-}12)$$

$$Q_{j,k} = Q_{j,k}(a_{j,k}, W_j, W_k, U_{j,k}),\ \forall (j,k) \in \{I^U\} \subset \{I\} \quad (6\text{-}13)$$

$$Q_{j,k} = Q_{j,k}(t),\ \forall (j,k) \in \{\partial G\} \quad (6\text{-}14)$$

where: W_j is water volume at the node j (m^3);
I_j^+, I_j^- are sets of arcs entering node j and existing node j, respectively;
q_j is cumulative local inflow (outflow) to/from the node in the form of precipitation, evaporation, etc. (m^3/s);
q_j^s is cumulative inflow (outflow) to/from the node of salts (kg/s);
S_j is mass of salts (kg);
$s_{j,k}$ is salinity (kg/m^3);
$Q_{j,k}$ is discharge between j and k (m^3/s);
$a_{j,k}$ is the function that characterizes the particular hydraulic structure located on arch (j,k);
$U_{j,k}(t)$ is control of arc (j,k),
$\{I^U\}$ is the subset of controlled arcs ($\{I^U\} \subset \{I\}$); and,
$\{\partial G\}$ is the outer boundary of the system.

Considering ***W*** and ***S*** as vectors with lengths of "J", we have the Cauchy problem for nonlinear equations (11) – (14), solution of which may be found only through numerical integration. Therefore, we proceed to discrete space in time. For this purpose time interval $\{t^0:t^K\}$ should be divided into equal intervals Δt in such a way that t can take values from the set $\{t^0, t^0+\Delta t, t^0+2\Delta t, \ldots, t^0+K\Delta t=t^K\}$. The system parameters in nodes are attributed to the points in time $t\in\{t^0, t^0+\Delta t, t^0+2\Delta t, \ldots, t^0+K\Delta t\}$, while parameters in arcs are attributed to the points in time $t\in\{t^0+0.5\times\Delta t, t^0+1.5\times\Delta t, t^0+2.5\times\Delta t, \ldots, t^0+(K-0.5)\times\Delta t\}$. Then:

$$W_j^{t+1} = W_j^t + \sum_{(k,j)\in I_j^+} W_{k,j}^{t+1/2} - \sum_{(j,k)\in I_j^-} W_{j,k}^{t+1/2} + w_j^{t+1/2} \quad (6\text{-}15)$$

$$S_j^{t+1} = S_j^t + \sum_{(k,j)\in I_j^+} (s\times W)_{k,j}^{t+1/2} - \sum_{(j,k)\in I_j^-} (s\times W)_{j,k}^{t+1/2} + w_j^{s,t+1/2} \quad (6\text{-}16)$$

$$W_{j,k}^{t+1/2} = \Delta t \times Q_{j,k}(a_{j,k}, W_j^{t+1/2}, W_k^{t+1/2}, U_{j,k}^{t+1/2}),\ \forall (j,k) \in \{I^U\} \subset \{I\} \quad (6\text{-}17)$$

where: $w_j = q_j \times \Delta t;$

Thus, the system of $2\times|\{J\}|$ differential equations on discrete spatial-temporal mesh is reduced to the system of $2\times(K+1)\times|\{J\}|$ nonlinear algebraic equations in variables in nodes connected through $2\times K\times|\{I\}|$ variables at arcs, of which $K\times|\{I\}|$ variables are controllers. Here $|\{.\}|$ is a number of elements in the specified set. The formula (17) for discharge at arc is translated; and the equation for $Q_{j,k}$ may be written as:

$$Q_{j,k}(a_{j,k}, W_j, U_{j,k}) = Q_{j,k}(f(a_{j,k}, U_{j,k}), W_j), \quad (6\text{-}18)$$

We replace $U_{j,k}$ by $\boldsymbol{U}_{j,k}$ (allowable control space) in the function $f(a_{j,k}, U_{j,k})$ and multiply it by Δt; the function $\boldsymbol{W}_{j,k} = \Delta t\times f(a_{j,k}, \boldsymbol{U}_{j,k})$ forms new allowable control space, but now according to variable $W_{j,k}$; thus instead of (17) we have:

$$W_{j,k}^{t+1/2} = W_{j,k}(W_j^t, W_j^{t+1}) \in \boldsymbol{W}_{j,k},\ \forall [\,(j,k) \in \{I^U\},\ t\in\{t^0:t^K\}] \quad (6\text{-}19)$$

To complete the process of describing the problem, it is necessary to determine formulas for computing discharge at arcs. By analyzing Prearalie's infrastructure, we may select three types of conjunction between water bodies. Every type of conjunction is described by its own equation of hydraulics, depending on characteristics of flow processes.

- Flow rate in an open channel, canal (Chezy Equation);
- Discharge over a broad-crested weir, (formula for weir);
- Discharge of a gated intake (formula to calculate discharge of a gated intake).

The first two types are uncontrollable and discharge is determined using channel parameters and a free surface slope as the function of free surface elevations of conjugated water areas, while the latter type is controllable, which besides design parameters and elevations includes the control parameter that specifies a value of the gate opening. The given mathematical model belongs to models of the so-called "compartment" type. These models strictly follow the law of conservation of mass and use semi-empirical equations of hydraulics for waterworks instead of laws of conservation of momentum and energy. Models of this type were studied in detail; therefore, here it is only necessary to note that calculation of salt precipitation and their consequent leaching that change both salinity and capacitance characteristics, is the most complicated task of modeling water bodies having high salinity levels. These problems have been settled by means of preliminary subdivision of the precipitation process (leaching) and salinity dynamics with the following combination of solutions at coincident time moments (it is clear the temporal meshes for both processes should be coordinated).

Identification of the Hydrological Model

At the first stage of numerical simulations using the hydrological model it is necessary to solve the following tasks:

- To calibrate the model using mean annual data;
- To define more exactly quantitative characteristics of the delta's water balance;

The first half of the twenty-year hydrologic record and the actual levels of the Aral Sea over the period of 1980 to 1989 were selected for calibrating the model. The delta parameters were determined by means of combining the bathymetric curves for the existing system of water bodies. The water surface occupied by reed was simulated using the above mentioned equation (6-6), where $\lambda(T)$ was calculated using monthly temperatures according to mean annual data. At the beginning of simulating, the area occupied by reeds was designed to be equal to the area of water bodies with a depth less than 1 m. The initial water level in the delta was set only for 1980, for subsequent years it was determined on the basis of calculations of a previous year. At this stage of simulating the filtration outflow (inflow) was taken as equal zero because its volumes were within the possible errors of source information.

Water Resources

Water resources supplied to the delta were comprised of:

- River run-off at the Samanbay gauging station
- Total drainage water volumes from drains

Precipitation and Evaporation

Precipitation was determined on the basis of mean annual data.
Evaporation was computed on the basis of its constituents:

- evaporation from the open water surface of a lake, **e (t)**
- evaporation from water surface overgrown by reed, 0.3* **e (t)**
- evapotranspiration of reed, 1.3* **e (t)**

The function e (t) is given as a monthly mean value computed on the basis of mean annual data according to the reports.

Salinity

Water salinity within the delta was averaged for the monthly volumes of water inflow. The initial salinity was specified only for 1980, as a permissible value of 5 g/l, while for subsequent years it was determined on the basis of calculations of a previous year.

Outflow

Outflow from the delta = runoff to the Aral Sea was considered as a control parameter, which regulated the level regime suitable for the existing system of the delta lakes or as an imbalance value at the stage of calibrating the model.

The Aral Sea

The last component is considered as one water body that merges all excessive water flowing out from the delta lake system of the Amu Darya River and has an average-weighted elevation of free-standing water surface being the main indicator for calibrating the model's coefficients.

Calibrating the Model

The issue of evaluating the validity of models used in numerical simulation of physical and engineering processes was addressed by many publications, in which as a general assertion it is emphasized that besides basic equations any mathematical model has a number of phenomenological parameters that are not determined within the framework of the model itself. Getting numerical values of these parameters (or formulas for their calculation) is usually known as model identification, while accompanying problems are referred to as inverse problems. It should be noted that it is more difficult to solve the arising inverse problem than the original one. The accuracy of investigation of regulated water bodies' behaviour, conducted on the basis of the above formulated model, largely depends on the accuracy of representation of bathymetric curves for an individual water body and on the ratio of the open water area and the water areas overgrown by reed. Since major water losses in shallow water bodies occur in an area with reed growth, at the first stage of given model identification it is necessary to adjust a ratio between intensity of reed growth in shallow water and its loss. Moreover, reed can be lost due to two reasons: as a result of increase of a water body's depth (h^{TR} is the critical depth for reed growth) or drying up of a water body because of water shortage. Field investigations have shown that $h^{TR} \approx 1$ m, at the same time, reed expansion and loss dynamics is the lower-order process in comparing with free water surface dynamics due to evaporation and inflow to water bodies. The differential equation of reed growth and loss has three phenomenological parameters, two of which (growth and loss rates) mainly depend on plant biology and soil fertility, while the third one (h^{TR}) is determined by plant biology and the water factor and is taken as a variation parameter in the course of model calibration. Moreover, variation by this parameter also compensates unavoidable errors of bathymetric curves. To calibrate the model apart from data on water inflow to the Prearalie, water outflow data is needed, which is not available due to spreading the flow through many branches where gauging stations are not installed. One of the ways to solve the problem is to make use of additional information, which is beyond the boundaries of the investigated system. In our case such information is related to the Aral Sea. The Aral Sea is an inland water body and its free-standing water surface dynamics can be presented by the ordinary differential equation:

$$\frac{dZ}{dt} = h^{oc}(t) - h^{E}(t) + \frac{W^{R}(t) + W^{G}(t,Z)}{F(Z)}; \qquad (6\text{-}20)$$

where:

Z	is sea water surface elevation,
$h^{oc}(t)$	is a precipitation depth;
$h^{E}(t)$	is an evaporation depth;
$W^{R}(t)$	is total inflow of river water;
$W^{G}(t)$	is total inflow of groundwater (seepage at $W^{G}(t,Z)<0$);
$F(Z)$	is the sea's water-surface area;

The analysis of the Aral Sea's water balance over various periods of time and made on the basis of actual parameters given in [3] has shown that the component $W^G(t,Z)$ has a negligible value and lies in the range of measurements accuracy (imbalance). According to mean annual data, the difference between rainfall and evaporation ($h^{oc}(t)$- $h^E(t)$) varies around «- 87 mm» when a standard deviation equals «= 2.2mm». The function *F(Z)* describes the configuration of the depression where the Aral Sea is located. It is not time-dependent ("***t***") within given time intervals. Consequently, having data on the Aral Sea level dynamics, one can establish the function $W^R(t)$. Then, the target value of h^{TR} (a limiting water depth for reed growth) will be determined by minimizing the functional:

$$\Im(h^{TR}) = \min_{h^{TR}} \int_{t1}^{t2} [W^R(t) - W(t, h^{TR})]^2 \, dt\,; \qquad (6\text{-}21)$$

where: $W(t, h^{TR})$ is a function of outflow from the South Prearalie derived from simulating.

Comparative results for *t1*=1980 and *t2*=1989, received by using actual mean monthly values of Aral Sea elevations (data of the gauging stations "Lazarev" and "Barsakel'mes") are shown in Figures 6-1 and 6-2. Forecasting parameters received by simulating are shown in Figure 6-3 under comparison with actual dynamics of the Aral Sea level provided by the project. Figure 6-3 gives actual dynamics of the Aral Sea water surface in the second half of the twentieth century.

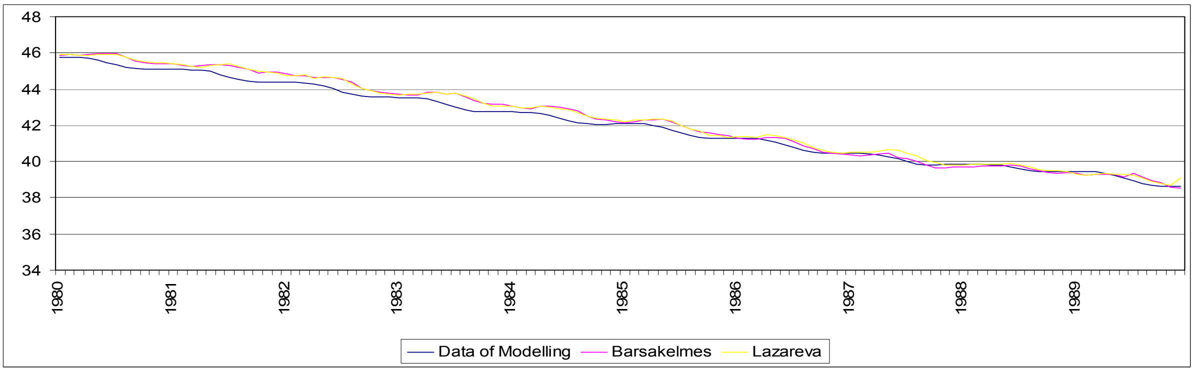


Figure 6-1

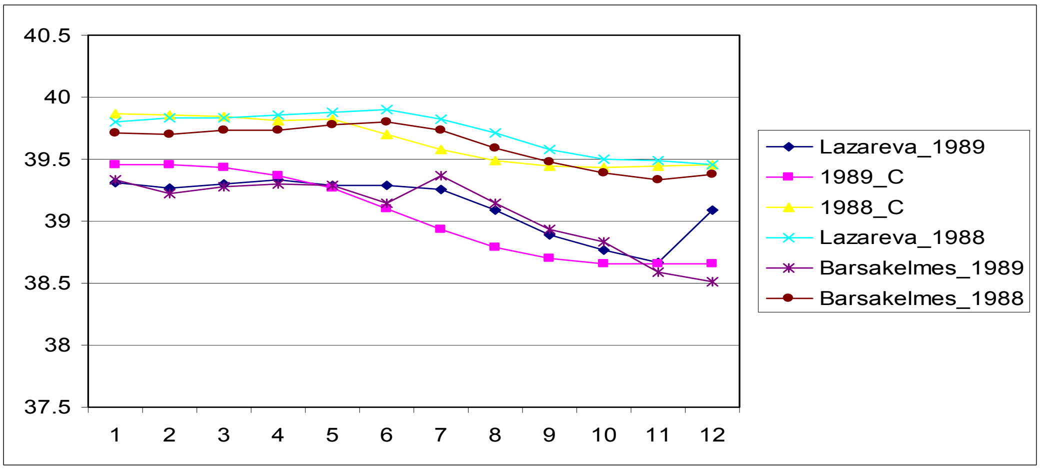


Figure 6-2

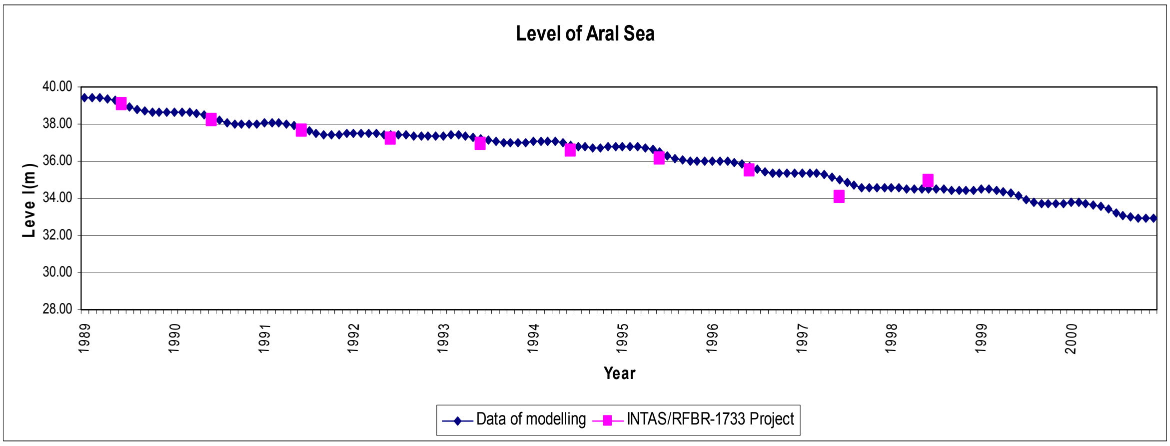


Figure 6-3 The Aral Sea water level

VII. THE GEOGRAPHIC INFORMATION SYSTEM

The Geographical Information System (GIS) developed within the NATO-SFP 974357 project enabled us to obtain qualitative and quantitative characteristics of objects and phenomena in the South Prearalie, to compare their properties and interrelation. The main task of the GIS Group was the mapping and spatial analysis of environmental, topographic, geological and other conditions in the South Prearalie in order to design the water infrastructure, and to select the optimal water management regime. In addition, the use of GIS enabled us to identify the representative areas. The series of data were also collected for the database "the Aral and Prearalie Ecology" (DB) that give qualitative and quantitative characteristics of river and drainage flows and present trends of environmental and landscape development in the South Prearalie. The current situation is a consequence of hydro-engineering and economic activities in the modern and ancient deltas of the Amu Darya River, shrinkage of the Aral Sea and changes in the water regime in the middle and particularly lower reaches of the Amu Darya River. This forces us to respond to both predictable cyclical changes in the object status and emergencies, i.e. those that occur suddenly and are caused by a combination of natural and anthropogenic factors, each of which separately does not present the basic landscape-forming factor. Since it is impossible to foresee all components of the environmental complex, we have to collect information on each object available for analysis. Thus, while establishing DB, the structure of datasheets was refined. Basic data containing in DB are as follows:

1. Environmental data;
2. Hydrological data;
3. Meteorological data;
4. Water-management data;
5. Socio-economic data.

The list of DB’s basic information is given below:

- data on the Amu Darya river water quality;
- data on drainage water quality;
- dynamics of South Prearalie lakes and their water areas;
- climatic data, etc.

The DB also includes data that describe the socio-economic situation in the South Prearalie (source: the INTAS RFBR 1733 Project). The map of the distribution of socio-economic damages throughout the South Prearalie has been produced on the basis of detailed analysis of current socio-economic situation (Figure 7-1).

As shown in the map, the reservoirs Mezdureche, Muynak and Ribache were subjected to maximum socio-economic damage. As a result of analysis of spatial data it was determined that the first option of placing man-made water bodies maximally mitigates the socio-economic stress since it ensures availability of water resources in the most densely populated areas; in addition, the Adjibay Polder 2 serves as a filter on the pathway of salt and dust transfer from the dried up bottom of the Aral Sea.

Field data used for mapping were inputted into the project’s geographical database. The GIS Group consisted of experts in such fields as mathematics, hydrology, hydrogeology, land reclamation, and ecology.

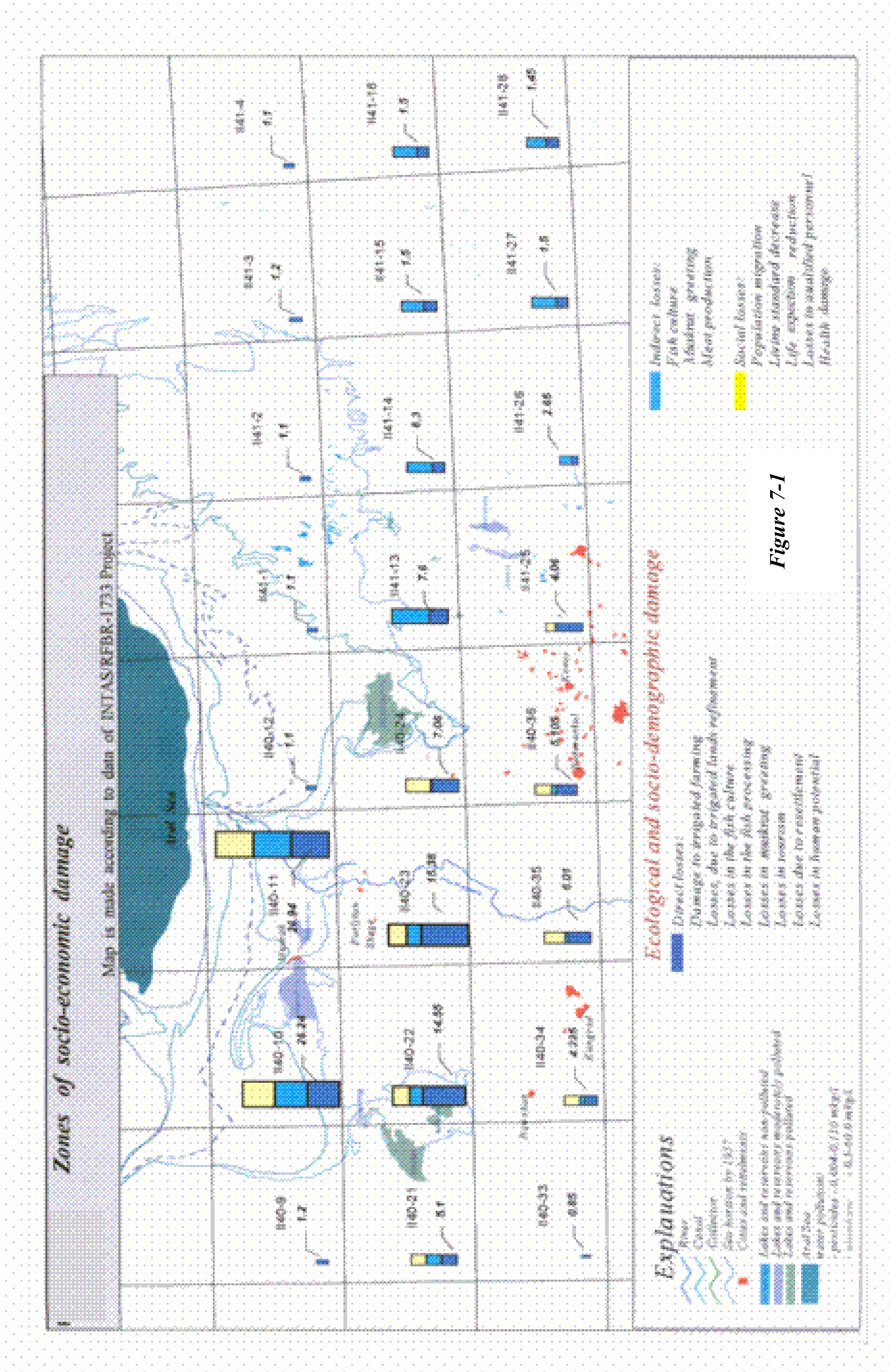

Zones of socio-economic damage
Map is made according to data of INTAS/RFBR-1733 Project
Aral Sea
Explanations
Ecological and socio-demographic damage
Direct losses:
Damage to irrigated farming
Losses due to irrigated lands refinement
Losses in the fish culture
Losses in the fish processing
Losses in muskrat growing
Losses in tourism
Losses due to resettlement
Losses in human potential
Indirect losses:
Fish culture
Muskrat growing
Meat production
Social losses:
Population migration
Living standard decrease
Life expectation reduction
Losses to qualified personnel
Health damage

Figure 7-1

The current hydrological, environmental and hydro-geological conditions were assessed according to several directions and stages. The following three main stages of GIS development of may be outlined:

- Preparation of initial materials (selection of topographic and thematic maps and satellite imageries);
- Information input - digitizing, development of linear and polygonal topologies, input of attributive information;
- Systematization of topographic and thematic information;
- Specification of morphometric characteristics of natural and man-made water bodies.

The main activities under establishing GIS were as follows:

- Handling thematic maps representing the historic and current state of the study area;
- Processing field data submitted by the NGO "ECO Prearalie" and SANIIRI;
- Three different schemes of placing the system of man-made reservoirs and water infrastructure in the Amu Darya delta are tied to the coordinate system;
- Specifying the lay-out and area of natural and man-made water bodies based on the documents submitted by the NGO "ECO Prearalie" and the firm "Aralconsult" as well as on the LANDSAT satellite image;

The analysis of spatial data derived from the digitizing of topographic maps by the SIC ICWC, and the data contained in the 1990 South Prearalie Landscape Map, the 1992 Soil Map, as well as the schematic landscape assessment map developed by the project 974101 in 2000 has permitted us to ascertain the following:

- Environmentally critical zones (Figure 7-2), which are characterized by dynamic, unstable landscapes (shifting sands in the form of *barkhans* and dunes), which remained stable for the last 10 years, occupy 127.5 thousand ha (the figure is derived from a GIS analysis overlay procedure) – **the First Zone**;
- Environmentally unstable zones, which are characterized by potentially unstable landscapes (sandy soils, devoid of shrubs and tamarix) and deemed risky over 8 - 20 year period, total 533.6 thousand ha (the figure is derived from a GIS analysis overlay procedure) - **the Second Zone**;
- Two extremely dry years - 2000 and 2001 practically resulted in the desiccation of all water bodies in the South Prearalie. According to remote sensing observations carried out during the summer of 2001, the wet area constituted 20.5 thousand ha and wetland area - 264.9 thousand ha, whereas in 1999 the wet area alone covered some 79.6 thousand ha.

Taking into account that dry years tend to follow each other in the Amu Darya river basin, it may be assumed that those conditions were the worst one, and the natural conditions in the delta will improve in future. This allows us to focus on a vulnerability of the first and second environmentally unstable zones. Additional processing of satellite images was performed with the purpose of determining areas of wetlands in the South Prearalie more precisely. The results of satellite images processing are shown in Table 7-1.

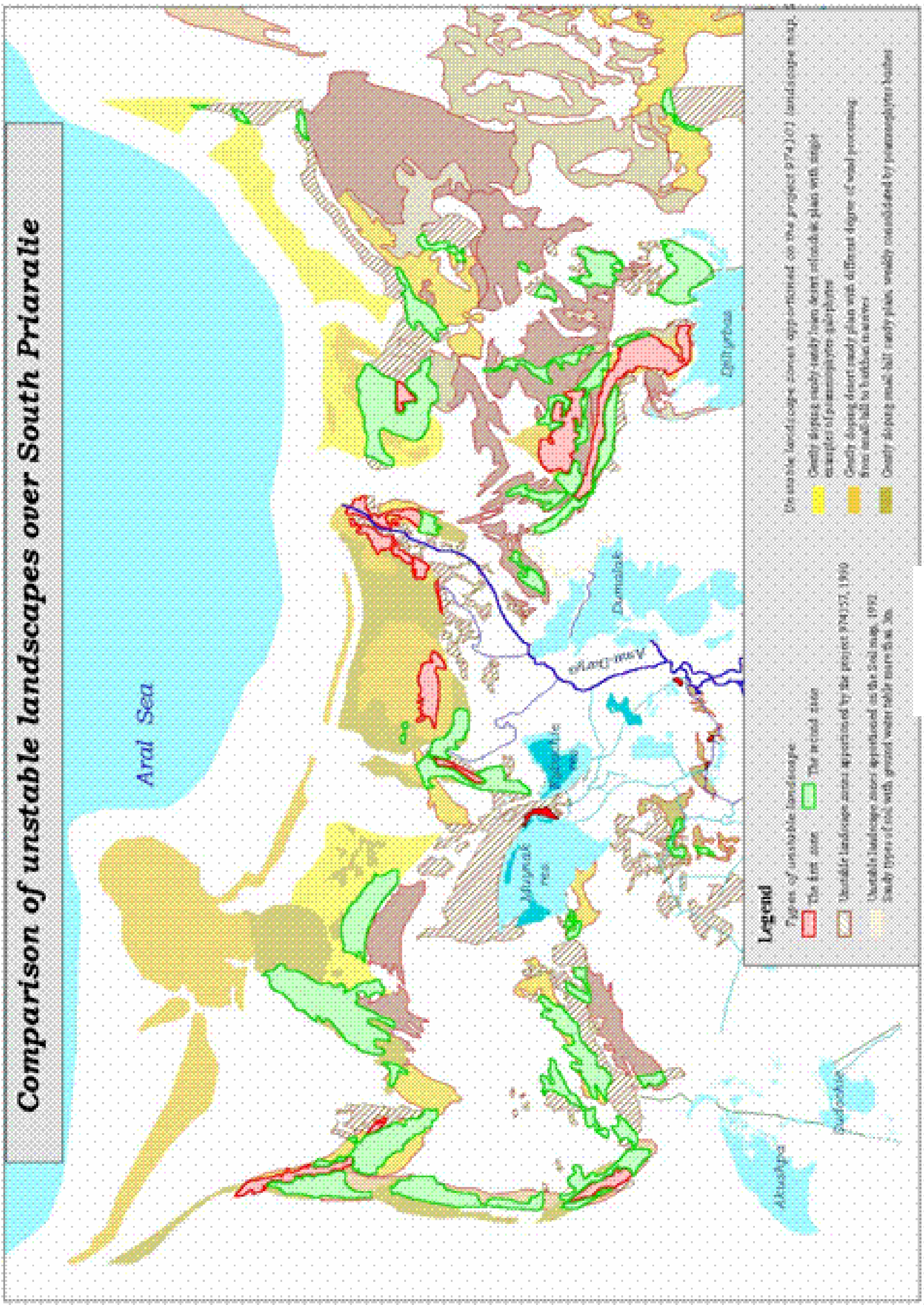

Comparison of unstable landscapes over South Priaralie
Aral Sea
Amu-Darya
Legend

Figure 7-2

Table 7-1 Wetland Areas in the Amu Darya Delta, ha

	Water body	Date		
		8.04.2000	14.06.2001	4.08.2002
1.	Sudoche	41,897.73	9,570.04	6,497.2
2.	Mezdureche	10,050.42	592.79*	18,375.21
3.	Ribache	5,317.64	2,019.68	5,513.1
4.	Muynak	8,623.34	1,292.23	5,163.2
5.	Djiltirbas	29,357.73	5,277.33	27,620.5
6.	Former Adjibay Bay	10,980.9	656.53	6,784.7
7.	Dumalak	4,576.89	927.23	6,784.9
8.	Mashankul-Karadjar	16,835.18	726.27	2,813.9
	Total	127,639.83	2,1062.1	79,552.71

*) Water surface area is negligible and overgrown with vegetation. Vegetation growth is concentrated along the Amu Darya River and Lake Shegekol.

The initial research stage relevant to placement of the man-made water bodies system allowed conclusions to be made on significant possible changes, which could be made to the study area landscape especially within the zone containing the dried seabed and the Mezdureche reservoir floor. Changes in the relief over the last 12 years have resulted in displacement of water body beds, and consequently, the entire proposed scheme of the man-made water bodies' placement should be corrected. For detailed assessment of the relief within the zone of proposed structures we used topographic maps (1: 50,000 scale); for some other project sites - e.g. the Adjibay 1 - more precise determination of morphometric characteristics was undertaken (Figure 7-3).

The location of the Adjibay 2 was corrected on the basis of field data provided by the NGO "ECO Prearalie". When plotting bathymetric curves for man-made and natural water bodies of the South Prearalie, the following data sources were used:

- documents submitted by "Aralconsult" company;
- topographic maps of different scales;
- field data (ECO Prearalie);
- satellite imagery.

The use of information representing conditions of the South Prearalie for various dates made it possible to evaluate sedimentation processes in a number of natural water bodies and transformation of their beds due to changes in morphology of the territory as a result of changes in landscape-forming factors of the South Prearalie. The accuracy of results was verified using available satellite images.

In addition, to define the wettest areas (i.e. the lowest elevations for polders) in vicinity of the dried seabed, satellite images were used (LANDSAT – purchased by the project SFP NATO 974357, and the satellite images supplied by the project SFP NATO 974101). The GIS Group used topographic maps (1: 25,000 scale) to identify morphologic characteristics of the Djiltirbas and Mezdureche wetlands. As a result of these studies, three schematic maps were generated showing the layout of the man-made water bodies, and corresponding sites' topology for 2000 (Figures 7-4, 7-5, and 7-6.)

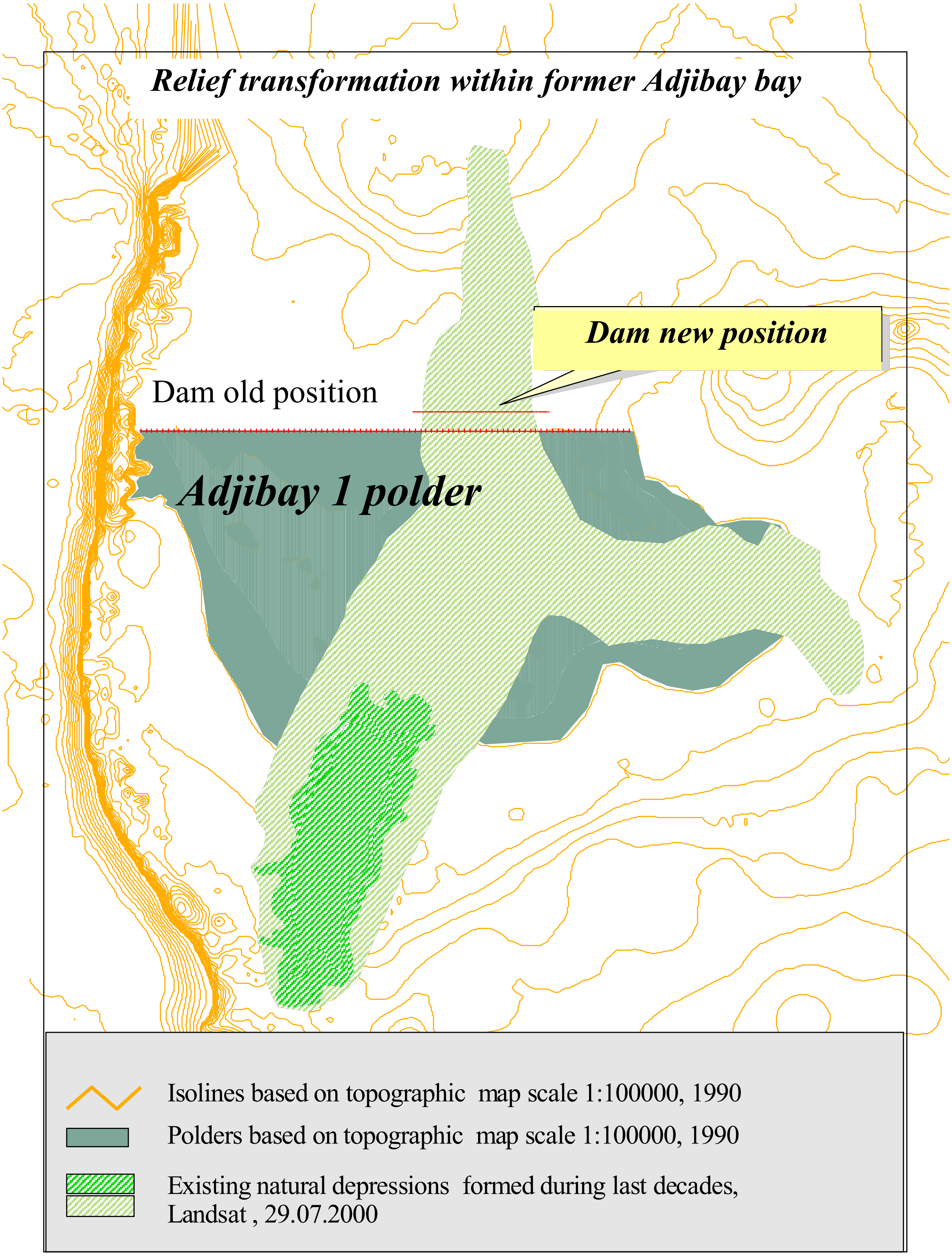


Figure 7-3 Relief Transformation within the Former Adjibay Bay

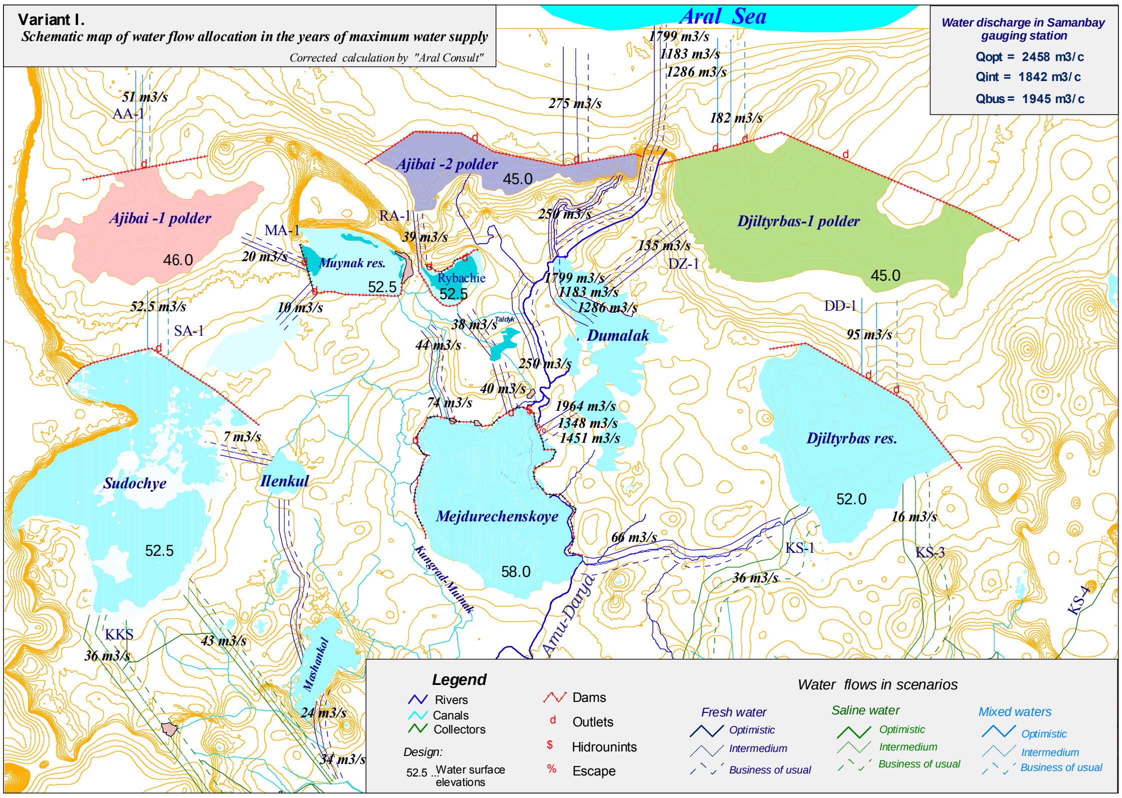


Figure 7-4

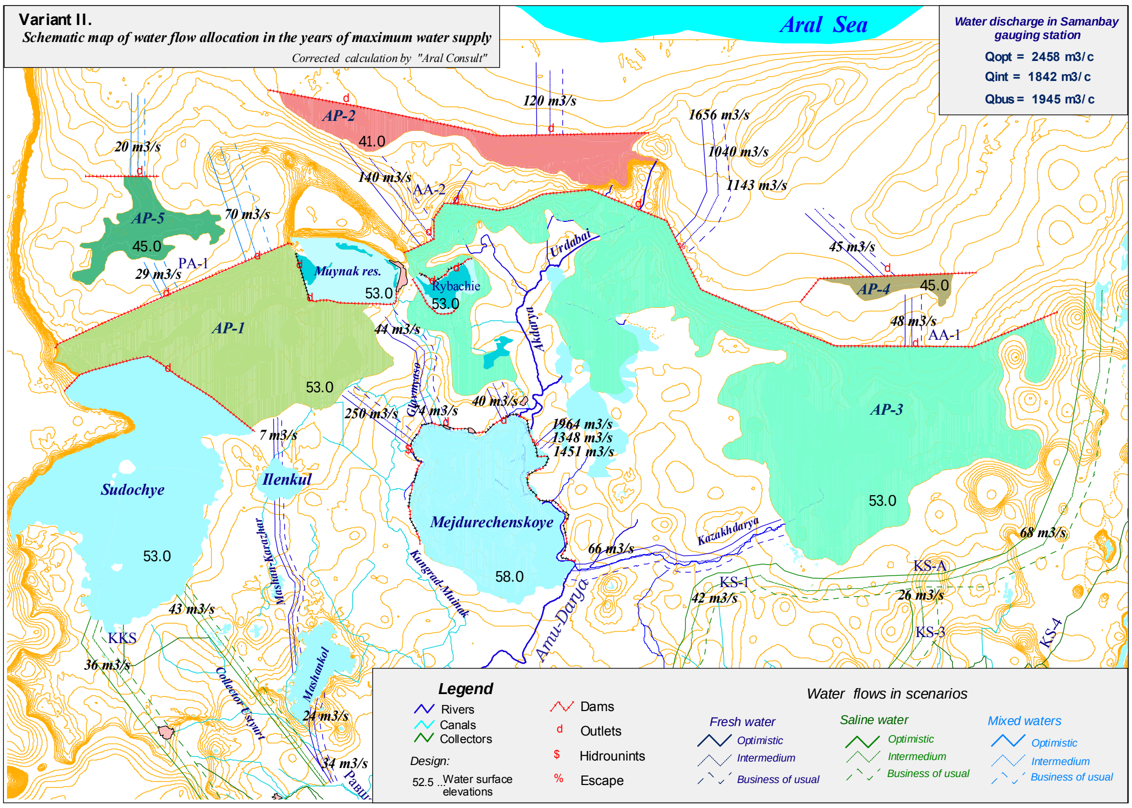


Figure 7-5

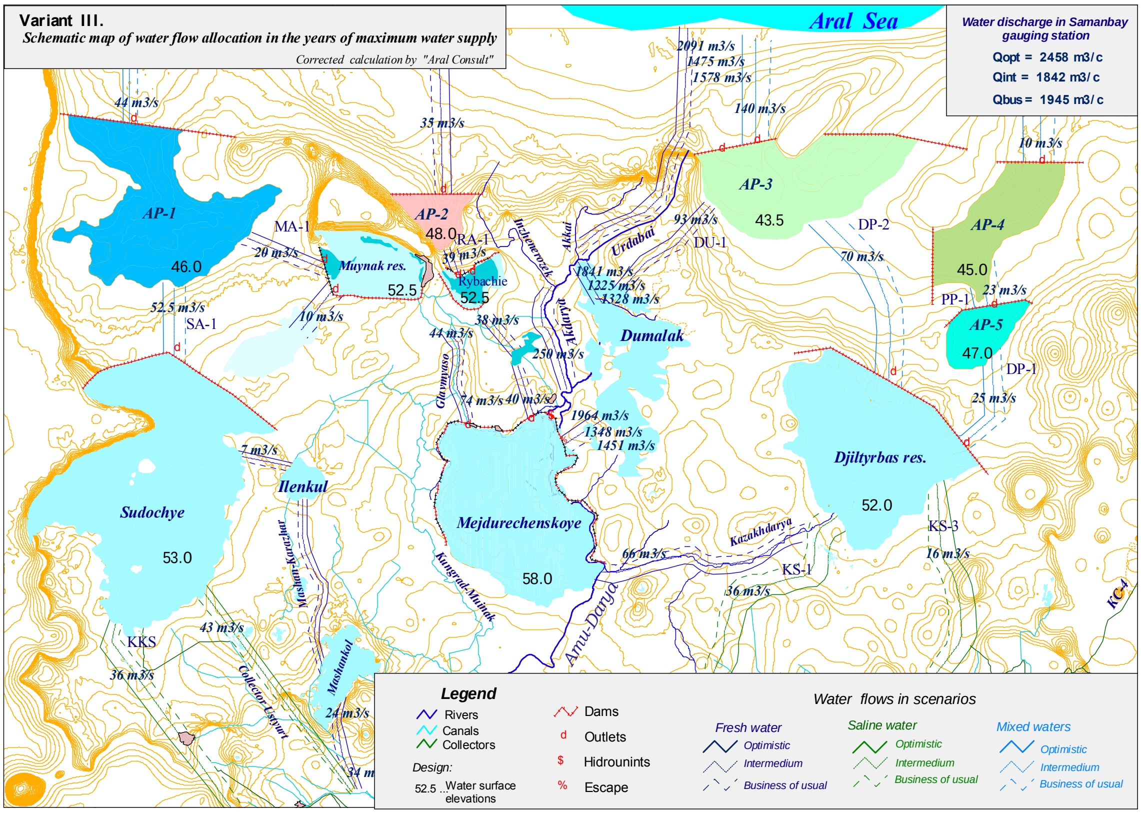


Figure 7-6

The SFP NATO 974101 Project provided the SFP NATO 974357 Project with the map representing dynamics of landscapes of the coastal part of the Amu Darya river delta and the dried seabed. The GIS Group compared unstable landscapes identified by the SFP NATO 974357 Project with landscapes where exogenous processes were taking place (posing environmental risk) identified by the SFP NATO 974101 Project.

