Federal Ministry for Economic Cooperation and Development (BMZ)

German Agency for Technical Cooperation (GTZ)

Interstate Commission for Water Coordination in Central Asia (ICWC)

COMPREHENSIVE REMOTE SENSING AND GROUND-BASED STUDIES OF THE DRIED ARAL SEA BED

Tashkent 2008

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Comprehensive remote sensing and ground-based studies of the dried Aral sea bed, edited by Prof. V.A. Dukhovny - Tashkent: SIC ICWC, 2008. – 172 p.

This book presents results from studies of the status and dynamics of the dried Aral seabed, based on ground surveys and remote sensing techniques. It describes environmental consequences and hazards resulting from the shrinking of the Aral Sea and highlights measures aimed at mitigating these hazards. Particular importance is given to the positive effects of afforestation of the former seabed on landscape dynamics and desertification processes. Based on these analyses, proposals are made for follow-up studies and mitigation strategies.

The book is intended for environmentalists, agronomists, hydrologists, as well as for students and those concerned about the future of the Aral Sea and the Prearalie.

ISBN 9965-32-616-9

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Acknowledgements

This research was undertaken within the framework of the GTZ-Project “Stabilization of the desiccated Aral Sea bed in Central Asia”, financed by the German Federal Ministry For Economic Cooperation and Development (BMZ). The remote sensing studies were conducted in cooperation with the German Aerospace Center (DLR) and Remote Sensing Solutions GmbH.

1. INTRODUCTION: INTEGRATED REMOTE SENSING AND GROUND SURVEYS ON THE DRIED BED OF THE ARAL SEA: BACKGROUND AND RESEARCH OBJECTIVES

The Aral Sea, Aral Sea basin, Aral Sea crisis, Aral Sea – a catastrophe of the century…

Such headings and slogans filled popular, scientific and general literature and publications in the late 1990s and still appear until now. Wherever you mention the Aral Sea, or may be just glancing at a certificate of membership to an organization associated with the International Fund for Saving the Aral Sea, people are asking about the incidents happening at the Aral.

Meanwhile, this major subject of universal and global attention remains out of sight of both, science and practice and of those who should have direct concern.

What is really going on there is only known to about two hundred scientists and specialists worldwide, as well as to the population of local settlements, mostly hunters, fishers and livestock breeders who still try to make a living under the most complicated and challenging conditions which prevail since a new desert has been formed on the dried bed of the Aral Sea. This desert is referred to as Aral Kum (the Aral sands) and develops its very own specific fauna, flora, natural landscapes and characteristics.

Desertification processes which usually occur over centuries have been accelerated by anthropogenic influence now and reveal their devastating effects within the life cycle of one generation. Even though the significance of a scientific monitoring these processes is obvious, science practically did not get down to this subject yet. Due to various reasons, including cost-intensive field campaigns, complex working conditions, the remote location and high risks in general, the Aral Sea bed remained a subject for one-time visits and impressions until today, without detailed observations and deeper scientific analysis taking place.

From this point of view, the GTZ Project "Stabilization of the desiccated Aral Sea bottom in Central Asia" is a successful exception. Since 1995, the Project has been dealing with the application of a technology for planting drought-resistant tree and shrub species (together with the Forestry Research Institute of Uzbekistan) on an area of more than 30,000 ha, and in 2005, a scientific component was included in the project. The objective of this component was to establish an integrated remote sensing and ground-based monitoring system in order to assess the processes taking place on the dried seabed, risks of desertification and other negative consequences of the on-going Aral Sea desiccation.

This work was undertaken by the Scientific Information Center of the Interstate Commission for Water Coordination (SIC ICWC) in cooperation with GTZ specialists (Gross, H. Wilps, P. Navratil) and the Kazakh enterprise "TERRA" (B. Geldiyev, Ye. Kozlova, N. Ogar) on a jointly agreed method, according to a decision made at a Coordination Meeting in Almaty on 13-15 December 2005.

Main research issues

1. Land cover classification from the perspective of dried seabed stabilization and desertification
2. Evaluation of the potential of remote sensing techniques for the identification of the land cover types on the desiccated sea bed
3. Accuracy assessment of the land cover maps by using ground-based observations
4. Analysis of landscape change dynamics on the dried seabed by comparing expedition, remote sensing and historical data
5. Assessment of environmental risk degree of the different land cover types
6. Assessment of the status and impact of afforestation measures on the dried seabed
7. Proposals for follow-up of the work

2. DESCRIPTION OF THE STUDY AREA

2.1. Aral - Current dynamics and recent research

The Aral Sea is situated in the northern desert part of Central Asia, within the territories of the states of Uzbekistan and Kazakhstan. The basin of the Aral Sea is a complex ecosystem. From 1900-1960, the last stable period of the Aral Sea, the sea level was at 53 m a.s.l., which was almost 80 m higher than that of the Caspian Sea. The longitudinal width was 265 km at 45°N, and the shoreline length was more than 4430 km. In the 1960s, before the phenomenal desiccation set in, the water surface area was 69.790 km^2, the maximum sea depth was 69 m, and the water-mass volume was about 1056 km^3 (as calculated by SIC ICWC on the basis of a bathymetry map).

The hydrological regime of the Aral Sea, as of most inland reservoirs in any arid environment, is subject to intensive variations caused by natural and anthropogenic factors. Geological, geo-morphological and archeological research in the Aral Sea basin have shown that fluctuations of the sea level have covered more than 20m amplitude in the preceding 4-6 thousand years (Bogdanov, Pinkhasov et al. 1995; Kes 1969; Lymarev 1967; Pinkhasov 1998; Rubanov et al. 1987). Sea level fluctuations have also been observed until 1960, but their amplitude did not exceed 4 m in the recent 200 years and was within 1 m in the first half of the 20th century. Until the 1950s, the environmental situation in the region was quite stable.

Since the beginning of regular observations of the Aral Sea water level, 2 periods can be emphasized:

1. 1911-1960 - Conditionally natural period, characterized by a relatively stable hydrological regime with sea level fluctuations around 53 m and inter-annual fluctuations at no more than 1 m.. The sea received annually about a half of the run-off in the Syr Darya and Amu Darya rivers, i.e. 50-60 km^3/yr.

2. since 1960 until now - Intensive anthropogenic impact period.

Since the 1960s, a vast expansion of irrigable land was carried out in Central Asia, which resulted in an intensive diversion of river run-off in the two tributary streams. Even worse, the agricultural activities concentrated on the cultivation of very highly water-demanding crops in vast monocultures, mostly cotton and rice. This is regarded as the main reason for the Aral Sea desiccation, as the sea level has been falling steadily since then. Due to the very shallow character of the Aral Sea bed the decrease in water volume and depths led to great changes in shoreline configuration, a dramatic reduction of the water surface area, and an expansion of the desert areas adjacent to the Aral Sea.

Fig. 1 displays the morphometry of the Aral Sea from 1965-2005, Table 1 shows the period from 1960 to 1985 when the sea was an integral water body. A rather slight lowering of the sea level was observed until the 1970s. For example, for the period of 1960-1970 the sea-level decreased by 2 m, i.e. the mean level lowering for 5 years was 1 m. The desiccation process accelerated visibly from the mid 1970s due to intensive diversion of river water for irrigation. In 1975-1980, the level decreased by as much as 3.26 m, i.e. 0.65 m a year on average. Moreover, the level dropped greatly, when the run-off of the Amu Darya did not reach the Aral Sea any more(1973-1990).

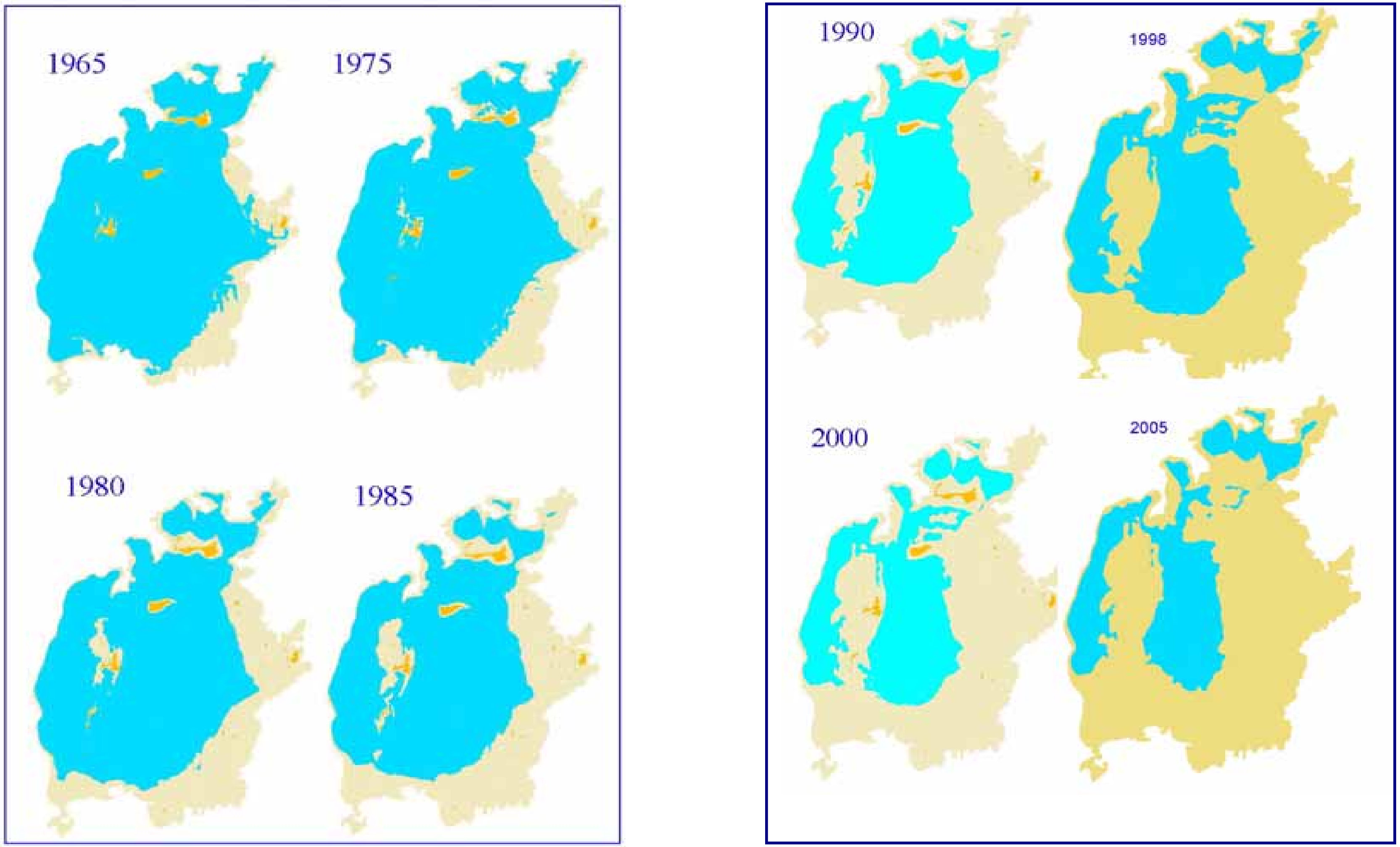


Fig. 1: The Aral Sea level dynamics

Table 1: Dynamics of the key morphometric characteristics of the Aral Sea, 1960-1985

Year	Water level (m)	Water surface area (thousand km^2)	Volume (km^3)
1960	53.40	69.79	1056.12
1965	52.30	62.38	972.47
1970	51.43	58.92	941.23
1971	51.06	57.73	902.43
1972	50.54	56.85	875.12
1973	50.22	56.17	845.47
1974	49.85	56.01	844.46
1975	49.01	54.67	802.74
1980	45.75	49.21	631.81
1981	45.18	48.63	625.78
1982	44.39	47.13	578.65
1983	43.55	46.07	532.58
1984	42.75	44.92	487.66
1985	41.94	43.08	444.58

Kokaral was the first of the large islands to transform into a peninsula, separating the small Aral Sea in the north-east by joining the shoreline in the west. By 1986, the peninsula practically detached the small Aral Sea from the large Aral Sea, leaving only a narrow flow passage in the east. Since that time, the hydrological regimes of the small and large seas have become separated (Table 2). The construction of the Kokaral dam in Kazakhstan, 12 km long and 8 m high, finally completely separated the small Aral Sea from the large Aral Sea and changed the hydrological regimes of the water bodies. Despite numerous dam breaks, the level in the small Aral Sea was slightly higher than in the large Aral Sea in 1990 - 2000. In this period, the area of the small Aral Sea varied within 2900-3200 km^2 (Chub 2000).

Table 2: Dynamics of the main morphometric characteristics of the Small and Large Seas, 1986 – 2005

	Large Aral Sea			Small (Northern) Sea		
Year	Water level (m)	Water surface area (thousand km^2)	Volume (km^3)	Water level (m)	Water surface area (thousand km^2)	Volume (km^3)
1986	41.02	38.56	380.63	40.90	2.83	22.47
1987	40.19	37.13	343.17	40.80	2.81	22.39
1988	39.67	36.18	312.65	40.50	2.75	21.84
1989	39.10	35.30	306.92	40.20	2.71	20.28
1990	38.24	33.67	280.44	40.50	2.75	21.84
1991	37.66	32.02	257.16	40.40	2.73	20.92
1992	37.20	31.83	240.17	40.20	2.71	20.28
1993	36.95	31.42	231.70	39.37	2.57	18.43
1994	36.90	31.31	229.87	40.10	2.69	20.01
1995	36.50	30.04	217.25	40.50	2.75	21.84
1996	35.48	28.54	195.63	40.50	2.75	21.84
1997	34.80	26.91	173.44	41.20	2.91	22.67
1998	34.21	25.75	168.43	42.50	3.24	27.03
1999	33.98	24.12	147.62	36.80	2.09	12.03
2000	33.50	22.93	139.53	39.80	2.62	19.26

	Large Aral Sea			Small (Northern) Sea		
Year	Water level (m)	Water surface area (thousand km^2)	Volume (km^3)	Water level (m)	Water surface area (thousand km^2)	Volume (km^3)
2001	32.40	21.00	131.16	39.20	2.55	17.97
2002	32.00	18.70	110.84	39.30	2.58	18.44
2003	31.50	17.30	97.23	40.00	2.65	19.77
2004	31.09	16.40	93.46	40.80	2.81	22.39
2005	30.70	15.77	89.79	41.00	2.86	22.52
2006	30.40	13.47	81.35	41.80	2.99	24.01

In 2003-2005, several structures were set-up within the northern Aral Sea (now referred to as the small Aral Sea) by the Chinese company "Chinahydro" under a contract with the Committee for Water Resources of Kazakhstan, supported by the World Bank. In consequence, due to two high-water years, a level of 42 m was reached in the water body.