Comparison of thematic information layers developed by the SFP NATO 974101 Project with thematic information (e.g. soil map, unstable landscapes map, etc.) prepared by the SFP NATO 974357 Project demonstrates that the environmental assessment of landscapes in the South Prearalie, made on the basis of different methodologies, can be sufficiently correlated with another set of data. In other words, the zones of unstable landscapes identified by the SFP NATO 974357 Project coincide closely with the zones that pose the highest environmental risk (the SFP NATO 974101 Project); thus, the thematic information layers prepared represent actual conditions in the Amu Darya river delta.

The spatial analysis shows that the selected scheme of locating polders in the zone of wind erosion processes ensures the greatest extent of environmental security for the most densely populated areas. The GIS Group has digitized a detailed map of the dried seabed from 1994. Comparison of this map with the soil map of 1992 shows that as the sea shrinks, a new-dried bed is being affected by similar salinization processes, i.e. a new-dried bed is comprised of the seaside hydromorphic and excessive hydromorphic solonchaks (including salt marshes) with groundwater levels ranging from 0.1 to 2.0 m. The detailed study of the territory using thematic maps and available field data demonstrates the main trends of landscape changes in the South Prearalie over the period of 1990-2002 (Figure 7-7.)

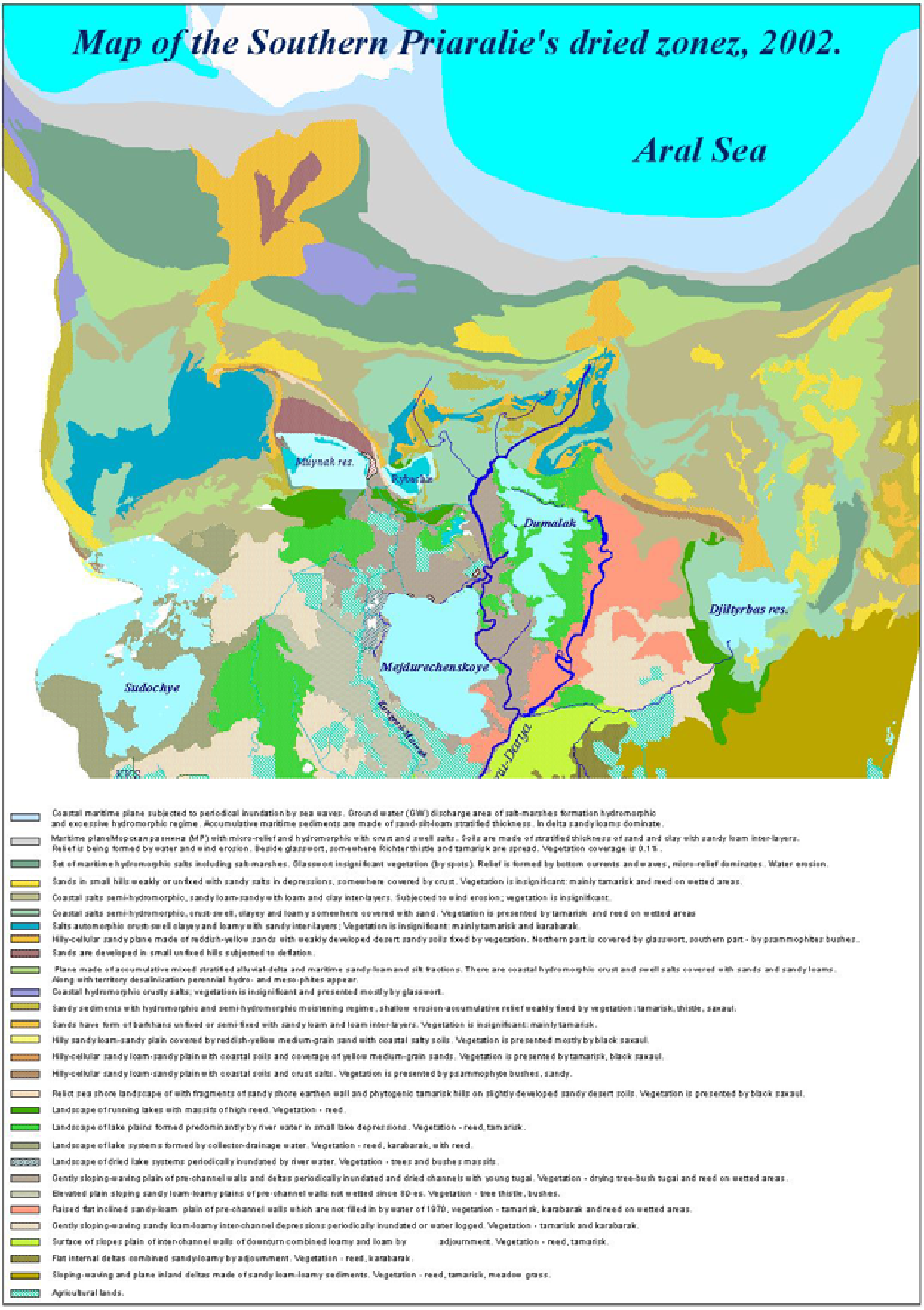

Map of the Southern Priaralie's dried zonez, 2002.
Aral Sea
Muynak res.
Rybachie
Dumalak
Djiltyrbas res.
Majdurechenskoye
Sudochye
Coastal maritime plane subjected to periodical inundation by sea waves. Ground water (GW) discharge area of salt-marshes formation hydromorphic and excessive hydromorphic regime. Accumulative maritime sediments are made of sand-silt-loam stratified thickness. In delta sandy loams dominate.
Maritime planeМорская равнина (MP) with micro-relief and hydromorphic with crust and swell salts. Soils are made of stratified thickness of sand and clay with sandy loam inter-layers. Relief is being formed by water and wind erosion. Beside glasswort, somewhere Richter thistle and tamarisk are spread. Vegetation coverage is 0.1 %.
Set of maritime hydromorphic salts including salt-marshes. Glasswort insignificant vegetation (by spots). Relief is formed by bottom currents and waves, micro-relief dominates. Water erosion.
Sands in small hills weakly or unfixed with sandy salts in depressions, somewhere covered by crust. Vegetation is insignificant: mainly tamarisk and reed on wetted areas.
Coastal salts semi-hydromorphic, sandy loam-sandy with loam and clay inter-layers. Subjected to wind erosion; vegetation is insignificant.
Coastal salts semi-hydromorphic, crust-swell, clayey and loamy somewhere covered with sand. Vegetation is presented by tamarisk and reed on wetted areas
Salts automorphic crust-swell clayey and loamy with sandy inter-layers; Vegetation is insignificant: mainly tamarisk and karabarak.
Hilly-cellular sandy plane made of reddish-yellow sands with weakly developed desert sandy soils fixed by vegetation. Northern part is covered by glasswort, southern part - by psammophites bushes.
Sands are developed in small unfixed hills subjected to deflation.
Plane made of accumulative mixed stratified alluvial-delta and maritime sandy-loamand silt fractions. There are coastal hydromorphic crust and swell salts covered with sands and sandy loams. Along with territory desalinization perennial hydro- and meso-phites appear.
Coastal hydromorphic crusty salts; vegetation is insignificant and presented mostly by glasswort.
Sandy sediments with hydromorphic and semi-hydromorphic moistening regime, shallow erosion-accumulative relief weakly fixed by vegetation: tamarisk, thistle, saxaul.
Sands have form of barkhans unfixed or semi-fixed with sandy loam and loam inter-layers. Vegetation is insignificant: mainly tamarisk.
Hilly sandy loam-sandy plain covered by reddish-yellow medium-grain sand with coastal salty soils. Vegetation is presented mostly by black saxaul.
Hilly-cellular sandy loam-sandy plain with coastal soils and coverage of yellow medium-grain sands. Vegetation is presented by tamarisk, black saxaul.
Hilly-cellular sandy loam-sandy plain with coastal soils and crust salts. Vegetation is presented by psammophyte bushes, sandy.
Relict sea shore landscape of with fragments of sandy shore earthen wall and phytogenic tamarisk hills on slightly developed sandy desert soils. Vegetation is presented by black saxaul.
Landscape of running lakes with massifs of high reed. Vegetation - reed.
Landscape of lake plains formed predominantly by river water in small lake depressions. Vegetation - reed, tamarisk.
Landscape of lake systems formed by collector-drainage water. Vegetation - reed, karabarak, with reed.
Landscape of dried lake systems periodically inundated by river water. Vegetation - trees and bushes massifs.
Gently sloping-waving plain of pre-channel walls and deltas periodically inundated and dried channels with young tugai. Vegetation - drying tree-bush tugai and reed on wetted areas.
Elevated plain sloping sandy loam-loamy plains of pre-channel walls not wetted since 80-es. Vegetation - tree thistle, bushes.
Raised flat inclined sandy-loam plain of pre-channel walls which are not filled in by water of 1970, vegetation - tamarisk, karabarak and reed on wetted areas.
Gently sloping-waving sandy loam-loamy inter-channel depressions periodically inundated or water logged. Vegetation - tamarisk and karabarak.
Surface of slopes plain of inter-channel walls of downturn combined loamy and loam by adjournment. Vegetation - reed, tamarisk.
Flat internal deltas combined sandy-loamy by adjournment. Vegetation - reed, karabarak.
Sloping-waving and plane inland deltas made of sandy loam-loamy sediments. Vegetation - reed, tamarisk, meadow grass.
Agricultural lands.

Figure 7.7

Revision of the South Prearalie Map taking into account changes of surveyed landscapes. The South Prearalie landscape-forming vegetation map generated on the basis of field studies and processing satellite images was used in this work.

Mezdureche Lake

Data from field topographic surveys (the NGO “ECO Prearalie” and "Aralconsult"), image processing and other information were used as a source for the detailed assessment of Mezdureche Lake morphologic characteristics and sedimentation processes. The assessment of sedimentation processes was based on the following data:

- topographic maps;
- Aralconsult’s data (as of 1985);
- the bathymetric chart of Mezdureche Lake (“ECO Prearalie”);
- field data;
- satellite images, which were used to verify data collected in the process of bathymetric surveys of the Mezdureche Lake.

The bathymetric chart of Mezdureche Lake as of July 2002 (“ECO Prearalie”) demonstrates outcomes of field works. Table 2 shows data derived from processing the bathymetric chart of Mezdureche Lake (1: 50,000 scale).

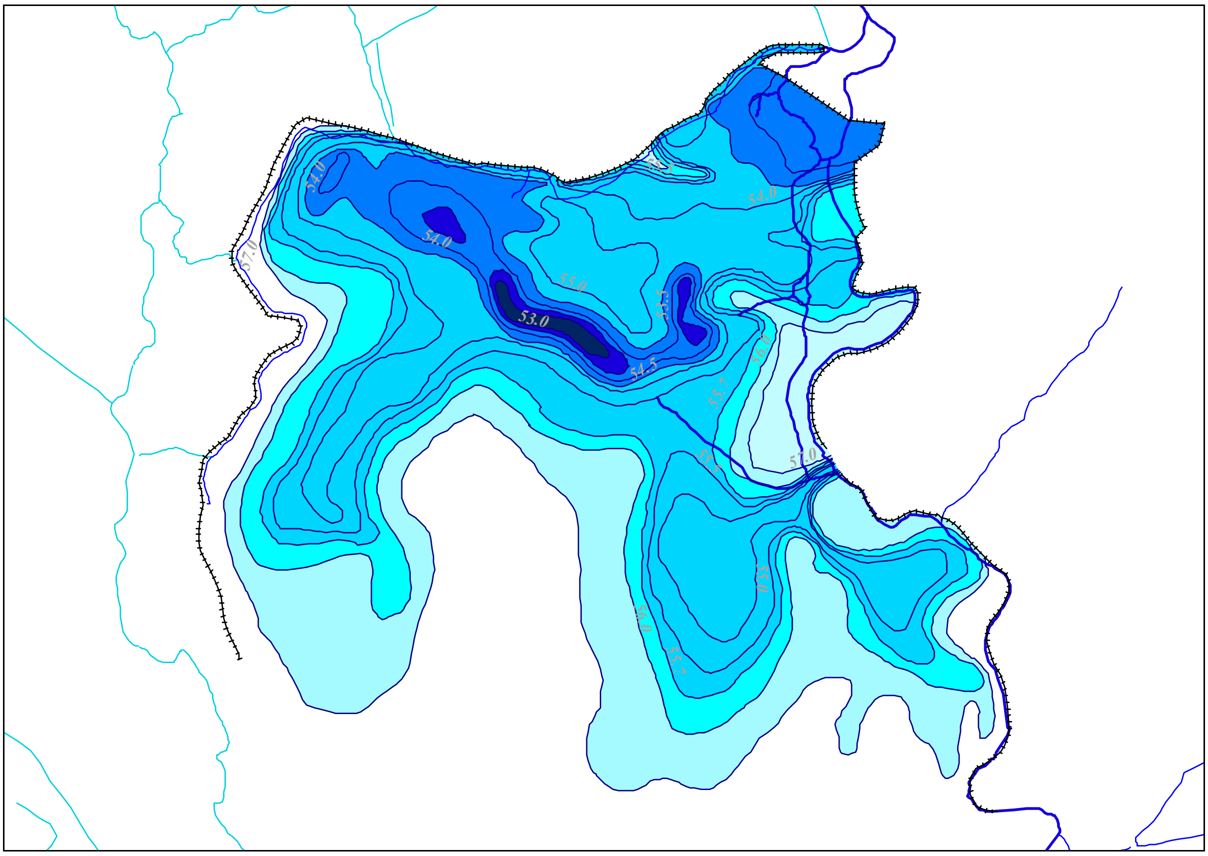


Figure 7-8 The Bathymetric Chart of Lake Mezdureche (ECO “Prearalie”)

Table 7-2 Results of ECO "Prearalie"'s Data Processing

(1 m increment; intermediate isolines are rounded; for instance, the value of 54.5 is rounded to 55)

	dS (m^2)	Sum S (m^2)	W (m^3)	Sum S (ha)	W (million m^3)
53	769,806.5	769,806.50	769,806.50	76.98	0.77
54	16,875,462.6	17,645,269.10	9,977,344.30	1,764.53	9.98
55	65,646,827.0	83,292,096.10	60,446,026.90	8,329.21	60.45
56	108,237,171.1	191,529,267.20	197,856,708.55	19,152.93	197.86
57	77,253,651.0	268,782,918.20	428,012,801.25	26,878.29	428.01

Sedimentation of Mezdureche Lake was assessed for the period of 1985-2002. Data of "Aralconsult" were used as the basic morphological characteristics for 1985. The relief conditions in 2002 were assessed using data of "Aralconsult", the spatial analysis (GIS processing) of data of "ECO Prearalie" and satellite images. The results are shown in Figure 7-8.

The comparison of data of "Aralconsult" and the NGO "ECO "Prearalie" and results of satellite image processing are given in Figure 7-9.

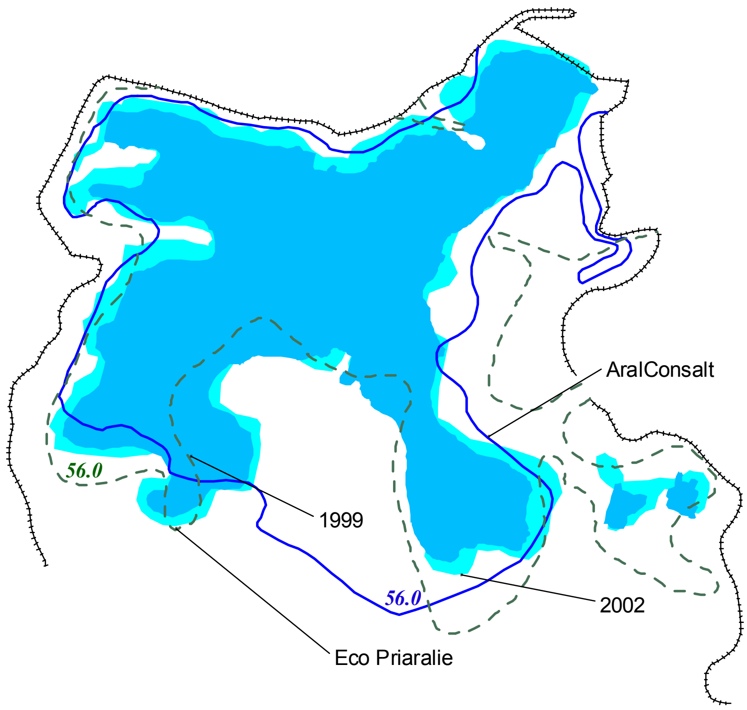


Figure 7-9

As an illustration of derived data accuracy, the result of a LANDSAT image processing is shown. The area of Mezdureche wetland was ***16,758.38 ha*** by August 4, 2002 that correspond actually the on-line data from Karakalpakstan.

Figure 7-10 Mezdureche Wetland (August 4, 2002)

VIII. THE SODOCHE LAKE IS A PILOT PROJECT IN THE SOUTH PREARALIE

Since October 1999 till December 2002 within the framework of the WEMP Project of the GEF Agency, the Sudoche Wetland Rehabilitation Project (Component E) had been implemented. The design work had been jointly undertaken by "Resource Analysis" (Dr. Joop de Schutter, the Netherlands), the VEP SANIIRI (A.I. Tuchin, Uzbekistan), and the “Aralconsult” (L. Gilenko, Uzbekistan).

The study area is the Sudoche wetland (Figure 8-1), which in the past was the bay in the southern part of the Aral Sea (the western part of the former Amu Darya river delta) and is located north-west of the Raushan farm in the Kungrad District of Karakalpakstan. This territory occupies the area of about 500 km^2 comprising the main lakes (water bodies with open water surface) Akushpa, Begdulla-Aidyn, Big Sudoche and Karateren. The major part of water supply consists of drainage water delivered through so-called the Main Left-Bank Collector (MLBC), the drainage canal entering from the south, as well as fresh water delivered through the Usturt Irrigation Canal entering from the south-east but during the limited period of time (only a few months per year). The area of open water surface at the level of 52.3 m +BSL (the Baltic Sea Level) is estimated as about 10,000 ha with the total wetland area of about 30,000 ha.

The key problems of the territory may be characterized as follows:

- Lack of infrastructure for water resources management: at present all the water delivered through the MLBC flow out through the outlet located at the Akkum ridge in the north;
- A high water salinity level especially in the south-west part (the Akushpa Lake) due to the lack of conditions for flushing. The MLBC (the major source of water) is separated from the wetlands by embankments formed in the process of its construction along both banks; therefore there is almost not water interchange between the canal and adjacent territories.

The project was focused on identifying the ways to improve water quality (reduction of salinity) and to stabilize water regime (levels, discharges) with the purpose of optimizing ecological conditions. At the same time, irrespective of the selected water regime it was necessary to avoid negative impacts on drainage conditions and the groundwater regime in an irrigated area of the Raushan farm situated south-east of the project area.

The Sudoche wetlands were formed in a shallow, but vast depression, and in the past the Sudoche Lake was the largest water body in the Amu Darya delta and was characterized by the following parameters: an open water surface - about 350 sq km; an average width - 15 km; a length - 250 km, an average depth - 2 m (the maximum depth did not exceed 3 m); salinity - 0.6 to 1.7 g/l.

Water supply of the north-west part of the Amu Darya delta was unstable and changed within relatively short periods of time that caused instability of hydrological and hydro-chemical regimes of the lake. When inflow of river water was being stopped and water circulation was absent, sea water intrusion into the lake has taken place resulting in a higher salinity level – up to 7.2 g/l in 1952 and 24 to 41 g/l in 1966. However, when water supply of the delta has improved, water circulation was recovered and a salinity level dropped to 0.6 g/l in 1953 and 2 to 3 g/l in 1961 and 1962 respectively. In the 1960s due to Aral Sea shrinkage and decreasing of river water inflow, the lake has become shallow, and by 1968 it disintegrated into several isolated small lakes.

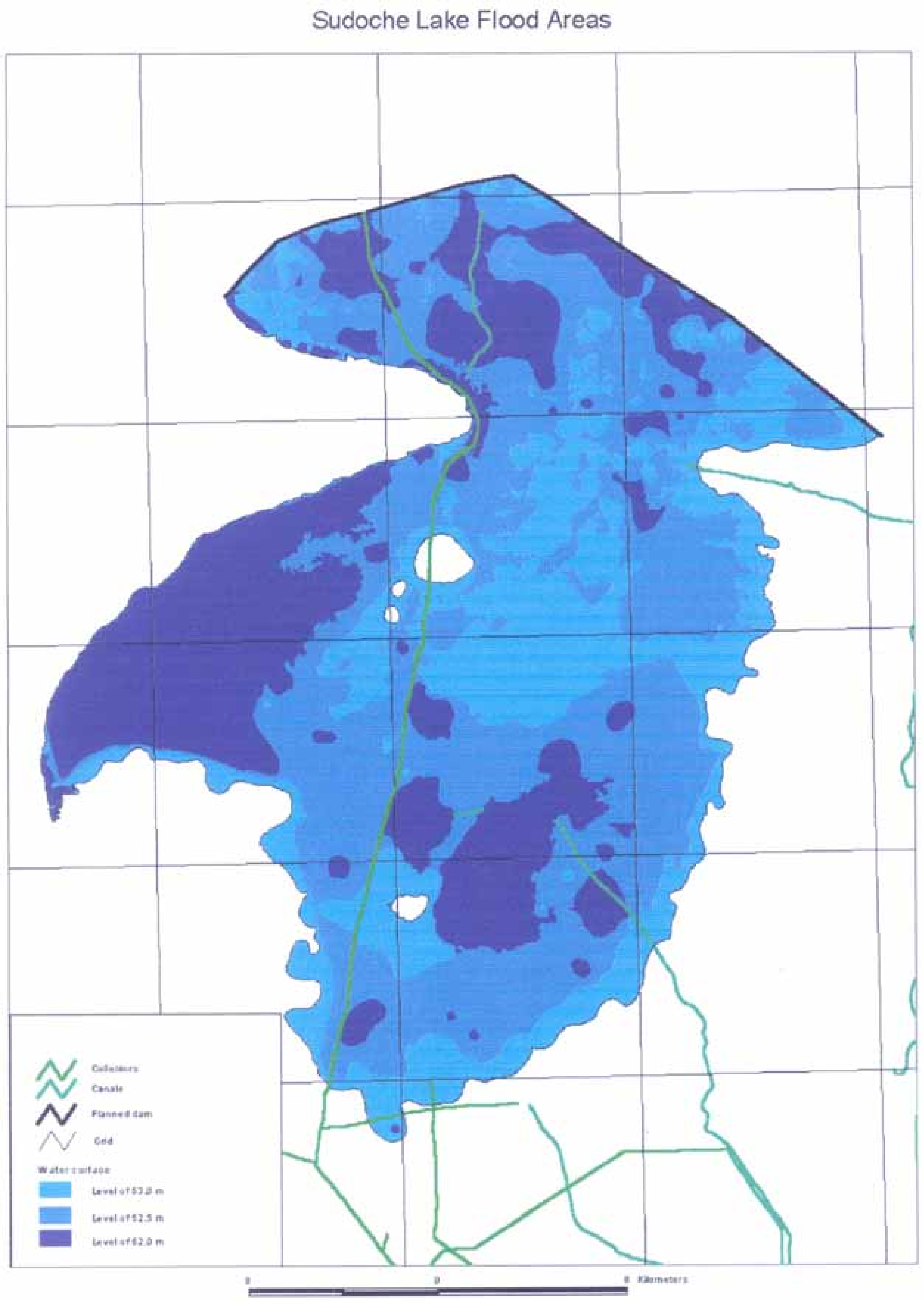

Sudoche Lake Flood Areas
Collectors
Canals
Planned dam
Grid
Water surface
Kilometers

Figure 8-1

Since the late 1960s, drainage water started to be disposed into the lake through the drains “KKC” and “GK”, and from that time, lake’s conditions became completely dependent on hydrological regimes of these watercourses. The mean annual inflow through these main drains (mainly “KKC”) makes up 0.64 km3 having salinity of 3 to 4 g/l.

On the basis of the retrospective analysis of Sudoche lake development, four successive periods of decline in water supply and subsequent rehabilitation of water regimes can be distinguished.

The multipurpose ecological field survey undertaken in autumn of 1999 shows that at present, Sudoche wetlands consist of four water bodies with the total area of 43.8 sq km:

- The Akushpa Lake with the area of 30.7 sq km occupies about 70 percent of the total water surface area of wetlands. The maximum length of the lake reaches 20 km; a width is 6.5 km; a depth does not exceed 1.5 m; and a length of the shore-line is equal to 62 km;
- The Karateren Lake with the area of sq km occupies about 2.1 percent of the total water surface area of wetlands. The maximum length of the lake reaches 6 km; a width is 1.25 km; a depth does not exceed 1.5 m, a length of the shore-line is 17 km;
- The Begdulla-Aidyn Lake with the area of 2.4 sq km occupies about 5.5 percent of the total water surface area of wetlands. The maximum length of the lake reaches 4 km; a width is 2.5 km; a depth does not exceed 1.5 m, a length of the shore-line is 11 km;
- The Big Sudoche Lake with the area of 9.8 sq km occupies about 22.4 percent of the total water surface area of wetlands. The maximum length of the lake reaches 10 km; a width is 4.5 km; a depth does not exceed 1.2 m, a length of the shore-line is 32 km;

During the entire period of Sudoche Lake existence, a flow-through was the key requirement for maintaining and rehabilitating water quality. Failure of this requirement inevitably resulted in its salinity increase; and at present the Akushpa Lake proves this pattern. According to salinity levels, the Sudoche Lake may be conditionally divided into three areas:

- The north-west part of the lake with salinity of 16-19 g/l;
- The central part of the lake with salinity of 20-24 g/l, which occupies 30 percent of the water surface area;
- The south part of the lake with salinity of 25-29 g/l, which occupies 60 percent of the water surface area;

The key factor determining the bio-diversity of lakes is a salinity level, which as it was shown above in many respects depends on water circulation in water bodies. Distinctive ecological features of some water bodies within the Sudoche wetland are considered below.

At the first phase, designers jointly with ecologists of nature protection agencies and scientific research institutes of Karakalpakstan evaluated an adequacy of the Sudoche Lake conditions regarding elaborated ecological requirements.

Long-term preservation of the water surface area of lakes and sufficient and accessible forage resources are basic ecological requirements to lakes as the ornithological sanctuary. The current water surface area of the Sudoche wetlands is not undergone significant seasonal fluctuations and in this respect it practically meets the above stated requirements. Sufficiently developed biomass of periphyton and zoo-benthos in all the lakes provides good forage resources for non-piscivorous birds. In autumn water surface area of the lake provides a refuge and food for 70,000 birds.

Development of ichthyo-fauna in lakes makes special demands to both biotic and abiotic conditions of the environment. Abiotic requirements are the following: (i) a salinity level should be less than 5g/l; (ii) dissolved oxygen content should exceed 4 to 5 g/l; (iii) neutral or alkalescent reaction of water -

pH 7 to 7.5; (iv) a water depth should be not less than 1.5 m.

The analysis of abiotic conditions in the Sudoche wetlands shows that the lakes Karaten, Begdulla-Aidyn and Big Sudoche do not meet the requirements regarding to salinity. The salinity level in the Akushpa Lake exceeds the admissible level several times.

The value of dissolved oxygen content in all the lakes does not go down below admissible levels; however, a depth of lakes, except relatively deep parts of the Karateren Lake, is less than 1.7 m, that does not meet the ecological requirements. At the same time, a shallow depth of water in the lakes is especially hazardous since it may promote heating-up of water resulting in night kills in summer, and in winter they may lead to deep kills during a long freezing-over period.

The ecological requirements for survival of musk-rat are the following: (i) the sustainable water surface area with a water depth exceeding 1.5 to 2.0 m, and (ii) the salinity level of less than 3 g/l. Basic requirements are water circulation within lakes and prevention of water level rise by 30 cm and higher during the freezing-over period.

Depth and salinity values do not meet these ecological requirements in all the lakes. According to the yield class, places of the musk-rat habitat within the present Sudoche wetlands refer to the third class (38 percent of the territory) and the second class (60 percent of the territory), which can be characterized as satisfactory and poor for use respectively.

Hydrological modeling to select the final option of water management interventions comparing cost and hydro-ecological impacts of seven options under four scenarios was carried out prior to the design works.

Within the framework of this project the hydrodynamic model was developed on the basis of the hydrodynamic module and the dispersion-advection module of the MIKE 11 software package.

The MIKE 11 is the hydrodynamic one-dimension model, which solves the vertically-integrated equation of conservation of continuity and impulse (driving force) based on the implied finite difference scheme with a net where Q-points are placed at a midway between H-points and in structures, at the same time, H-points are set at cross-sections. The dispersion-advection module of the MIKE 11 software package is based on the one-dimension equation of conservation of mass of solute and suspension, and requires input of data from the hydrodynamic module.

Simulation covers the period since January 1994 until December 1998. In the course of the hydrodynamic simulations, flooded areas were computed and water losses owing to evapotranspiration and evaporation were assessed for each two-day period. After the hydrodynamic simulation had been completed, simulation of salinity in lakes was made using the dispersion-advection module.

On the basis of this simulating the following conclusions were drawn:

- At present, only the MLBC has the continuous flow and therefore its salinity (including the Karateren Lake) does not reach high values;
- The designed sizes of the dam outlet at the Akkum ridge allow to control water levels and discharges all the year round;
- The Akushpa Lake remains isolated water body after floods; and then its water level drops due to evaporation, and at the same time salinity increases;
- The Sudoche lake inflow is provided through the Usturt Drain. When water supply is less than 6 m^3/sec, its salinity starts increasing;
- Water management infrastructure should be complemented with a canal providing continuous water conveying from the MLBC to the Akushpa Lake, that enables to maintain the required levels of salinity;

- To ensure water supply to different water bodies, water level control is necessary, however, the available inflows are not sufficient for compensating losses due to evaporation and for maintaining the constant water level of 52.5 m + BSL all the year round;
- The additional inflow of fresh water through the Usturt Drain would improve the current situation in the Sudoche Lake, but salinity will remain at the high level reaching 13 g/l;
- To decrease the salinity level in the Sudoche Lake additional water supply is required. This extra inflow is needed during the summer period, especially in dry years, and extra water can be supplied from the MLBC after constructing the second deeper canal or by regulating inflows to the Usturt Drain;
- Routine measurements of salinity and water levels are needed to be conducted for improving the database regarding The Sudoche lake wetlands and for calibrating the model.

On the basis of simulating, the designers have developed the following set of structures (Figure 8-2):

- The dam at the Akkum ridge with the design water level of 52.50 m +BSL;
- The outlet at the Akkum ridge with the maximum carrying capacity of 52.8 m^3/sec at the depth of 2.5 m above the floor level (49.50 m +BSL);
- The interceptor drain “KC-3A” for drainage water disposal in the north part of the Raushan farm with the flow rate of 4.5 m^3/sec;
- The Raushan Pumping Station is located about 8 km north-west of the Raushan farm with six electric pumps with the overall capacity of 3.0 m^3/sec;
- The head works of the Usturt Drain, which is used for river water conveying into the Big Sudoche Lake with the maximum carrying capacity of 55 m^3/sec;
- The reconstructed spillway of the Altynkul control structure for delivering river water from the Raushan canal to the Usturt Drain with the maximum carrying capacity of 34 m^3/sec;
- The connecting canal between the ecological channel and the Akushpa Lake.

In addition, the entire territory is affected by: the hydrological regime of the Amu Darya River near the Takhiatash Barrage; the hydrological regimes of the Main Left-Bank Collector-Drain (MLBC or “KKC”), the Usturt Drain, and the Raushan Canal. The guidelines on water management promote creating optimal conditions for appropriate ecological functioning of the Sudoche wetlands.

Though every year differs from the previous one, the key principle of water management is to maintain as much as possible the design water level at elevation of 52.50 m + BSL and as long as possible during a year. Only that part of inflow should be released, which ensures increase in a water level up to the above stated elevation. Maximum levels of water should be ensured in early spring (the spawning period) and during the winter period (survival of fish).

Under the current water supply regime, inflow of about 600 million m^3 is provided through the MLBC and of approximately 200 million m^3 through the Usturt Drain. Taking into account that minimal standard of water quality in the lakes Big Sudoche and Begdulla-Aidyn needs to be maintained, the agreement on additional maximum possible amount of water supply through the system of the Raushan Canal and Usturt Drain should be provided every year. The amount of annually required additional fresh water is in the limits of 600 million m^3 and it must be provided through the agreement between the BWO “Amu Darya” and the Committee for Sudoche Lake Management (CSLM), which has a mandate to carry out general management of Sudoche wetlands in accordance with the Decree issued by the Council of Ministers of the Republic of Karakalpakstan No 263/12 dated November 12, 1997.