In 1985, the islands of Vozrozhdeniye, Komsomolskiy and Lazarev merged (Zavyalov 2005) into one large island, which gradually increased in size, more and more separating the western part of the sea from its eastern part. In 1998, the large island transformed into a peninsula that disclosed a latent feature of the sea basin - a ridge stretched from Muinak peninsula to Kulunda peninsula. A flow passage with a length of 21.8 km as shown in Fig. 2 (INTAS-Aral, 2005) remained in the north of this peninsula, between the eastern and the western part. This flow passage is 1.86 km wide and reaches 6 m depths in some sections, according to data from Zavyalov (Zavyalov et al. 2005; Zavyalov 2005). For the large Aral Sea, one should note that the western and northern slopes of the basin are steeper, and the eastern and southern slopes are very gentle. The eastern part of the sea, where the bed is much more shallow and the slope is more gentle, is more subjected to shrinking then the western part.

The intensive changes of coastal formations, the generation of beach ridges, and the aeolian transport of sand deposits from the exposed bed lead to a gradual smoothing of the eastern coast. Since the Barsakelmes island joined the eastern coast, a poorly-dissected coastal strip has been formed. The strip receded from the shore line of 1960 by 60-100 km. The configuration of the southern coast experienced severe changes: the Adzhibay bay and Tiger Tail (Uch Say) peninsula have disappeared, while the Dzhiltyrbas bay has changed into a lake. As compared to 1960, the sea area decreased by 4.76 million hectares. Thus, all this territory should be considered as subjected to desertification.

Studying the Aral Sea, its adjacent areas and the natural environment in this ecological disaster zone is a long-term mission for water professionals, ecologists and others. The huge work of S. Berg has been expanded in many detailed and more or less systematic studies of this territory since the late 1950s and early 1960s. During century-old research of the sea water area, interesting results were achieved on the sea's water regime characteristics (hydrochemical, hydrological, hydrobiological, etc.), as well as on its impact on the climate in its coastal zones. However, systematic research was not conducted from the 1970s on, when the environmental degradation progressed at a rapid pace. Fragmented studies rested on different methodical approaches of local sectoral programs. Many of the research results of this time were difficult to compare to each other. The main reason for this development is seen in an insufficient attention to the problem itself and an underestimation of the growing crisis situation, especially in terms of the environment. That is why, despite a large number of studies, there were no reliable materials enabling important decisions to be made regarding the future of the Aral Sea and its coastal zones.

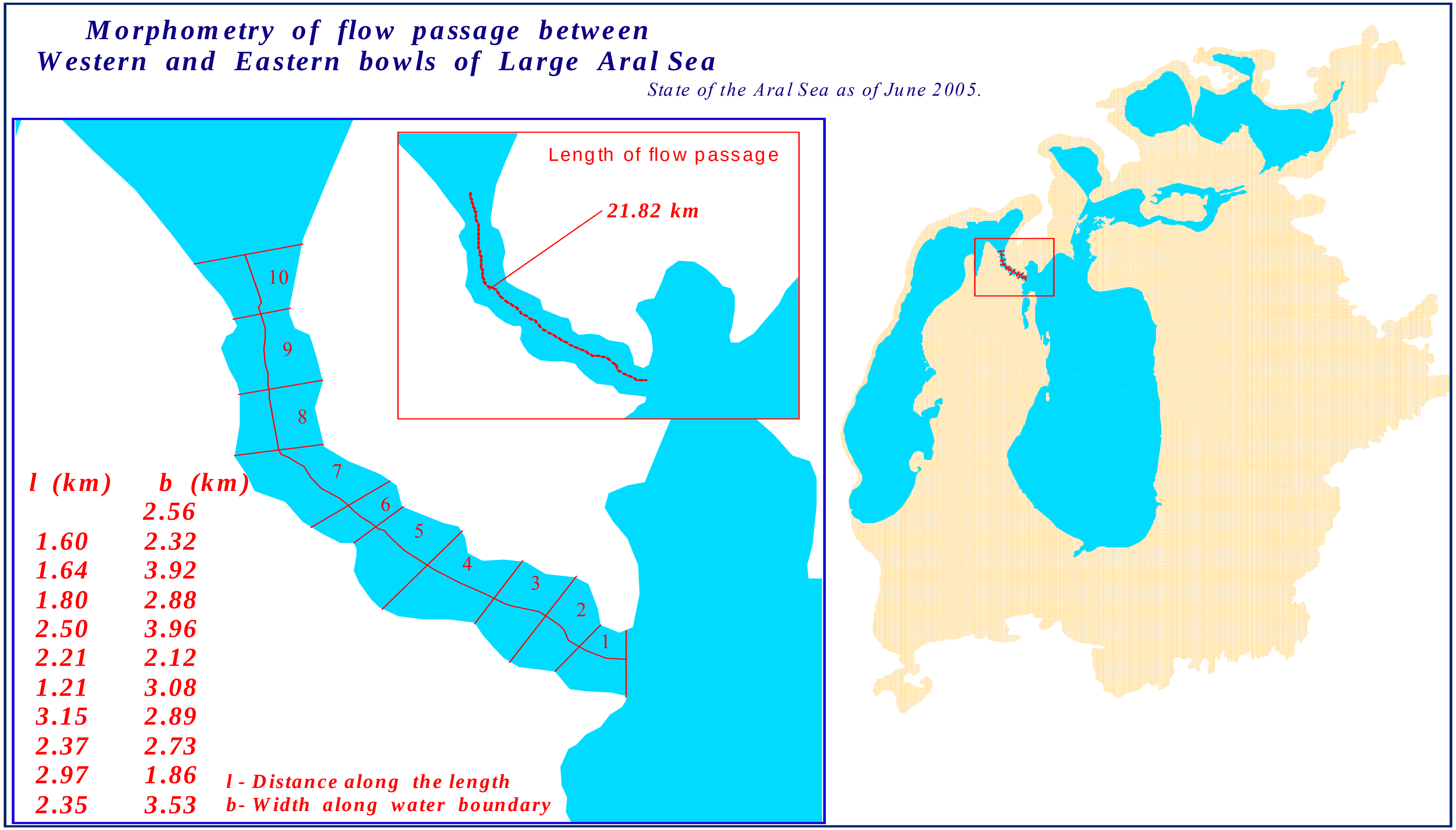


Fig. 2: Morphometry of the flow passage between western and eastern bowls of large Aral Sea

In spite of warnings given by scientists, the Soviet government recognized the Aral Sea problem too late. A large-scale program of specific measures planned by the Decree of the USSR's government "On Improvement of the Socio-Economic and Ecological Situation in the Aral Sea Basin" in 1987 only covered the main economic areas in order to improve water use and management in the basin. A program of comprehensive studies in Aral and Prearalie planned by the State Committee for Science and Technology and the Academy of Sciences of USSR was not implemented due to the loss of central control in the country and the line of conduct, under which environmental programs were usually laid on a shelf.