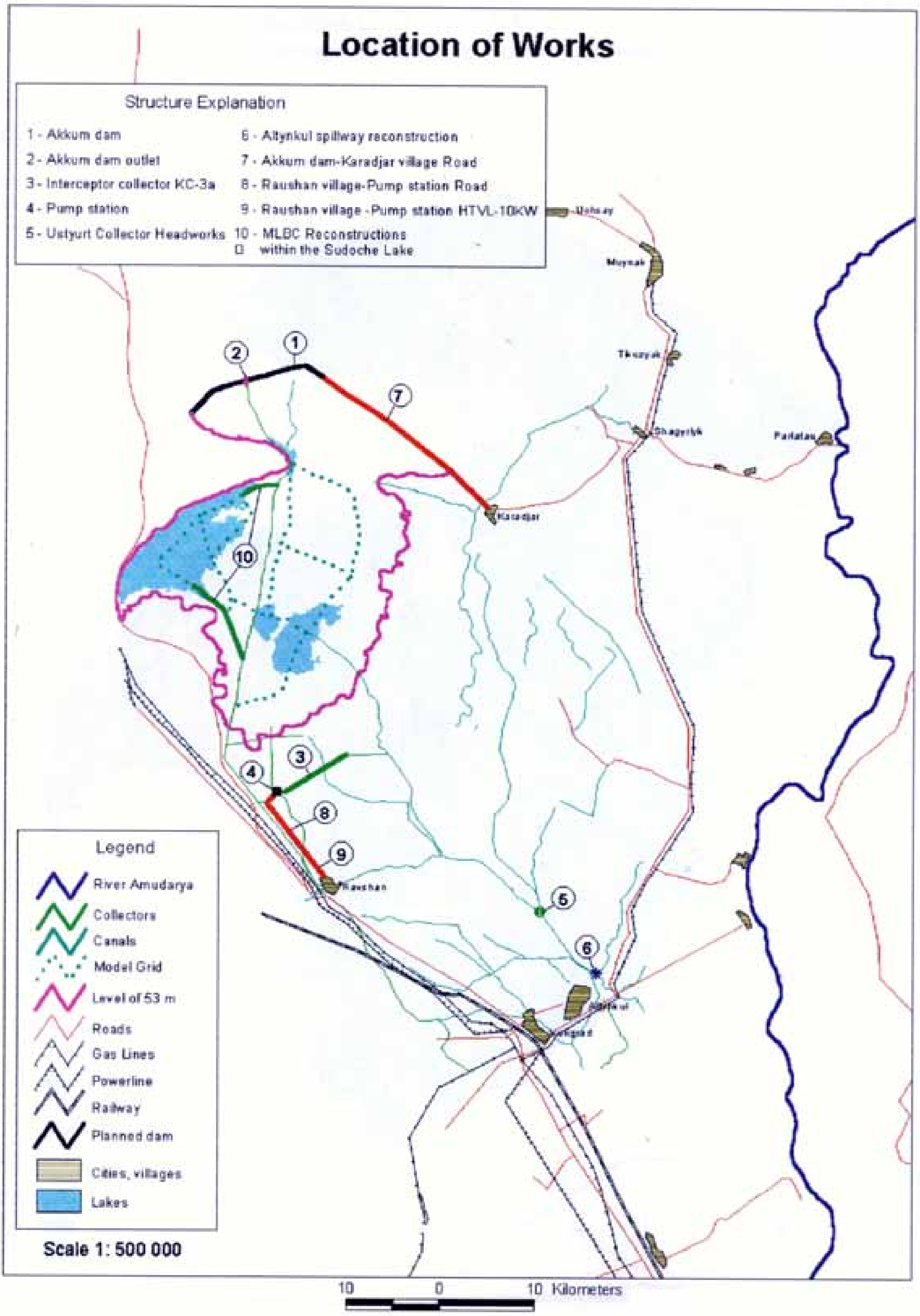

Location of Works
Structure Explanation
1 - Akkum dam
2 - Akkum dam outlet
3 - Interceptor collector KC-3a
4 - Pump station
5 - Ustyurt Collector Headworks
6 - Altynkul spillway reconstruction
7 - Akkum dam-Karadjar village Road
8 - Raushan village-Pump station Road
9 - Raushan village - Pump station HTVL-10KW
10 - MLBC Reconstructions
within the Sudoche Lake
Muynak
Shagyrlyk
Karadjar
Raushan
Legend
River Amudarya
Collectors
Canals
Model Grid
Level of 53 m
Roads
Gas Lines
Powerline
Railway
Planned dam
Cities, villages
Lakes
Scale 1: 500 000
10 0 10 Kilometers

Figure 8-2

It is very important to develop proposals for institutional improvements of Sudoche Lake management. The Committee for Sudoche Lake Management established according to the project conception is a non-governmental organization with such associated members as the State Joint-Stock Company "Karakalpakbalyk" (fishery company), the State Committee for Nature Protection of the Republic of Karakalpakstan, the Department of Natural Reserves and Game-Preserves. The main function of the CSLM is to operate and maintain the Sudoche Lake jointly with its associated members and public steering committees established in settlements adjacent to the Sudoche Lake.

The CSLM Board consisting of the representatives appointed by the association members and public steering committees makes decisions providing strict implementation of relevant rules, regulations and guidelines regarding operation and maintenance of the Sudoche Lake. Decisions made by the CSLM Board are to be unconditionally observed and implemented by all associated members and representatives of public steering committees. After the decision of the CSLM Board is made regarding the specific hydrological regime stipulated by the Sudoche Lake Project, every associated member of the CSLM arranges their internal office regulations and rules in the manner, which promotes implementation of the CSLM Board's decision.

Unfortunately, the CSLM Board's activity was not sufficiently effective, perhaps owing to the water scarcity in 2000-2001, and may be due to the imperfect legal status of this organization.

Nevertheless, in the subsequent wet year the project water infrastructure has started to operate, and the Sudoche Lake's regime regarding water levels and distribution of flows was in line with the design objectives.

IX. FIELD SURVEYS

The South Prearalie lies in the delta of the Amu Darya and comprises an area stretching from the Mezdureche Reservoir in the south to the Aral Sea coast in the north and from the cliffs of the Usturt Plateau in the west to the Kyzyl-Kum Desert in the east.

The South Prearalie has a harsh continental climate with dry hot summers - maximum temperatures of 44-45^0 C - and cold winters - minimum temperatures of - 30^0 C, with insignificant precipitation - 133 mm/year, on the average, and high evaporation rates - 1200 to 1600 mm/year.

The relief of the South Prearalie is characterized by the absence of more or less large hills and depressions. As a rule, intra-deltaic water bodies with relatively spacious water surface areas have small depths (1.0-2.0 m). Marginal parts of lakes are covered with continuous thickets of semi-aquatic vegetation and mostly have not a well-defined coastline.

Prior to the 1970s, water bodies of the South Prearalie had existed owing to the Amu Darya runoff. At that time, water salinity levels in lakes did not exceed 0.4-1.25 g/l. Since the 1960s, the water inflow into the delta began decreasing, and by the late 1980s it amounted to several percents of the average annual value. As a consequence, the most part of the intra-deltaic fresh water lakes has disappeared. At the same period, the construction of a number of drainage canals had been completed that led to creation of a new type of water bodies in the South Prearalie - tail flow-through and closed desert sinks of saline drainage water.

Water circulation within intra-delta lakes was the basis for water quality preservation and rehabilitation. The lack of water circulation has inevitably resulted in an intensive increase of water salinity levels and water quality deterioration.

In 2000-2001, the Amu Darya runoff had the least value during all the period of water-flow records. River flow reduction started since April 2000 and continued till spring 2002. Due to such an extreme shortage of water, the amount of drainage water has considerably decreased. A discharge of the MLBC has diminished from 568.2 million m^3 (a mean annual discharge) to 46.24 million m^3; water salinity levels have increased up to 9.7 to 14.4 g/l. The GK and KS drainage canals have completely dried up; and water was retained only in the tail part of the KS-3 drainage canal but without a visible stream, water salinity levels have reached 13.2 g/l.

As a result of drought, a flow through water bodies in the South Prearalie has been lost, and due to high rates of natural evaporation and the absence of a water inflow, most of water bodies have become shallow or completely dried up. These are the following water bodies: the lakes Mashankol, Khodjakol, Ilmenkol, Akushpa, Begdulla-Aidyn, Big Sudoche, Makpalkol, as well as the Mezdureche Reservoir, and the Djiltirbas Bay. In other water bodies such as the lakes Taily and Karateren, and former bays Muynak and Ribache, a water surface area and a depth have considerably decreased, at the same time water salinity levels have increased up to 14 g/l in the bays, and up to 50-60 g/l in these lakes.

The ecological condition in the Sudoche wetland, which is the biggest system of lakes in the South Prearalie, is a vivid example of negative impacts of the last drought. Prior to 2000, the water surface area of lakes in this wetland was 20,000 ha, but by the end of 2001 it has decreased to 6,500 ha. Water salinity levels in the Akushpa Lake, which is the biggest water body of this system (11,600 ha) have increased up to 90-100 g/l by the mid of 2001, and by the end of that year this water body has completely dried up (Figure 9-1).

An increase in water salinity levels has caused in degradation of fresh-brackish water fauna and flora of the lakes and their replacement by brackish-marine species under a progressive reduction in overall bio-productivity. Complete drying up of the lakes and their salinization has resulted in the extinction of water biota.

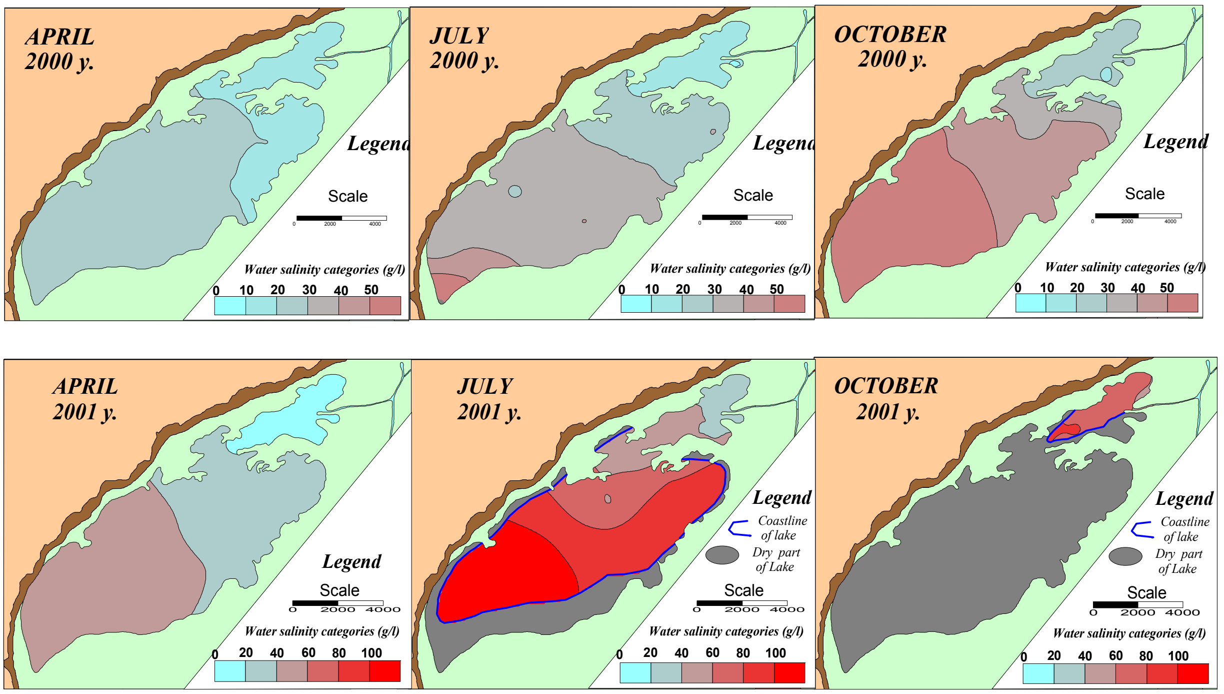


Figure 9-1 Dynamics of Akushpa Lake Drying up and Salinization in 2000-2001

The lacustrine fauna has degraded everywhere, and high-yield fish species like silver carp, grass carp, aral carp were replaced by less-yield ones: crucian carp and roach. Fish productivity of lakes has decreased from 36 - 61 kg/ha in 2000 to 16 - 36 kg/ha in the first half of 2001or two times. Eventually, shallowing, drying up and salinization of lakes have resulted in extinction of the fish population. The MLBC has remained the only place suitable for fish habitat on the wetland territory. However, the extensive fish catch has led to destruction of a reproductive composition of the fish population.

As a result of shallowing and drying up of lakes all reed and cattail thickets, which were a habitat for muskrat, endemic and migrating birds were found to be located on a dry terrain. Eventually, the population of 20,000 to 25,000 muskrats has actually disappeared during the period of two years; only some single specimens have remained.

Prior to 2000, the Sudoche wetlands were a unique place according to high diversity and quantity of waterfowl and other birds breeding near water bodies. There were 218 bird species here including 12 species included in the Red Book. During dry years, the population of birds has decreased in the number from 70.5 to 2.6 thousand birds, at the same time the percentage composition of hygrophilous species reduced from 91.6 percent to 38.2 percent (Figure 9-2).

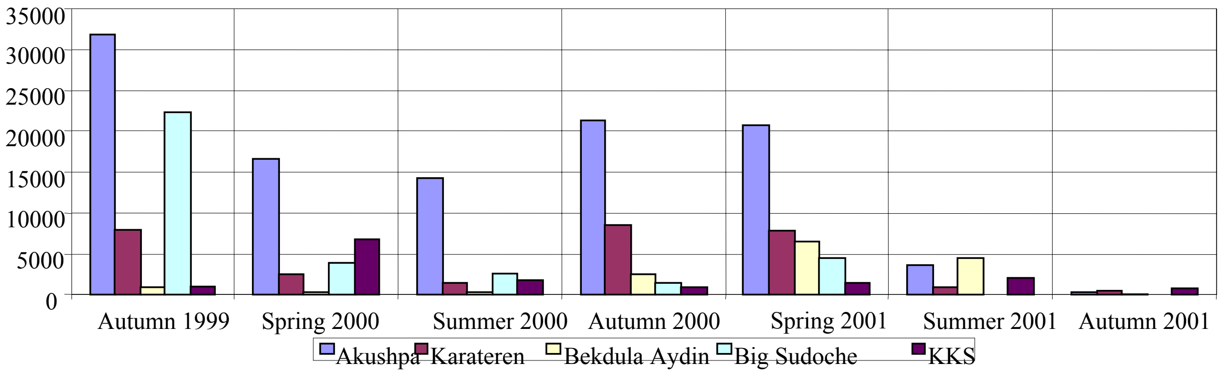


Figure 9-2 Bird Population Inhabiting Lakes of the Sudoche Wetland

Difficult ecological conditions have arisen almost throughout the delta of the Amu Darya River. The Muynak and Ribache bays were the most preserved water bodies, which remained here. However, in this case reed and cattail thickets were also found to be located on a dry terrain, nests of aquatic birds were destroyed by foxes and jackals. The fish population of the water bodies was subjected to intensive catch by the residential population and fishermen crews.

As a result of droughts no stable natural landscapes have been preserved in the South Prearalie. Unstable landscapes are currently prevailing; and most of them are slowly degrading.

In 2002, the two-year period of droughts gave place to the situation with sufficiently high water availability. The flood that has started in June 2002 lasted two months with the peak flow rate of 920 cu m per second at the Samanbay gauging station. Total runoff recorded at the Samanbay gauging station amounted to 2144 mln. m^3. However, in spite of water surplus, water supply to such first-priority water bodies as the Sudoche wetland, Ribache and Muynak bays was not provided. About 80 to 84 percent of water was unproductively released to the right-bank part of the delta.

Transformation of the ecological situation is the indispensable consequence of changes in the water supply regime in the wetlands. To monitor these changes, the field survey was undertaken in the Left Bank, Central and Right Bank zones of the South Prearalie in summer 2002.

9.1. The Karadjar lakes

Water supply of the Karadjar lakes is provided through the Raushan Canal, which is divided into two branches in the vicinity of the Mashankul village – the Sudoche Canal and the Raushan channel. The latter flows into the Mashankul Lake, then water runs through local channels into the Hodjakol and Ilmenkol lakes. The control structure was built at the Raushan canal close to the Mashankul village with the purpose of diversion of river water through the GK (the former Usturt) drainage canal into the lakes of the Sudoche wetland.

Water supply through the Raushan canal was started at the end of June. Water discharge to the GK drainage canal has reached 12 m^3/s in the mid of July; at the same time, a flow rate amounted to 5.1 m^3/s in the Raushan branch and 0.11 m^3/s in the Sudoche Canal. Water after filling the most part of the Mashankul Lake bed has flooded vast reed thickets and formed impassable marshlands. Water salinity levels in the littoral zone were 1.3-1.5 g/l.

The Hodjakol Lake started to fill up at the end of July, and by the end of this month, the water has only flooded the dried bed of the central stretch of the lake. A length of water surface area did not exceed 2 km and a width was 0.8-1.0 km. Water salinity levels have reached 4.7 g/l. Water did not flow further beyond the bounds of the Hodjakol Lake, and all downstream lakes, including the Ilmenkol Lake, remained to be dried up.

In fact, no waterfowl was found in the lakes. The absence of birds seems to be caused by the fact that water biota could not develop during a too short rehabilitation period of this lake, and consequently forage resources necessary for birds were unavailable here.

By the end of July, a water supply through the Raushan Canal was actually stopped - a discharge amounted to only 1.8 m^3/sec; there was no water in the Sudoche Canal; the Sudoche control structure and all downstream canals were semi-dry.

Littoral zones of the lakes and canals were occupied by the following landscape-forming plant associations:

1. The *Phragmites australis* association occupied all shores of the lakes. The floristic composition consisted of 2 to 3 species. The projective cover degree has reached 100 percent.

2. The *Tamarix hispida-Phragmites australis* association was widely spread close to coastal zones of the lakes and outside of them; this association forms vast reed meadows. The projective cover degree was 80-90 percent. A reed-bed and meadows were intensively used for haymaking and cattle pasturing.

3. The *Atriplex lasiantha- Tamarix hispida* association has occupied vast territories of arid lands, including single bushes of *Alhagi pseudalhagi* and *Zygophyllum oxianum*. The projective cover degree was 80-90 percent.

4. The *Glysyrrhza glabra* association was found only on side-slopes of canals. Plants reached 80-120 cm height, the projective cover degree has reached 100 percent. Apart from single reed specimens, the association did not include other species of vegetation.

5. The *Tamarix hispida-Alhagi pseudalhagi-Karelinia caspica* association consisted of two layers. *Tamarix hispida* has dominated in the first layer (a height of plants reached 2.5 m), *Alhagi pseudalhagi* and *Karelinia caspica* have dominated in the second layer (a height of 0.8-1.2 m). The overall projective cover degree amounted to 80 percent, on the average.

6. The *Karelinia caspica-Halimodendron halodendron-Tamarix hispida- Elaeagnus turcomanica* association consisted of four layers. *Elaeagnus turcomanica* has dominated in the first layer, *Tamarix hispida* in the second layer, *Halimodendron halodendron*, *Karelinia caspica*, *Alhagi pseudalhagi*, and *Zygophyllum oxianum* in the third grass layer, *Aeluropus litoralis* and annual grasses in the fourth layer. The first layer had a height of 5- 6 m, the second one - 2.5-3.0 m, the third one - 0.8-1.0 m and the fourth one – up to 0.4 m. The projective cover degree has reached 100 percent.

7. The *Populus pruinosa-Tamarix hispida-Eleaegnus turcomanica-mixtoherbosa* association had a clear-visible four-layer structure. The first layer was presented by *Populus pruinosa* having a height of 10-15 m; the second layer - *Eleagnus turcomanica* with a height of 5-7 m; the third one consisted of bushes with prevalence of *Tamarix hispida* and *Halimodendron halodendron*. The projective cover degree of grass was 50-60 percent.

Plant associations on the territory of the Karadjar lakes were characterized by the intensive development and sound physiological conditions of grass and bush vegetation as well as the absence of *Salsola* and *Halostachys caspica* in its composition – these plants are inherent to salt-affected soils. By the end of 2002 and in the first half of 2003, as a result of the intensive water supply through the Raushan Canal, recovery of the water regime in all the Karadjar lakes took place with outflow of surplus water towards the Sudoche wetland.

9.2. The Sudoche Wetland

The KKC and GK drainage canals and the Sudoche Canal are the main water sources for the wetland. Their construction has been not entirely completed in due time. The channels of the Sudoche Canal and the GK drainage canal has come to their end at the distance of 2-3 km short of the Big Sudoche Lake; at the same time the KKC drainage canal has come to its end at the site located between the Karateren and Taily lakes.

In summer of 2002, filling of the wetland lakes with water was very slowly. The GK drainage canal was empty during the last ten-day period of July, and a discharge in the KKC drainage canal was only about 8.3 m^3/s (an average annual discharge of 20.4-22.1 m^3/s). The most part of the central stretch, eastern and southern parts of the Akushpa Lake remained a dry terrain. The water surface area amounted to 2,795 ha (24 percent of the original water surface area), its length did not exceed 8.5 km. Water covered only a small part of the Karateren Lake (an area of 21 ha or 4.2 percent of the original water surface area) having a length of 1.4 km and a width of 0.15 km. Reed thickets have remained on a dry terrain. The Begdulla-Aidyn and Big Sudoche lakes were filled with water but their depth did not exceed 20-30 cm. Shallow depths of these lakes promoted aquatic vegetation development; at present the vegetation covers the central stretches of lakes, which were usually actually bare.

Water levels of the wetland lakes as of the 2002 spring-summer period (a mean annual level of the Akushpa Lake is 52.61 m + BSL) are given in Table 9-1.

Table 9-1 Water Level in Lakes of the Sudoche Wetland, 2002 (in m + BSL)

Lake	March	April	May	July	August
Akushpa	51.41	51.46	51.44	51.49	51.520
Karateren	49.99	50.03	50.07	49.65	50.003
Big Sudoche	51.33	51.60	51.44	51.66	51.760
Begdulla-Aydin	51.56	51.64	51.49	51.70	51.807

Water salinity levels in the Big Sudoche and Begdulla-Aydin lakes have reached 2.9-3.1 g/l, in the Karateren Lake – 15.0 g/l, and in the Akushpa Lake – 32.5 g/l. Water salinity in the KKC drainage canal was 2.1-3.6 g/l. The analysis of heavy and non-ferrous metal concentrations in bed deposits has showed that strontium had the highest concentration (Table 9-2). At the same time, in the course of field gamma radiation surveys excess of the natural background of 5-7µR/h (vrhP/h) was not found, and therefore it is possible to assume that strontium in bed deposits has its natural origin rather than man-caused one. High concentrations of heavy and non-ferrous metals (zinc, nickel, lead, uranium and arsenic and others) in bed deposits resulted from soil properties to absorb these substances from water masses.

Fishermen crews that used to fish on these lakes have left the wetland. Waterfowl was not actually observed. Fauna of the wetland was notable for mass concentration of Asian locusts; the basis for heavy locust breeding was vast territories covered by dried up reed thickets providing favorable conditions for egg laying and developing larvae. Especially big swarms of locusts were observed in the vicinity of the lakes Karateren and Taily. Locusts damaged most of reed thickets around these lakes and started exerting a threat to adjacent agricultural lands. The agricultural aviation of Uzbekistan was employed for combating locusts using insecticides sprayed by planes. Main swarms of locusts were annihilated, but single, sometimes numerous, gatherings of these insects have still remained.

The vegetation cover of the wetland was characterized by the poor floristic composition. Coastal vegetation along the GK and KKC drainage canals was presented by the following species: *Phragmites australis*, *Tamarix hispiga*, *Tamarix ramosissima*, *Halostachys caspica*, *Alhagi pseudalgagi*, *Karelinia* *caspia*, *Zygophyllum oxianum*, *Aeluropus litoralis,* and *Salsola*. The projective cover degree was 50-60 percent; in some places it has reached 100 percent. The driest zone of the wetland was its southern part. Solonchaks prevailed in this area; vegetation was presented by the following associations:

1. The *Salsola dendroides* association consisted of Russian thistle with a height of 60-80 cm. The projective cover degree was 60-70 percent.

2. The *Halostachys caspia-Tamarix hispida-Salsola sp* association is the most widespread one. The projective cover degree ranged from 10 to 80 percent. Vast bare plots have dominated in this association's area.

3. The *Climocoptera aralensis-Suaeda sp*. association is characterized by poor floristic composition. The projective cover degree was 20 to 40 percent.

4. The *Alhagi pseudalhagi-Tamarix hispida-Haloxylon aphyllym* association had the three-layer structure. The first layer consisted of *Haloxylon aphyllym* 2.5 to 3 m high, the second layer was presented by *Tamarix hispida* (a height of 1-1.5 m), and third one - by *Alhagi pseudalhagi* (a height up to 0.7 m). The projective cover degree was 70 percent.

The south-western part of the wetland close to the Usturt Plateau cliff was characterized by domination of different species of *Salsola*, *Halostachys caspica,* and *Tamarix hispida*. The projective cover degree varied from 20 to 90 percent.

Halostachys caspica, *Tamarix hispida*, *Salsola dendroides,* and *Atriplex sp.* dominated in the northern part of the wetland. The projective cover degree varied over the range of 10 to 70 percent. Thickets of *Atriplex sp* had the most projective cover degree.

Table 9-2 Heavy Metal Concentrations in Bed Deposits in Lakes of the Sudoche Wetland, mg/kg

Water Body	Cu	Zn	Ni	Mn	W	As	Sb	Co	Cr	U	Th	Sr	Pb	Mo	V	Se
Taily Lake	22	68.4	47.6	704	0.7	41	0.1	12.1	64	9.7	7	1234	24.4	0.6	62	0.51
Taily Lake	24	66.5	50.4	814	2.1	36.7	0.2	10.6	59	10.9	5.8	1404	14.6	0.5	50	0.39
Taily Lake	30	119.7	44.8	616	6	40.5	0.7	12.3	71	11.5	6	932	24.2	4	62	0.32
Akushpa Lake	20	62.7	39.2	550	2	50.3	0.7	9.4	49	16.6	6.2	1781	22.6	3.3	56	0.35
Akushpa Lake	10	89.3	33.6	484	5.1	41.7	0.6	7.7	38	15.7	4.2	2724	17.2	0.5	45	0.39
Akushpa Lake	12	47.5	39.2	396	1.7	26.8	0.7	5.5	31	17.5	4.5	2643	17.6	2.1	39	0.35
Akushpa Lake	24	68.4	42	616	1.6	29.1	1.1	10.4	56	8.2	5.7	1265	20.8	1.6	67	0.25
Akushpa Lake	10	41.8	28	352	2.7	21.3	0.6	4.4	37	10.3	3	2305	14.9	1.3	50	0.29
Akushpa Lake	20	45.6	28	396	1.1	30.1	0.3	6.4	45	14.6	3.9	2809	16.3	1	34	0.44
Karateren	22	114	81.2	792	0.1	25.3	0.6	10.1	83	9.1	6.3	1503	14.3	1.5	39	0.24
Karateren	24	66.5	44.8	1210	2.7	24	1.1	10.6	80	10.3	5.8	1443	22.2	3.4	56	0.51
Begdulla-Aydin	22	60.8	36.4	748	1.2	18.3	1	9.6	66	5.6	3.9	1191	13	0.5	50	0.33
Big Sudoche	18	43.7	44.8	572	0.1	3.9	0.4	6	37	23.3	3.1	2120	18.8	4.2	62	0.33
Big Sudoche	14	36.1	42	352	0.1	6.8	0.3	3.9	51	16.1	2.9	2051	15.2	0.5	39	0.4

Salsola, *Halostachys caspica* and to a lesser extent *Tamarix hispida* were major landscape-forming vegetation species in the wetland. Reed meadows were in the suppressed state due to overgrazing, insufficient soil moisture and damage by locusts.

In August 2002, intensive filling of the wetland lakes resulted in a water level rise - by February 2003 the Akushpa Lake water level had reached an elevation of 52.5 m +BSL. The water surface area in the Karateren Lake had spread to the Akkum Dam; here water was discharged through the spillway towards the Adjibay Bay with the flow rate of 3-5 m^3/c, by May 2003, the discharge have increased up to 10-15 m^3/c.

9.3. Muynak Bay

The Glavmyaso Canal is the source of water supply for this reservoir. The most part of the water body is presented by a strip located along the dam with a round-shaped central sand bar. The reservoir was 6.5 km long and 150-200 m wide; the central sand bar was 2.0 km long and 1.2 km wide. A depth close to the dam was 2.5-3.0 m, at the shallow stretch - 0.7- 0.9 m. The northern part of the bay to the point of the Muynak Bay was filled with water. The southern part of the bay was dry. The water level in the reservoir was 50.94 m +BSL.

Water salinity levels were 3.5-3.8 g/l. According to its chemical composition, water belongs to the sulfate class and the sodium group; according to salt content it can be referred to moderately brackish water adequate for fishery. However, due to over-catching that has taken place last year, the reservoir has lost its fishery significance. Waterfowl was not observed in the bay.

The offshore strip as well as new-flooded areas and the southern part of the bay were overgrown by reed (*Phragmites australis*) and to a lesser extent by cattail (*Typha angustifolia*). Reed thickets in the zone adjacent to the dam were partly damaged by locusts.

Tamarisk formations (*Tamarix hispida*) prevailed in vegetation cover of this area. *Tamarix ramosissima-Calligonium caputi-medusea* and *Tamarix ramosissima-Karelinia caspia* associations were the most typical ones for the area adjacent to the Muynak Bay.

The territory adjacent to the dam at the opposite side represents a slightly undulating dry plain overgrown by the *Halostachys caspia- Tamarix hispida- Salsola dendroides* association with the projective cover degree of 40 to 50 percent.

In the northern part of the bay there were small associations of *Ammodendron longiracemosum.* The association had the poor composition of species with plants 0.6-1 m high. The projective cover degree ranged from 20 to 30 percent.

9.4. Ribache Bay

The sources of water supply are the Glavmyaso Canal and the Kabulbay canal, which escapes from the Makpolkol Lake. Water drawdown is made through the Gonchak Canal at the northern end of the water body.

In autumn 2001, the reservoir consisted of two isolated parts: the small one close to the dam and the big one in the central part (the so-called Lake Sarybas). During summer 2002, both parts of the lake have merged creating a single water body 8 km long, 6.6 km wide, and 2.5 m deep. The water level was 51.9 m +BSL. Water salinity was 2.4-2.8 g/l. Sulfates, chlorides and sodium ions prevailed in the chemical composition of its water. Water was classified as the sulfate-sodium one of the second class; according to salt content it can be referred to moderately brackish water adequate for fishery. However, similar to the Muynak Bay, due to over-catching that has taken place last year the reservoir has lost its fishery significance. Waterfowl was not observed in the bay

The offshore strip of the reservoir was covered by newly-grown reed thickets, but with increasing the distance from this zone, the following plant associations dominate within the local phytocenosis:

1. The *Tamarix ramosissima-Alhagi pseudoalhagi* association has spread throughout the territory, but occupied relatively small areas with the projective cover degree reaching 60 to 70 percent;

2. The *Atriplex sp.-Tamarix hispida* association has spread over dry areas; *Zygophyllum oxianum* and *Alhagi pseudoalhagi* were found in its composition. The projective cover degree changed over the range of 30 to 70 percent.

3. The *Karelinia caspia- Alhagi pseudoalhagi* association was one of the dominating assotiations in the tugai forest complex. The projective cover degree has reached 100 percent;

4. The *Tamarix ramosissima-Salsola sp*. association occupied salt-affected areas adjacent to the bay. The projective cover degree did not exceed 40 to 60 percent.

5. The *Populus sp*. association was characterized by trees degradation, which become apparent in a top-wither of aging trees and complete drying of some of them. Some of them were 5-6 m high. Degradation of soft poplar groves is one of the first indicators of desertification.

The tamarisk formation was dominating in the vegetation cover of the area around the Ribache Bay.

9.5. Makpalkol Lake

The Marinkinuzyak Canal 9 m wide and 3 m deep and its distributary - the Zinetjargan Canal (a width of 35 m; a depth of 5.5 m) are the sources of water supply for this lake.

In summer 2002, the lake 8 km long and 3.6 km wide was filled with water, and lakesides have become swamps abundantly overgrown by semi-aquatic and grass vegetation. The open water surface was veiled by terrestrial plants, which have completely covered the water body's bed during previous dry years.

Water salinity levels in the lake have reached 1.1-1.2 g/l. According to the water salinity level, the lake was referred to low-brackish water bodies with water suitable for crop irrigation and fishery.

The following plant associations have spread over the offshore strip:

1. The *Tamarix ramosissima-mixtoherbosum* association was characterized by diversity of species. The bush layer was presented by tamarisk; the main components of the grass layer are *Glycyrrhiza glabra*, *Alhagi pseudoalhagi*, *Aeluropus sp*, *Zygophyllum oxianum*, *Karelinia caspia* and other species. Some plants were 1.0-1.5 m high. The projective cover degree was of 80-100 percent.

2. The *Phragmites australis-Glycyrrhiza glabra-Atriplex sp.* association. Thick newly-grown reed thickets prevailed in this association. The projective cover degree has reached 90 to 100 percent.

Banks of the Glavmyaso and Zinetjargan canals were overgrown with tree species - poplar (*Populus pruinosa*) and oleaster (*Elaeagnus turcomanica*). Poplars were 10 to 12 m high. *Tamarix ramosissima*, *Halostachys caspica*, *Karelinia caspia*, *Alhagi pseudoalhagi,* and *Zygophyllum oxianum* have prevailed in areas adjacent to canals.

The vegetation cover in the offshore strip was distinguished by the intensive development and good physiological state of green biomass.

9.6. Mezdureche Reservoir

The western and northern parts of the dam, which forms this reservoir, stretch out along the Kipchak-darya channel, and the eastern part of the dam rounds the Akdarya river channel. The water intake of the Glavmyaso Canal has been built in the body of the dam in the vicinity of the Kyzyljar village. The water intake of the Mainkinuzyak canal is located near the Porlopau village. In the second part of July, water withdrawal by both canals amounted to 15 and 40 m^3/sec respectively. In August, water inflow into the Amu Darya delta stopped due to decrease in water availability in the river. Consequently, water releases into the above named canals were cut off. The water surface area in the Mezdureche Reservoir during the summer high water period had a length of 18-19 km and a width of 15-16 km.

In 2002, the construction of a lateral weir was completed in the lower part of the eastern dam. The weir length was 1800 m; its designed discharge was 3600 m^3/sec. In summer, during 31 days, water has been released over the weir towards the Dumalak system of lakes. During that period, subsidence of some concrete slabs took place, which resulted in damage of the weir surface.

Water levels at the lateral weir for the second and third ten-day periods of July (the design elevation of the weir crest is 56.0 m) are given in Table 9-3

Table 9-3 Mezdureche Reservoir Water Levels, 2002

Days of month							12	13	14	15	16
Water level, m							56.28	56.32	56.36	56.41	56.47
18	19	20	21	22	23	24	25	26	27	28	29
56.52	56.52	56.41	56.37	56.28	56.23	56.16	56.16	56.05	56.03	56.00	55.97

When operation of the lateral weir was stopped, the unaccounted outflow from the reservoir continued through the Tishkanuzyak watercourse towards the Dumalak lakes system. The flow rate through this watercourse was 12-15 m^3/sec.

The water salinity level in the reservoir has decreased to 0.6-0.9 g/l. In the chemical composition of water, primary anions were sulfates and chlorides, and primary cations were sodium and magnesium. Water was referred to the sulfate-sodium class of the group of sodium and magnesium; according to concentration of salts, water is fresh and suitable for household, drinking and industrial water use as well as for fishery. Newly-formed fauna of fish had low productivity.

There were not closed reed thickets in the reservoir. Reed occupied relatively small isolated sections of the coastline. Coastal vegetation of the reservoir was represented by the following plant associations:

1. The *Phragmites australis-Karelinia caspia-Atriplex sp* association, which was most often found in the northern and western parts of the reservoir. The projective cover degree has reached 100 percent.

2. The *Salsola dendroides-Tamarix ramosissima* association was the most widespread one. The projective cover degree was 80 percent.

3. The *Tamarix ramosissima* association covered some relatively small areas. The projective cover degree was ranging from 40 to 60 percent.

4. The *Populus pruinosa-Tamarix ramosissima-Elaeagnus turcomanica* association occupied the banks of the Akdarya River and, to a lesser extent, of the Kipchakdarya River. The projective cover degree was 90 percent. The association had the four-layer structure. The first layer consisted of poplar trees 10-12 m high. The second layer was presented by *eleagnus* (a height of 3-4 m). The third layer was presented by tamarisk and the fourth one by grasses.

5. The *Alhagi pseudalhagi- Karelinia caspia* association occupied relatively small isolated areas most often located in natural depressions. The projective cover degree was 80-100 percent.

The Amu Darya channel, downstream the Porlatau Village, remained dry. The river bed was covered with dune sand; the banks were overgrown with tamarisk (*Tamarix sp*.) and poplar (*Populus pruinosa*).

9.7. Djiltirbas Bay

The most part of water that reached the Amu Darya delta was used for filling the Djiltirbas Bay, the water surface area of which stretched for 20-22 km from the north to the south and come closely to the KKC drainage canal. The water level in the part of the bay close to the dam was 50.51 m +BSL.

Water salinity levels have reached 3.4-3.5 g/l. Sulfate and chloride anions and sodium cations prevailed in the chemical composition of water. Water was referred to the sulfate-sodium class, according to the salinity level - to moderately brackish waters suitable for fishery.

The central shallow stretch of the bay, especially its southern part, was surrounded by flooded reed thickets forming vast wetlands. In summer, the Djiltirbas Bay area with newly-grown reed thickets and open water surfaces attracted a great number of waterfowl and birds breeding near water bodies.

Halostachys caspica and *Tamarix hispida* dominated in the vegetation cover of the offshore strip of the bay. Two phases of plant association development have been distinguished: the transition phase – from *Tamarix hispida* to *Halostachys caspica* and the phase of the typical *Halostachys caspica-Tamarix hispida* association. The two-layer structure is typical for this association: the first layer 1-2 m high is presented by *Tamarix hispida* and *Halostachys caspica,* and the second one consists of low-density and floristic-poor grass vegetation. The projective cover degree was 50- 60 percent.

Suaeda crassifolia-Climocoptera sp associations were rarely found. The projective cover degree did not exceed 30 percent. Single spots of *Salsola nitraria* and *Atriplex sp* were observed.

Vast areas along the south-western wet coast of the Djiltirbas Bay were occupied with thickets of *Alhagi pseudalhagi*, *Karelinia caspia*, *Zygophyllum oxianum,* and *Phragmites australis*. The projective cover degree was 80-100 percent.

There are several self-discharging artesian wells on the dried up territory of the bay with brackish (1.5-2.0 g/l) and warm (38 - 40 C^o) water. Camps of herders who are engaged pasturing their cattle and harvesting reed for forage are located around artesian wells.

9.8. The КС-3 Drainage Canal

The КС-3 drainage canal close to the southern extremity the dam forming the Djiltirbas Bay turns towards the Right Djiltirbas channel. At this point the drainage canal had its width of 45 m and its depth of 1.2-1.8 m. The water level was 48.85 m +BSL; the flow rate was 5.6 cu m per second.

The water salinity level did not exceed 2.-2.3 g/l. Sulfate and chloride anions and sodium and magnesium cations prevailed in the chemical composition of water. Water was referred to the sulfate class of the sodium-magnesium group, according to salinity - to brackish waters suitable for fishery.

The middle section of the drainage canal runs through a deep ravine with the right steep and the left gently-sloping slopes. Several destroyed and operable bridges cross the drainage canal; and three rusty hulls of big dredgers lay at its banks. The drainage canal banks are covered by scattered reed thickets.

Coastal vegetation is presented by the following plant associations:

1. The *Karelinia caspia-Alhagi pseudalhagi-Elaeagnus turcomanica* association is the most wide-spread one in the mid section of the drainage canal. The projective cover degree was 60-70 percent.

2. The *Tamarix ramosissima-Populus pruinosa-miztoherbosum* association occupied the wet territories and had the diverse composition (more than 20 species). The projective cover degree has reached 100 percent.

3. The *Salsola dendroides-Alhagi pseudalhagi* association. Russian thistle dominated here. The projective cover degree did not exceed 70 percent.

4. The *Haloxylon aphyllum-Halostachys caspica-Salsola sp.* association covered relatively small elevated areas. The projective cover degree was 40-60 percent.

5. The *Suaeda crassifolia-Salsola sp*. association occupied the driest areas. Rare haloxylon bushes 1.5 m high were found within the association. The projective cover degree did not exceed 20 percent.

6. The *Atriplex sp*. association formed small but dense vegetation covers with the projective cover degree of 100 percent.

9.9. The КС-1 Drainage Canal

A flow rate of this drainage canal has reached 12-15 m^3/s. Water salinity level did not exceed 2.1g/l. According to the salt content, water was classified as the sulfate-sodium type, moderately brackish and applicable for fishery. Large gatherings of fry were observed in this drainage canal.