The heritage of the Aral and Prearalie was found beyond the strength of the five newly independent Central Asian states because of their economic and political weakness. Nevertheless, decisions of the heads of Central Asian states such as "On the establishment of International Fund for Saving the Aral Sea" (26 March 1993) and "On a concept for solving problems of Aral, Prearalie and the Aral Sea basin" (11 January 1994) have demonstrated an understanding of the whole complexity of the situation and of the need for taking joint measures. The latter decision in essence gave up the Aral Sea itself as hopeless, since the "Concept" clearly indicated that "…creating man-made ecosystems in deltas and on the dried seabed is of top-priority for Prearalie". It should be realized through:

- the establishment of a regulated system of water bodies for Amu Darya and management of a part of the small Aral Sea for Syr Darya
- polder systems on the dried seabed
- afforestation measures to fix loose sands
- supply of collector-drainage water to the sea through loose-sand zones.

At the same time, protection zones in the Aral Sea water with increased salinity should be determined, and forecasts of sea-water salt and water balance, sea levels and characteristics of the drying part should be made together with development of measures for consolidation of this part.

Since the sea level lowering is inevitable, now it is necessary to assess the scale of its impact on the socio-economic and ecological situation in Central Asia that will enable to determine a list of measures required for preventing undesirable ecological changes in these areas. However, one should note that the long-term consequences of the Aral Sea desiccation cannot be foreseen at the current stage of science development.

Since 1994, thanks to efforts of the World Bank, UNDP and other international organizations, the world community was attracted to the Prearalie problem. As a result, a great number of research efforts have been made for the recent years in the region under different research programs.

The first practical step in improving the situation in Prearalie was the GEF Project's Component E "Sudochie Wetland Restoration" – the design and implementation of engineering measures for the restoration of the wetland and its controlled water-salt regime, including social and ecological monitoring. This was implemented under a tender in an amount of USD 750,000 through the World Bank and the Dutch ODA Grant Funds in 1999-2002. The project aim was to provide an environmentally stable situation in the Sudochie lake wetland.

The successful implementation of this project demonstrated the possibility of creating a sustainable environmental profile of water bodies in Prearalie using local and European approaches. This got its follow-up in the NATO SFP 974357 Project "Integrated Water Resources Management for Wetlands Restoration in the Aral Sea Basin" for 2000-2003, where a set of engineering and organizational measures was developed for the restoration of the environmental regime in the Amu Darya river delta and in the southern part of the dried seabed by forming a system of wetlands with controlled water-salt regime. Unfortunately, the total project cost of USD 90 million was not requested from donors for comprehensive project implementation, and the implementation was started under local financing, which has been lasting for tens of years. Moreover, a number of engineering faults in the work of designers and resulting dam breakages reduced the effectiveness of the implementation. However, even relatively little measures contributed to a certain improvement of the situation in South Prearalie.

Two projects were important for a demonstration to governmental agencies of both Kazakhstan and Uzbekistan of the need for taking specific measures:

- Project INTAS - Aral 79998 REB: "Assessment of socio-economic effects of ecological disaster - the Aral Sea desiccation" (South Prearalie).
- Project INTAS - Aral 2000-1059: "Economic evaluation of local and joint measures for reduction of socio-economic damage in Prearalie" (North Prearalie).

- The characteristics of Aral and Prearalie's habitat degradation under impact of the sea desiccation are presented in SIC ICWC 2001.

Among the most striking consequences of the Aral Sea desiccation, apart from a decrease in its water volume and surface area and the associated increase of water salinity and modification of salinity pattern, is certainly the formation of a vast saline desert with an area of almost 5 million ha on the exposed seabed. As a result, this former unique freshwater body was replaced by a huge bitter-saline lake and this saline desert at the interface between three sand deserts.

The soils of the new desert are saline (5-20 kg/m^3), fixed poorly by vegetation and subjected to intensive deflation and the salts contained in the soils are exported to the surrounding areas. The dried bed of the Aral Sea is an example of arid salt accumulation. Shallow, highly saline groundwater in beach sites of the dried seabed contributes to complete and march salinization of the seabed. The dried seabed, especially the eastern and northern part, has become the main source area of large and frequent dust storms and the heart of dust and salt exportation to surrounding areas.

An analysis of wind rose data and satellite images shows that the export of salt and dust from the dried seabed and solonchaks in the Amu Darya delta has the same direction as the wind rose constructed for Prearalie, and saline dust is mainly transported to the Khorezm oasis (Karakalpakstan and Khorezm province) (Gidrometeoizdat 1990; Gelayeva 1998; Popov 1998).

Factors of intensive desertification are divided into 2 groups in this context: primary factors of desertification that have caused the lowering in the Aral Sea level and recession of its shoreline; and, secondary ones caused directly by the recession of the sea. Of course, both the factors are closely interrelated and mutually increase the negative effect on the environment.

The basic degradation consequences (in the Republic of Uzbekistan) are given below (SFP NATO 974357 project results):

- decrease in lake area in the Amu Darya delta from 400,000 ha (1960) to 26,000 ha
- reduction in fish productivity by 20 times as compared to 1960
- lowering of groundwater level to 8 m, depending on the distance from the sea coast
- transport of salt and dust within a belt of 500 km wide, with load capacity of 0.1-2.0 t/ha
- top-soil changes: the area of hydromorphic soils in South Prearalie decreased from 630,000 to 80,000 ha
- increase in the area covered by solonchaks from 85,000 to 273,000 ha
- substantial climatic changes in the coastal zone
- decrease in the area of reeds, Tugai forests and so on

All these processes resulted in an economic damage amounting to USD 115 million per year and social damage of USD 28.8 million per year. Similarly to south Prearalie, we estimated the socio-economic and ecological consequences in north Prearalie, where the damage amounted to USD 49.5 million a year.

The Kazakh government deserves credit for the improvement of the situation in north Prearalie financed by a first loan of the World Bank (USD 61.2 million), and is already negotiating on a second tranche in an amount of USD 350 million. It is planned to improve the lake systems in north Prearalie through modeling and research proposed by SIC ICWC Kazakh branch, "Kazgiprovodkhoz" Institute, CWSIR Enterprise, State Committee on water resources of Kazakhstan and other partners under the NATO - 980986 Project. The project partners are trying to adjust the unstable inflow regime in the Syr Darya delta to the environmental and social requirements of the lake systems.

As mentioned above, rather little attention was and still is being laid on the Aral Sea itself. An exception is the NATO Science for Peace Program, which has initiated a number of research projects dealing with a possibility of growing actinia in the Aral Sea waters, the effect on climate change and level fluctuations in the Aral Sea.

The 36th NATO scientific series (Nihol et al. 2004) and Zavyalov 2005 are especially notable among the recent publications. Unfortunately, both works were only published in English, thus making them inaccessible to the wide Russian-speaking readership.

Only the INTAS 2001-0511 Project "The rehabilitation of the ecosystem and bioproductivity of the Aral Sea under conditions of water scarcity" (REBASOWS) aimed at modeling different scenarios for the sea's existence has been dedicated to a problem of the future of the sea itself. However, it remains difficult to apply the results of those programs and projects in practice because, since 1993, systematic observations and any reliable data on the Aral Sea and the dried seabed are missing. Information on the current ecological situation in the sea is highly fragmented due to both, high dynamics of natural parameters and limited research conducted in this region. At the same time, changes taking place in the ecosystems of the large and small seas and the dried seabed are critical.