Phytocenosis on banks of the drainage canal is presented by the following plant associations:

1. The *Alhagi pseudoalhagi-Salsola dendroides* association occupied the wettest areas. The projective cover degree has reached 100 percent. Sprouts of reed were often observed among alhagi thickets.

2. The *Karelinia caspica-Alhagi pseudoalhagi* association prevailed on the right bank of the drainage canal. The projective cover degree was 80-90 percent.

3. The *Tamarix ramosissima-Alhagi pseudoalhagi* association prevailed on the left bank and had the two-layer structure: the first layer was formed by tamarisk, and alhagi prevailed in the second one.

9.10. Assessment of the Ecological Situation

The field survey of Prearalie’s territory shows that water inflow into the Amu Darya delta has caused a decrease in water salinity in all water bodies except the lakes Akushpa and Karateren, and the Sudoche wetland, which remained without a sufficient water supply (Table 9-4). As a result, the ecological situation in water bodies of the Central and Right Bank Zones has improved significantly. The situation in the Left Bank Zone has not undergone considerable changes.

Table 9-4 Chemical Water Composition of the South Prearalie Water Bodies (g/l /meq)

No	Water body	Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	HCO_3^{-}	SO_4^{2-}	Cl^{-}	Σ 2002	Σ 2001
1	Mashankol Lake	0.1 4.9	0.12 9.7	0.44 19.28	0.03 0.16	0.85 17.68	0.56 15.69	2.1	Dry
2	Hodjakol Lake	0.36 0.98	0.27 12.26	1.0 24.56	0.05 0.501	2.12 25.74	1.3 20.45	5.1	5.8
3	KKC Drainage Canal	0.35 17.5	0.21 17.5	0.29 11.6	0.219 3.6	1.2 25.0	0.639 18.0	2.92	14.4
4	Karateren Lake	0.74 37.0	1.03 109.0	2.8 120.5	0.39 6.45	6.5 135.0	4.1 125.0	15.36	54.0
5	Akushpa Lake	0.96 48.0	2.56 209.0	6.21 270.0	0.35 5.75	12.91 254.0	9.49 267.3	31.56	Dry
6	Begdulla-Aydin Lake	0.480 24.0	0.232 19.0	0.291 12.6	0.317 5.2	1.248 26.0	0.869 24.48	3.280	Dry
7	Ribache Bay	0.16 7.45	0.26 19.7	0.3 13.17	0.09 1.53	0.99 20.53	0.67 18.32	2.47	14.0
8	Ribache Bay	0.17 8.67	0.28 22.8	0.35 15.2	0.104 1.77	1.15 23.75	0.78 21.2	2.83	8.9
9	Muynak Bay	0.18 8.91	0.28 16.92	0.71 30.61	0.07 0.48	1.47 30.59	0.91 25.5	3.62	14.6
10	Muynak Bay	0.19 9.66	0.31 18.3	0.76 33.18	0.08 0.52	1.59 18.56	0.98 27.6	3.91	19.5
11	Makpalkol Lake	0.17 7.52	0.05 4.48	0.16 5.47	0.17 2.59	0.32 7.0	0.30 8.46	1.17	Dry
12	Mezdureche Reservoir	0.8 4.0	0.87 7.2	0.28 11.2	0.17 2.8	0.65 13.6	0.85 24.0	1.35	Dry.
13	Djiltirbas Bay	0.26 12.51	0.19 15.2	0.64 27.9	0.1 1.60	1.47 32.1	0.9 23.6	3.56	Dry.
14	KC-3 Drainage Canal	0.1 4.9	0.12 9.7	0.44 19.28	0.03 0.16	0.85 17.68	0.56 15.69	2.1	13.2

The improvement of water quality in the South Prearalie has resulted in the most positive impact on terrestrial vegetation. This positive impact is most visible in physiological improvements of plants, enhancement of their growth coverage, and biodiversity. The intense natural regeneration of phytocenosis is occurring within the Amu Darya delta due to these improvements (Figure 9-3).

The following major terrestrial plants populate the landscape in the South Prearalie: *Phragmites australis, Tamarix hispida*, *Halostachys caspica*, *Salsola dendroides,* and *Atriplex sp*. Regeneration of phytocenosis has resulted in a noticeable increase in pheasant and hare populations.

The study of ecological condition in the South Prearalie during 2000-2003 has shown that after the severe draught of 2000-2001, which caused disastrous deterioration of ecological conditions, the rehabilitation of water runoff into the Amu Darya river resulted in some improvement by the end of 2001 and then, by the middle of 2003, to a full recovery of the hydrological regime in key water bodies, and eventually, to an all-round improvement of the ecological conditions of this region.

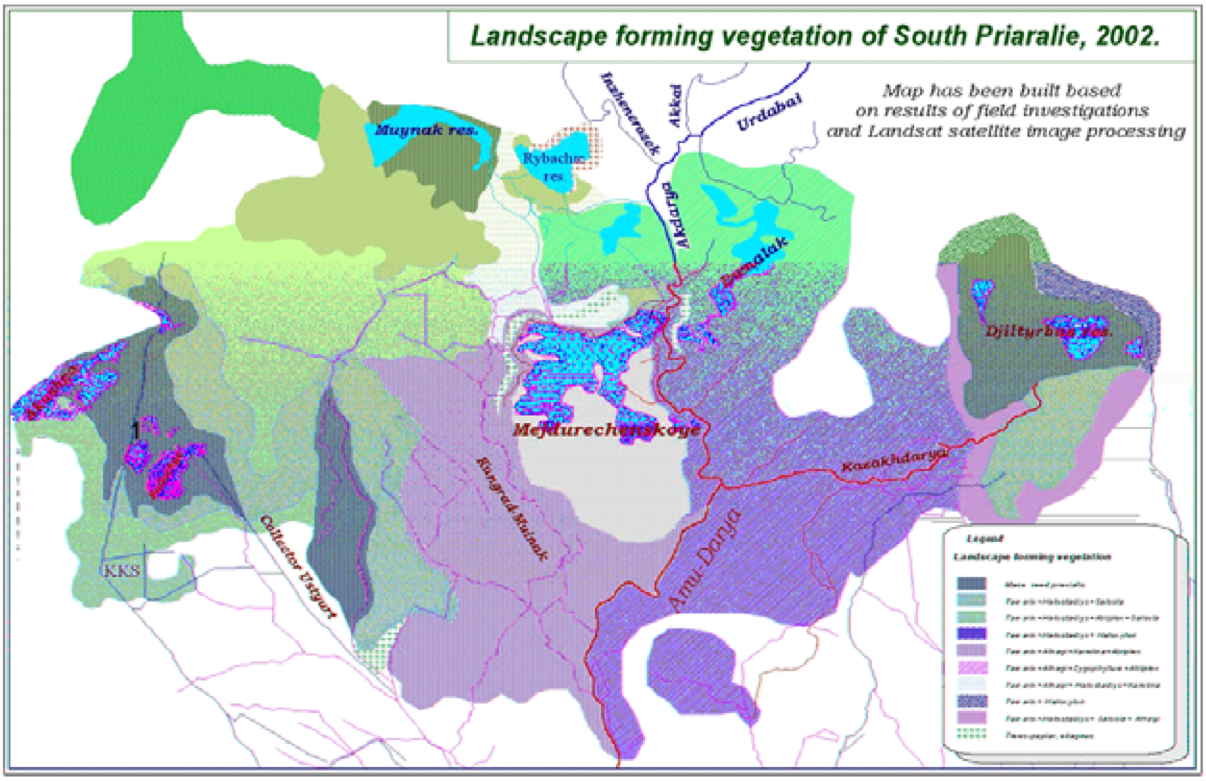


Figure 9.3

9.11. Wetlands Classification

The retrospective analysis of the ecological condition in the South Prearalie has shown that out of all local ecosystems, wetlands have the highest capabilities for rehabilitation and conservation of biodiversity, and productivity of biological resources. Wetland ecosystems are widely used by local population for purposes such as:

1. A source of vegetative row materials – primarily reed;
2. Fish-breeding areas;
3. Muskrat hunting grounds.

Therefore, the creation of a widespread system of controlled wetlands will be the most effective means to reduce negative social consequences of the Aral Sea crisis.

However, current water management practices in the Amu Darya river delta do not ensure a secure water supply for all wetlands in the South Prearalie. Perennial and transient lakes, short-lived water bodies and flood-plains, which are able to provide sustainable development of only certain biological resources will form depending on the existing water supply regime. In turn, each water body has its own environmental requirements (Figure 9-4).

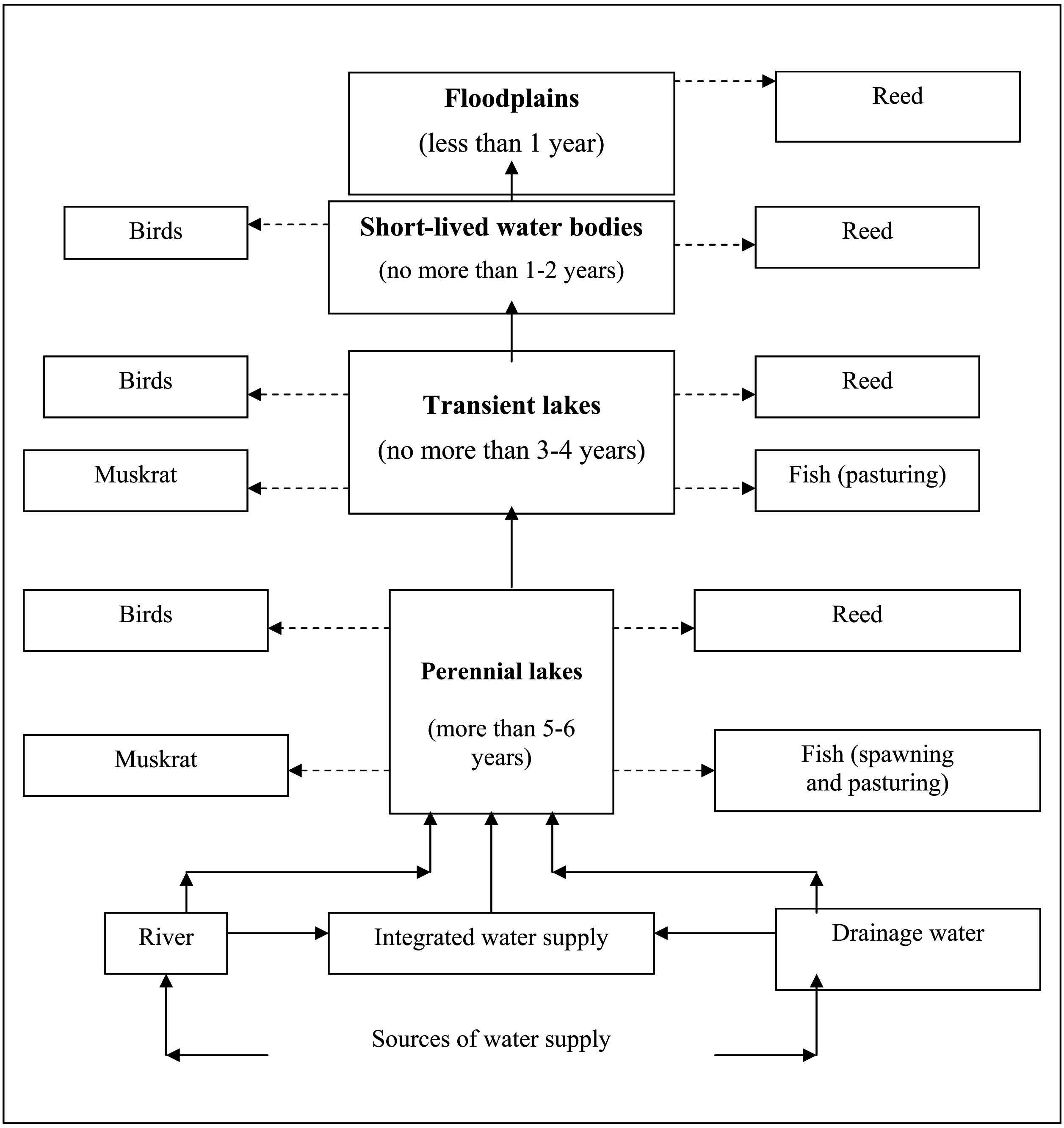


Figure 9-4 Wetland Classification and Manner of Their Bio-Resources Use

9.12. Environmental Requirements

The basic bio-resources from wetlands that are desired by the local population are reed, commercial fish species, muskrat and waterfowl.

Reed

Prior to the Aral Sea crisis, reed thickets have occupied the most part of the Amu Darya delta. The reed biomass reached 40 t/ha (a dry weight). At present, the area under reed growth has considerably reduced, and reed itself has degraded to a greater or lesser extent. The reed biomass does not exceed 20-25 t/ha of a dry weight (mainly 10-15 t/ha, and at sites with high salinity – 1.5-5 t/ha).

Reed grows in the South Prearalie wetlands in two forms – aquatic and meadow. Because of the complexity of economic use, aquatic reed thickets play mostly an ecological role by providing shelters and food to local and global (migratory birds) fauna. Meadow reed thickets have a greater economical significance and are extensively used for forage and summer cattle pasturing.

One of the basic parameters for good water reed stand development is the water salinity level. Salinity within the limits of 4 to 10 g/l does not impede plant growth, but any increase over 15 to 20 g/l results in a decline of reed thicket growth to total disappearance.

Flow-through in water bodies is another key condition for good reed development. Reed thickets growing in water bodies with low flow-through and water salinity less than 8 to 10 g/l are usually replaced by cattail, which has a low economic value. As water depth within a dense stand of reed thickets reaches 1.2 to 1.3 m, this exceeds the most optimal water body conditions for reed thicket development, which are depths of no greater than 1.0 to 1.2 m.

The basic conditions necessary for good meadow reed thicket development are a high level of moisture content and acceptable soil salinity that result in an osmotic effect of no greater than 30 to 40 bar.

Soils found in the South Prearalie are composed of chloride-sulfate soils with chlorine-ion content less than 0.1-0.25 percent and total salt content less than 0.9 percent. On more saline soils reed growth is constrained, and on heavy saline soils (salt content is 6 percent, and chlorine-ion content is 1.85 percent) – reed growth practically ceases.

In dry years the groundwater table maintained at the depth of 2.5 to 3 m enables reed roots to retain their viability for a period of 2 to 3 years. Restoration of a water regime will permit the recovery of reed thickets of wetlands.

Recovery of reed thickets also occurs as a result of seed reproduction. Exposed to sufficient light and moisture, the reed seeds generate significant new growth and by the end of the first growing season visible roots of about 5 cm in diameter are formed. By the second year, reeds grow to 1m in height, and by the third-fourth year full-fledged thickets are spreading out.

Fish

For the reproduction and development of fish species specific abiotic and biotic environmental conditions should be provided. Abiotic conditions should meet the following requirements: dissolved oxygen content not less than 4-5 mg/l, a free water surface should occupy not less than 50 percent of a water body; with an average depth no less than 1.5 m. A free standing water surface is required for mixing water masses by wind – the main source of dissolved oxygen; the above mentioned depth – for maintaining fish population in winter.

In spawning water bodies during fish reproduction (April-June) water level fluctuations should not result in abrupt shoaling of shallow waters, where spawning and fry growth take place. Salinity in spawning water bodies must not exceed 5 g/l. Exceeding this salinity level may lead to the loss of spawn, larva and fry. Adult fish can endure higher levels of salt concentration. Salinity levels up to 10-15 g/l do not exert adverse influence their weight, fertility, and rate of growth.

Ideal biological conditions are, first of all, adequate forage resources – sufficiently large areas of shallow waters overgrown with aquatic vegetation, with well developed plankton and benthos, and acceptable levels of food competition along with pressure from predators.

As a rule, the South Prearalie water bodies possess good forage resources for development of local fish species – Common Carp, Crucian Carp, Roach and such introduced herbivorous species as Bighead Carp, Grass Carp and others. However, if conditions for reproduction of local fish species were sufficiently favorable in the lakes, then for introduced species (30 percent of the total catch) these conditions would prove unsuitable. Replenishment of these fish species population is assured through a supply of young fish from the Amu Darya River. Therefore, river water releases during the period of reproduction of these fish species play a significant role in augmenting the natural resources of the wetlands.

Muskrat

Muskrat, which was introduced into the South Prearalie in the late 1940s, have populated the entire territory of the Amu Darya delta by the beginning of the 1960s. Output of commercial trapping of this fur-bearing animal reached several hundred thousand pelts per year. However, due to the deterioration of ecological conditions the muskrat population, and the area of its habitat has decreased significantly and at present this economic activity has virtually stopped.

The basic conditions for providing suitable habitat for muskrat are well developed reed and cattail thickets (for protective cover and forage), and water bodies having a depth more than 1.5 m. This depth is required for maintaining passageways to forage grounds in winter. During colder periods, as a rule, water level changes exceeding 30 cm result in a decline of suitable wintering conditions and consequently in the death of animals. Salinity does not directly have an impact on muskrat, but it does impact on the development of reed and cattail thickets and plays a serious mitigating role in the stabilization and development of the muskrat population. Muskrat population density of 4-5 families/ha and the commercial trapping of 20-25 animals per a year does not exert a significant impact on reed thickets.

In winter, predators (wolves, foxes, and jackals) most notably affect the muskrat population; much greater damage is inflicted by wild boars, which destroy muskrat lodges. Heavy muskrat population losses are mostly caused by pouching, especially during the reproductive period.

Birds

The main ecological conditions required for birds are the preservation of suitable water areas with well-developed surface aquatic vegetation providing shelter and protection, especially during periods of nesting and hatching. As a rule, destruction of reed and cattail thickets results in the reduction of populations of waterfowl and water-related birds. Another required condition is the presence of vast shallow water areas, bays, and stretches with abundant and accessible forage resources – hydro-flora, benthos, and young fish. Water salinity does not directly have an impact on waterfowl but, as in the case with muskrat, its influence becomes apparent through hydro-flora and hydro-fauna productivity.

Composition of ornithological fauna is determined by water body patterns: waterfowl prevail on relatively deep lakes: swans, pelicans, ducks, cormorant, etc, on shallow water bodies – birds of wetlands: sandpiper, herons, sea-swallow, etc.

The degree of human influence plays an important role in the development of the ornithological complex of wetlands; in any case, humans can exert disturbing influences, and if they behave aggressively bird-flocks fly away.

9.13. Requirements to Ecological Conditions of Wetlands

Perennial lakes as a part of the socio-ecological structure of the South Prearalie are the reproductive base of all bio-resources. Consequently, they should provide the ecological conditions necessary to meet the requirements for the successful development of aquatic vegetation, fish, birds and muskrat. These requirements are the following:

Perennial Lakes

- An average depth of no less than 1.5 m, well-developed semi-aquatic vegetation (reed, cattail) covering no more than 50 percent of the water body area.

- Concentration of dissolved oxygen at a level of no less than 4 - 5 mg/l, water salinity levels during spawning and nesting (April-July) of no more than 5 g/l.
- Muskrat population density within the limits of 4-5 families/ha of reed and cattail thickets.
- Water level fluctuations during the period of fish reproduction and in winter – no more than 30 cm.
- Flow-through of lakes and water releases from the Amu Darya River.
- Presence of protected shallow water areas, bays and stretches with well-developed aquatic vegetation, zooplankton, and zoobenthos.
- Prevention of unsustainable economic activities and poaching.

Transient Lakes
The duration of transient lakes is not sufficient to ensure the reproduction of fish shoals. Commercial reproduction of fish in transient lakes would not be practical, and therefore in contrast to water bodies of the first type there is no requirement to meet ecological requirements for fish reproduction. Commercially significant fish shoals will be formed by supply of young fish with the river water inflow. Productivity of fish-farming may be substantially augmented through man-made fish stocking. According to other ecological requirements applied to these lakes, they do not differ significantly from the perennial lakes:

- An average water depth of no less than 1.5 m, well-developed semi-aquatic vegetation (reed, cattail) covering no more than 50 percent of the water body area.
- Concentration of dissolved oxygen at a level no less than 4-5 mg/l, water salinity during spawning and nesting (April-July) of no more than 5 g/l.
- Flow-through of lakes and water releases from the Amu Darya River.
- Muskrat population density within the limits of 4-5 families/ha of reed and cattail thickets.
- Water level fluctuations in winter – no more than 30 cm.
- Presence of protected shallow water areas, bays and stretches with well-developed aquatic vegetation, zooplankton, and zoobenthos.
- Prevention of unsustainable economic activities and poaching.

Short-Lived Water Bodies
Duration of short-lived water bodies is not sufficient for the development of commercial fish and muskrat populations. In terms of economic value, such wetlands are of no importance to the local population, therefore the degree of human disturbance here will be reduced to a minimum. The absence of human disturbance will translate into favorable habitat conditions for waterfowl and birds breeding near water bodies. These wetland territories will be able to serve as a refuge for the conservation of local and global ornithological fauna, and therefore they should meet the following ecological requirements necessary for the development of semi-aquatic vegetation and sustaining birds' habitats:

- Maximum water depth of no more than 1.0-1.2 m.
- Water salinity should be not more than 15 g/l.
- Presence of protected shallow water areas, bays and stretches with well-developed aquatic flora and fauna.

Floodplains
Floodplain wetlands are territories favorable for the development of swamp-meadow and meadow reed thickets and can be used for cattle pasturing and hay harvesting. Short-term water availability limits the development of fish, muskrat and waterfowl and birds breeding near water bodies. Environmental conditions should meet requirements for optimal development of meadow reed:

- Meadow soil salinity no more than 0.9 percent of dry weight with content of chlorine-ion of no more than 0.25 percent.
- Groundwater table - no deeper than 2.0 to 2.5 m.

9. 14. Ecological Importance of Wetlands

Preservation of biodiversity and an increase in natural productivity of biological resources are the most important ecological and social goals that should be achieved in the Prearalie. The determinative role in solving these issues belongs to lakes which possess the high potential bio-productivity and at the same time are the natural refuges for local and global fauna.

The water supply regime of wetlands, especially in dry years, should be based on ecological and social priorities. In this respect, an undoubted priority belongs to the perennial lakes because in dry years they should play the role of refuges to preserve bio-diversity. The lessons learned from the experience of the previous dry years prove that ecosystems of transient and short-lived lakes degrade and fully perish within 1-2 years. Under such conditions, bio-diversity restoration of wetlands will be mainly provided at the expense of bio-resources accumulated in perennial water bodies. The role of these lakes as major reserves of biological diversity and resources stipulate for the need to maintain appropriate hydrological and hydro-chemical regimes of these water bodies, which ensure preservation of their biological potential. The status of perennial lakes within the South Prearalie can be given to such water bodies as the Ribache and Muynak Bays, and the Sudoche Lake.

Transient lakes play the lesser role in conservation of bio-diversity in the South Prearalie but they are more important as sources of socially demanded resources. They are at the second position in ranking the water supply priorities. The status of transient lakes can be given to the Mezdureche Reservoir, the Karadjar system of lakes, and the Malpalkol Lake.

The special importance of short-lived water bodies consists in providing habitats for birds. The South Prearalie is the primary location in the West-Asian flyways of migratory birds. Therefore, the role played by such lakes in preserving bio-diversity of the local and global ornithological fauna is invaluable. However, their bio-resources are used by the local population and therefore these water bodies are subject to intensive man-caused impacts. The status of such a wetland may be given to the Djiltirbas Bay, which is located in an uninhabited area of the Prearalie. The presence of wetlands providing a refuge for ornithological fauna is the indispensable condition for preserving bio-diversity of birds. Under conditions of water scarcity, short-lived water bodies or, in the last resort, perennial lakes should carry out such a function.

The status of short-lived water bodies can be given to the water bodies Adjibai-1, Adjibay-2, and the Djiltirbas, which are located in the tail parts of water distribution systems. Under a sufficiently high level of water supply, water bodies may be formed on the territory of these wetlands, which could be preserved for longer time that will result in changing their status.

Floodplain wetlands are very important from the point of view of support of reed productivity and the natural flora. As shown by the last surveys, it is important to secure their reproduction ability by preventing their drying up during the period more than two years.

X. CONSTRUCTION OPTIONS AND THEIR ASSESSMENT

10.1. Introduction

Establishing the buffer protection zones in the form of a series of local water bodies with the purpose of forming artificial wetland ecosystems had been started in the South Priaralie prior to 1995 according to the temporary plans. In that time, unregulated water bodies such as Ribache, Muynak, Djiltirbas, Dumalak and others, with the total water surface of about 1600 sq km, had been constructed in the Amu Darya delta and at the dried Aral Sea bed. Despite of a limited scale of implemented measures, an ecological effect was quite significant and resulted in a twofold reduction of a salt and dust transfer to adjacent cultivated lands, partial flora and fauna restoration in the delta, as well as in improvements of fishery and livelihoods of the local population. However, the project works were not being implemented for a long time due to the lack of funds until the GEF Agency has begun to finance the WEMP Project (Component E) and the Small Water Bodies Project at the expense of IFAS' funds, that it has imparted new impetus to those activities. In particular, at the expense of these funds, the Sudoche lakes system was constructed, and the Mezdureche Reservoir was partially reconstructed.

The project SFP-974357 provides for the construction of water infrastructure and artificial wetland ecosystems in the Amu Darya delta and at the adjacent dried seabed in order to rehabilitate the natural ecological regime throughout the South Priaralie. As mentioned above, in general, the Priaralie rehabilitation is differentiated for three zones: the Amu Darya delta, the dried seabed and the sea itself. Within the framework of this project the design was performed for two zones:

- ***The first zone*** – rehabilitation of the Amu Darya delta in order to restore as much as possible its natural ecological regime and create conditions for good living. Water bodies to be filled at the first phase were identified within this zone including reservoirs Mezdureche, Ribache, Muynak and Djiltirbas, and lakes Mashankul, Ilenkul, Makpalkul and Dumalak.
- ***The second zone*** – development of the dried seabed in order to mitigate impacts of its desiccation. Water bodies to be filled at the second phase were selected for this zone including Adjibai-1, Adjibai-2, and Djiltirbas-1 (water will be supplied depending on its availability).

10.2. Scope of Works at the First Phase

On the basis of the analysis of proposals on solving the Priaralie problem, that were developed by SANIIRI, Uzvodproekt, Euroconsult, and Uzgipromeliovodhoz in different years, three options of water infrastructure were selected to be considered in this project.

A comparison of these options shows that there are a number of water bodies under construction or partially put into operation, as well as natural water bodies that are components of all project options, including reservoirs Mezdureche, Ribache, Muynak, and Djiltirbas and lakes Sudoche, Mashankul, Ilenkul, Makpalkol, and Dumalak. Within the framework of planned measures, these water bodies will be used, depending on water inflow into the Priaralie, for fishery, muskrat breeding and reed production.

In addition, each option includes a number of artificial water bodies located on the dried seabed that are envisaged to mitigate negative impacts of the exposed Aral Sea bed. They would be the finishing ponds for fishery in wet and average years, but may be desiccated in dry years.

Parameters of water bodies and main water infrastructure for all options were specified, and tentative technical and economic indices for each construction object were estimated.

Data of earlier implemented projects on constructing water bodies in the Amu Darya delta, the geographical database developed within the framework of the Project SFP-974357, and field survey data of the NGO “ECO Priaralie” were used for design works.

At the end of the first phase, in the process of analysing data of field surveys, remote sensing data and maps, it was established that earlier developed projects needed to be revised taking into account the relief transformations over the last ten years. As a result of the revision, parameters and a bathymetry of some water bodies were defined more exactly.

Specified parameters of water infrastructure used by the project are given in Table 10-1.

Table 10-1 Specified parameters of water infrastructure used by the project

Water body	**Water surface elevation, m**	**Dam crest elevation, m**	**Water surface area, km^2**	**Capacity, million m^3**	**Dam length, km**
Option I					
Adjibai-1	46.0	47/5	281.3	258.6	18.0
Adjibay -2	45.0	46.5	174.4	390.4	39.2
Djiltirbas-1	45.0	46.5	624.2	894.8	54.0
Muynak Reservoir	52.5	54.0	97.4	162.2	8.1
Ribache Reservoir	52.5	54.0	62.4	134.2	8.0
Mezdureche Reservoir	58.0	59.5	398.5	797.0	45.1
Sudoche Lake	52.5	53.5	432	283.8	18.8
Djiltirbas	52.0	53.5	353.0	372.4	38.0
Total			2423.2	3293.4	229.2
Option II					
AP-1	53.0	54.5	722.8	1106.7	36.30
AP -2	41.0	42.5	202.5	133.0	56.3
AP -3	53.0	54.5	1577.2	3040.3	108.2
AP -4	45.0	46.5	43.3	31.0	30.5
AP -5	45.0	46.5	118.8	63.3	10.4
Muynak Reservoir	53.0	54.5	125.3	217.9	8.4
Ribache Reservoir	53.0	54.5	71.2	167.6	8.2
Mezdureche Reservoir	58.0	59.5	398.5	797.0	45.1
Sudoche Lake	53.0	54.5	450.0	283.8	19.1
Total			3709.6	5840.6	322.5
Option III					
AP-1	46.0	47.5	372.	377.	24.
AP -2	48.	49.5	50.	79.	12.
AP -3	43.5	45.0	303.0	239.4	32.9
AP -4	45.0	46.5	171.7	144.2	34.4
AP -5	47.0	48.5	29.4	15.9	13.9
Muynak Reservoir	52.5	54.0	97.4	162.2	8.1
Ribache Reservoir	52.5	54.0	62.4	134.2	8.0
Mezdureche Reservoir	58.0	59.5	398.5	797.0	45.1
Sudoche Lake	52.5	53.5	432.0	283.8	18.8
Djiltirbas	52.0	53.5	353.0	372.4	38.0
Total			2269.5	2606.3	236.1

The parameters of natural water bodies such as Mashankul, Ilenkul, Dumalak, and Makpalkol lakes are given in Table 10-2

Table 10-2 Natural water bodies' parameters used by the project

Water body	Water surface elevation, m	Water surface area, km^2	Capacity, million m^3
Mashankul and Ilenkul lakes	54.0	291.6	267.7
Dumalak Lake	55.5	256.3	333.7
Makpalkol Lake	53.5	47.5	46.8
Total		595.4	648.2

Water requirements were estimated for specified parameters of the structures, and are shown in Table 10-3.

Table 10-3 Estimated water requirements over options (km^3)

Option I			Option II			Option III		
Filling	Evaporation and seepage losses	Total	Filling	Evaporation and seepage losses	Total	Filling	Evaporation and seepage losses	Total
1. The system of reservoirs								
1.75	2.153	3.903	1.466	1.672	3.138	1.75	2.153	3.903
2. The system of natural lakes								
0.65	1.021	1.671	0.65	1.021	1.671	0.65	1.021	1.671
3. The system of artificial water bodies								
1.544	1.728	3.72	4.374	4.321	8.695	0.857	1.482	2.339
Total								
3.944	4.902	8.846	6.49	7.014	13.04	3.257	4.656	7.913

According to an estimation performed by the VEP SANIIRI regarding river water inflow and drainage water formed within the Amu Darya delta over a period of 20 years, the distribution of water supplied into the delta among existing and designed water bodies is planned in coordination with national development scenarios and the alternative water infrastructure. Waterway routes for filling water bodies were determined; and, in addition, in order to identify the parameters of hydraulic structures and canals, the hydrological regimes under the distribution of the maximum river flow and drainage flows from Samanbay site downstream to the Aral Sea were simulated taking into account evaporation and seepage losses in designed water bodies.

On the basis of parameters of the designed infrastructure, the bill of quantities for three options was made up (Table 10-4).

Table 10-4 Tentative Bill of Quantities according to Options

Works	Unit	Option I	Option II	Option III
Excavation and cutting	000' m^3	17.477	47.424	15.323
Fill	000' m^3	57.000	475.9	51.308
Mass concrete and reinforced concrete	000' m^3	45.8	63.38	44.17
Precast concrete	000' tons	7.64	9.742	7.298
Reinforcement	000' tons	1.964	2.322	1.758
Stone	000' m^3	167.7	192.3	160.0
Crushed stone, gravel	000'm^3	858.7	228.9	905.7
Mechanical equipment and metal-	ton	398.4	450.2	389.1

work				
Cost (US dollars)	000' US$	347.762	792.483	329.716

A comparison by other parameters is given in Tables 10-5 and 10-6.

In order to assess an ecological effectiveness of each option, water bodies' areas, which were revised using satellite images for a series of years (see Section VII) were superimposed, using the GIS method, on maps of environmentally unstable landscapes to be protected by proposed measures. In turn, environmentally unstable landscapes were identified (see Section IX) by comparing data of soil-landscape surveys conducted by the SANIIRI in the early 1990s with data of soil-landscape surveys conducted by the Project 974101 (N. Novikov, A. Ptichnikov) in 2000. Risk zones were identified by the GIS overlay procedure performed for landscapes, which remained unstable over a period of almost ten-year transformations. This comparison has showed a low effectiveness of Option 3, and an almost identical effectiveness of Options 1 and 2 according to this criterion.

Table 10-5 Tentative assessment of mitigation of environmental risk in the South Priaralie according to design options and development scenarios

Area of environmentally unstable landscapes by zones	**Protection rate of environmentally unstable landscapes by the options (percent)**		
	Option 1	**Option 2**	**Option 3**
Development scenarios	Optimistic/Pessimistic	Optimistic/Pessimistic	Optimistic/Pessimistic
Zone 1 – 127.5 km^2	38.4 /15.2	42.3 / 15.2	19.8 /15.2
Zone 2 – 533.6 km^2	19.1 / 6.8	36.5 / 6.8	14.3 / 6.8

Another important factor is coverage by planned measures of the zones of socio-economic damage due to desiccation of the Aral Sea, which were assessed within the framework of the Project INTAS-RFBR 2000. The damage level was differentiated over the Priaralie area on the basis of such factors as a residential area, population density, areas of fishery and muskrat grounds, etc.

Overlaying of damage differentiation themes with alternative sets of protective structures has identified (Table 10-6) almost similar and quite large degree of effectiveness of Options I and II and lesser effectiveness of Option III.

Table 10-6 Tentative assessment of coverage of socio-economic damage zones in the South Priaralie according to the alternative sets of protective structures

Socio-economic damage, million US $	Coverage of socio-economic damage zones (percent)		
	Option 1	Option 2	Option 3
Development scenarios	Optimistic/Pessimistic	Optimistic/Pessimistic	Optimistic/Pessimistic
Direct and indirect losses ***149.56***	89.4 / 64.7	91.8 / 63.9	52.5 / 33.4

Thus, a comparison of three options demonstrates that Option III is the cheapest one, Option I is slightly expensive (difference is about 5 percent), and the cost of Option II is 2.4 times higher.

Regarding water requirements for infrastructure functioning, Options I and III have acceptable level of water requirements even in a dry year. Under Option II, water requirements exceed available water resources even in an average year.

According to an assessment of environmental risk mitigation, Option I is close to Option II by main indices, but it provides a degree of mitigation twice as much as Option III. Options II and I are close to each other regarding the estimated coverage of socio-economic damage zones, while the coverage in Option III is two times less. Thus, Option I is taken for further development in the Feasibility Study.

The Government of Karakalpakstan has approved the proposed option at the meeting of the Steering Committee on February 6, 2002.

10.3. Final Phase of Works

Zonal field studies were performed in the process of project development. The NGO "ECO Priaralie" carried out the repeated target assessment of critical points in Mezdureche Reservoir within the Dumalak zone. In order to specify actual parameters of major water infrastructure, the detailed geodesic survey of the northern and eastern dams of 26.8 km long with cross-sections (a spacing of 500 m) was conducted, and the Mezdureche reservoir bed profile was plotted. The Kazakhdarya channel, the route of Mezdureche-Dumalak-Djiltirbas-Akkala, and a former Amu Darya channel as far as the Abbas Bay, the Ribache and Muynak reservoirs, and the Glavmyaso Canal were inspected.

In general, the field survey of water infrastructure in the delta revealed its unsatisfactory conditions and the need of its rehabilitation.

In addition, it was taken into account that under the support of the Global Environmental Facility and the World Bank, the Sudoche Lake System Rehabilitation Project has been developed and implemented (as an object of the Ramsar Convention).

Later on, the design was carried out regarding the following main water infrastructure:

- Mezdureche Reservoir;
- Glavmyaso Canal;
- Muynak Reservoir;
- Ribache Reservoir;
- Djiltirbas Reservoir;
- Water body Adjibay -1;
- Water body Adjibay -2;
- Water body Djiltirbas-1.

Specified parameters of reservoirs and water bodies for the final design are given in Table 10-7.

Table 10-7 Design parameters of reservoirs and water bodies

Water body	Water surface elevation, m	Dam crest elevation, m	Water surface area, km^2	Capacity, million m^3	Dam length, km
Adjibay –1	46.0	47.5	281.3	258.6	18.0
Adjibay –2	45.0	46.5	174.4	390.4	39.2
Djiltirbas –1	45.0	46.5	624.2	894.8	54.0
Muynak Reservoir	52.5	54.0	97.4	162.2	19.3
Ribache Reservoir	52.5	54.0	62.4	134.2	8.0
Mezdureche Reservoir	57.0	59.0	267.4	421.2	53.33
Djiltirbas	52.0	53.5	353.0	372.4	39.0
Total			**1860.1**	**2633.8**	**230.83**

The Mezdureche Reservoir. The project provides for creation of the Mezdureche Reservoir with a capacity of 450 million m^3, a normal storage level (NSL) of 57.00 m + BSL, and a water surface area of 320.5 km^2.

The following scope of works is planned to implement:

- Remodelling the Eastern Dam;

- Remodelling the Northern Dam;
- Remodelling the Western Dam;
- Construction of the outlet at PK 293+00 of the Northern Dam;
- Remodelling the lateral weir.

- Remodelling Eastern, Western and Northern dams (a total length of 45.75 km) includes constructing a quality embankment using loam with a crest elevation of 59.00 m + BSL, a width of 8.5 m, and an upstream side slope ratio (z = horz./vert.) of 7.0. In addition, the upstream side slope of the Northern Dam at sections from PK 240+00 to PK 250+00, from PK 265+00 to PK 280+00, and from PK 295+00 to PK 327+00 (sum total of 5.7 km) shall be reinforced by riprap.
- The outlet-regulator is designed for releasing flood and low-flow waters to the Akdarya River with their further disposal to the Adjibai-2 at a discharge capacity of 250 m^3/s and to the Dumalak depression at a discharge capacity of 300 m^3/s, as well as to control a water level in the Mezdureche Reservoir. This structure consists of a regulator combined with a transition structure, intake and discharge channels. A design discharge capacity of the structure is 550 m^3/s. The regulator is an open-type structure with a diaphragm and consists of upstream apron, gate section, floor, transition section and downstream apron. The gate section is represented by a frame with 6 bays of 5 m wide and sill elevation of 51.8 m +BSL. Each bay has two lines of gate grooves (for service and guard gates).
- As remodelling of the existing lateral weir, an 1880 m earthen dam is built 80 m downstream. PK0 of the dam is the point of conjunction with the Northern Dam of the Mezdureche Reservoir, while PK 18+80 is the point of conjunction with the Western Dam. The dam crest 8 m wide is located at an elevation of 59.00 m + BSL. An upstream side slope ratio is 7.0, and a downstream side slope ratio is 3.0. To ensure self-acting water release to Dumalak lakes when a water level in the Mezdureche Reservoir exceeds the NSL, a weir 360 m long is constructed within the dam body. A weir discharge capacity is of 570 m^3/sec at a water head of 1 m above its crest. The trapezoidal weir (6 m wide, an upstream and downstream side slope ratio of 3.0, and a sill elevation of 57.00 m +BSL) is made of reinforced mass concrete.

Thus, a total discharge capacity of all structures diverting water from the Mezdureche Reservoir exceeds 1200 m^3/s that was proved by final computations under simulating.

The Glavmyaso Canal is designed to delivery water from the Mezdureche Reservoir to the Muynak Reservoir. Its length is 26.2 km. A carrying capacity of the canal, except some sections, is 40 m^3/s. At present, it needs to be remodelled to convey water with a flow rate of 70 m^3/s.

Canal hydraulic parameters

Q, m^3/s	B, m	h, m	n	i	Side slope ratio, m	V, m/sec
70	20	3.48	0.03	0.00013	3.0	0.7

Construction of two new outlet-regulators is planned to deliver water from the reservoir to the canal.

The first regulator with a discharge capacity of 44 m^3/s is built at PK 2+00 of the new Glavmyaso route downstream the bridge across the Shege-Porlitau road. The regulator consists of five precast box culverts with a cross-section area of each is 2*2 m. Vertical-lift gates with screw hoists are used for discharge control.

The second regulator with a discharge capacity of 26 m^3/s is located 100 m east of the first one at the same transect. Intake and discharge canals with a total length of 300 m should be built. The regulator consists of a precast three-box culvert with a cross-section area of each box of 2*2 m.

The Muynak Reservoir. This reservoir located within the former Muynak Bay is created in the western-southern part of the bay by damming up. Water is supplied through the Glavmyaso Canal from the Mezdureche Reservoir. The project provides for reconstruction of the existing western dam and construction of the southern dam.

The western dam 8 km long constructed without a proper design have crest elevations varying from 53.50 to 55.00 m + BSL. The upstream dam slope along all its length is eroded (an nearly vertical side slope). To ensure the dam safety, a loam is filled on the downstream side slope, increasing a crest width up to 25.5 m and providing a downstream side slope ratio of 3.0. Such a filling pattern is designed owing to impossibility of repairing the upstream side slope since the reservoir is permanently filled with water. Under operation, the upstream slope subjected to erosion will become less steep, until it will reach the side slope ratio close to 7 to 10. This will provide long-term stability of the dam. A total length of rehabilitated dam is 7.9 km. A dam crest is located at elevation of 54.00 m +BSL, and an operational road with a gravel paving runs along the dam crest.

At PK 28+00 of the western dam, an outlet consisting of a precast two-box culvert (a cross-section are of each box is 2*2 m) with a total discharge capacity of 40 m^3/sec, is designed. Water is released to the water body Adjibay 1 through an off-take canal 2 km long.

The southern earthen dam has a crest width of 8 m and upstream and downstream side slope ratios of 7 and 3 accordingly.

At PK-0 the southern dam conjoins with the eastern dam. The dam crest is located an elevation of 54.00 m, and an operational road with a gravel paving runs over it. A total dam length is 11.4 km, and its maximum height is 3 m.
At PK 44+00 an outlet consisting of a precast two-box culvert (a cross-section area of each box is 2*2 m) with a total discharge capacity of 28 m^3/sec is designed. Water is disposed into a basin irrigation zone through the canal 2.5 km long.

The Ribache Reservoir. Damming up its north part creates the reservoir within the former Ribache Bay. The reservoir will be filled by water supplied from the Mezdureche Reservoir through the Marinkinuzyak Canal. The earthen dam 8 m wide at the crest is designed with an upstream side slope ratio of 3.5 below the design water level and in the zone of wave setup and 3.0 above the design water level. The downstream side slope ratio is of 3.0.

An operational road with gravel paving is to be constructed along the dam crest (elevation of 54.00 m + BSL), which joins with the existing road with an asphalt covering running from Muynak. A total dam length is of 8 km, and its maximum height is 7.2 m.

According to water balance calculations and for better flushing of the reservoir two outlets with discharge capacity of 20 m^3/s each are envisaged.

Outlets are designed as the precast two-box culverts with a cross-section area of each box of 2*2 m. The canal with a total length of 5 km is designed to release water into the Motor channel and further into the water body Adjibai-2.

The Djiltirbas Reservoir. The Djiltirbas Reservoir is created by construction of the dam 38 km long, which is stretching from the north and the east. The reservoir will be filled by water supplied from the Mezdureche Reservoir through the existing Kazakhdarya Canal and by drainage water from the KC-1 drainage canal. The earthen dam 10 m wide at the crest is designed with an upstream side slope ratio of 3.5 and a downstream side slope ratio of 3.0; at sites, where the dam foundation is at elevations above the design NSL, its crest width is 6 m and side slope ratios of 3.0 at both sides. A road with gravel paving runs along the dam crest (at an elevation of 53.50 м). Two outlets, each with discharge capacity of 50 m^3/s, are built for better flushing of the reservoir and mixing river and drainage water. Outlets are designed as the three-box reinforced concrete culverts (a cross-section area of each box is 2.5 * 2.5 m). The canal 5 km long is projected to release water into the Djiltirbas 1.

Water bodies Adjibay-1, Adjibay-2, and Djiltirbas-1. Under construction the main components are dams and outlets. The number of outlets in each water body depends on its parameters, conditions for flow-through over the entire water area, and maximum design discharges:

- Adjibay-1 – one outlet, a discharge capacity of 51 m^3/s;
- Adjibay-2 – three outlets with a discharge capacity of 90 m^3/s each;
- Djiltirbas-1 – three outlets with a discharge capacity of 60 m^3/s each.

- Dikes are earthen, with a maximum construction height of 3.1 to 6.5 m. The dam crest is 10 m wide. The crest is 1.5 m higher than the design NSL. The dam profile is designed with a flattened side slope resistant against water level fluctuations and wave impacts. An upstream side slope ratio is 35. A downstream side slope ratio is 3.0. Gravel road is built on dike crest for construction and service purposes.
- Outlets are designed as the three-box reinforced concrete culverts (a cross-section area of each box is 2.5 * 2.5 m) with vertical-lift gates.

The scope of works is given in the summary bill of quantities (Table 10-8).

As a result of designing at the final phase, the cost of all works has been reduced more than three times in comparison with the early cost estimate and amounted to US$ 96.2 million (Table 10-9) for the construction period of 12 years.

The design work of water infrastructure taking into account actual costs and site topography has required conducting the numerical simulating.

The analysis of an actual operational practice of Priaralie water bodies shows that in wet years the main burden is put on the Mezdureche Reservoir, which distributes runoff of the Amu Darya River among reservoirs Muynak, Ribache, Dumalak, and Djiltirbas. Most of runoff goes in the direction of Mezdureche⇒ Dumalak⇒ Urdabay⇒ the Aral Sea, where water inrush towards reservoirs Dumalak and Djiltirbas is possible. The analysis of field data for 2002 allows drawing a conclusion that dam breach by peak flow is the long-drawn process rather than short-term effect. In turn, this situation results in drawdown of water reserves of the Mezdureche Reservoir up to elevations greatly lower than an elevation of the emergency spillway crest and leads to irrevocable losses of some part of river runoff. Therefore, at this phase it was decided to extend the modeling area to the Takhiatash Barrage assessing a possibility to intercept a part of river runoff in wet years and to reduce extreme loads on water infrastructure of the Mezdureche Reservoir.

Numerical simulating of water bodies in the Priaralie was based on hydrological records at Samanbay over the period of 1980 to 2000. Actual runoff in 2001 and 2002 gave a new combination of years with low water availability (2000-2001) and a decrease in mean annual runoff. Therefore, at the fourth study phase the extended hydrological data including values of runoff over the period of 2001 to 2002 was taken into consideration.

Table 10-8 Summary Bill of Quantities for Main Water Infrastructure

No	Project Component	Construction works							
		Excavation and cut-ting, 000' m^3	Fill and back-fill, 000' m^3	Mass and reinforced concrete, 000' m^3	Reinforcement, tons	Precast concrete, 000'm^3	Stone, 000'm^3	Crushed stone, gravel, 000'm^3	Equipment and metalwork, tons
1.	Mezdureche Reservoir: - 3 dams	494.12	1616.76	-	-	-	43.4	-	-
	- lateral weir reconstruction	148.00	273.00	7.0	130.0	-	5.2	3.5	-
2.	Outlet-regulator	600.0	20.0	9.45	105.0	0.35	9.7	1.2	67.0
3.	Glavmyaso canal: - canal;	1619.0	946.0	-	-	-	-	17.7	-
	- 2 outlets	98.34	15.5	2.738	46.28	0.276	0.325	0.203	17.882
4.	Muynak Reservoir: - 2 dams	130.2	1327.5	-	-	-	-	25.4	-
	- 2 outlets	34.17	2.68	0.663	19.22	0.179	0.64	-	4.26
5.	Ribache Reservoir: - 1 dam	391.8	3962.8	-	-	-	-	5.34	-
	- 2 outlets	32.65	5.70	0.65	20.3	0.108	7.12	-	18.04
6.	Djiltirbas Reservoir: - 1 dam	417.7	3263.80	-	-	-	-	26.32	-
	- 2 outlets	37.67	5.9	1.68	44.08	0.004	8.2	-	9.022
7.	Adjibay -1: - dam;	175.2	1144.2	-	-	-	-	12.5	-
	- outlet	17.62	3.42	0.494	19.254	0.002	3.37	-	27.06
8.	Adjibay -2: - dam;	1411.2	16459.4	-	-	-	-	26.46	-
	- 3 outlets	64.63	7.95	2.58	68.82	0.006	16.14	-	27.06
9.	Djiltirbas-1: - dam;	1022.9	10726.8	-	-	-	-	36.45	-
	- 3 outlets	63.74	7.6	2.55	67.5	0.006	18.6	-	27.06
	TOTAL:	**6,758.94**	**39,788.51**	**27.805**	**520.434**	**0.931**	**112.695**	**142.763**	**174.584**

Table 10-9 Summary Cost Estimate of Construction Works for the Project "the Integrated Water Resources Management in the Aral Sea Basin to Rehabilitate Wetlands in the South Prearalie"

#	Project Component	Cost based on prices of the 1991year, 000' Uzbek Soums			Cost in US$, 000' US$		
		Investment	Other expenses	Total	Investment	Other expenses	Total
1.	Mezdureche Reservoir	7,848.68	2,943.26	10,791.94	6,017.58	1,083.16	7,100.74
2.	Outlet-regulator Q=550 m^3/s	2,962.66	1,111.00	4,073.66	2,271.47	408.86	2,680.33
3.	Glavmyaso Canal System	4,258.61	1,596.98	5,855.59	3,265.08	587.71	3,852.79
4.	Muynak Reservoir	3,908.84	1,465.82	5,374.66	2,996.90	539.44	3,536.34
5.	Ribache Reservoir	9,890.13	3,708.80	13,598.93	7,582.76	1,364.90	9,847.66
6.	Djiltirbas Reservoir	6,980.05	2,617.52	9,597.57	5,351.60	963.28	6,314.88
7.	Adjibay-1 Water Body	3,077.09	1,153.91	4,231.00	2,359.20	424.66	2,783.86
8.	Adjibay-2 Water Body	36,529.00	13,698.38	50,227.38	28,006.78	5,041.22	33,048.00
9.	Djiltirbas-1 Water Body	22,761.75	8,535.66	31,297.41	17,451.43	3,141.26	20,592.69
10.	Power line 10 kW and the transformer substation 63/10/0.4 kW for an outlet-regulator	33.52	12.57	46.09	25.70	4.63	30.33
11.	Access roads	1,333.00	499.88	1,832.88	1,022.01	183.96	1,205.97
12.	Service road for construction purposes	1,705.20	639.45	2,344.65	1,307.38	235.32	1,542.70
	TOTAL:	**101,288.53**	**37,983.23**	**139,271.76**	**77,657.89**	**13,978.40**	**91,636.29**
13.	Design surveys	6,371.10	494.44	6,865.50	4,192.82	325.39	4,518.21
	GRAND TOTAL:	**107,659.63**	**38,477.67**	**146,137.30**	**81,850.71**	**14,303.79**	**96,154.50**

XI. MODELING OPTIMAL PARAMETERS OF WATER INFRASTRACTURE

11.1. Characteristics of Simulation Objects

The system of water bodies and hydraulic structures is formalized in the form of an oriented graph **G**(J,I), where J = {0,1,...,j} is a set of nodes corresponding to volume objects, while I = {0,1,..., i} is a set of arcs reflecting links as to water distribution within the system. Each element $i \in I$ is characterized by such a pair (j, k) as ($\forall$(j, k), $j \in J$, $k \in J$, $k \neq j$), where j is the starting node and k is the end node of arc i. Thus, each node **G** (J, I) is associated with some object having water volume, while each arc is associated with a hydraulic structure generating water flow between nodes. Each node is characterized by its own bathymetric curve, *F (z)* – the free-standing water surface area at *z*-elevation, and by additional parameters that determine the system requirements for the node:

zMax	- the maximum possible water level (m),
zMin	- the lowest drawdown water level (m),
zNorm	- a normal storage water level (m),
zBeg	- a level at the initial point of time (m),
dzMax	- a maximum permissible range of level fluctuation in the winter period (m),
solMax	- a maximum permissible water salinity (g/l),
kFilt	- a permeability coefficient of bed ground,
Prior	- a rank of a water body within the entire system.

Each arc is characterized by a set of parameters relevant to its type and by a relative effectiveness of water movement in the given direction:

Type A - River:

Width	- a width (m),
i0	- gradient,
C0	- Chezy coefficient,
Qmax	- a maximum permissible discharge (m^3/s),
Cost	- the relative flow effectiveness in the given direction.

Type B	- Weir:
Mark	- weir crest elevation (m),
Width	- an overall flow width (m),
mq	- a weir discharge factor,
Cost	- the relative flow effectiveness in the given direction.

Type C	- gated hydraulic structure,
Mark	- hydraulic structure sill elevation (m),
Width	- an overall flow width (m),
TopMax	- a maximum gate opening (m),
mq	- hydraulic structure discharge coefficient,
Qmax	- a maximum permissible discharge (m^3/s),
Cost	- the relative flow effectiveness in the given direction.

11.2. Identification of Optimal Water Surface Elevation in the Mezdureche Reservoir and Parameters of Outlets

To specify an optimal normal storage level for the Mezdureche Reservoir, the operation of all water infrastructures was numerically simulated for five design options of the outlet in the direction of Mezdureche ⇒ Akdarya being given five different values of a normal storage level. Flows to the Suenly and Kyzketken diversion canals were assumed as zero. Water conditions were simulated using a water-flow record for 1980-2002. In the process of simulating it was assumed that a weir having a width of 1750 m with a crest elevation under consideration maintains the normal storage level in the Mezdureche Reservoir. By using simulation data, the curves of water resources distribution (the sum of flows in priority directions - Muynak, Ribache, and Akdarya) as functions of the normal storage level in the Mezdureche Reservoir and the carrying capacity of the outlet in the direction of Mezdureche ⇒ Akdarya were plotted.

The total volumes of drawdown through all outlets of the Mezdureche Reservoir, under different discharges in the direction of Mezdureche-Akdarya, are shown in Figure 11-1.

Analyzing the results of numerical experiments (Figures 11-1, 11-2, and 11-3), one can see that under the given water-management situation (which is presented by dynamics of river flows for the period of 1980-2002) the outlets of the Mezdureche Reservoir would enable to control effectively about 112 km^3 out of 166 km^3 of inflow, i.e. approximately 67.5 percent. It should be noted that earlier considered options of the engineering design (Phase 3) have provided the maximum volume of the controlled flow at the rate less than 40 percent of the inflow.

Dynamics of a controlled flow increase (Figures 11-2, 11-3,) shows that controlled flow is mainly limited by a storage capacity of the Mezdureche Reserve at elevations over the range of 56.0 to 57.0 m +BSL, while at elevations over the range of 57.0 to 58.0 m +BSL volumes of the controlled flow are stabilized and depend exclusively on inflow fluctuations, i.e. an increment of the controlled flow volumes is fully compensated by evaporation. Therefore, the following conclusion can be drawn:

> **Taking into account current bathymetric and inflow parameters of the Mezdureche Reservoir, it is not advisable to increase the storage capacity raising its water level above 57.0 m + BSL.**

This conclusion is the most important result of mathematical modeling at the given stage.

The final selection of a carrying capacity of the outlet in the direction of Mezdureche ⇒ Akdarya can be made only on the basis of the cost analysis of different design options, since only a range of discharges of 400–850 m^3/s can be taken for optimal water management. The results of simulating the Mezdureche reservoir's structures operation under the given discharges in the direction of Mezdureche ⇒ Akdarya are presented in Figure 11- 4.

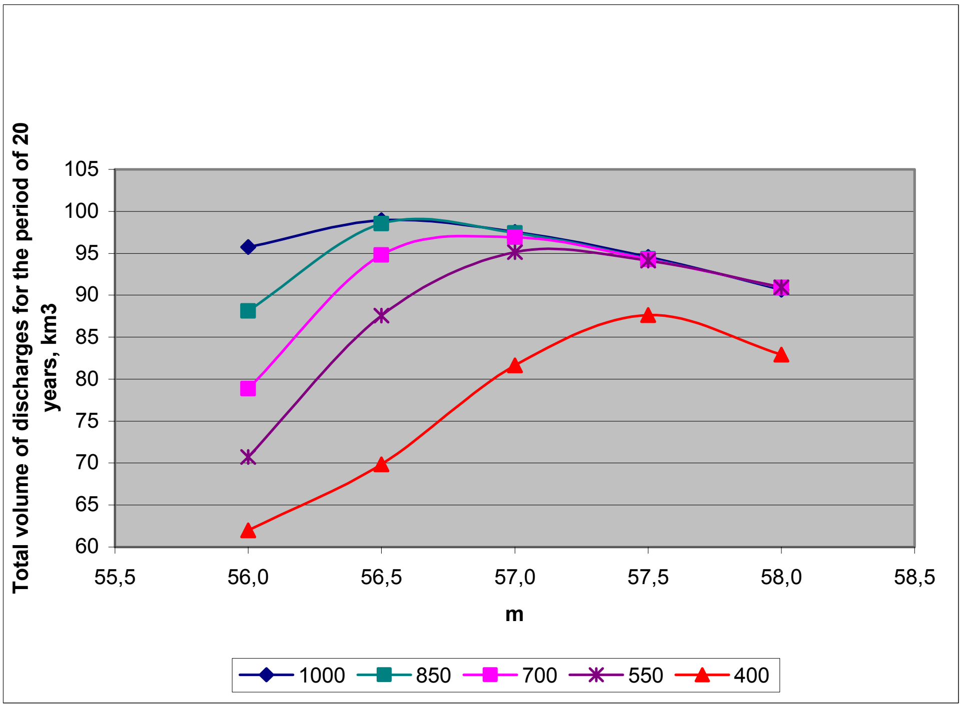


Figure 11-1 ***Change in the total controlled volume of Prearalie water bodies during the period of 20 years depending on various outlet discharges (without the Djiltirbas water body)***

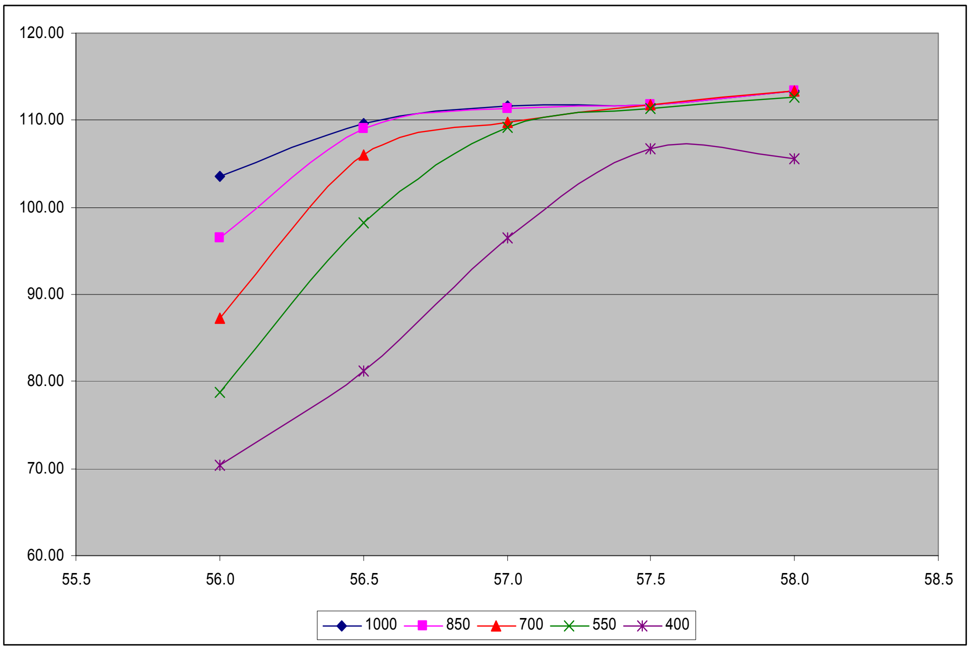


Figure 11-2 ***Change in the total controlled volume of Prearalie water bodies during the period of 20 years depending on various outlet discharges (with the Djiltirbas water body)***

Discharge = 700 m^3/sec

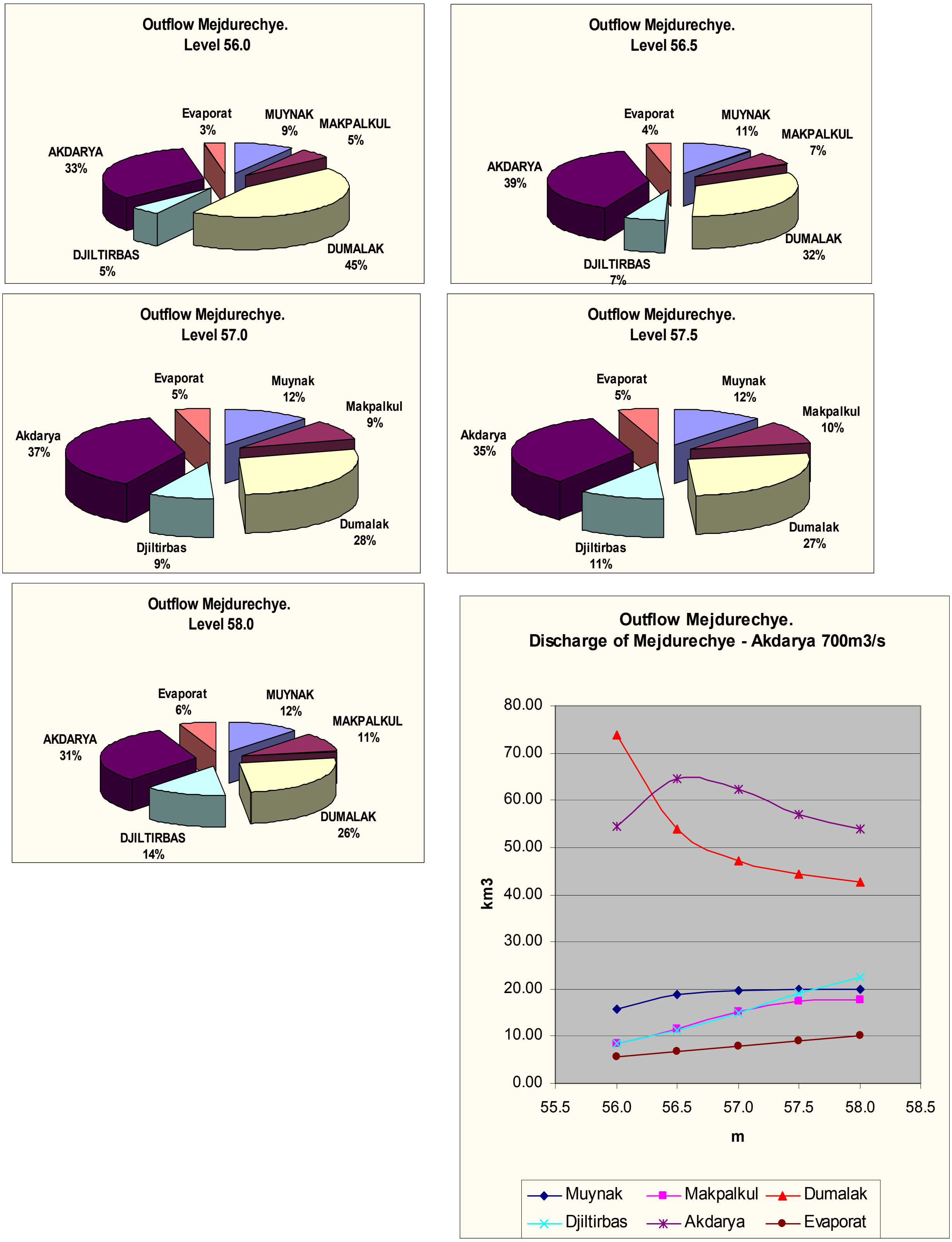
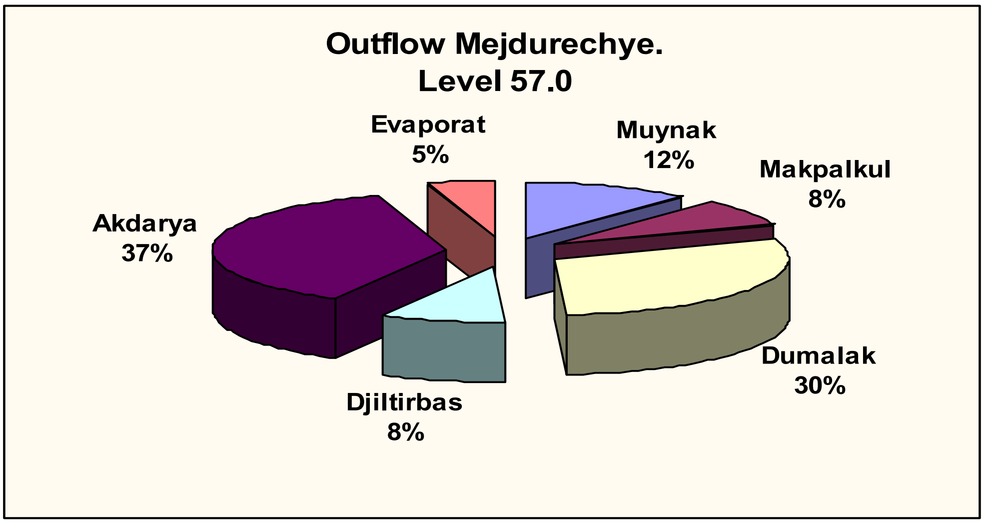


Figure 11-3

Discharge = 550 m^3/s



Discharge = 1000 m^3/s

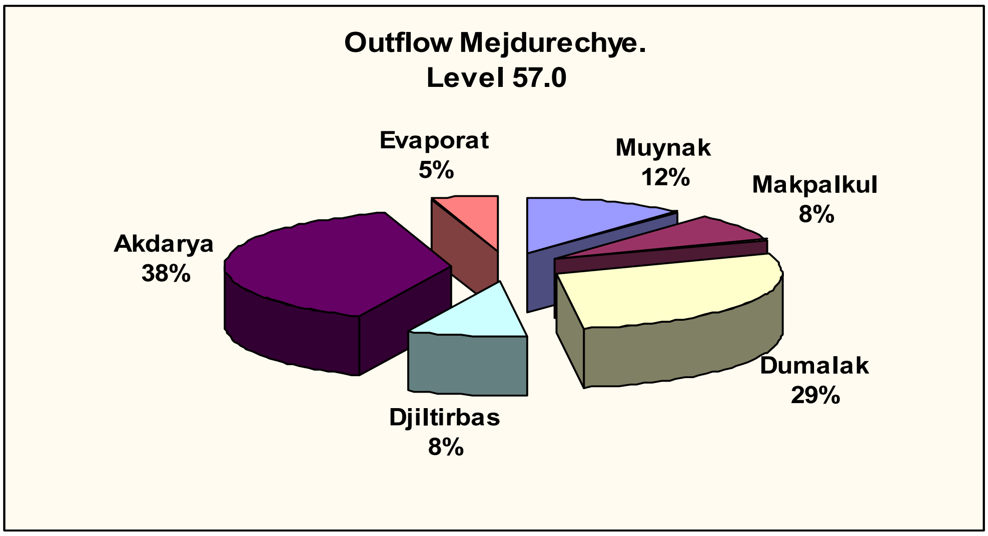


Figure 11-4

11.4. Possibility to Intercept Peak Flows

The analysis of field data of surveying the Mezdureche Reservoir in 2002 shows that elimination of peak inflows due to dam breach in the direction of the Dumalak Reservoir results in deeper drawdown of this reservoir than is required. It is evident that periodic weir breaches and spills over its crest at elevation of 56 m +BSL, as proposed by the temporary design, or conveying water through the anabranch in bypass of the weir, as it was done in 2003, will exclude water inflow into the system of water bodies. In this context, it is very important to intercept inflows, which according to previous computations (Figure 11-4) would potentially form a discharge of 1450 to 1964 m^3/s through the reservoir.

Therefore, it was decided to extend the modeling area in order to study possibilities to intercept peak flows by main canals located upstream of Samanbay. At this phase, the Amu Darya river section between Takhiatash and Samanbay was studied. There are two systems of big main canals at this section: the south branch (the Suenly canal), through which conveying a part of inflow to the Sudoche Lake is possible, and the north branch (the Kyzketken canal), which is conveying water to the north areas of the delta. In this scheme, the Takhiatash Barrage has been selected as a controlled water distributor and, for purposes of simulation, the initial site of water inflow according to Scheme 1, stage 3, was shifted to the Takhiatash site with two aggregated watercourses - the Suenly and Kyzketken canals - at the section "Takhiatash-Samanbay" with carrying capacity characteristics determined on the basis of surplus of discharges. On the one hand, such a method allows not considering operation of these canals under an ordinary water-management regime (i.e. it is assumed that during years of maximum water availability, industrial and agricultural water demands are fully satisfied) and, on the other hand, it enables to avoid additional calibration of the model necessary for taking into account water losses at the Takhiatash-Samanbay section. The extended modeling area is shown in Figure11-5.

Figure 11-5

In the process of numerical simulation, the additional inflow to the Suenly and Kyzketken systems was considered at the given stage as the negative management impact on the Takhiatash-Samanbay section and was used only as a tool preventing dam breaches of the Mezdureche Reservoir.

The possibility of intercepting large water volumes using water intakes, which are located downstream of the Tuyamuyun Dam, was demonstrated in 2003, when water releases from the Tuyamuyun Reservoir (Figure 11-6) were with the maximum discharge of 2400 m^3/sec, and further downstream at the Kipchak - 2100 m^3/sec, and at the Samanbay - 1400 m^3/sec accordingly.

Taking into account the prospective design and management of the water distribution regime of the Mezdureche Reservoir, the non-overflow dam around the reservoir is to be built up to elevation of 59.0 m + BSL, as the maximum possible water level (MPWL) of 58.5 m +BSL was assigned and higher water levels would create conditions for overflows over the dam. Under specified parameters of all outlets, dynamics of water level fluctuations around the MPWL will depend only on elevation and a width of an emergency spillway. Since elevation of the emergency spillway sill was selected for conditions of maximum water availability (it was set at elevation of 57.0 m +BSL), only a width remains as a free parameter. Therefore, numerical experiments regarding the regime of filling and drawdown of the Mezdureche Reservoir were conducted for emergency spillways with a sill elevation of 57.0 m +BSL and various values of a width. Assuming that the system of delta lakes is managed in the best way, the diagram demonstrating the relationship between discharges into Suenly and Kyzketken systems and a weir width was plotted (Figure 11-7). Figure 11-8 demonstrates dynamics of water level fluctuations in the Mezdureche Reservoir for years with different water availability, while flows distribution depending on a width of the spillway is represented in Figure 11-9.

Thus, it was determined that the optimal carrying capacity values for the outlets in the direction of the Mezdureche ⇒ Akdarya are within the range of 450 to 550 m^3/s, while the optimal width of the emergency spillway are within the range of 360 to 440 m.

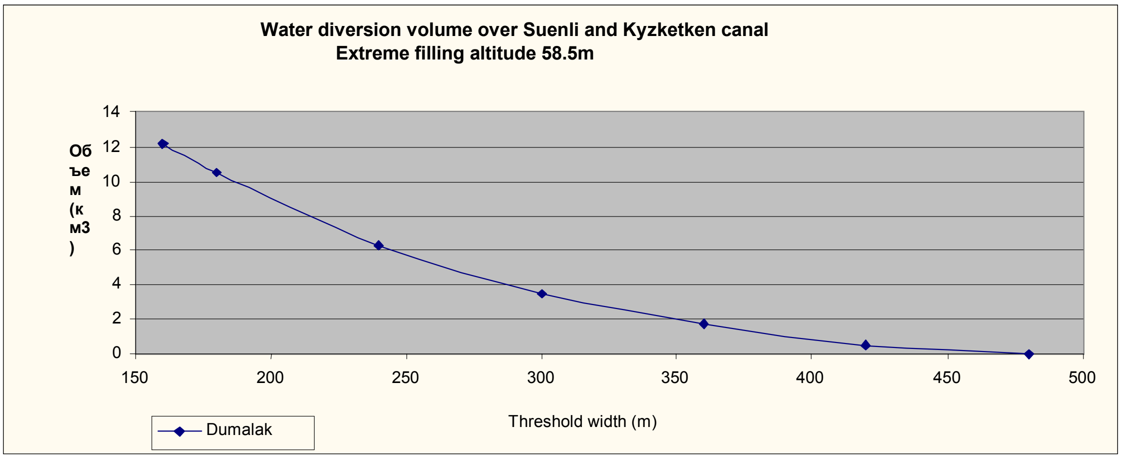


Figure 11-6

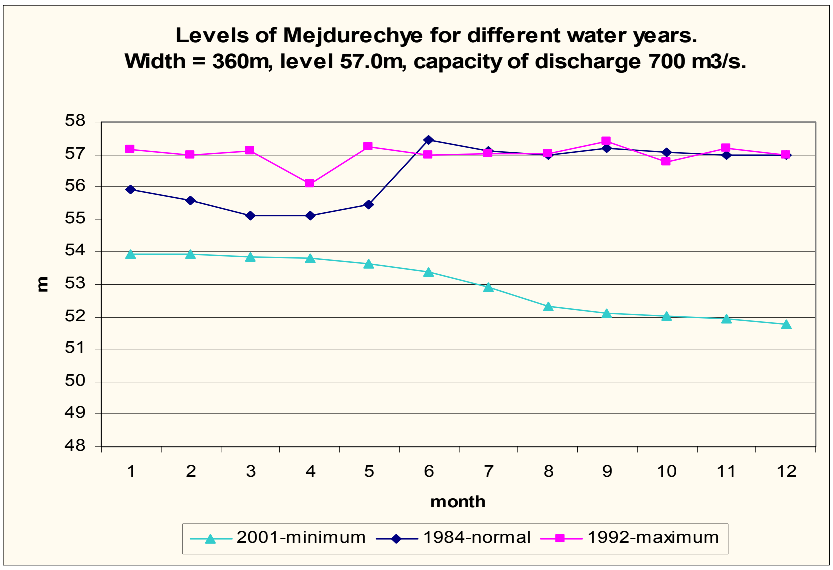
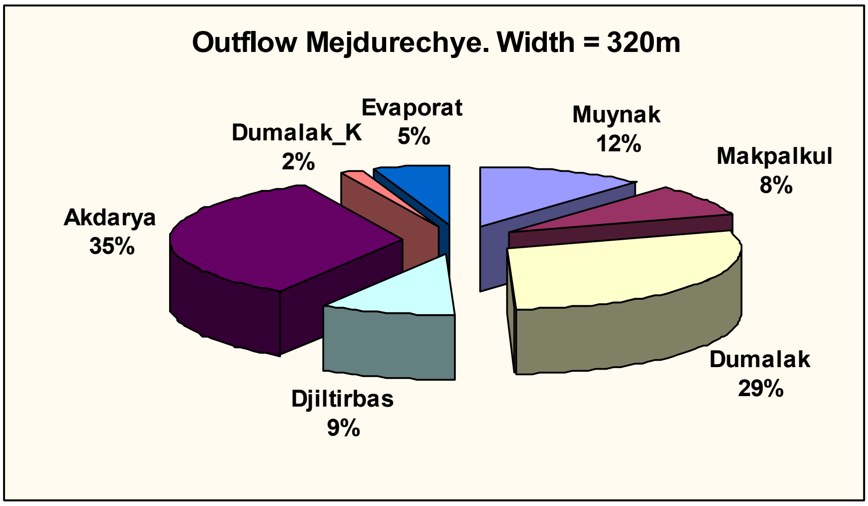
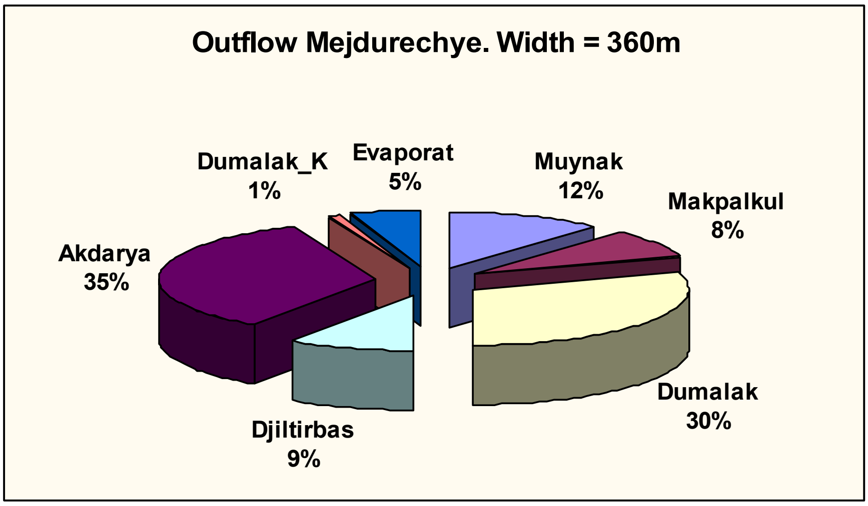


Figure 11-7


Outflow Mejdurechye. Width = 320m
Evaporat 5%
Dumalak_K 2%
Muynak 12%
Makpalkul 8%
Akdarya 35%
Dumalak 29%
Djiltirbas 9%


Outflow Mejdurechye. Width = 360m
Dumalak_K 1%
Evaporat 5%
Muynak 12%
Makpalkul 8%
Akdarya 35%
Dumalak 30%
Djiltirbas 9%

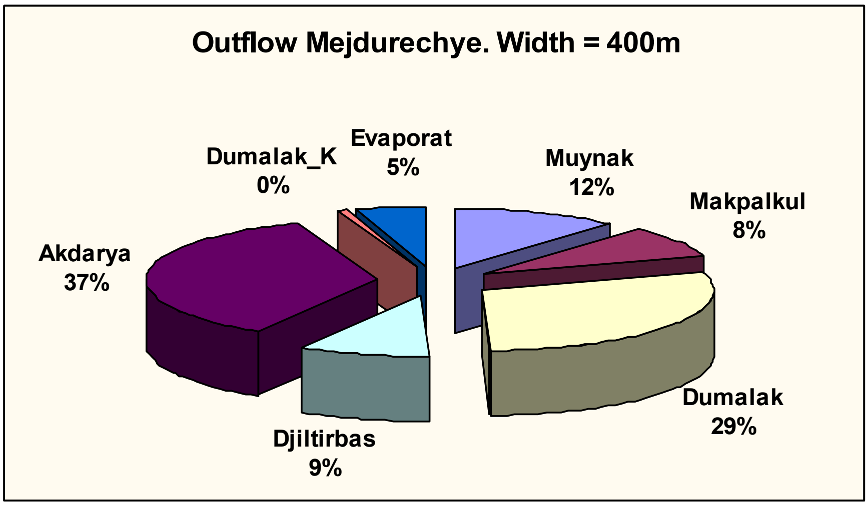
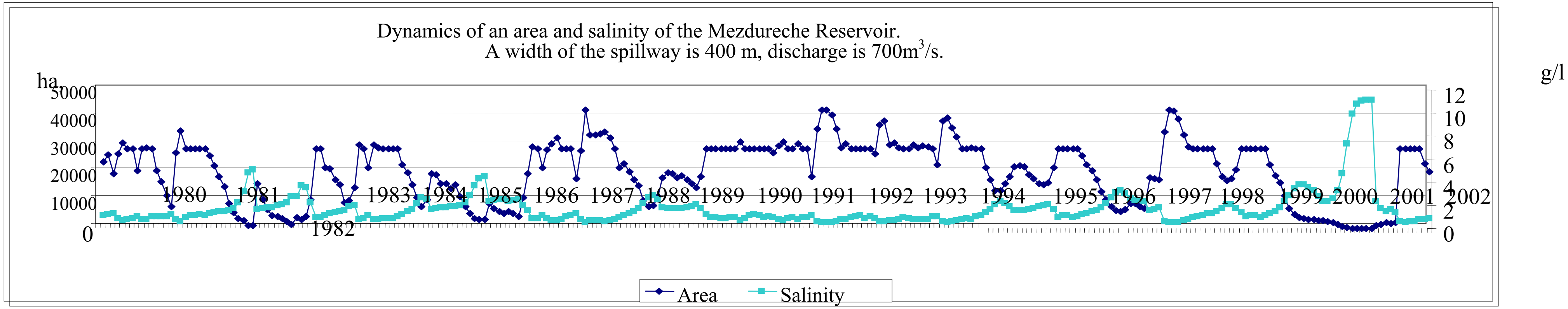

Outflow Mejdurechye. Width = 400m
Evaporat 5%
Dumalak_K 0%
Muynak 12%
Makpalkul 8%
Akdarya 37%
Dumalak 29%
Djiltirbas 9%

Figure 11-8


Dynamics of an area and salinity of the Mezdureche Reservoir.
A width of the spillway is 400 m, discharge is 700m³/s.
ha
g/l
50000
40000
30000
20000
10000
0
12
10
8
6
4
2
0
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002
Area
Salinity

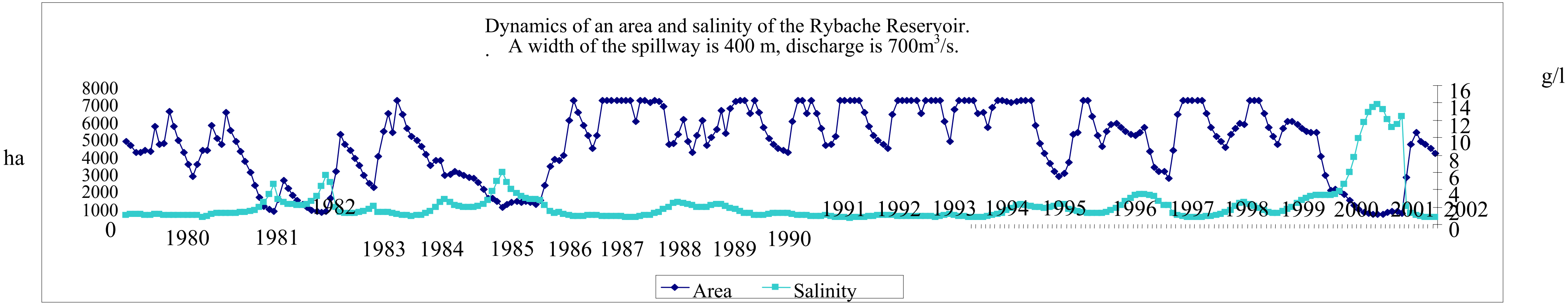

Dynamics of an area and salinity of the Rybache Reservoir.
A width of the spillway is 400 m, discharge is 700m³/s.
ha
g/l
8000
7000
6000
5000
4000
3000
2000
1000
0
16
14
12
10
8
6
4
2
0
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002
Area
Salinity

Figure 11-9

XII. OPERATION OF WATER INFRASTRUCTURE IN THE DELTA AND ITS MODELING

The current water resources management system in the South Prearalie based on a “residual” principle of water supply is low-efficient. As a result, either almost complete drying up or sudden inundation of the delta when, at the best, only 16 to 20 percent of the inflow is accumulated and properly used take place. Undoubtedly, a management potential may be considerably improved developing wetlands’ infrastructure, this does not however ensure that as a matter of fact this infrastructure will be capable to perform water-saving, environmental and socio-economic functions. The analysis of functioning of water infrastructure in the South Prearalie in previous years and of the Mezdureche Reservoir in 2002 show that water infrastructure under its current condition can be only partly managed, and the Mezdureche Reservoir is the most weak point of the existing water infrastructure (both in dry and wet years). Taking into account that water supply of all downstream water bodies (Muynak, Ribache) will completely depends on discharge capacities and parameters of hydraulic structures of the Mezdureche Reservoir, this water body should be ranked among the objects of the principle concern at both construction and operation stages.