Despite limited observations over the sea itself, a great number of data on available water resources and their use and on plausible development scenarios using a modeling tool ASBMM was collected in the CAREWIB Information System. Thus, the executors of the REBASOWS project (A.I. Tuchin, A.T. Sorokin) were able to simulate 18 development scenarios regarding the future of the Aral Sea. The extreme scenarios, pessimistic and optimistic, linked with different options of water use in the deltas of the both rivers show that the area of the dried bed would increase in all scenarios to a greater or lesser extent (see chapter 5.3).

It is necessary to recognize the large scale of the ecological disaster related to the disappearance of the Aral Sea. We have a unique opportunity to make observations over radical changes occurring as a result of the water level lowering. At the same time, observations on soil cover on the dried seabed adjacent to Amu Darya river delta, where new soil-environmental formations appear under the influence of aeolian and thermic processes are of no less importance. Moreover, it is necessary to note that there have been soil assessments based on remote sensing (RS) data for desertification zones in Syr Darya and Amu Darya river deltas, while there were none for the dried seabed.

The environmental assessment of the dynamic processes taking place in the Aral Sea waters, accompanied by soil-landscape change investigations of the dried seabed would serve as a scientific and practical basis for the development of proposals on the use of water bodies under new natural and anthropogenic-induced conditions.

2.2. General description of the territory

There is evidence that the level of the Aral Sea has always been changing as a result of climatic and other natural cycles. It seems that the considerable increase of water withdrawals from the rivers in the basin since 1913 till early 1960s was compensated by positive shifts in these natural fluctuations. However, since 1961, the intensified diversions of river water to meet the growing needs of the expanded agricultural areas for both irrigation of crops and leaching of saline lands started to cause a fatal imbalance in the natural equilibrium of the Aral Sea basin. This can be regarded as the trigger to the Aral Sea crisis that is widely known as one of the major environmental disasters in the world.

The degradation of the Aral Sea's resource potential seems irreversible, the preservation and restoration of the sea is practically impossible in the foreseeable future. The catastrophic decrease in sea-level, reduction in water mass volume and the resulting increase in salinity have led to the almost total loss of the sea's biodiversity. Changes in the basic physical and chemical properties of the aquatic habitat led to a fatal decrease in population of microorganisms by 66% in the small Aral Sea and in the north of the large Aral Sea as early as in 1990.

In the near future, the Aral Sea will consist of a few isolated landlocked water bodies with independent level regimes. Nevertheless, life will go on there, through inflows from the Amu Darya and Syr Darya rivers into the basin, precipitation, groundwater, and human activity. The latter especially depends on the policy of the neighboring countries on the handling of the Aral Sea basin. This might include creating new afforestations and new water bodies, on the one hand, and destroying his own results, on the other hand. It is especially necessary to note here the destructive activities of gas and oil explorations that are not aware of the fragile stability of a newly formed ecosystem.

2.3. Climate

The changes in basic climatic parameters in the coastal area were discussed widely enough in scientific literature (Zhitomirskaya 1964; Ivanov et al., 1996; Moloskova & Il'nyek 1991; Prokhorov 1972; Razakov & Kosnazarov 1998). The authors give quantitative indicators of the change in wind and temperature-humidity regime in the region.

The impact of the Aral Sea on the climatic conditions in Prearalie before the dramatic sea level decrease was of local nature and tracked enough distinctly. Zhitomirskaya (1964) and Prokhorov (1972) identified a remarkable mitigation of climate aridity in the Aral Sea coastal zone at a distance of 150-200 km. In winter, the air temperature in this zone was 1-2^{o} C higher than at the site of land stations, and the summer temperatures were 1-3^{o} C lower. Table 3, Table 4 and Fig. 3 show observation data of the Muinak weather station on air temperature, precipitation and evapotranspiration for the period of 1881-1996.

Table 3: Air temperature (°C) at Muinak weather station

Years	Month												Annual average
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1881-1960	-7.1	-6.2	0	8.5	17.3	23.2	25.9	24.7	19.3	11.1	3.7	-2.7	9.8
1961-1985	-6.5	-6.2	0.5	10.3	18.6	24	27.1	24.8	18.7	10.3	3.5	-1.9	10.3
1986-1996	-6.3	-5.3	1.2	11.9	20.1	26.8	26.4	25.3	19	12	1	-3.1	10.8
1996-2006	-5.7	-2.1	2.3	13.9	19.9	26.7	28.7	27.0	19.3	13.4	0.9	-4.1	10.6

Table 4: Precipitation (mm) at Muinak weather station

Years	Month												Annual average
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1981-1960	7	11	12	14	7	7	4	5	4	11	8	8	98
1961-1985	9	10	13	18	8	7	5	4	5	13	12	9	113
1986-1996	9	7	13	14	17	3	3	2	3	8	8	9	96
1996-2006	10.1	12.6	22.7	20.7	15.3	6.6	7.1	2.8	0.5	8	10.3	9.4	131.8

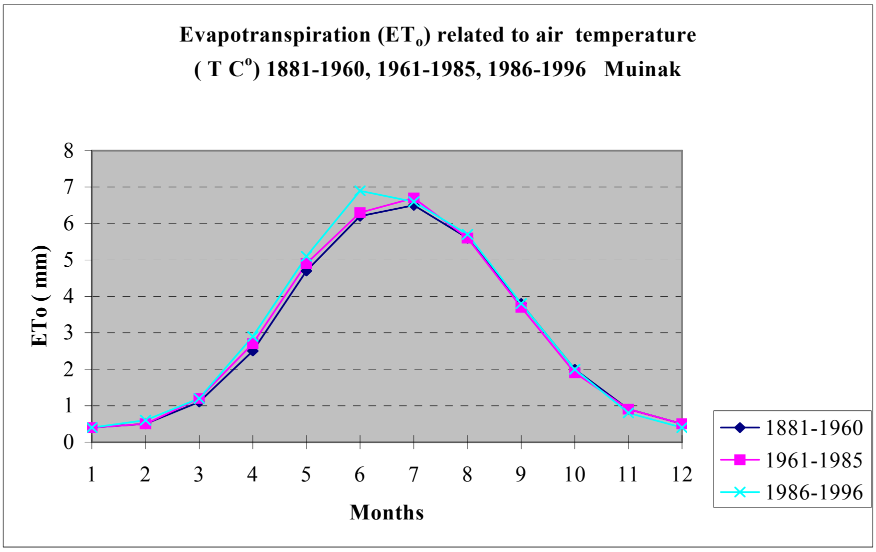


Fig. 3: Evapotranspiration depending on air temperature, Muinak weather station, 1960-1996

Especially the microclimate experienced significant changes (Zhitomirskaya 1964; Ivanov et al., 1996; Moloskova& Il'nyek 1991; Prokhorov 1972; Zolotokrylin 1999). These were particularly dramatic when the shoreline recession reached about 40-60 km. Back then, it was difficult to predict their future impact. The overall climate change in the immediate proximity to the former water body was reflected in a temperature increase in the summer months, especially in March-August, and a temperature decrease in November-December.