In this context, rational management of water infrastructure and control of water releases into the delta can be provided by developing management tools such as a mathematical model with the appropriate Decision Support System (DSS), and by capacity building that includes establishing organizations that are based on the public participation principle and responsible for water supply of wetlands taking into account interests of all stakeholders.

12.1. The Mathematical Background of Management - Theoretical Aspects

Previous simulating the South Prearalie water area was planned for selecting options of water infrastructure and wetland locations, then for improving parameters of hydraulic structures, water bodies and conjunction canals, and finally for determining the designed productivity of water bodies under different options.

The modeling task during the period of operation consists in:

- logical design and software development for sustainable management of the system of water bodies on the basis of solving the optimization equation;
- adjustment of the model parameters with expected river and drainage flow rates;
- elaborating management criteria;
- identification of environmentally sustainable regimes of water distribution within the South Prearalie.

The prototype system is determined as the chain of shallow water bodies in which for water supply and distribution hydraulic structures are used. Management is based on information regarding water and salinity levels in water bodies and requires detailed monitoring of operation of all hydraulic structures under different operational conditions, including the emergency one. The object path is described by the system of non-linear, ordinary differential equations representing water and salt flow conditions in the system of water bodies.

The Management Plan for the system of water bodies is based on the current state of the system and forecasts of water inflow till the end of a year. The Management Plan is drawn for the entire system on the basis of actual capabilities of hydraulic structures regarding water distribution. In terms of the theory of optimal management, the problem to be solved is defined as the task of searching the «program path» of the controlled object. The problem solution is based on the mathematical model developed within the framework of this project, Stages 2 and 3. The management object under consideration is formalized in the form of oriented graph **G**(J, I), where J = {0, 1,...,j} is a set of nodes corresponding to volume objects, while I = {0,1,...,i} is a set of arcs reflecting links as to water distribution within the system of canals. Each element $i \in I$ is characterized by such a pair (j, k) that ($\forall$(j, k), $j \in J$, $k \in J$, $k \neq j$), where j is the starting node and k is the end node of arc i. Thus, each node **G**(J, I) is associated with some object having water volume, while each arc is associated with a structure generating water flow between nodes. Equations that describe functioning of individual water bodies are based on a system of ordinary differential equations reflecting inflow, outflow, evaporation and seepage losses of water, taking into account its salinity levels. The equations are associated with objects from the set of nodes J = {0, 1,...,j}. The objects relating to the set of arcs I = {0, 1,...,i} are determined by conjunctions of water bodies themselves and the outer boundary, where the control object is located. By eliminating an equation, which describes phenomenology of reed development, as an equation of the long-term type, from the basic model equations, the optimal control problem is formulated as a whole. Under assuming low salt concentration and using the law of conservation of mass, equations for each node have the following form:

$$\frac{dW_j}{dt} = \sum_{(k,j)\in I_j^+} Q_{k,j} - \sum_{(j,k)\in I_j^-} Q_{j,k} + q_j^p - q_j^f - q_j^E \tag{12.1}$$

$$\frac{dS_j}{dt} = \sum_{(k,j)\in I_j^+} (s \times Q)_{k,j} - s_j \times \sum_{(j,k)\in I_j^-} Q_{j,k} + q_j^s \tag{12.2}$$

$$s_{j,k} = s_{j,k}(S_j / W_j, v_j, T_j^o) \le S_j / W_j \tag{12.3}$$

$$Q_{j,k} = Q_{j,k}(a_{j,k}, W_j, U_{j,k}),\ \forall (j,k) \in \{I^U\} \subset \{I\} \tag{12.4}$$

$$\aleph(W_j(\bullet), S_j, (\bullet), U_{j,k}(\bullet), t^0, t^K) = \int_{t^0}^{t^K} [\sum_{(j,k)\in\{I^P\}} P_{j,k}(p_{j,k}, W_j, W_k, Q_{j,k}, s_{j,k})]dt +$$
$$+\phi_j\,(t^0, W_j(t^0), s_j, (t^0); t^K, W_j(t^K), s_j, (t^K)) \to \mathbf{sup},\ \forall\,(j,k) \in \{I^P\} \subseteq \{I^U\} \tag{12.5}$$

$$\psi_j\,(t^0, W_j(t^0), s_j, (t^0), t^K, W_j(t^K), s_j, (t^K)) = 0 \tag{12.6}$$

$$W_j(h_j) = \int_0^{h_j} \Omega_j(z)dz \tag{12.7}$$

$$q_j = q_j(W_j, t) \tag{12.8}$$

$$q^s{}_j = q^s{}_j(W_j, s_j, t) \tag{12.9}$$

$$U_{j,k}(t) \in \mathbf{U}_{j,k}\ \forall\,[\,(j,k) \in \{I^U\}\,\},\ t \in \{t^0 : t^K\}] \tag{12.10}$$

$$s_{j,k}(t), Q_{j,k}(t) \ge 0,\ \forall\ (j,k) \in \{I\};\ W_j(t), S_j(t) \ge 0,\ \forall\ j \in \{J\},\ t \in \{t^0 : t^K\} \tag{12.11}$$

where: W_j is water volume at j–node (m^3), I_j^+, I_j^- are sets of arcs entering node j and existing node j, respectively; $q^p{}_j$, $q^f{}_j$, $q^E{}_j$ are local inflows (outflows) to/from the node in the form of precipitation, seepage, and evaporation, respectively (m^3/s), q_j^s is local inflow (outflow) to/from the node of salts (kg/sec), S_j is mass of salts (kg), $s_{j,k}$ is salinity (kg/m^3), v_j is velocity of flow at node "j"(m/s), T^o is temperature (degree C), $Q_{j,k}$ is discharge between j and k (m^3/s), $a_{j,k}$ is function that characterizes the particular hydraulic structure located on arch (j,k); $U_{j,k}(t)$ is control of arc (j,k), $\{I^U\}$- is the subset of controlled arcs, $P_{j,k}(t)$ is effectiveness produced (consumed) by arc (j,k), $p_{j,k}$ are energy or equivalent characteristics of particular hydraulic structure located on arc (j,k), $\{I^P\}$ is a subset of controlled arcs $\{I^P\}\subseteq\{I^U\}$) having energy or equivalent properties, $\aleph$ is a criterion of system management quality, $\boldsymbol{U}_{j,k}$ is admissible management space, ψ_j are system requirements at a start and end points of time, ϕ_j is requirement effectiveness at a start and end points of time, $\Omega_j(z)$ is water body surface area (m^2) at elevation z_j, h_j is a water depth at node j (m), t is current time, t^0 and t^K are a start and end time of the process. To complete the formulation of the management problem in a differential form it is necessary to point among which functions the extremum (***sup***) is to be found. The problem (1) to (11) belongs to the class of optimal management problems with fixed time, for which a feasible solution is represented as a set of functions $(W_j(\bullet),S_j,(\bullet),U_{j,k}(\bullet))$ under the following requirements:

1. vector-function $U_{j,k}(\bullet)$ is determined and piecewise continuous in a segment $\{t^0:t^K\}$;
2. the condition (1) holds true for all $t\in\{t^0:t^K\}$;
3. functions $W_j(\bullet),S_j,(\bullet)$ are differentiable in all points, excluding those where $U_{j,k}(\bullet)$ discontinues; conditions of (12.1) to (12.2) hold true in all points of differentiability;
4. boundary conditions (6) hold true;
5. functions $q_j(t)$ and $q^s{}_j(t)$ are determined and are piecewise continuous in segment $\{t^0:t^K\}$,(these functions are uncontrollable since they characterize river basin runoff, and in addition they are stochastic functions; however, statistical expectation of these functions is used in given statement).

Just among such feasible solutions the extremum of the system (12.1)-(12.11) will be found.

The problem (12.1)-(12.11) cannot be studied by analytical methods (we are not able to find analytical solutions for such a class of problems); therefore, a discrete space in time should be considered. For this purpose, the time interval $\{t^0:t^K\}$ should be divided into equal intervals Δt (Δt = one ten-day period) in such a way that t can take values from the set $\{t^0, t^0+\Delta t, t^0+2\Delta t, \ldots, t^0+K\Delta t=t^K\}$. System parameters at nodes are attributed to the points in time $t\in\{t^0, t^0+\Delta t, t^0+2\Delta t, \ldots, t^0+K\Delta t\}$, while system parameters in arcs are attributed to the points in time $t\in\{t^0+0.5\times\Delta t, t^0+1.5\times\Delta t, t^0+2.5\times\Delta t, \ldots, t^0+(K-0.5)\times\Delta t\}$. Then, instead of (1) and (11) the following equations are derived:

$$W_j^{t+1} = W_j^t + \sum_{(k,j)\in I_j^+} W_{k,j}^{t+1/2} - \sum_{(j,k)\in I_j^-} W_{j,k}^{t+1/2} + w_j^{t+1/2} \qquad (12.12)$$

$$S_j^{t+1} = S_j^t + \sum_{(k,j)\in I_j^+} (s\times W)_{k,j}^{t+1/2} - \sum_{(j,k)\in I_j^-} (s\times W)_{j,k}^{t+1/2} + w_j^{s,t+1/2} \qquad (12.13)$$

$$W_{j,k}^{t+1/2} = \Delta t\times Q_{j,k}(a_{j,k}, W_j^t, W_j^{t+1}, U_{j,k}^{t+1/2}),\ \forall (j,k)\in\{I^U\}\subset\{I\} \qquad (12.14)$$

where: $w_j=q_j\times\Delta t$;
Thus, the system of $2\times|\{J\}|$ differential equations (equations (12.1) and (12.2)) on discrete spatial-temporal mesh is reduced to the system of $2\times(K+1)\times|\{J\}|$ nonlinear algebraic equations in variables in nodes connected through $2\times K\times|\{I\}|$ variables at arcs, of which $K\times|\{I\}|$ variables are controllers. Here $|\{.\}|$ is the number of elements in the specified set. Before transforming the management quality criterion (12.5), the following transformation for formula (12.14) needs to be made. An equation for $Q_{j,k}$ can be rewritten as: $Q_{j,k}(a_{j,k},W_j,U_{j,k})= Q_{j,k}(f(a_{j,k},U_{j,k}), W_j)$, and $U_{j,k}$ is replaced by allowable control space $\boldsymbol{U}_{j,k}$ in function $f(a_{j,k},U_{j,k})$ and multiply it by Δt, the function $\boldsymbol{W}_{j,k}= \Delta t\times f(a_{j,k},\boldsymbol{U}_{j,k})$ forms new

allowable control space, but now in variable $W_{j,k}$; thus instead of (12.14) the following equation is derived:

$$W_{j,k}^{t+1/2} \le W_{j,k}(W_j^{t+1/2}, W_k^{t+1/2}) \quad \forall [\, (j,k) \in \{I^U\}\, ,\, t \in \{t^0 : t^K\}] \tag{12.15}$$

the functional (12.15) changes accordingly

$$\aleph(W_j(\bullet), S_j,(\bullet), W_{j,k}(\bullet), t^0, t^K) = \sum_{t\in\{t^0,t^K\}} \sum_{(j,k)\in\{I^P\}} P_{j,k}^{t-1/2}(p_{j,k}, W_j^t, W_k^t, W_{j,k}, s_{j,k}) +$$
$$+\phi_j\,(\, t^0,\, W_j(t^0), s_j,(\, t^0); t^K, W_j(t^K), s_j,(\, t^K)) \to \mathbf{sup},\ \forall\ (j,k) \in \{I^P\} \subseteq \{I^U\} \tag{12.16}$$

Other expressions of the problem (12.1) – (12.11) do not change.

To complete formulation of the optimal management problem it is necessary to specify concepts of the management efficiency in equations for $P_{j,k}$, ϕ_j, and to make more exact the meaning of allowable control space $W_{j,k}$. The unit of water volume with relative salinity equal to 1 at a given time unit can be considered as the basic unit. Identifying the temporal factor as "$\zeta^t(t)$" – relative significance of water at various phases of flora and fauna development in water bodies, the effectiveness of filling of a specific water body may be expressed as:

$$w_j(t) = \zeta_j^t(t) \times W_j(t) \times [1 + \frac{(W_j^{\max} - W_j^*(t)) \times (W_j^*(t) - W_j(t))}{W_j^*(t) \times (W_j^{\max} - W_j(t))}]; \tag{12.17}$$

where: $W_j(t)$, W_j^{max} are volumes of j – water body at running time and at the maximum water level, respectively; $W_j^*(t)$ is some optimal volume of filling.
Since $\zeta^t(t)$ is a dimensionless parameter, the dimension of w(t) corresponds to that of water volume for the given period, therefore, the previously adopted symbol for water is kept in the equation (12.17). The function is graphically given in Figure 12-1.

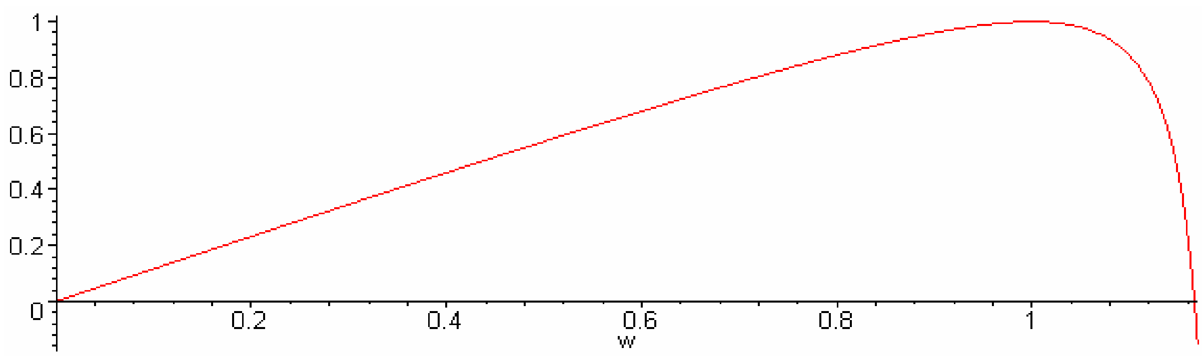


Figure 12-1 Water body filling efficiency function (W_j^*=1, W_j^{max}=1.2)

If in the equation (12.17) to take $W_j^*(t) = W_j^N$ – water body capacity at the normal storage level, and to sum values of ***"j"***, then the criterion of effective filling of the entire system of water bodies can be derived, i.e. depending on water inflow to the system the model is searching the possibility to fill each water body up to the normal storage level avoiding its overfilling. By limiting function $W_j^*(t)$ as $0 \le W_j^*(t) \le W_j^N$ and still leaving it open-ended, quasi-assumption is made that the normal storage level is not always optimal for a water body operating under conditions of high evaporation and salinity levels. Therefore, the next step is to define an equation for $W_j^*(t)$ that takes into account a salinity level in a water body. The important characteristic used in practice for assessing operation of water bodies in the South Prearalie is a flow-through coefficient, which is determined as a ratio between outflow and inflow when the stable level is maintained in a water body. In the special case (when *dw/dt =0; ds/dt =0*) equations (12.1) and (12.2) allow determining outflow salinity by means of the proportion of inflow and outflow of the water body:

$$Q^I \times s^I = Q^O \times s^O; \; Q^O = Q^I \times kp; \tag{12.18}$$

Where: Q^I, s^I ; Q^O, s^O are discharge and salinity of inflow and outflow, respectively; kp is a water body flow-through coefficient. (The formulas (12.18) are not valid for closed water bodies, since the condition of *ds/dt =0* is not performed).

The basic destabilizing factor for water bodies in the South Prearalie is evaporation, which in its turn depends on a water surface area of water bodies and a season. Considering a water surface area as a monotone increasing function of filling (this condition is valid for all existing and planned water bodies in the South Prearalie), the formula of optimal filling of a water body as a function of inflow and designed salinity is derived:

$$W^* = \frac{W^i \times (s^* - s^i)}{\alpha \times s^*}; \; \alpha > 0; \; s^* \geq s^i; \tag{12.19}$$

where: W^i , s^I are a volume and salinity of inflow, s^* is recommended salinity level of a water body, α – a mean annual evaporation coefficient.

Formulas (12.17) and (12.19) allow enclosing the optimal management problem for the system of shallow water bodies, however a decision maker should decide what salinity level is optimal for water bodies.

The function ϕ_j determines the degree of importance of getting parameters t^K, $W_j(t^K)$, s_j,(t^K) at the end of the control period, since for the Cauchy problem the function ϕ_j at the start time is not subject to variation and hence $\phi_j(t^0, W_j(t^0), s_j, (t^0)) \equiv 0$. Therefore:

$$\phi_j = (W^T_j(t^K) - w_j(t^K)) \times (w_j(t^K) - W^T_j(t^K)) / (W^T_j(t^K))^2; \tag{12.20}$$

where: $W^T_j(t^K)$ is required storage volumes at the end of the control period. It should be noted that the function $\phi(t^0, W_j(t^0), S_j, (t^0); t^K, W_j(t^K), S_j, (t^K))$ is of importance only for fishery water bodies, while for water bodies with high salinity levels (the second and third levels) its contribution is close to zero.

12.2. Development of DSS for Operation of Water Bodies

On the basis of previous works related to development of hydrological, engineering and economic models, the scope of works was specified for developing the DSS for decision makers concerning wetlands' planning and management.

According to recommendations provided by the Project Coordinator Mr. Joop de Schutter, which were based on the RAP method (the Rapid Assessment Programme, Ir. Peter Kouwenhoven), the technical approach was adopted consisting of the following successive steps:

- problem identification;
- components;
- component relations;
- possible scenarios;
- selection criteria;
- possible measures;
- analysis;

- assessment;
- resume

It is assumed that the database, a set of models, design water infrastructure structures, and the planned effectiveness can be used as the basis for developing the DSS.

1. Problem Identification

1.1. Under conditions of uncertain variations of the Amu Darya River discharges, intensive construction of water infrastructure, and the presence of water users representing different economic sectors in the delta, the basic objective of developing the DSS is to provide management of limited water and physical resources, which enables:

- to meet water demand of all water users and to practice those economic activities that provide their social survival;
- to maintain the sustainable environment in the region and to prevent desertification meeting requirements elaborated by environmental beneficiaries;
- to utilize as much as possible water supplying into the delta.

1.2. The current state of the region is as follows:

- the low level of social security of the population depending on opportunities to be engaged in the traditional sectors of economic activity (fishery, muskrat trapping, agriculture, animal husbandry, services, reed processing, etc.);
- all these activity categories, to a greater or lesser extent, depend on water and environmental conditions in the delta and the system of water bodies;
- the low level of capital investments into the proposed infrastructure and for support of social and economic environment as a whole;
- population growth and a high rate of migration;
- a high vulnerability of eco-systems due to unreliable water supply of the delta and the South Prearalie.

1.3. The main factors determining future development are the following:

- the seasonal variation of river water inflow into the delta at Samanbay, as well as drainage runoff;
- funds allocated for O&M of water infrastructure and capital investments in improvement of the situation in the delta;
- the institutional framework for delta water infrastructure management with involvement of stakeholders;
- accuracy of water availability forecasts.

2. Components of the system

2.1. Hydrological Components:

- Amu Darya River's discharges and water quality at the Tuyamuyun Dam and their transformation downstream to Takhiatash and further to Samanbay. Hydrological data of the Samanbay gauging station (since 1924) is the input data for the mathematical model of optimal water management in the delta, depending on a status and parameters of water infrastructure and management methods;
- Day-to-day fillup of water bodies;
- Discharges and water quality of drainage canals depending on water supply at the Takhiatash Barrage;

- Carrying capacity of existing canals and regulators;
- Simulation series with forecasting for 25 to 50 years, based on three scenarios of region development.

2.2. Climatic Components:

- climatic data of all weather-stations in the South Prearalie;
- data on precipitation and evaporation including from the water surface area;

2.3. Socio-economic Database:

- the population, including able-bodied citizens with the distribution over economic sectors and levels of employment;
- population growth rates and migration trends;
- economic indices of productivity over the following activity categories: fishery and muskrat trapping, reed processing, agriculture, services, and development trends;
- actual income of the population over all activity categories;
- Public health (a sickness rate, the distribution over diseases and ages groups including water-born diseases).

2.4. Environmental Indicators

- water quality in rivers and drainage canals;
- water quality in each water body;
- drinking water quality and access to drinking water sources for the population;
- fish reserves in water bodies;
- the number of migratory birds;
- a decrease/increase in desertification areas.

2.5. The morphological framework of the delta system is presented by:

- a linear scheme of the river and its branches and water intakes;
- a layout of water bodies, canals and drains and their function graphs such as $Q = f(h)$; $Q = f(h; \omega)$; $Q = f(h; \omega; Q_o)$; etc.;
- command areas of canals;
- water body parameters (an area, water levels, etc).

2.6. Management decisions are made on the basis of results of simulating; however, implementation of these decisions depends on physical capabilities of hydraulic structures and controllability of the institutional framework.

3. Interrelations of Components

Interrelationships of components at the logical level are defined by a matrix of components and their logical and actual linkages (Table 12-1). Component relations given in the matrix form enables us to evaluate not only indirect, multi-stage, and other links, but, first at all, direct links that are marked in the matrix by criss-crosses in bubbles. These very links are the most important elements of modeling, expert assessments or analytical works that should identify such links and incorporate them in the DSS.

4. Delta development scenarios

Apparently, the possible scenarios of development in the delta are the most important determinant in making decision within the DSS. An attempt to determine these scenarios using the matrix of components (regarding options labeled by square-markers) is undertaken.

4.1. The level of water availability in the river and water sources:

- Wet years less than a 20-year runoff;
- Average years more than a 20-year runoff;
- Dry years close to a 90-year runoff.

4.1.1. Including the level of water availability in drainage canals (this option is of importance when discharges of drainage canals decrease, especially those that feed the Sudoche Lake).

4.2. Construction options are determinative for the development period of the complex and determine both volumes of potential water accumulation (buildup of water bodies' capacity), and capabilities of water management and distribution.

4.3. Management options are the decisions that determine the strategy of economic and social development in the region depending on a scope of construction works content, buildup of water bodies' capacity and their influence.

The task of a set of models is to integrate different layers of the options 4.1, 4.2, and 4.3.

5. Selection Criteria

Taking into account the above combination of basic conditions of Para 4, it is necessary to develop criteria for selection of solution options observing the following provisions:

- environmental requirements to water bodies approved by the Steering Committee subordinated to the Government of Karakalpakstan;
- maximum utilization of water inflowing to the delta, particularly during dry and average years;
- trouble-free flood flow releases;
- limitations with respect to available water resources and investments.

6. Possible Measures

If the requirements with respect to criteria from Para 5 cannot be met, the DSS should provide selection of possible extra measures using other components. For example, it was determined that due to fullness of Tuyamuyun Reservoir predictable flood flows will exceed those that could be passed through the reservoir. In this case supplementary measures can be undertaken, for example, to distribute water between the Tuyamuyun and Takhiatash hydroschemes, within the limits of carrying capacity of the irrigation canals, or to direct water through the old river channel in bypass of the Mezdureche Reservoir or supplement these measures with another solution.

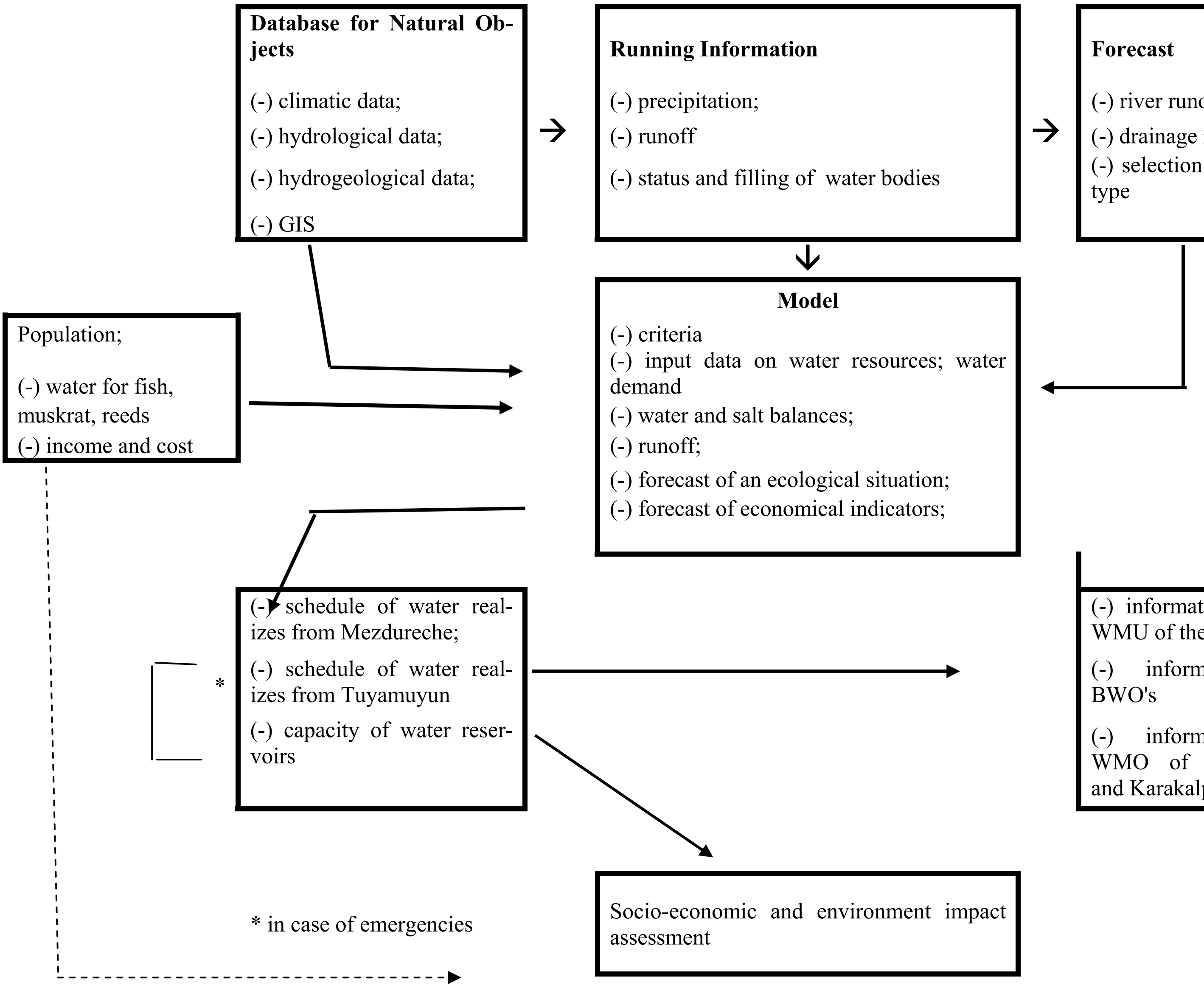
An another example: during the construction period some supplementary measures, which are not planned in the Feasibility Report, may be undertaken regarding water releases to water bodies of the second line or any other decisions such as water releases via the Sudoche Lake to the West Aral Sea. In addition, the DSS has to provide for decision makers its database, methodology, etc.

Table 12-1 Matrix of Components

	1	2	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2	5.3	6	7
1. Input hydrological components	▤			+	+	+	⊕	+	+	+	+	+	-	-	+		⊕
2. Input climatic components	+	▧				+		+				+					
3. Socio-economic indicators:																	
3.1. Demography;			▧	+	+						+	+					
3.2. Employment;				▧	+	+			+							+	+
3.3. Incomes;					▧	+										+	+
3.4. Public health;			+	+	+	▧										+	+
4. Environmental indicators:																	
4.1. River water quality;			+		+	+	▧	⊕	+	+					+		+
4.2. Water bodies' quality;					+	+	▧		⊕								
4.3. Drinking water quality;			+		+	+		⊕	▧								
4.4. Fish stock in water bodies;							+	⊕		▧							
4.5. The number of birds;											▧				⊕		
4.6. Desertification dynamics.			+	+	+						+	▧	▧			⊕	⊕
5. Morphology																	
5.1. Linear scheme														▧		⊕	⊕
5.2. Command areas															▧	⊕	⊕

	1	2	3.1	3.2	3.3	3.4	4.1	4.2	4.3	4.4	4.5	4.6	5.1	5.2	5.3	6	7
5.3. Water areas and volumes of water bodies;	+			+	+			⊕		⊕						⊕	⊕
6. Construction options.	+		+	⊕	⊕		+	+		+						▨	+
7. Management options			+	+	+	⊕	+	+	+	+						+	▨

The DSS Scheme of the SFP NATO 974357 Project



The main element of the DSS is the interface of the hydrological model, operational procedures of which is described below.

The goal of hydrological modeling is to specify the optimal parameters of the lake system and the sea based on current and planned water supply taking into account changes in the infrastructure of canals and drains, and to forecast annual water level fluctuations depending on runoff of the Amu Darya and Syr Darya rivers and the selected water policy, parameters of water distribution among water bodies, etc.

The main form includes:

1. Data input.
2. Calculations of the model.
3. Review and analysis of results.

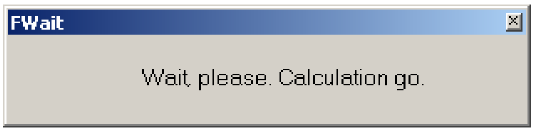
Data input is subdivided into the following blocks:

1. Water objects (water bodies – their names and characteristics);
2. Links of water bodies (identification of links and their characteristics).

Information is put in the simulation module and saved. Then, an input file is generated and transmitted into the GAMS model for further calculations.

Model calculating – the GAMS model is based on the system of ordinary differential equations describing structural relations within the system of water bodies and all components of a water balance taking into account water salinity.

Calculating takes several minutes, and a user is informed with the following message:



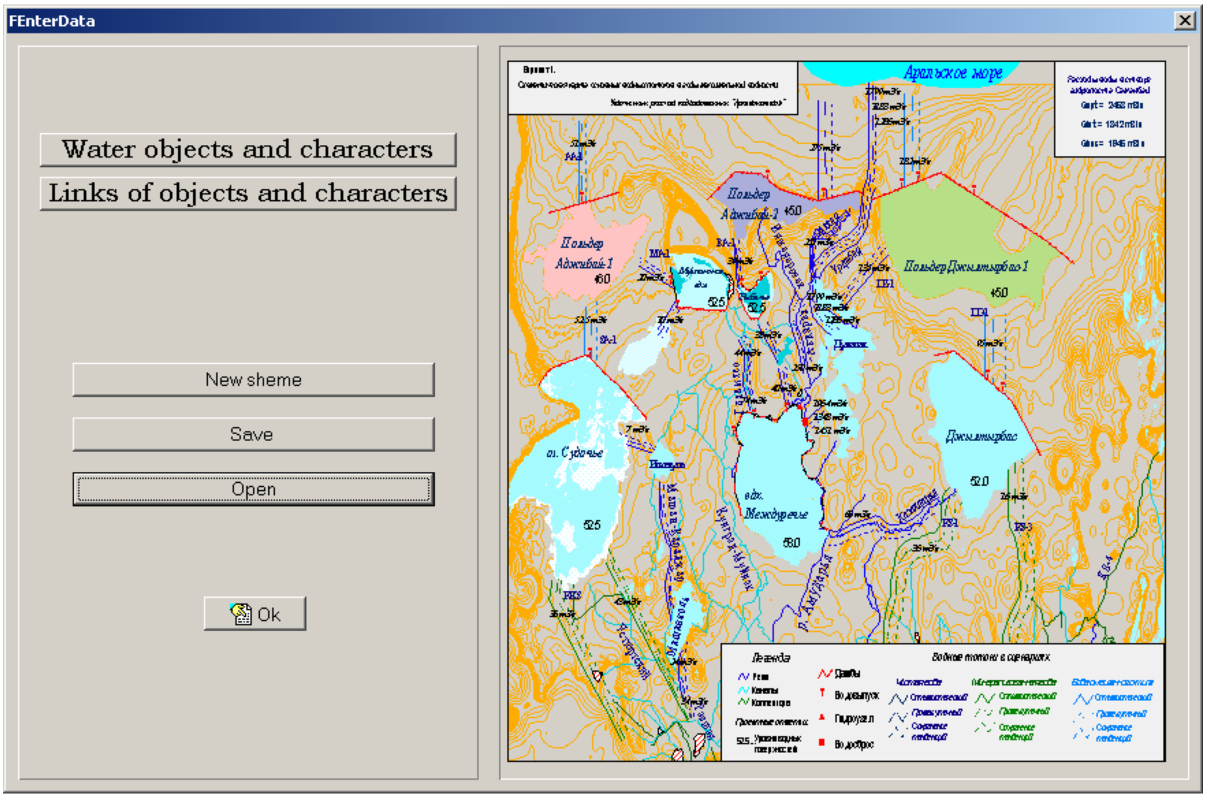
Review of the results includes an analysis of the following components:

- Inflow and outflow for each water body (on the mean annual basis);
- Dynamics of water areas and salinity of water bodies (mean monthly values for the period of 1981 to 2002);
- A total capacity and an area of wetlands in the South Prearalie (mean monthly values for the period of 1981to 2002);
- Inflow and outflow for the South Prearalie;
- Filling of water bodies;
- Overall and biologically active areas of water bodies.

The information can be viewed both in text and graphical forms.

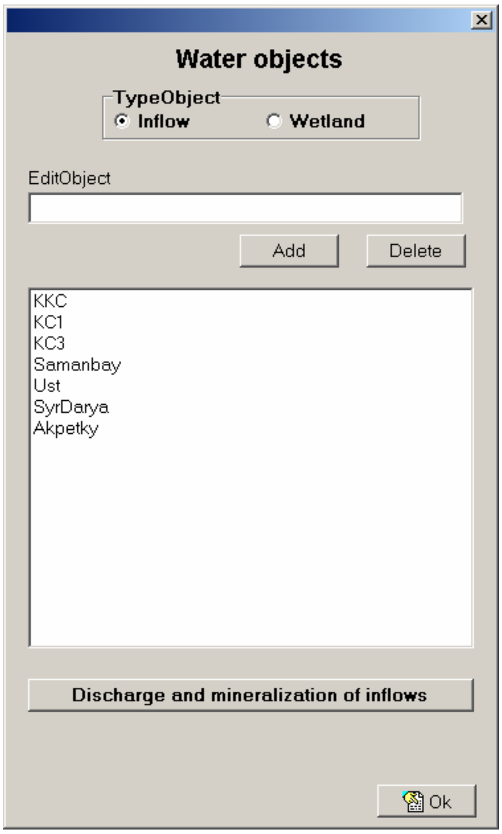
It is possible to open the previously created scheme in order to adjust object parameters or links and to save a new option of the scheme.

On the right part of the form the map of the selected scheme is presented.



Click the “Water objects and characteristics” menu item to open a window for water objects.

Clicking the “Links of objects and characteristics” menu item opens a dialog box for links between water objects.



The “New scheme” menu item provides creation of a new scheme. At the same time, all objects, links and their parameters are deleted.

The “Save” menu item provides saving inputted information in a scheme (generating an input file for the GAMS model).

The “Open” menu item provides opening of the already existing scheme.

In order to input a new water object it is necessary to select the type of an object:

1. Inflow;
2. Wetland.

Then, enter a name of a water object into the “EditObject” line.

Under pressing the “Enter” key or clicking the “Add” menu item, a new object is added to the general list.

Clicking the “Delete” menu item or pressing the “Del” key one can delete any selected object from the general list.

Working with the already existing scheme, under selection of the option "Inflow" the list of appropriate water objects is displayed.

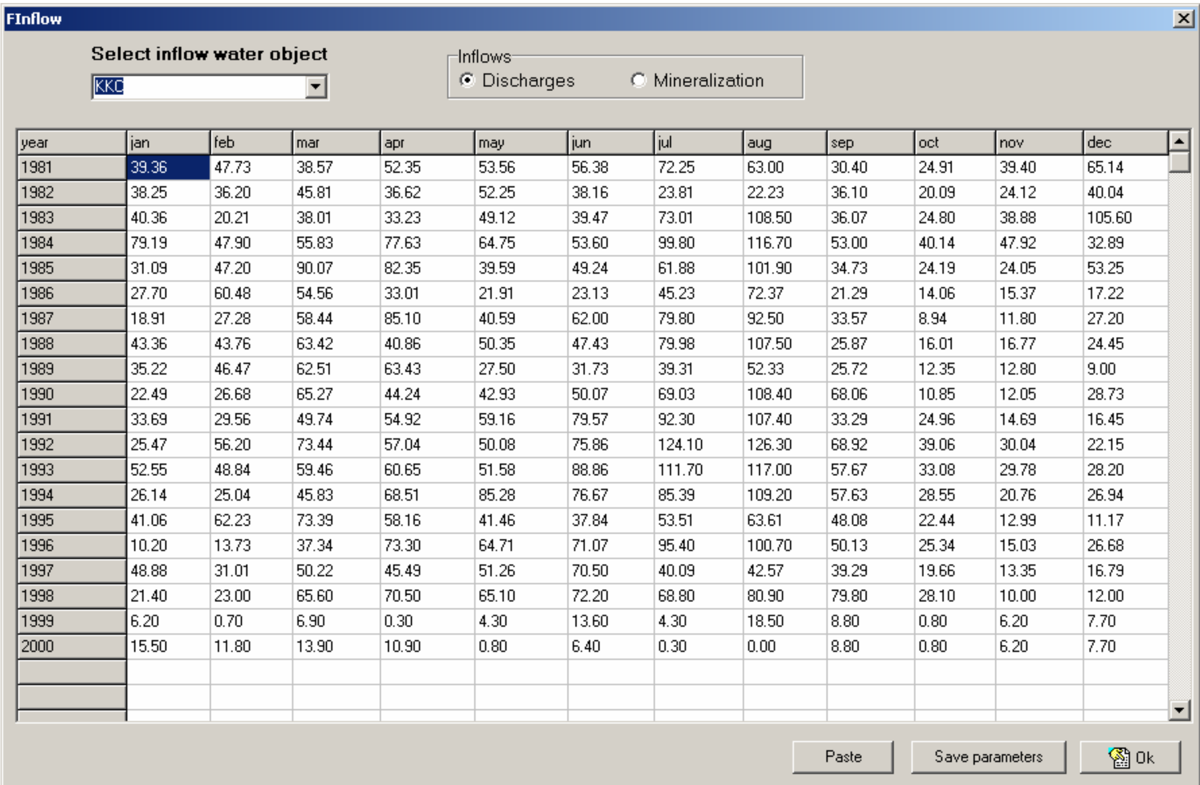
The "Discharges and inflow salinity" menu item opens the dialog box "FInflow", in which the following characteristics of objects are displayed:

- Discharges (million m^3/month);
- Salinity (g/l).

Clicking on the "Ok" key closes the window "Water objects".

A water object is selected in the "FInflow" window, for instance, KKC (the type "Inflow"), and monthly discharges and salinity for the period of 1981 to 2000 are displayed.

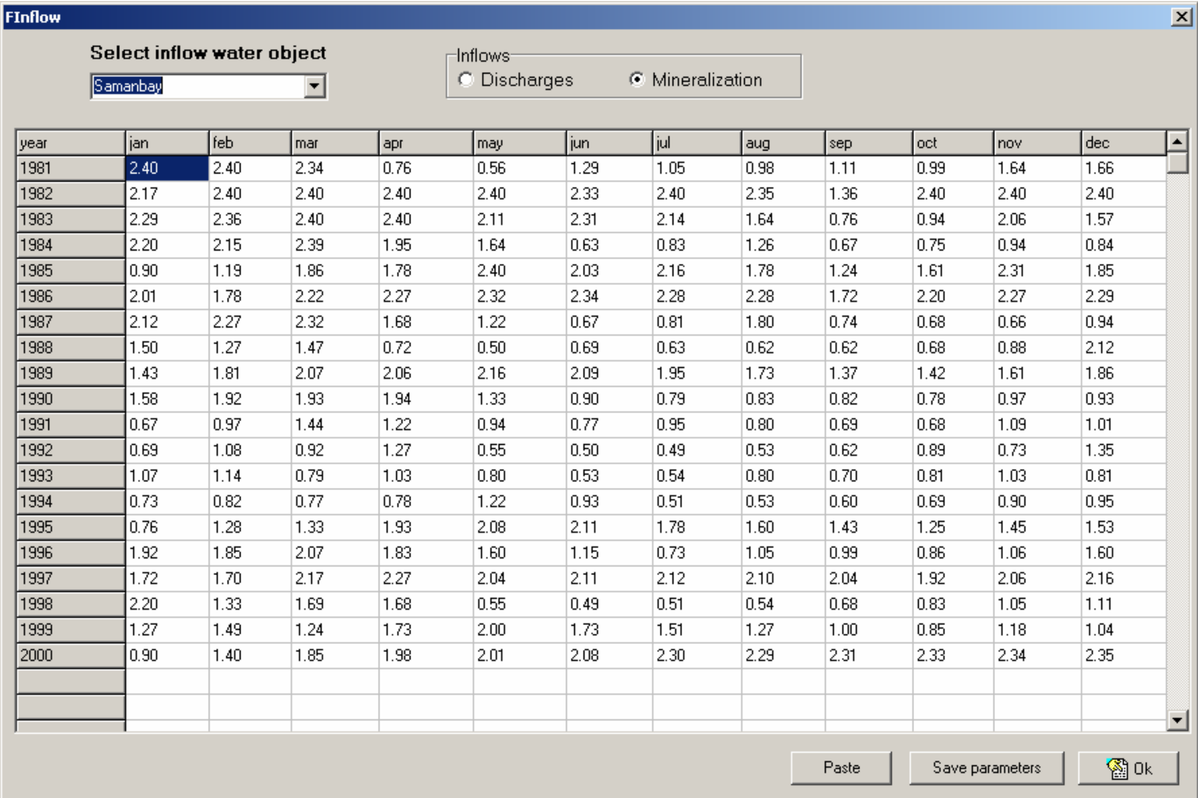
In case of the already created scheme, previously entered values are presented in the datasheet, which can be adjusted and saved. If data on discharges is contained in another software environment, for instance, in Microsoft Excel, necessary information can be copied by a block and inserted into a datasheet by clicking the "Paste" menu item or pressing "Shift+Insert" keys.



year	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
1981	39.36	47.73	38.57	52.35	53.56	56.38	72.25	63.00	30.40	24.91	39.40	65.14
1982	38.25	36.20	45.81	36.62	52.25	38.16	23.81	22.23	36.10	20.09	24.12	40.04
1983	40.36	20.21	38.01	33.23	49.12	39.47	73.01	108.50	36.07	24.80	38.88	105.60
1984	79.19	47.90	55.83	77.63	64.75	53.60	99.80	116.70	53.00	40.14	47.92	32.89
1985	31.09	47.20	90.07	82.35	39.59	49.24	61.88	101.90	34.73	24.19	24.05	53.25
1986	27.70	60.48	54.56	33.01	21.91	23.13	45.23	72.37	21.29	14.06	15.37	17.22
1987	18.91	27.28	58.44	85.10	40.59	62.00	79.80	92.50	33.57	8.94	11.80	27.20
1988	43.36	43.76	63.42	40.86	50.35	47.43	79.98	107.50	25.87	16.01	16.77	24.45
1989	35.22	46.47	62.51	63.43	27.50	31.73	39.31	52.33	25.72	12.35	12.80	9.00
1990	22.49	26.68	65.27	44.24	42.93	50.07	69.03	108.40	68.06	10.85	12.05	28.73
1991	33.69	29.56	49.74	54.92	59.16	79.57	92.30	107.40	33.29	24.96	14.69	16.45
1992	25.47	56.20	73.44	57.04	50.08	75.86	124.10	126.30	68.92	39.06	30.04	22.15
1993	52.55	48.84	59.46	60.65	51.58	88.86	111.70	117.00	57.67	33.08	29.78	28.20
1994	26.14	25.04	45.83	68.51	85.28	76.67	85.39	109.20	57.63	28.55	20.76	26.94
1995	41.06	62.23	73.39	58.16	41.46	37.84	53.51	63.61	48.08	22.44	12.99	11.17
1996	10.20	13.73	37.34	73.30	64.71	71.07	95.40	100.70	50.13	25.34	15.03	26.68
1997	48.88	31.01	50.22	45.49	51.26	70.50	40.09	42.57	39.29	19.66	13.35	16.79
1998	21.40	23.00	65.60	70.50	65.10	72.20	68.80	80.90	79.80	28.10	10.00	12.00
1999	6.20	0.70	6.90	0.30	4.30	13.60	4.30	18.50	8.80	0.80	6.20	7.70
2000	15.50	11.80	13.90	10.90	0.80	6.40	0.30	0.00	8.80	0.80	6.20	7.70

If values are changed they should be saved by clicking the "Save parameters" menu item. If adjusted data are not saved in time, then under clicking the "Ok" key the window will not be closed with a pop-up message about data saving. Similarly, switching between menu items of "discharge" and "salinity" will not be activated until the data are saved.

By selecting the next water object, for example, Samanbay, using the “Select inflow water objects” menu item and switching between menu items of “discharge” and “salinity”, a salinity datasheet for Samanbay can be received.

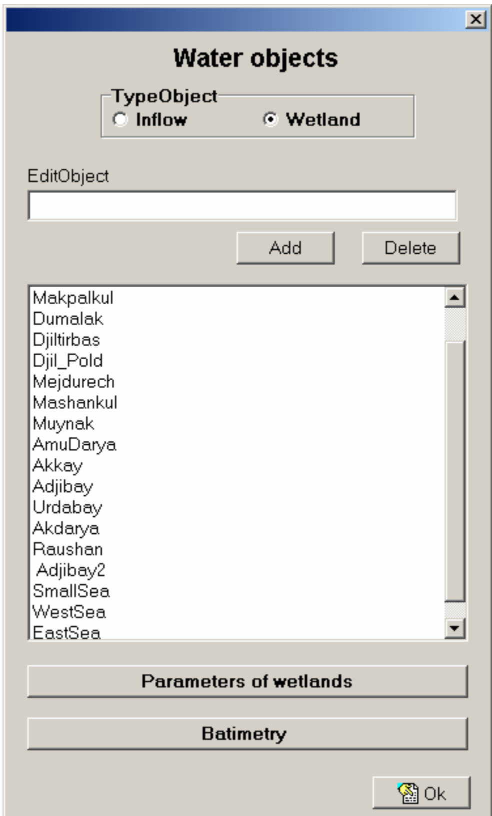


year	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
1981	2.40	2.40	2.34	0.76	0.56	1.29	1.05	0.98	1.11	0.99	1.64	1.66
1982	2.17	2.40	2.40	2.40	2.40	2.33	2.40	2.35	1.36	2.40	2.40	2.40
1983	2.29	2.36	2.40	2.40	2.11	2.31	2.14	1.64	0.76	0.94	2.06	1.57
1984	2.20	2.15	2.39	1.95	1.64	0.63	0.83	1.26	0.67	0.75	0.94	0.84
1985	0.90	1.19	1.86	1.78	2.40	2.03	2.16	1.78	1.24	1.61	2.31	1.85
1986	2.01	1.78	2.22	2.27	2.32	2.34	2.28	2.28	1.72	2.20	2.27	2.29
1987	2.12	2.27	2.32	1.68	1.22	0.67	0.81	1.80	0.74	0.68	0.66	0.94
1988	1.50	1.27	1.47	0.72	0.50	0.69	0.63	0.62	0.62	0.68	0.88	2.12
1989	1.43	1.81	2.07	2.06	2.16	2.09	1.95	1.73	1.37	1.42	1.61	1.86
1990	1.58	1.92	1.93	1.94	1.33	0.90	0.79	0.83	0.82	0.78	0.97	0.93
1991	0.67	0.97	1.44	1.22	0.94	0.77	0.95	0.80	0.69	0.68	1.09	1.01
1992	0.69	1.08	0.92	1.27	0.55	0.50	0.49	0.53	0.62	0.89	0.73	1.35
1993	1.07	1.14	0.79	1.03	0.80	0.53	0.54	0.80	0.70	0.81	1.03	0.81
1994	0.73	0.82	0.77	0.78	1.22	0.93	0.51	0.53	0.60	0.69	0.90	0.95
1995	0.76	1.28	1.33	1.93	2.08	2.11	1.78	1.60	1.43	1.25	1.45	1.53
1996	1.92	1.85	2.07	1.83	1.60	1.15	0.73	1.05	0.99	0.86	1.06	1.60
1997	1.72	1.70	2.17	2.27	2.04	2.11	2.12	2.10	2.04	1.92	2.06	2.16
1998	2.20	1.33	1.69	1.68	0.55	0.49	0.51	0.54	0.68	0.83	1.05	1.11
1999	1.27	1.49	1.24	1.73	2.00	1.73	1.51	1.27	1.00	0.85	1.18	1.04
2000	0.90	1.40	1.85	1.98	2.01	2.08	2.30	2.29	2.31	2.33	2.34	2.35

If all parameters are saved, clicking the “Ok” key will close the current form.

Objects of the “Wetland” type are described by bathymetric data (a water area [ha] of a water body at the given elevation (m) and the following characteristics:

zMax is a maximum water level in a water body (m);
zMin is a minimum water level in a water body (m);
zNorm is a normal storage level in a water body (m);
dzMax is a permissible range of water level fluctuation in the winter period (m);
solMax is a permissible water salinity level (g/l);
kFilt is a hydraulic conductivity of bed’s ground (m/day);
Prior is a rank (priority) of the given water body within the wetland system.



Wetland parameters

FWetland

Characters of wetlands

Объект	zMax	zMin	zNorm	dzMax	solMax	kFilt	Prior
Rebachy	53.00	47.00	52.50	1.00	10.00	0.01	4.00
Sudochy	53.00	49.00	52.50	1.00	10.00	0.01	3.00
Makpalkul	54.50	52.00	54.00	3.50	50.00	0.01	1.00
Dumalak	54.00	51.00	53.50	1.00	10.00	0.01	3.00
Djiltirbas	53.00	49.00	52.00	2.00	10.00	0.01	1.00
Djil_Pold	46.00	41.00	44.60	3.50	30.00	0.01	1.00
Mejdurech	59.00	52.00	58.00	1.00	10.00	0.01	1.00
Mashankul	54.00	51.50	53.50	1.00	10.00	0.01	3.00
Muynak	53.00	48.50	52.50	1.00	10.00	0.01	4.00
AmuDarya	62.00	56.00	60.00	1.00	10.00	0.01	0.00
Akkay	53.00	48.00	51.00	1.00	30.00	0.01	0.00
Adjibay	47.00	44.00	46.00	3.50	50.00	0.01	0.00
Urdabay	53.00	48.00	51.00	1.00	50.00	0.01	0.00
Akdarya	55.00	50.00	52.00	1.00	10.00	0.01	0.00
Raushan	59.00	54.50	58.00	1.00	10.00	0.01	0.00
Adjibay2	46.00	40.00	45.00	2.00	50.00	0.01	0.00

Paste | Save parameters | Ok

Bathymetric data

FBatimetry

Batimetry of wetlands

Rebachy	Level	46.50	47.00	47.50	48.00	49.00	49.50	50.00	50.50	51.00	52.00	52.50	53.00
Rebachy	Area	0.00	51.22	121.05	253.22	978.54	1647.21	2562.71	3386.23	4072.20	5395.88	6241.22	7124.56
Sudochy	Level	49.00	50.00	50.50	51.00	51.25	51.50	51.75	52.00	52.25	52.50	52.75	53.00
Sudochy	Area	0.00	139.04	2017.03	3971.76	5641.50	9633.30	11040.00	17311.30	19500.80	23611.80	27688.80	33443.80
Makpalkul	Level	51.70	52.00	52.17	52.33	52.50	52.63	52.75	52.88	53.00	53.13	53.50	54.00
Makpalkul	Area	0.00	1176.24	1562.21	1948.17	2334.14	2617.00	2899.87	3182.73	3465.60	3787.23	4108.87	4430.50
Dumalak	Level	49.50	50.00	50.50	51.00	51.50	52.00	52.25	52.50	53.00	53.25	53.50	53.75
Dumalak	Area	0.00	412.85	1534.58	3764.52	5412.53	10219.54	11541.78	13336.54	19247.23	22336.54	25632.95	30632.95
Djiltirbas	Level	48.75	49.00	49.25	49.50	50.00	50.25	50.50	51.00	51.50	51.75	52.00	52.50
Djiltirbas	Area	0.00	63.79	216.21	368.63	1432.61	4591.71	7750.80	18466.17	28757.84	32028.30	35298.77	45517.34
Djil_Pold	Level	41.00	41.50	41.75	42.00	42.50	43.00	43.25	43.50	44.00	44.50	45.00	45.50
Djil_Pold	Area	0.00	76.01	2092.57	4109.13	6836.48	12354.19	18405.02	24455.85	45790.30	54137.37	62418.01	70795.38
Mejdurech	Level	51.50	52.00	53.00	53.50	54.00	55.00	55.50	56.00	56.50	57.00	57.50	58.50
Mejdurech	Area	0.00	32.47	197.80	708.02	3146.67	8778.31	15708.68	18906.76	22759.61	28858.35	34642.93	42682.20
Mashankul	Level	51.00	51.50	51.67	51.83	52.00	52.25	52.50	52.75	53.00	53.25	53.50	54.00
Mashankul	Area	0.00	1921.44	2866.90	3812.36	4757.82	6234.06	7710.30	8573.60	9436.90	12282.97	15129.03	29162.39
Muynak	Level	48.50	49.00	49.50	49.75	50.00	50.50	51.00	51.50	51.75	52.00	52.50	53.00
Muynak	Area	0.00	2.45	171.43	517.64	863.85	2721.93	5520.46	8772.25	9143.38	9514.52	9741.02	12528.25
AmuDarya	Level	56.00	56.50	57.00	57.50	58.00	58.50	59.00	59.50	60.00	60.50	61.00	61.50
AmuDarya	Area	0.00	68.48	76.25	84.11	93.39	136.91	178.69	371.52	572.07	609.01	788.47	868.47
Akkay	Level	48.00	48.50	49.00	49.50	50.00	50.50	51.00	51.50	52.00	52.50	53.00	53.50
Akkay	Area	0.00	2.00	4.00	11.00	24.00	33.00	45.00	52.00	70.00	81.00	88.00	95.00

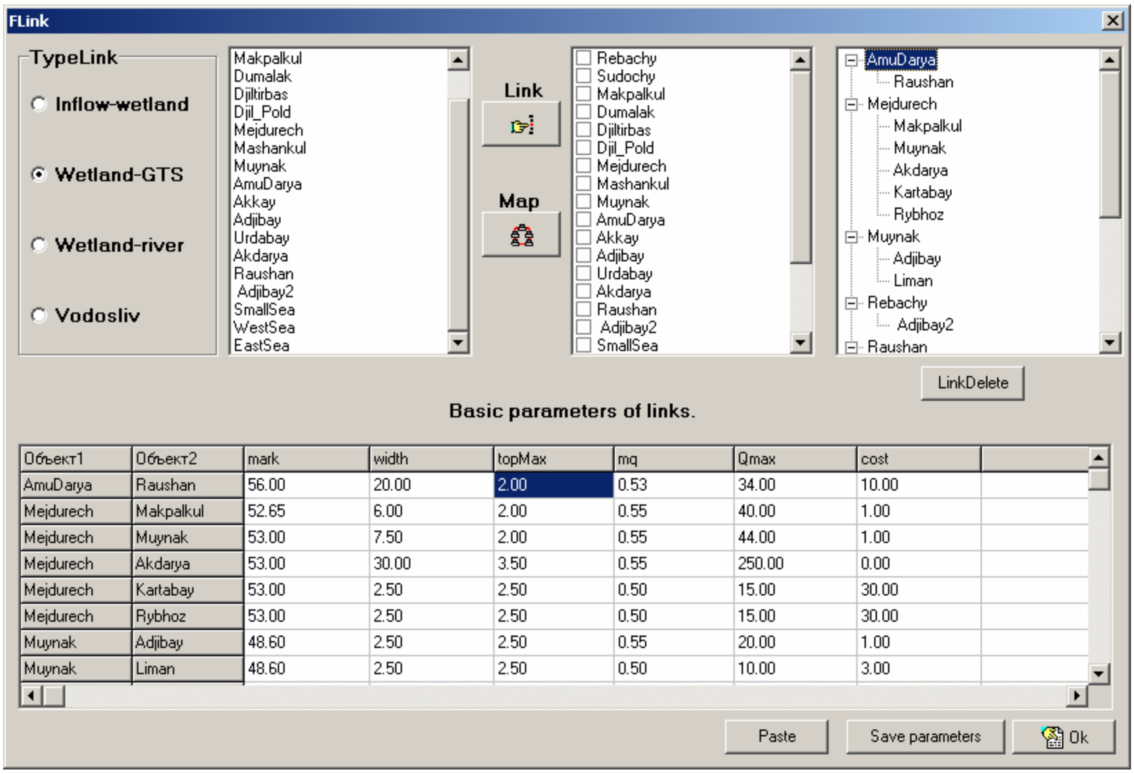
Paste | Save parameters | Ok

Creating links it is necessary to perform the following operations:

1. To select a type of a link.
2. To indicate objects for establishing links, clicking the “Link” menu item
3. The tree of links is displayed on the right side of the window, and underneath this window the data-sheet with parameters for a selected type of links.

The “LinkDelete” menu item serves for deleting links or sub-links selected at the tree of links.

The “Map” menu item displays the layout of a water body.



Each type of links is characterized by a set of relevant parameters:

A) Wetland-GTS

Where:

Mark	is elevation of a hydraulic structure sill (m + BSL),
Width	is a total bay width (m),
topMax	is a maximum gate opening (m),
mq	is a discharge coefficient,
Qmax	is a maximum permissible discharge (m^3/s),
cost	is a rank (priority) of water supply.

B) Wetland-river:

Where:

Width	is a width (m),
i0	is slope,
C0	is the Chezy coefficient,
Qmax	is a maximum permissible discharge (m^3/s),

C) Vodosliv:
Where:

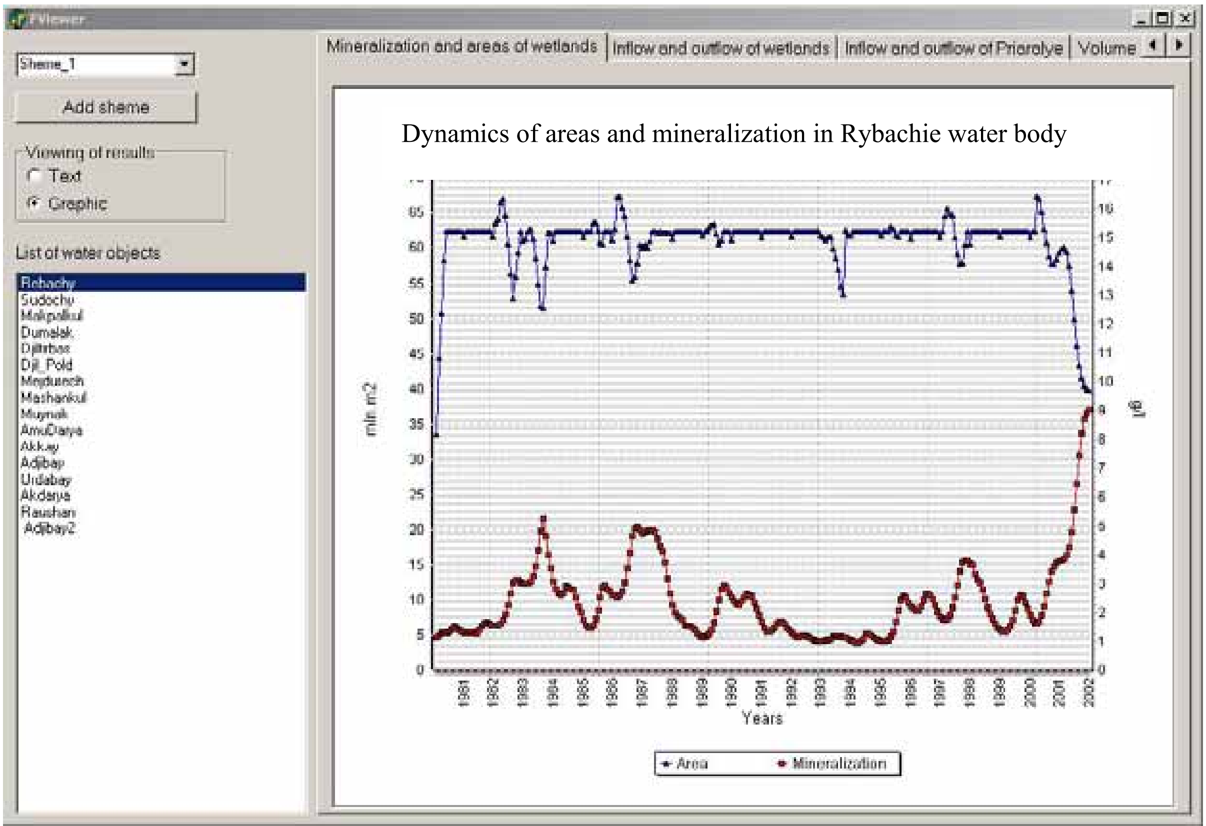
Mark	is weir sill elevation (m + BSL),
Width	is a total bay width (m),
mq	is a weir discharge coefficient.

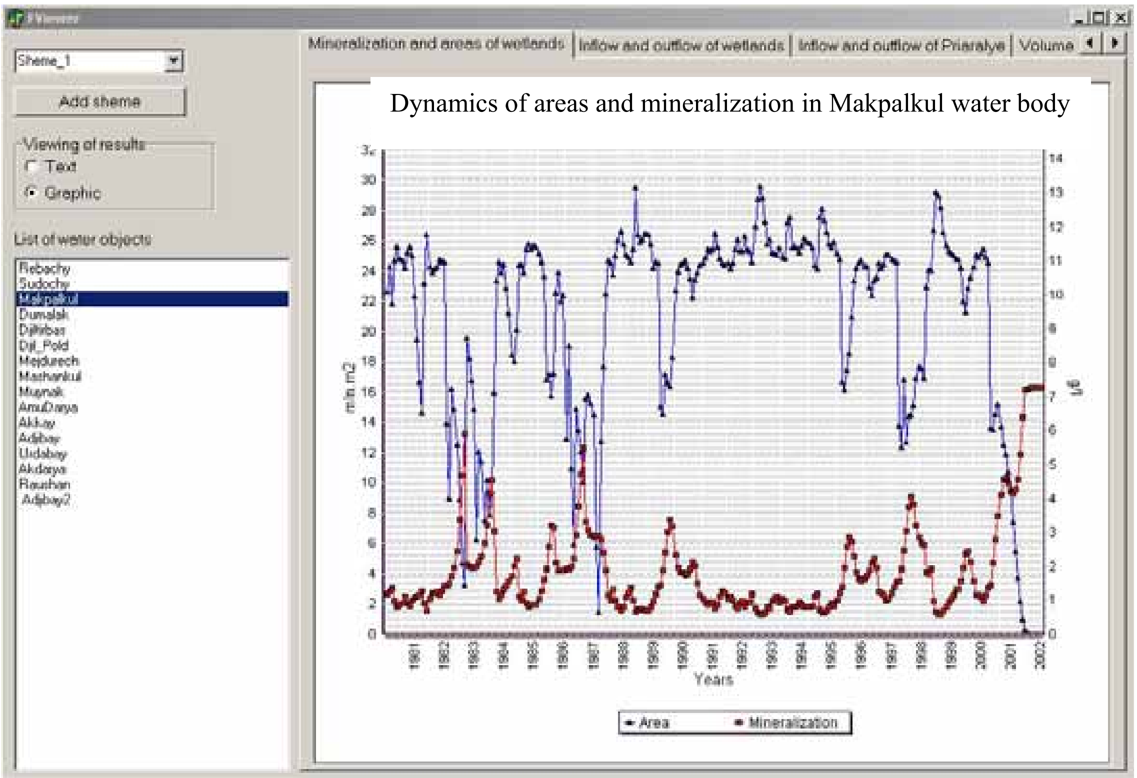
When all water objects and links between them are specified and all necessary parameters are set, the scheme is saved and simulated.

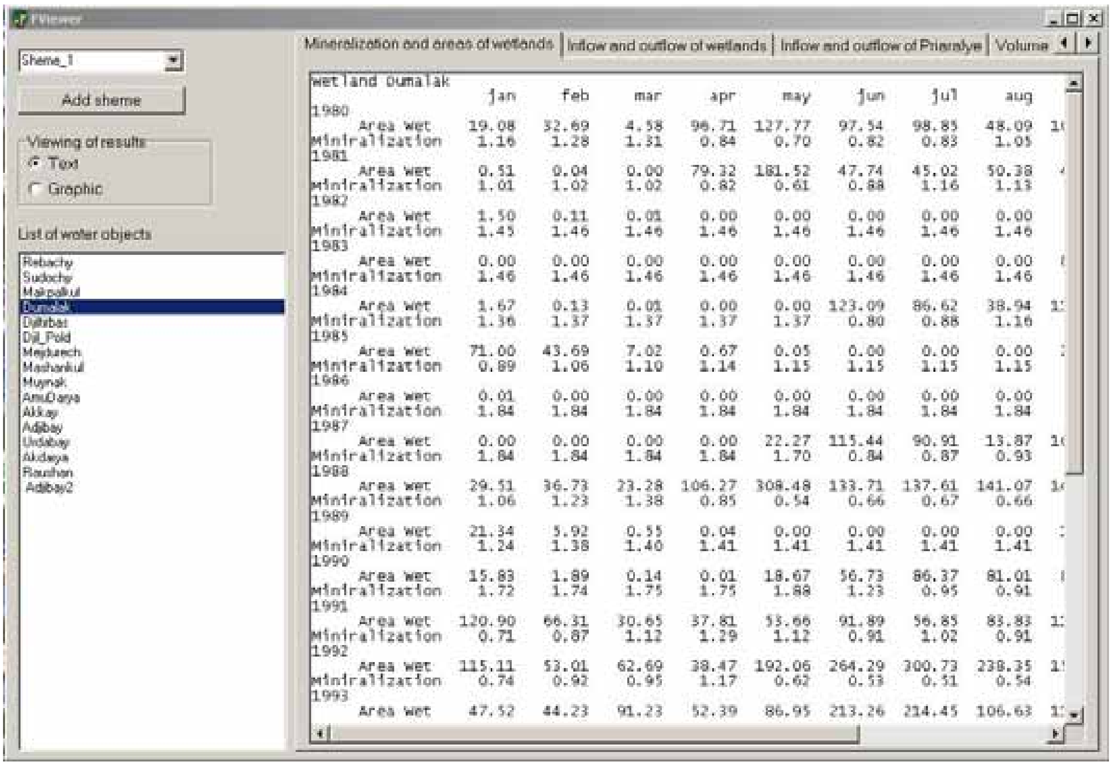
Calculation results are given below.

The information related to each scheme, which has been already calculated can be displayed in a text or graphic form.

Each tab represents information in the form of various diagrams.