Dust storms became more frequent, with the maximum observed from April to July. Local climate transformation in the dried territory was accompanied by an increase of sunny and extremely hot days by 15% and decrease of sunny humid days by the factor 4. Overall, periods of weather conditions unfavorable for human activity became more frequent.

The wind regime is mainly continental. On average, winds of the north-eastern quarter with a mean speed of 5-6 m/s dominate over the year. There are quite often strong winds, the mean annual frequency of which reaches 50 days at Aktumsuk station, and 44 days at Barsakelmes station (Molosnova et al. 1987). Strong winds are observed more frequently in winter. Breeze circulation has a significant impact on the coastal microclimate in summer, which affects the meteorological conditions in the coastal zone up to 50 km from the sea shore. On the northern coast, the daily breeze blows south-west, and night breeze north-west. Daily change in wind directions is less sharp at stations on the southern coast: wind blows from the north-east in the daytime and from the west at night.

2.4. Geomorphology

2.4.1. Geomorphological processes on the desiccated sea bed

The geomorphological processes on the dried seabed are complex (Fig. 4). First of all, they are determined by the type of dried coast, including its exposed area width, slope, lithology, micro-relief, salinity, etc. (Gryaznova 1979, 1982, 1986; Gorodetskaya 1978; Geldiyeva & Budnikova 1985; Pinkhasov et al. 1999; Pinkhasov 1984; Rubanov 1994; Rafikov 1982).

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

1. Before the sea level decrease, the coastal area was characterized by a complex structure and highly indented shoreline, except for the western coast due to structural and geomorphological features of Prearalie. The dried areas inherit the basic characteristics of the adjacent land.
2. During a long time period, the areas that have emerged from under the sea were subjected to coastal processes under sea level fluctuations around +53 m a.s.l. Furthermore, for the last one hundred fifty years, the sea level lowered twice to +50 m (in the 1820s and 1880s). In this context, a wide variety of coastal formations was generated in the given territory (Gryaznova 1982).
3. According to the principles of coastal-marine sedimentation, the dried territory developed under littoral conditions is mostly composed of sands, interchanged with siltstones and silt in meso- and micro-depressions. The lithology of the zones formed under influence of native shores depends on the structural features of the latter.

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

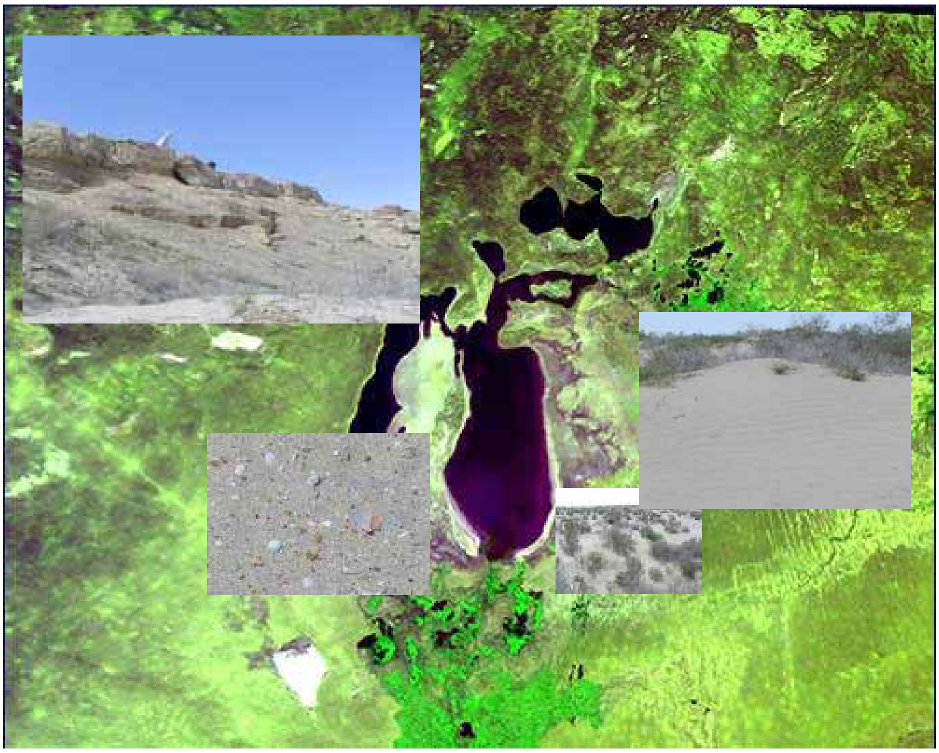


Fig. 4: Some dried coast types

2.4.2. Relief of the dried coast

Depending on structural and geomorphological conditions, the nature of coastal processes and lithological features, the following main relief types can be distinguished on the dried seabed (Yepifanov 1961; Kleine & Kravchuk 1966; Pinkhasov 2000; Pinkhasov & Mavlyanov 1997) (Fig. 5):

I. The **Abrasion plain** (abandoned bench) is developed in former abrasion coast areas and extends along the western and partly northern coast under cliffs of the Ustyurt plateau and farewell uplands. The dried surface is mainly a wave-cut terrace or platform developed on marls, sandstones, clays of Palaeogene and Neogene, overlain by thin (about several tens of centimeters) accumulative stratum.

II. The **Accumulative plain** is widely developed on the Aral Sea coast. A slightly sloped sandy coastal strip is the most typical landform. Typical features of this coastal formation before the sea level lowering were broadly developed accumulative sandy coastal forms such as spits, bay bars and separated lagoons of different size and shape. At present, former lagoons are completely disconnected from the sea, dried up and changed into solonchaks, while accumulative coastal forms bordering them became a part of the dried strip.

III. IIa. The southeastern coast within the former Akpetki archipelago, which was previously a part of the Kyzyl Kum desert flooded by the sea, has quite specific, more indented and heterogeneous relief.

Two types can be distinguished among the exposed territories: former shelves and shoals occupying vast areas in the west of the archipelago as well as beds of former channels and bays with complex micro-relief. Major salt precipitation occurs here after the desiccation of highly saline residual lakes. Accumulative coasts comprised of sandy loam, loam and clay deposits are also typical.

Fig. 5: Locations of the main relief types

I. The **Delta plain** (Holocene modern) of the Syr Darya and Amu Darya rivers is located on the eastern and southern coast. The surface of the ancient Syr Darya delta plain (Kazalinsk, Holocene) is particularly large and spans over 40-50 km in width. The plain nature of its relief is broken by former sand-bar islands joined to the mainland.
II. Fore-delta plain covers the youngest Amu Darya and Syr Darya delta plains.

In the eastern part of Akpetki archipelago, which has dried up first, beds of all channels, lagoons and piezometric lakes are represented by matured solonchaks being mostly free of vegetation. The thickness of salt deposits is 1-2 m in some places. For example, areas comprised of salts mainly were detected in the coastal part of the dried Toguzarkan channel.

The comparison of soil formation and salinization conditions in different parts of the dried Akpetki archipelago shows that the salinity of channels, lagoons and piezometric lakes is decreasing in its eastern outskirts. This is proved, for example, by habitation of the most salt-tolerant halophytes (Karabarak - *Halostachys belangeriana,* Sarsazan - *Halocnemum strobilaceum*, *Karelinia caspica*), reed (*Phragmites australis*) and rare bushes of Black Saxaul (*Haloxylon aphyllum*). One should note that the tops of sand ridges are less saline here than in its central parts. These facts indicate that the salt accumulation in the eastern outskirts of the Akpetki archipelago became less intensive than the salt transport over time.