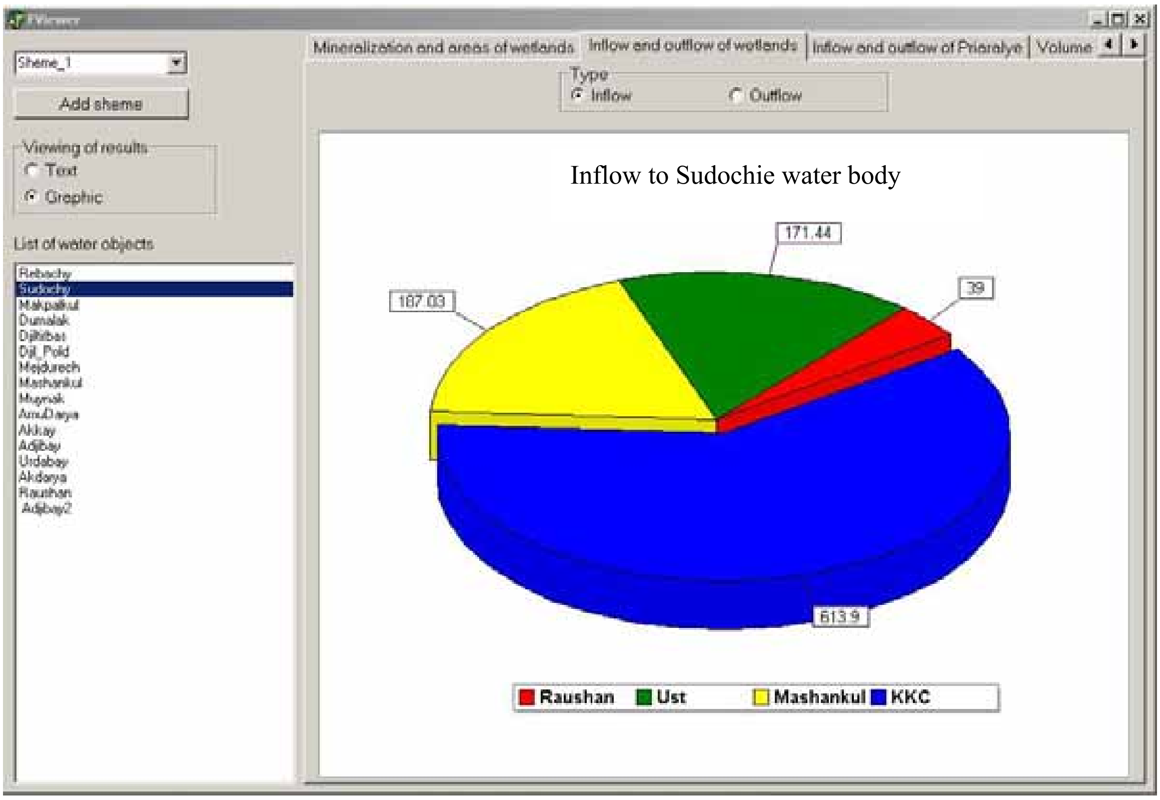


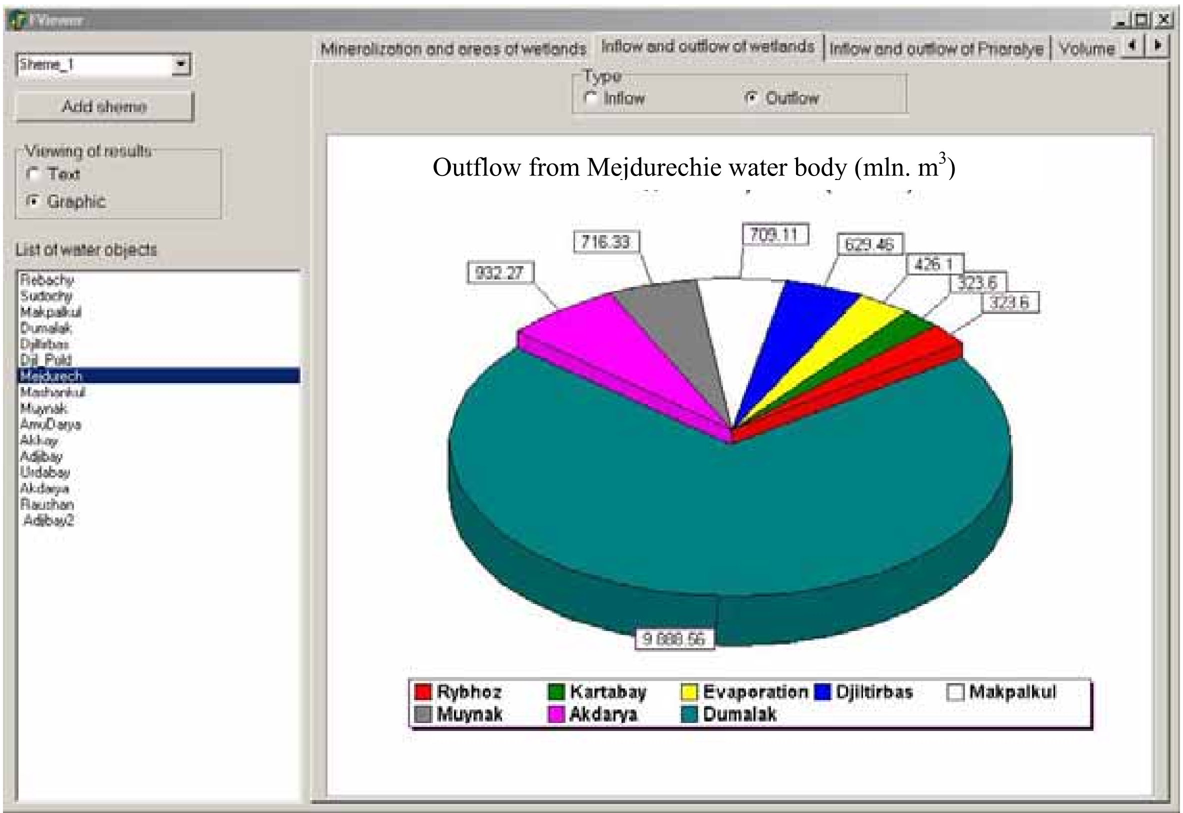


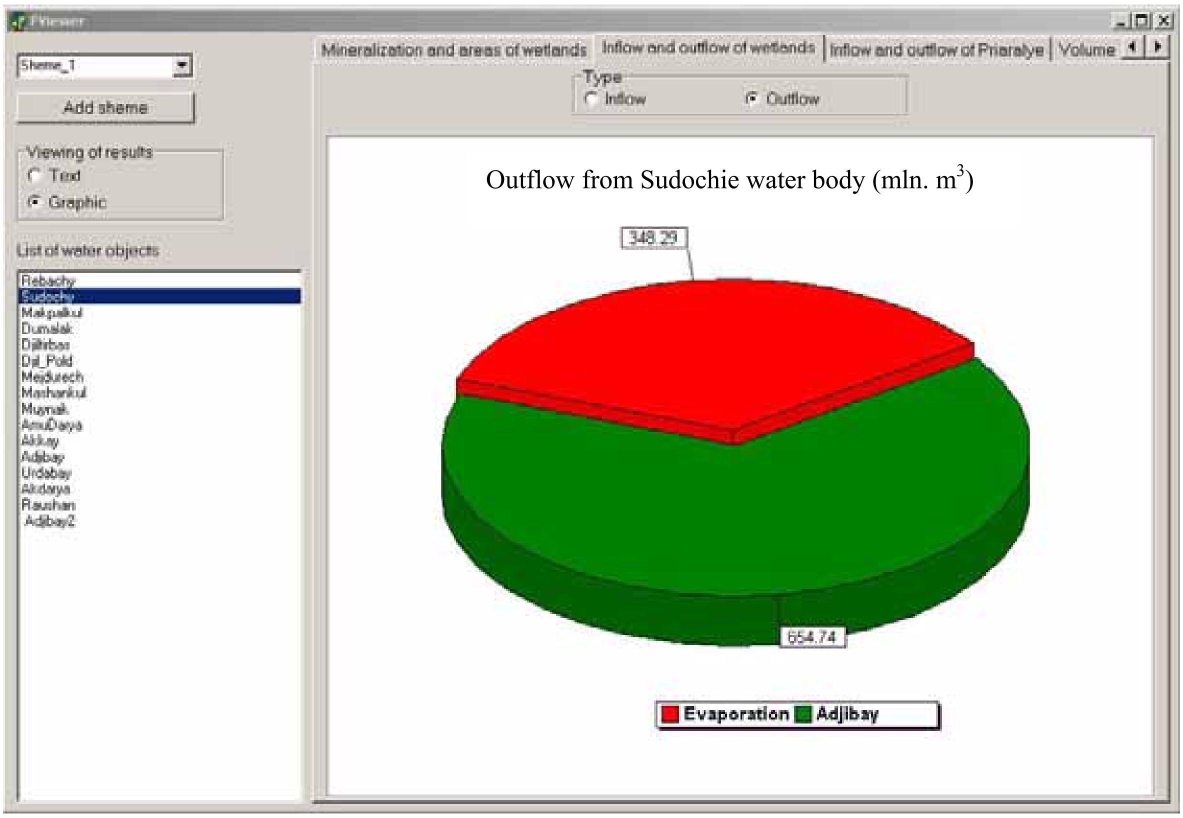


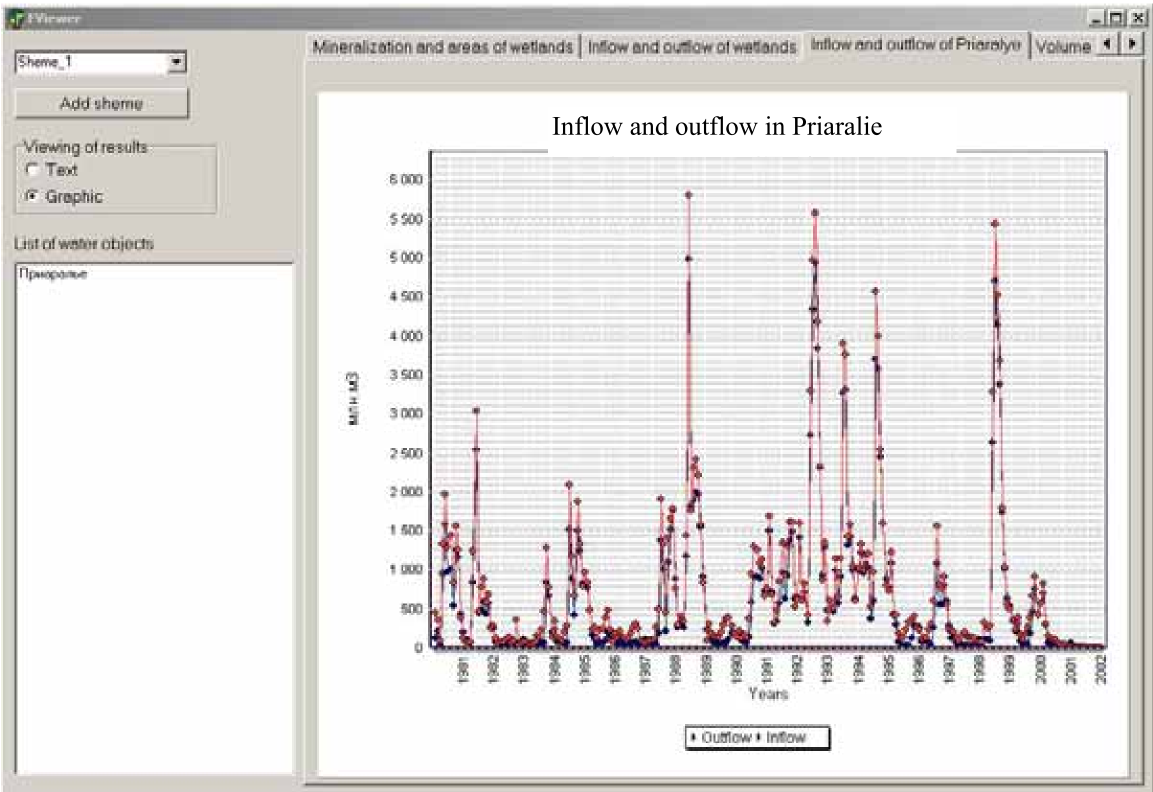
wetland Dumalak

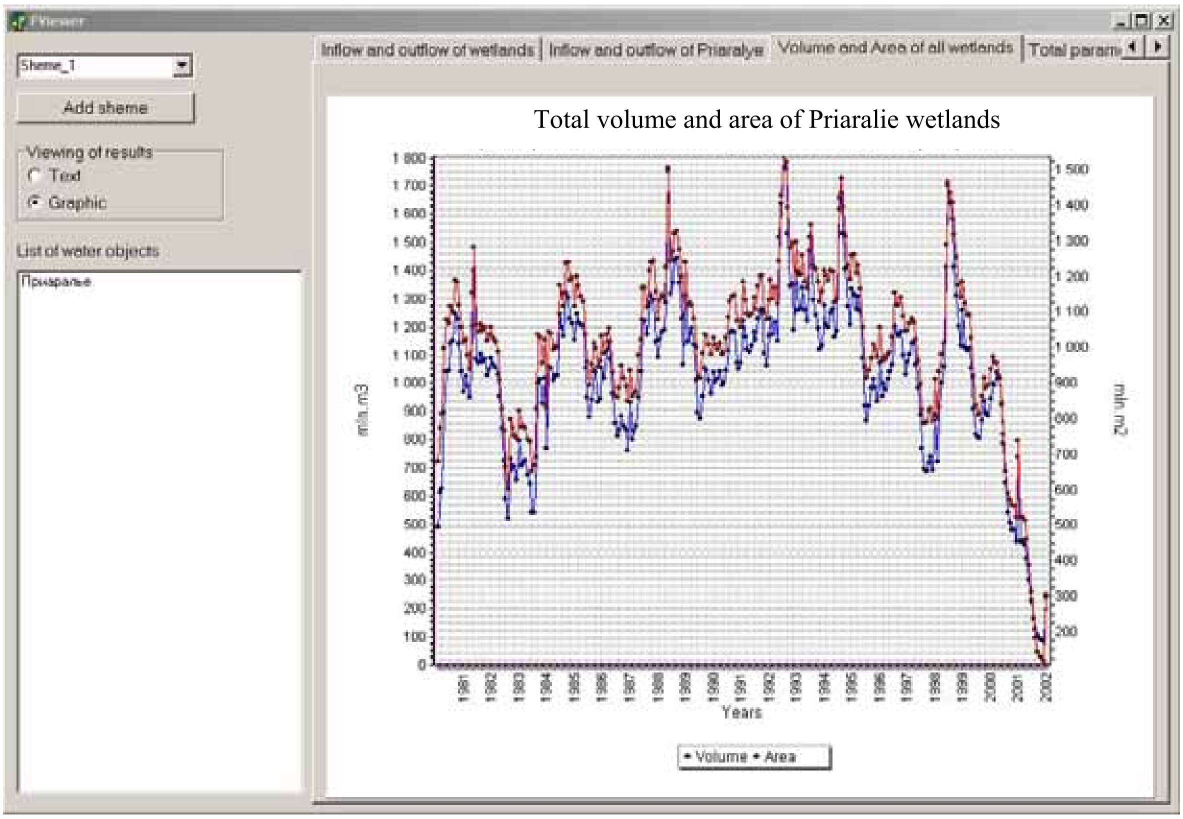
	jan	feb	mar	apr	may	jun	jul	aug
1980								
Area wet	19.08	32.69	4.58	96.71	127.77	97.54	98.85	48.09
Minirallzation	1.16	1.28	1.31	0.84	0.70	0.82	0.83	1.05
1981								
Area wet	0.51	0.04	0.00	79.32	181.52	47.74	45.02	50.38
Minirallzation	1.01	1.02	1.02	0.82	0.61	0.88	1.16	1.13
1982								
Area wet	1.50	0.11	0.01	0.00	0.00	0.00	0.00	0.00
Minirallzation	1.45	1.46	1.46	1.46	1.46	1.46	1.46	1.46
1983								
Area wet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minirallzation	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46
1984								
Area wet	1.67	0.13	0.01	0.00	0.00	123.09	86.62	38.94
Minirallzation	1.36	1.37	1.37	1.37	1.37	0.80	0.88	1.16
1985								
Area wet	71.00	43.69	7.02	0.67	0.05	0.00	0.00	0.00
Minirallzation	0.89	1.06	1.10	1.14	1.15	1.15	1.15	1.15
1986								
Area wet	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minirallzation	1.84	1.84	1.84	1.84	1.84	1.84	1.84	1.84
1987								
Area wet	0.00	0.00	0.00	0.00	22.27	115.44	90.91	13.87
Minirallzation	1.84	1.84	1.84	1.84	1.70	0.84	0.87	0.93
1988								
Area wet	29.51	36.73	23.28	106.27	308.48	133.71	137.61	141.07
Minirallzation	1.06	1.23	1.38	0.85	0.54	0.66	0.67	0.66
1989								
Area wet	21.34	5.92	0.55	0.04	0.00	0.00	0.00	0.00
Minirallzation	1.24	1.38	1.40	1.41	1.41	1.41	1.41	1.41
1990								
Area wet	15.83	1.89	0.14	0.01	18.67	56.73	86.37	81.01
Minirallzation	1.72	1.74	1.75	1.75	1.88	1.23	0.95	0.91
1991								
Area wet	120.90	66.31	30.65	37.81	53.66	91.89	56.85	83.83
Minirallzation	0.71	0.87	1.12	1.29	1.12	0.91	1.02	0.91
1992								
Area wet	115.11	53.01	62.69	38.47	192.06	264.29	300.73	238.35
Minirallzation	0.74	0.92	0.95	1.17	0.62	0.53	0.51	0.54
1993								
Area wet	47.52	44.23	91.23	52.39	86.95	213.26	214.45	106.63

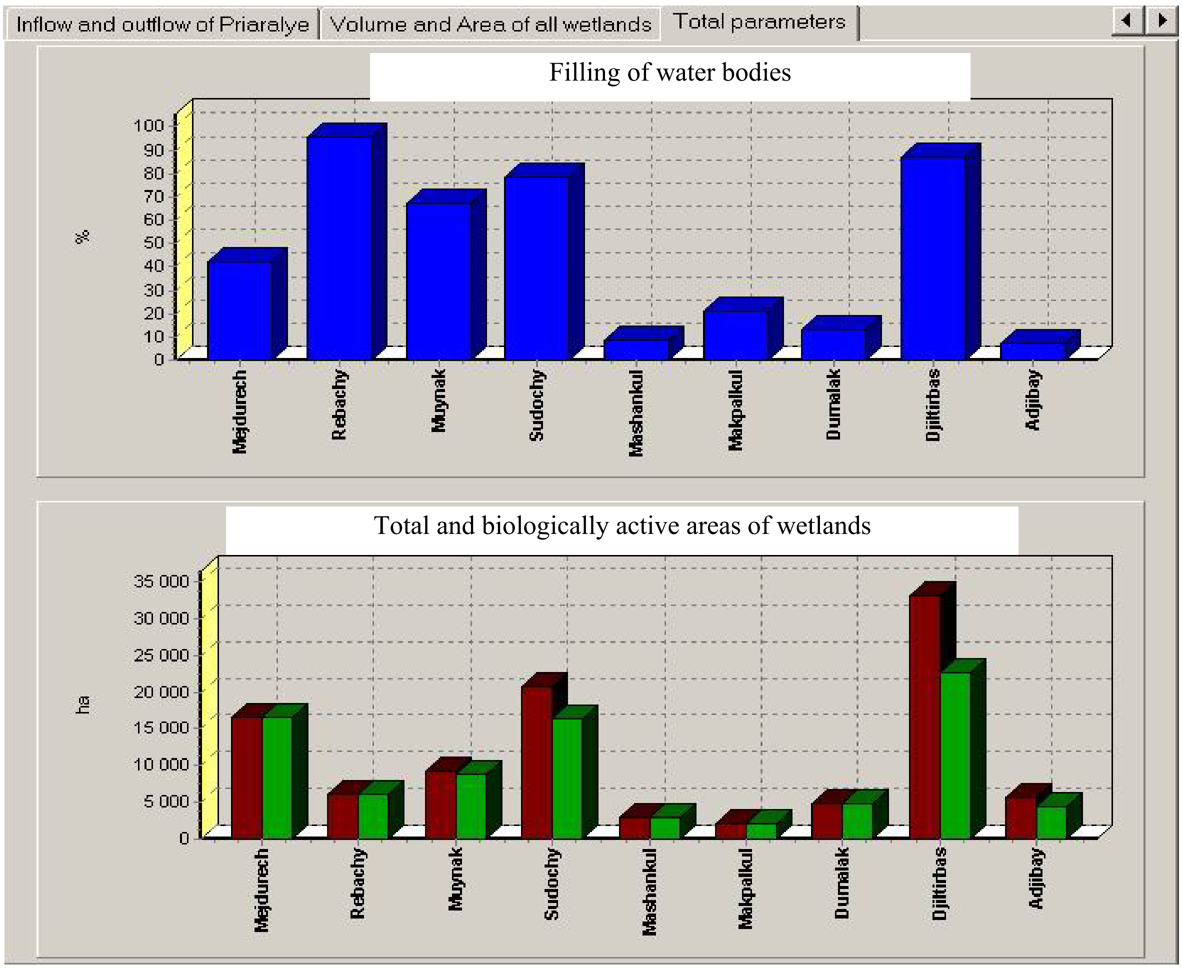

Sheme_1
Add sheme
Viewing of results
Text
Graphic
List of water objects
Rebachy
Sudochy
Makpalkul
Dumalak
Djiltirbas
Djil_Pold
Mejdurech
Mashankul
Muynak
AmuDarya
Akkay
Adjibay
Urdabay
Akdarya
Raushan
Adjibay2
Mineralization and areas of wetlands
Inflow and outflow of wetlands
Inflow and outflow of Priaralye
Volume
Type
Inflow
Outflow
Inflow to Sudochie water body
171.44
187.03
39
613.9
Raushan
Ust
Mashankul
KKC


Sheme_1
Add sheme
Viewing of results
Text
Graphic
List of water objects
Rebachy
Sudochy
Makpalkul
Dumalak
Djiltirbas
Djil_Pold
Mejdurech
Mashankul
Muynak
AmuDarya
Akkay
Adjibay
Urdabay
Akdarya
Raushan
Adjibay2
Mineralization and areas of wetlands
Inflow and outflow of wetlands
Inflow and outflow of Priaralye
Volume
Type
Inflow
Outflow
Outflow from Mejdurechie water body (mln. m3)
932.27
716.33
709.11
629.46
426.1
323.6
323.6
9 888.56
Rybhoz
Kartabay
Evaporation
Djiltirbas
Makpalkul
Muynak
Akdarya
Dumalak


Sheme_1
Add sheme
Viewing of results
Text
Graphic
List of water objects
Rebachy
Sudochy
Makpalkul
Dumalak
Djiltirban
Dal_Pold
Mejdurech
Mashankul
Muynak
AmuDarya
Akkay
Adjibay
Urdabay
Akdarya
Raushan
Adjibay2
Mineralization and areas of wetlands
Inflow and outflow of wetlands
Inflow and outflow of Priaralye
Volume
Type
Inflow
Outflow
Outflow from Sudochie water body (mln. m3)
348.29
654.74
Evaporation
Adjibay


Sheme_1
Add sheme
Viewing of results
Text
Graphic
List of water objects
Mineralization and areas of wetlands
Inflow and outflow of wetlands
Inflow and outflow of Priaralye
Volume
Inflow and outflow in Priaralie
Years
Outflow
Inflow


Sheme_1
Add sheme
Viewing of results
Text
Graphic
List of water objects
Приаралье
Inflow and outflow of wetlands
Inflow and outflow of Priaralye
Volume and Area of all wetlands
Total param
Total volume and area of Priaralie wetlands
mln.m3
mln.m2
Years
Volume
Area


Inflow and outflow of Priaralye
Volume and Area of all wetlands
Total parameters
Filling of water bodies
%
Mejdurech
Rebachy
Muynak
Sudochy
Mashankul
Makpalkul
Dumalak
Djiltirbas
Adjibay
Total and biologically active areas of wetlands
ha

12.3. Establishing the Basis for Wetlands Management

At present, each sector of economy subordinated to the sectoral department or ministry performs its direct functions and at the same time there is not an integrated system of environment and water resources management. The economic activity of different sectors is not coordinated, and ultimately this results in irrational use and exhaustion of natural resources.

Water management in the delta is proposed to establish on the basis of IWRM principles. The non-encouraging experience of the Coordination Council established for management the Sudoche Lake system resulted in distrust to performance capabilities and prospects of such institutions. Nevertheless, the international experience (especially, the experience of the Netherlands, France, Spain and other European countries) has clearly shown that under the appropriate institutional framework and providing the adequate legal and financial base, such institutional arrangements could ensure benefits using rather small inputs.

It is proposed to establish the Amu Darya Delta Water Management Consortium. The Consortium with appropriate commitments at national and local levels could coordinate activities of all stakeholders on the territory of the delta and coastal lakes with the local government, District Khakimiats (district administration organs), and other beneficiaries. This will allow increasing fish and muskrat production, to solve an unemployment problem, and to facilitate delta environment protection and its development.

The Consortium could integrate all stakeholders (as the founders) interested in the delta rehabilitation and operation, including:

- water management associations (Rayon Water Management Authorities and water users);
- construction firms and operation services (contractor units, rayon and farm operation services, etc.);
- nature protection services of the Goskompriroda (the State Committee for Nature Protection);
- associations of farmers, fishermen, muskrat hunters;
- fish-processing factories and fish hatcheries;
- Crop farms in the project zone (the Muynak, Kungrad, Chimbay, and Takhtakupyr rayons);
- Cattle-breeding farms (cattle-breeders, stock keepers);
- Forestry management bodies.

All these target groups and beneficiaries will use the Consortium’s services. The following republican and interstate agencies should act as the founders of the Consortium:

- Goskompriroda;
- Ministry of Agriculture and Water Resources;
- Uzbekbalyk (the Republican Fishery Consortium);
- Forestry Department of the Ministry of Agriculture and Water Resources;
- BWO "Amu Darya".

The base of the Consortium activities should be:

- the legal status of entity that is responsible for conservation and use of water, forest and other reserves in the delta;
- delegation to the Consortium by all republican agencies of their rights to grant licenses and permissions for all kind of economic activities in the South Prearalie (fishery, forestry, agriculture, hunting, etc.);
- independence to develop fishery, cattle-breeding, agriculture, ancillary crafts, reed processing, etc.

and to contact with the stakeholders for these purposes.

The Consortium will sign an agreement with BWO "Amu Darya" on water delivery, data acquisition services and notification of potential changes in water delivery.

Establishment of the Consortium will provide the opportunity for the delta development taking into consideration the following issues:

- institutional and economic support to organizations and other economic entities engaged in economic activities (fishery, muskrat, agriculture, cattle-breeding, etc.), which at present are subordinated to different ministries and agencies due to absence of the integrated system of nature protection and water management;
- improvement of conditions for different target groups, such as farmers' associations, rayon water management organizations, commercial enterprises of small and medium-scale business;
- provision of wide opportunities for establishing private fishery, muskrat-breeding, and cattle-breeding farms. This ensures that most of the population will be provided with job, and respectively will get a profit under proper farm management.

The beneficiaries (the most vulnerable groups of the local population, which at present are in very difficult economic conditions) would receive considerable benefits from the project implementation. This idea was submitted for consideration by NGOs of Karakalpakstan (the ECO Prearalie, “Persent”, and others) and preliminary discussed at the governmental level (the Cabinet of Ministers of the Republic of Karakalpakstan, ‘Karakalpakbalyk’, Goscompriroda, etc), at local and national institution levels, and approved with some comments and proposals.

As a whole, the idea of establishing the Consortium is supported by majority of state organizations such as Goskompriroda, the Hakimiyat of Muynak District, and “Karakalpakbalyk”. Beneficiaries show high interest in this idea, especially in establishing private fishery farms, which will be integrated with the “Karakalpakbalyk”.

XIII. SOCIO-ECONOMIC EFFECTIVENESS OF PROPOSED MEASURES

Based on methods proposed by the Scientific Information Center of the Interstate Coordination Water Commission (SIC ICWC) within the framework of the Socio-Economic Assessment of Environment Disaster - the Aral Sea Desiccation Project (the Project INTAS RFBR-1733), the classification of both direct economic and socio-environmental losses was developed.

In contrast to the production projects, where their effect is estimated by comparing their profit “prior to and after” implementation, under estimating an effectiveness of the social-ecological projects it is necessary to consider to what extent the total losses that are a result of current trends could be reduced due to the project implementation.

In this context, the following classification of socio-economic losses is proposed:

1. Direct losses:

1.1. Agriculture:

- Irrigated farming within the sea-desiccation-affected zone;
- Fishery due to decreased catches;
- Muskrat breeding;
- Livestock farming.

1.2. Recreation and tourism.

1.3. Industry:

- Fish processing factories;
- Muskrat pelts production;
- Reed processing;

1.4. Transportation (decreased flow of traffic)

2. Social losses:

- Population migration
- Loss of experienced labor force
- Health impairment
- Deterioration of living conditions
- Deterioration of water supply
- Deterioration of foodstuff supply
- National income losses
- Increase of unemployment and loss of workplaces.

To estimate direct effect it was necessary to determine to what extent the project will cause an increase in amount of fish catch and processing, an increase in muskrat population, catch and processing, as well as reed growth and harvesting with follow-up processing.

Toward this end, the model of wetland bio-productivity within a set of mathematical models was elaborated.

Under calculating reed bio-productivity, the following plant requirements regarding the environment – a depth of water body in the zone of active reed growth shouldn't exceed 1.0 to 1.2 m and water salinity is less than 15 g/l - were taken into account. Under such conditions, reed bio-productivity will average 2 t/ha of a dry mass. Depending on a depth of the watertable and soil salinity, productivity of meadow reed usually is less than that on wetlands 2 to 4 times.

The following relationship between a dry mass of reed and its area was derived from the analysis of above-mentioned conditions:

$$M_j^{c.в.}(S) = Area_j^r \times \frac{S^r}{S^r + (S_j / S^r)\text{^}2.5} \times P^r , \qquad (13.1.)$$

where: $S^{\hat{e}}$ is a value of salinity at which reed growth starts to decline; this value was assumed as 5 g/l.

$P^{\hat{e}}$ is maximum reed productivity (at the low salinity level), which was assumed as 1.6 t/ha.

When calculating muskrat bio-productivity it was assumed that average yield of one muskrat female is 17 muskrat-cubs, a natural death rate is 30 percent, and allowable catch for muskrat's pelts production shouldn't exceed 30 percent of the population size. Muskrat families live in flooded reed thickets that amount to about 30 percent of the total reed-growth area. The rest of a reed thicket area is practically unsuitable for muskrat habitats (Table 13-1).

Table 13-1 Typology of muskrat habitats within the Sudoche wetlands and dynamics of muskrat yield

Index	1960-1970				1990-1995				1999			
Quality of habitat	H	G	S	P	H	G	S	P	H	G	S	P
Area (%)	20.0	35.0	40.0	5.0	5.0	9.0	30.0	55.0	1.0	2.0	38.0	59.0
Biological productivity (families per 1 ha)	3.0-5.0	2.0-3.0	1.0-1.5	0.2-0.5	3.0	1.0-2.0	0.5-0.9	0.1-0.5	2.0-3.0	1.5-2.0	0.5-1.0	0.1-0.5
Economic productivity (muskrat pelts per 1 ha)	20.0-30.0	15.0-20.0	7.0-12.0	1.0-3.0	20.0	14.0-20.0	5.0-9.0	5.0-9.0	10.0-15.0	8.0-10.0	5.0-7.0	1.0-2.0

H - High G - Good S - Satisfactory P -Poor

The table demonstrates economic productivity of the muskrat population in the Sudoche Lake area since 1960 till 1999. When calculating muskrat productivity, it is assumed that implementation of wetland rehabilitation measures in the South Prearalie will ensure a good quality of muskrat habitats.

Extreme droughts of 2000 to 2001 have resulted in practically complete damage of grounds suitable for muskrat habitats and in extinction of the population of these animals. Restoring the muskrat population requires introduction of new groups of animals (not less than 50 couples) and ban of catch for production purposes, at least, during two years.

When calculating a fish stock it was assumed that natural bio-productivity of water bodies in the presence of herbivorous fish averages 50 kg/ha. In addition, for fish development and active reproduction it is necessary to provide conditions under which the dissolved oxygen content should not be less than 4-5 mg/l, and the salinity level should be less than 5 mg/l during spawning and early stages of young fish growth and less than 10-15 g/l for adult fish fattening, while an average water body depth should not be less than 1.5 m.

Salinization and drying up of water bodies in the South Prearalie during last dry years along with over-fishing in active water bodies have resulted in the loss of reproductive population of commercial fish. Therefore, fish productivity of restored water bodies will not be high during initial three-four years necessary for recovering the breeding fish shoals. Fish introduced into delta water bodies with river water inflow will form the base of fishery during this period.

An algorithm for calculating fish productivity depending on water bodies area and water salinity was developed. The algorithm is described below.

At the beginning of a year, an amount of fish for each age group was determined. Then, this amount was reduced by an amount of fish caught by fishermen and eaten by birds.

In addition, the relationship between an amount of fishes and salinity was derived.

$$K_f(S) = K_0 \times \frac{S_j^f}{S_j^f + (S / S_j^f)\verb|^|5}, \tag{13.2.}$$

where: S^f is salinity which affects considerably on the adult fish population; the Ecological Group recommended to take S^f equal to 15 g/l;

K_0 is the maximum number of fish without taking into consideration effect of salinity.

The amount of fish caught by fishermen was determined according to time series under high salinity conditions.

At the same time, fish eaten by birds was also taken into account in fish productivity calculations. It was assumed for simulating that birds eat three kilograms of one- and two-year-old fish per 1 ha.
For simulating fish reproduction a relationship between an amount of survived spawn and salinity was specified. It was presented as an amount of fish what will be next year (one-year-old fish).

$$K_{f0}(S) = P^{f0} \times \frac{S^{f0}}{S^{f0} + (S_j / S^{f0})\verb|^|5}, \tag{13.3.}$$

where: S^{f0} is the salinity level at which negative impacts on spawn start to become apparent; the Ecological Group recommended to take S^{f0} equal to 5 g/l;

P^{f0} is a maximum increase of fish stock per year; it was taken as 30 kg/ha/year.

As it is obvious from the formula, a maximum amount of one-year-old fish cannot exceed 30 kg/ha/year. If under simulating the process of water body drying up was found then fish catch should not take place next two years.

The estimation has shown that profit from all direct economic activities amounts to US$236 million at a mean annual profit rate of US$ 5.7 million during the project life (Table 13-2).

Table 13-2 Averted Losses, 000'US$

Total averted losses	**Average annual**
Environment	12,250.0
Cattle breeding	2,844.0
Loss of experienced force	218.8
Public health	390.3
Life expectancy growth	439.1
Living standard improvement	4,162.0
Total	**20,304.2**

At the same time, the main effect is reached due to reduction of damage caused by the Aral Sea desiccation, desertification, etc.

Diminishing damage involves prevention/mitigation of both environmental and social losses that are basic factors since they directly impact on welfare of local population.

1. Social losses diminishing

As the Project INTAS/RFBR 1733 has demonstrated, annual social losses, for a year reduced to 1995, amounted to US$ 28.81, of which:

- Population migration US$ 0.25 million;
- Loss of experienced force US$ 4.4 million;
- Health damage US$ 1.65 million;
- Decreasing of electric energy sale US$ 3.51 million;
- Deterioration of living conditions US$ 19.0 million.

According to recent data, during last 5-8 years, except two dry years, these indicators have stabilized.

It is necessary to determine what part of this damage will be compensated towards the final terms of achieving project productivity. For this purpose, a quantity of people involved in project implementation is specified:

- Need in labor force for construction increases from 1000 to 2500 people at the output rate of 4,000 US$/person/year). Thus, migration of the able-bodied population will be stopped completely (approximately 1750 persons/year);
- Number of working places will increase:

a) water-management infrastructure operation 250 persons;
b) fishery 500 persons;
c) hunters 250 persons;
d) fish and muskrat processing 1000 persons;
e) livestock farming 1800 persons;
f) reed processing 800 persons;
g) transport 500 persons

Total without construction 5100 persons
Including construction (on average, 1750 persons) 6850 persons
Services sector usually constitutes 30 percent of working people 2055 persons
Total 8905 persons

The total population with permanent income at a family factor of 3.1 is 27,600 persons

Involvement of the local population in project implementation will allow diminishing losses:

h)	population migration	US$0.25 million;
i)	losses due to illnesses (8,905 * US$ 50/workday)	US$0.445 million;
j)	increased life expectancy (27,600 * 0,013 * 450 * 3)	US$0.485 million;
k)	improved living conditions (8,905 * 500)	US$4.450 million;
	Total	US$5.630 million.

All these indices should be achieved when full-scale operation will start, i.e. in 2017-2020. Further, these indices will increase since income and life cost will be increasing, at least, by 8 percent/year.

2. Ecological losses reduction

Main ecological losses in the South Prearalie were determined in the same INTAS project as follows:

- desertification of 800,000 ha – US$ 25.6 million per year under decrease in soil fertility rating by 20 points;
- tugai vegetation losses on 260,000 ha - US$10.4 million per year;
- crop yield losses due to salt and dust transfer – US$3.8 million per year;
- livestock farming losses due to deterioration of forage reserves – US$ 8.4 million.

As a result of project implementation, damage due to desertification will be reduced by US$ 13.1 million at the expense of plant growing, landscape stabilization, and groundwater table rise on the territory of 420,000 ha; conditions for stable water supply will be created in the area of 70,000 ha of the former tugai zone, and this will allow to reduce losses by US$2.8 million (by 2017-2020).

It is supposed that by the end of the implementation phase, adverse affect of salt and dust transfer from the exposed seabed will decrease due to the development of water and vegetation cover of the territory, thus reducing impact of salt and dust transfer on crop yield (averted losses are US$ 3.8 million).

Total averted environmental losses amount to US$19.7 million.

The project will provide three-fold increase of a reed area that will lead to restoration of a forage base and two-fold (or US$ 4.1 million) reduction of losses in livestock farming by 2030.

Conclusions

Project efficiency indicators under the construction period of 12 years (calculation of indicators till 2050 – 48 years) are the following:

- Net present value, US$ million 78.9
- Internal rate of return, percent 18
- B/C ratio 2.5
- Discounted payback period, years 16
- NPV 149,338.5
- IRR 0.18

Project efficiency indicators under the construction period of 12 years (calculation till the payback time) are the following:

- Net present value, US$ million 78.9
- Internal rate of return, percent 8
- B/C ratio 0.1

- Discounted payback period, years 16
- NPV 4,235.1
- IRR 0.08

Project efficiency indicators under the construction period of 9 years are (calculation till 2050 to 2048 years):

- Net present value, US$ million 97.8
- Internal rate of return, percent 15
- B/C ratio 2.2
- Discounted payback period, years 17
- NPV 132,234.3
- IRR 0.15

Project effectiveness indicators under construction period of 9 years are (calculation till the payback time):

- Net present value, US$ million 97.8
- Internal rate of return, percent 7
- B/C ratio 0.1
- Discounted payback period, years 17
- NPV 4,151.5
- IRR 0.06

From the economic point of view, the project is more attractive under the construction period of 12 years. The B/C ratio is low in each project option but one should bear in mind that the project is of great social and ecological importance improving well-being of the local population and the ecological situation in the region.

AFTERWORD

SOLUTIONS FOR THE ARAL SEA: A TECHNICAL, ENVIRONMENTAL, ECONOMIC, POLITICAL, AND HUMAN CHALLENGES

During the fall of 1999, Dr. Philippe Lazar, President of IRD, and Dr. Antoine Cornet, President of the French Committee of Desertification Control, asked me if I was interested to intervene as the expert-consultant for the NATO Science for Peace Programme to assess two projects regarding the environmental and hydrologic conditions of the Amu Darya Delta. Working basically in Africa and South America, I knew very little from the Aral Sea: I had seen the first TV-movie and several journal pictures with the Muynak's fishing boats aground in the desert and I kept in mind some summary information about the overuse of the water resource for cotton irrigation in the Soviet Republics of Central Asia. In first reflex, I consulted two basic references: the book *Aral* from René Letolle and Monique Mainguet[2] and the famous paper of Prof. Philip Micklin in *Science*[3]. Both documents cited the works of Prof. Dukhovny and his team. A few days after, I had a conversation with Prof. Létolle in a small *bistro* of Paris. Finally, I took fast the decision to accept the NATO invitation. I do not regret it.

The Aral Sea issues and solutions are a perfect combination of all main questions studied by the scientists and the engineers involved in water and/or environmental sciences:

- impact of climate variability;
- organisation and dynamics of cultivated areas, with or without irrigation;
- porous or discontinuous groundwater reservoirs;
- water contamination;
- water management: resources, needs and uses, regarding territories, societies and policy;
- risks;
- water and health.

During the last two years, I gave several lectures to the postgraduate students of the Montpellier and Paris Universities on the concept of sustainable development in the area of water renewable resource. I took examples through different parts of the world, and, obviously, I presented the Aral Sea case, using results obtained and published by the SIC-ICWC and its partners. The great interest of the students and the numerous questions concerned not only the scientific and technical approach, but also the ethic, the decision process, the impact of the Soviet Union collapse, etc., and led to a thought on the interaction between politicians, scientists and human societies.

The International United-Nations Conference on Water in Dublin (1992) established principles in order to give a common world directive for a sustainable management of the water resource[4]. The second and the forth principles are:

2. Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
4. Water has an economic value in all its competing uses and should be recognized as an economic good.

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[2] **Létolle, R., Mainguet, M.** - 1993. Aral. Springer-Verlag France, Paris, 358 p.
[3] **Micklin, P. P.** - 1988. Desiccation of the Aral Sea: a water management disaster in the Soviet Union. *Science*. 241 (2 September 1988): 1170-1176.
[4] http://www.wmo.ch/web/homs/documents/english/icwedece.html

More recently, the 3rd World Water Forum in Kyoto (March 2003) insisted on this last point that the right way to improve the water management through the whole world is to consider the water as an economic good. This approach is revolutionary in the sense that the water, *present of the sky* (*or of God*), is everywhere considered as a free basic life necessity, like fire, air or earth, unlike oil or agriculture products which have an added value due to manpower, soil property and/or mechanical intermediaries.

The Aral Sea issues are an excellent example to justify such new view angle to consider the water world patrimony. I am not an economist, but I try a very rough analysis, taking for an instant, this view angle:

- In the fifties, the Soviet Union took the decision to develop the irrigation in Central Asia using the Syr Darya and Amu Darya Rivers water resources with the justification of an economic central planning at large spatial scale and long time term. The flux of produced goods in the Aral Basin's irrigated areas in direction of all the soviet republics and associated countries was equilibrated by a return flux of other goods, money, skill, etc.
- Today, the new world order, based on the economy market and budgeted at country scale, has changed this equilibrium. The local economic inputs can no longer balance the environmental cost of the Aral Sea shores and deltas wet zones in order to maintain an acceptable social level for the population. Presently, in Uzbekistan and in Kazakhstan, the inhabitants of the deltas do not receive a return flux from the investments made upstream giving a benefit to the production. On the contrary, the economic, social and environmental degradation is increasing[5].

This tentative analysis shows why the funding institutions have to consider the solutions of mitigation for the deltas environment with an economical angle and why they have to analyze the cost to pay for technical solutions taking into account who are the real beneficiaries of the investments made to regulate and distribute the water offer.

During the last fifteen years, the scientific community led numerous studies on the Aral Sea basin[6]. However, after the report and the diagnostic, few of them proposed realistic solutions, which can improve the environmental and human issues in the coastal zones of the Aral Sea or within the deltas of Amu Darya and Syr Darya.

The great interest of the present book is to approach the complexity of the South Prearalie issues with fundamental honesty. It succeeds in convincing that simple and flexible technical solutions could lead to significant mitigation not only of the wet-zones' landscapes and wild life, but also for the construction of a sustainable framework for the benefit of the human communities.

I hope that the funding institutions will follow the proposed projects and I insist on two special points:

- The basic hydraulic new constructions or restorations within the delta must be coupled with a severe control of the hydraulic structures upstream on the Amu Darya valley and its tributaries, canals, collectors or reservoirs.
- The new works and management strategies proposed in the project must not be considered as definitive. Along the time and in accordance with the global changes, not only the technical management of the water fluxes, but also the global governance of the Amu Darya Delta environment and communities should be adapted to the conditions of the moment.

[5] From 1980 to 1995, the life expectancy increased from 69,0 to 70,1 years in all Uzbekistan, and the children mortality decreased from 37,7 to 30,3/1000. On the contrary in the Amudarya delta, the life expectancy increased significantly slower (64,2 to 64,8 years), and the children mortality, already two times higher, increased from 59,4 to 61,0/1000. (source: Intas and Nato SfP data, 2001).

[6] The European Union Copernicus-2 Project established a very complete list of references, most of them in English or Russian, in: **Nihoul, J. C. J., Kosarev, A. N., Kostianoy, A. G., Zonn, I. S.** - 2002. The Aral Sea: selected bibliography. EU Copernicus-2 Project "ARAL-KUM. Noosphere, Moscow, 232 p.

However, it is fundamental, especially in the Aral Sea Basin, to adopt and respect the second and forth principles of Dublin, in order to improve the global water resource management for the benefit of the human societies and the respect for the environment.

Dr. Pierre Chevallier

Senior Scientist
Institut de Recherche pour le Développement (IRD, Paris)

Director of the Languedoc Research Institute on Water and Environment (ILEE)

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