However, it is difficult to assume that the very small amounts of annual precipitation (80-100 mm) in this area could wash out thick salt layers over a short time (7-15 years). Therefore, it may be assumed that the key relief-forming factor is the very intensive and strong wind. Some circumstances further promote salt transport by wind such as increasing aridity and air temperature; and decreasing groundwater level. Due to a high concentration of sulfates, salt horizons regularly become loosened and vulnerable to wind erosion, which is additionally assisted by low precipitation. Therefore, dried bays, channels, lagoons and piezometric lakes are considered as the main sources of aeolian salt transport to adjacent territories.

2.4.3. Salt accumulation processes in the Aral Sea bed

The salt accumulation processes on the dried bed of the Aral Sea are addressed in the papers of Bogdanova (1977, 1978, 1981), Budnikova (1987), Geldiyeva (1996), Gryaznova (1982), Mavlyanov et al. (1998), Pinkhasov (1997), Rafikov (1982, 1981), Nekrasova (1979), Sektimenko et al. (1991), Popov (1998).

The current land salinization on the desiccated Aral Sea bed results from the interaction of several natural factors. The development of salinization processes is mostly related to the geographical situation of the sea: location in a desert area with extremely arid climate, strong winds, high summer temperatures and low precipitation. These conditions are common for the whole southern part of the desiccated seabed.

However, the character of salinization processes in different parts of the dried area is highly heterogeneous and primarily related to geomorphological and lithological features. The shape of the relief defines the drainability of the area. Minor elevations of the relief create favorable conditions for desalination of hypsometrically elevated areas and salt accumulation in sinks.

The heterogeneity of the lithological structure in the aeration zone influences its filtration properties and capillary rise of solutions and consequently the intensity of salinization.

Several factors like groundwater depth, groundwater salinity and chemical composition determine the character and degree of soil salinity. The closer the groundwater table is to the ground surface (i.e. the higher the groundwater level is) and the higher its salinity is, the more intensive soil salinization occurs.

Thus, salt accumulation is a multiple-factor process, and the dynamics of its development highly depend on the parameters and conditions of interaction between the components of the natural environment already mentioned above: water table and salinity, relief shapes, lithological structure, drainability of area, etc.

The specificities of soil salinization under different natural conditions are considered below:

1. A severe obstruction of groundwater flow due to low slopes on the dried bed surface and poor filtration characteristics of component layers cause a stagnation of groundwater. As a result, highly-saline groundwater is discharged mainly through ground evaporation. Thereby, water solutions rise up to the ground surface and discharge through evaporation. When their salt concentration grows and reaches the saturation point, salts start to precipitate in the soil. When the water table is at depths of 1-2 m, the capillary fringe (i.e. the layer where capillary water ascent is possible) reaches the ground surface. At 2-4 m depths, the contribution of groundwater to salt accumulation in the soil is much less since the rate of capillary influx to such a depth slows down significantly. When groundwater depth is more than 5 m, the contribution of capillary influx to salinization of surface horizons abruptly decreases or stops.

2. The lithological structure of the layers in the aeration zone determines their water permeability, drainability and height of capillary rise. The following lithological sections in the aeration zone are widespread within the dried seabed: homogeneous layer of sand; heavy loam and clays; interstratifying loam, sandy loam and sand; silt, sand and salt deposits. Sand with light texture in the top layer, which is 0-0.04 m thick, contains about 0.1-0.5% of salt with 0.03-0.10% of chlorine. The capillary head is not more than 0.4-1 m. The stock of highly soluble salts is no more than 10 - 60 t/ha, and is 35-350 t/ha in two-meter aeration zone. As soon as groundwater level goes down 1-2 m, the process of salt accumulation stops. Heavy loam and clay with a thicker capillary head of 4-6 m are characterized by higher salt content (4-27%) and chlorine percentage (1.3-3.1%). Salt stock is 40-200 t/ha, while it is 280-1200 t/ha in two-meter layer.

3. The character and degree of soil salinization are closely interrelated with the chemical composition and salinity of the groundwater. Sulfate-chloride type of water has almost completely determined the mixed chloride-sulfate character of soil salinization, while mirabilite and halite deposits begin to form at higher concentrations and shallow groundwater.

4. Numerous solonchak depressions situated to the north from the archipelago and meridionally stretched for tens of kilometers, impact the salt redistribution pattern. Salt is removed by groundwater and accumulated in topographic depressions in relatively elevated (1-3 m), stabilized sand massifs, with hypsometric domination in the locality. In this direction, at a distance of 70-200 m, groundwater salinity varies from 30 to 323 g/l and from chloride-sulfate to chloride type. While the salt content at elevated topographic sites rarely exceeds 0.2-1%, salt concentration reaches 15-40% in depressions. If all the seabed sediments had the same salinity during the full limnic sedimentation period, then an abrupt differentiation of the dried seabed has begun in terms of salinity due to salt redistribution caused by different degrees of drainability of the territory since the sea recession in 1960.

5. Depending on the lithology of cover deposits, there are differences in the degree of wind deflation. Every year 3-4 cm of sand is blown out. In a process of repetitive wind erosion, salts are also blown-out together with light silty-clay fractions. Salt content is 0.5-3.0% in the bed sand of inter-dune depressions and aerial deflation fields. In aeolian sand, salt content decreases to 0.07-0.3%. Thus, aeolian desalination is taking place in vast dune fields. Heavy loam, salty crust and gypsum are almost not subjected to deflation, and their salt content reaches 4-27%.

6. As lakes dry up and groundwater level lowers in solonchak depressions on the dried bed (shors), former bays and straits in Akpetki, the lowest areas on the bed are covered with thenardite puffed solonchak, stratal mirabilite and halite with thickness varying from 0.02 - 1.0 m. Dried mirabilit transforms into thenardite powder lime, which is easily removed by wind. Easily soluble salts in puffed salt-bearing horizons are accumulated through intensive evaporation and capillary solutions of sulfates and sodium chlorides, thus forming sources of salt and dust transport.

Hence, salt accumulation is a function of continuous interrelated natural processes: seabed exposure - groundwater level lowering - intensive evaporation and salt accumulation in the aeration zone - salt transport by wind - capillary fringe separation from the surface – stop of salt accumulation.

2.4.4. Landscape changes and emerging ecosystems

The assessment of land cover change in the ecosystems in Prearalie, including the dried seabed were undertaken as early as in the Soviet time by Rafikov and Tetyukhin (1981), Veinsbergh & Ulst (1972), Kurbaniyazov (1999, 2000), Novikova (1997), Novikova & Ptichnikova (2000-2001). Detailed assessments of ecosystems on the desiccated areas were made in 1993-1996 by Pinkhasov B.M. (Gidroingeo), Geldiyeva G.V., Budnikova T.I. and others.

In 1992, SANIIRI (Chernyshev A.) made a landscape map of South Prearalie and partially of the dried seabed, which was digitized later in 2000 at SIC ICWC (Roschenko E. and Zherelyeva S.) within the framework of the NATO SFP 974357 Project ("Integrated Water Resources Management for Wetland Restoration in the Aral Sea Basin"). Here, the author selected 11 main landscape types, excluding water surface of the sea and coastal lakes, of which 5 types had vegetation cover of more than 50%. This map was analyzed for the assessment of stable and unstable landscapes in order to identify areas to be protected by water bodies or plantations and for the determination of approaches to the areas representing a danger to the local population and ecosystems.

The term "unstable landscapes" is understood here as "the territories subjected to negative changes". The following information sources were used in the work:

- "South Prearalie's Landscape Map", conditions as of 1990, produced in 1991 by SANIIRI (Fig. 6);
- "Landscape Map for the year 2000" provided by NATO SFP 974101 Project (Authors: Ptichnikov A., Novikova N.M., Reyimov P.) (Fig. 7).

The results of those studies served as a basis for a spatial division according to environmental risk degree.

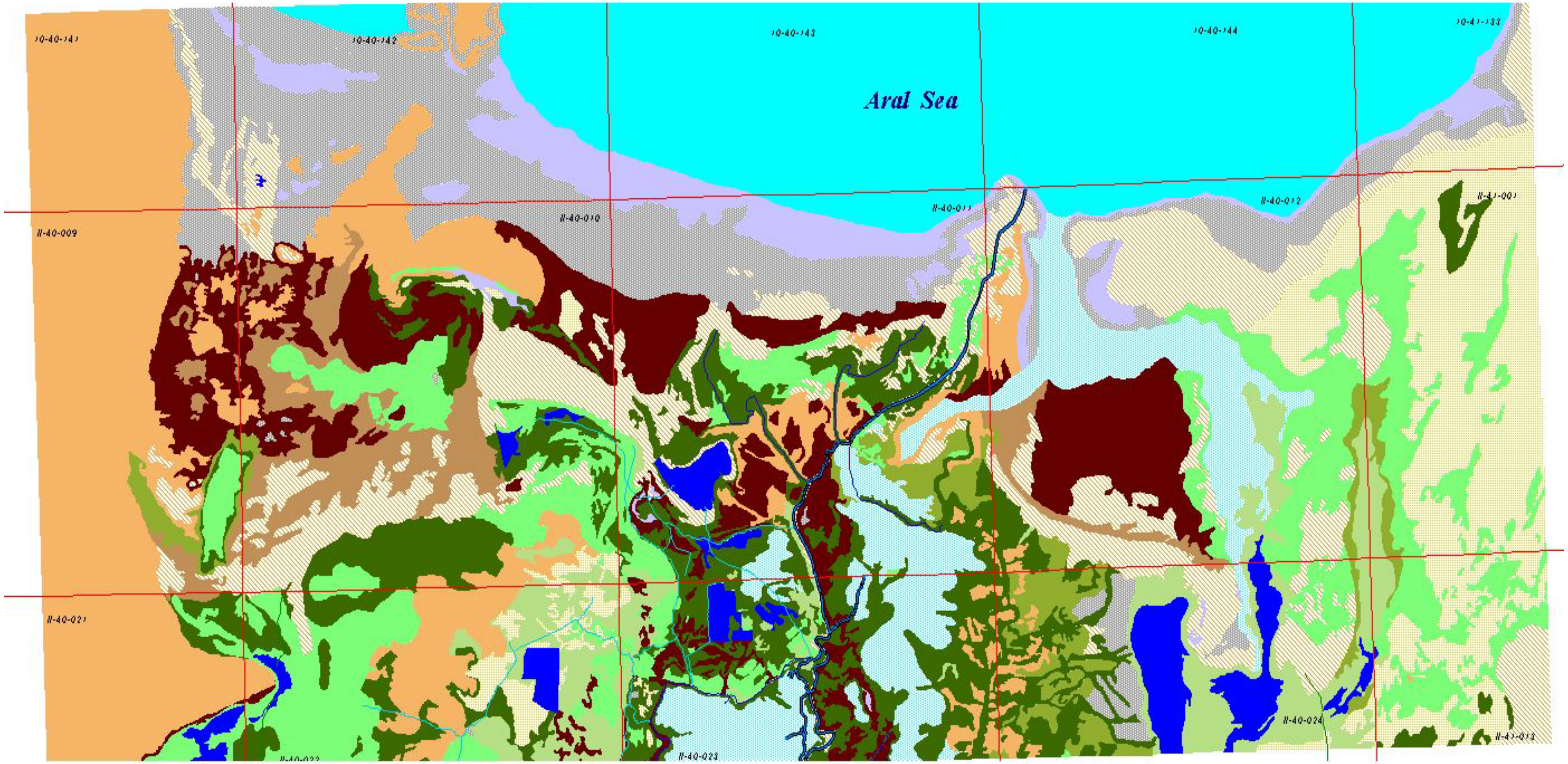


Fig. 6: South Prearalie's landscape map, as of 1990

Legend

Coastal plain. Area of groundwater (salinity at 25-50 g/l) discharge with hydromorphic conditions for maritime alkalic soils; sandy loam is prevalent in the delta. Microrelief. Water erosion. Saltwort vegetation. The Area relates to formation of polygonal soil structures.

Sea plain with microrelief and maritime hydromorphic alkalic soils. Soils comprise of sand and clay with sandy loam interlayer. Vegetation *Salsola richteri*; general coverage - 0,1 %. The area relates to the end of polygonal soil structures formation.

The plain is comprised by alluvial-delta and marine sandy, loamy and silty soils. Maritime hydromorphic and semihydromorphic thin and thick alkalic soils covered by sands and sandy loams. Polygonal structures induced by shrinkage of soils, suffer from rainfall and winds, are filled by sandstones, and promote salt transfer. Polygonal elements make for ephemeral and perennial vegetation. On heavier soils minimum size of polygonal structures is 40-50 m.

Differs from coastal plain by soil texture and finer structure. Topsoil allows for salt migration. Vegetation is presented by the Orach group. Water and soil erosion.

Wide sea plain comprised by clays with sandy loam and sand interlayers. Automorphic and semiautomorphic soils; thin alkali soils in microsinks. Salts, sands and sandy loams are easily washed off by rainfall to cracks in polygonal desalination and takyr development. Vegetation: annual and perennial plants (up to 5%)

Area with unstable landscape. Sea plain comprised by sandy -loamy and sandy silty-loamy sediments. Coefficient of vegetation cover is 15-30%. Favorable conditions for ephemeral and perennial plants due to partial desalination of top soil.

Sea plant within Adzhibay. Soil Texture: sandy loam, loam and clay (fine fractions prevalent). Vegetation: Orachs and Tamarix.

Sea plant comprised by clays, heavy and medium loam with sandy loam and sand interlayers. Area of potential desalination and takyr development. Vegetation: annual and perennial plants.

Sea plain, relief is formed by streams. Most area is presented by mesorelief. Vegetation: annual Saltworts.

Area comprised by heavy silty-loamy sediments with sandy loam interlayers. Soils suffer from secondary salinization. Vegetation cover is less than 1-2%.

Area with unstable landscape. Sands, mostly unfixed, i.e. moving sands. Fixing process is slow and relates to formation of barchans and ridges. Sand mobility causes salt transfer. More intensive fixing of sand is observed in the Amudarya delta. Vegetation spreads over the areas where sand layer (10-15 cm) combines with sandy loam and clays. Such combination keeps soil moisture.

Natural sinks, flooded from time to time.

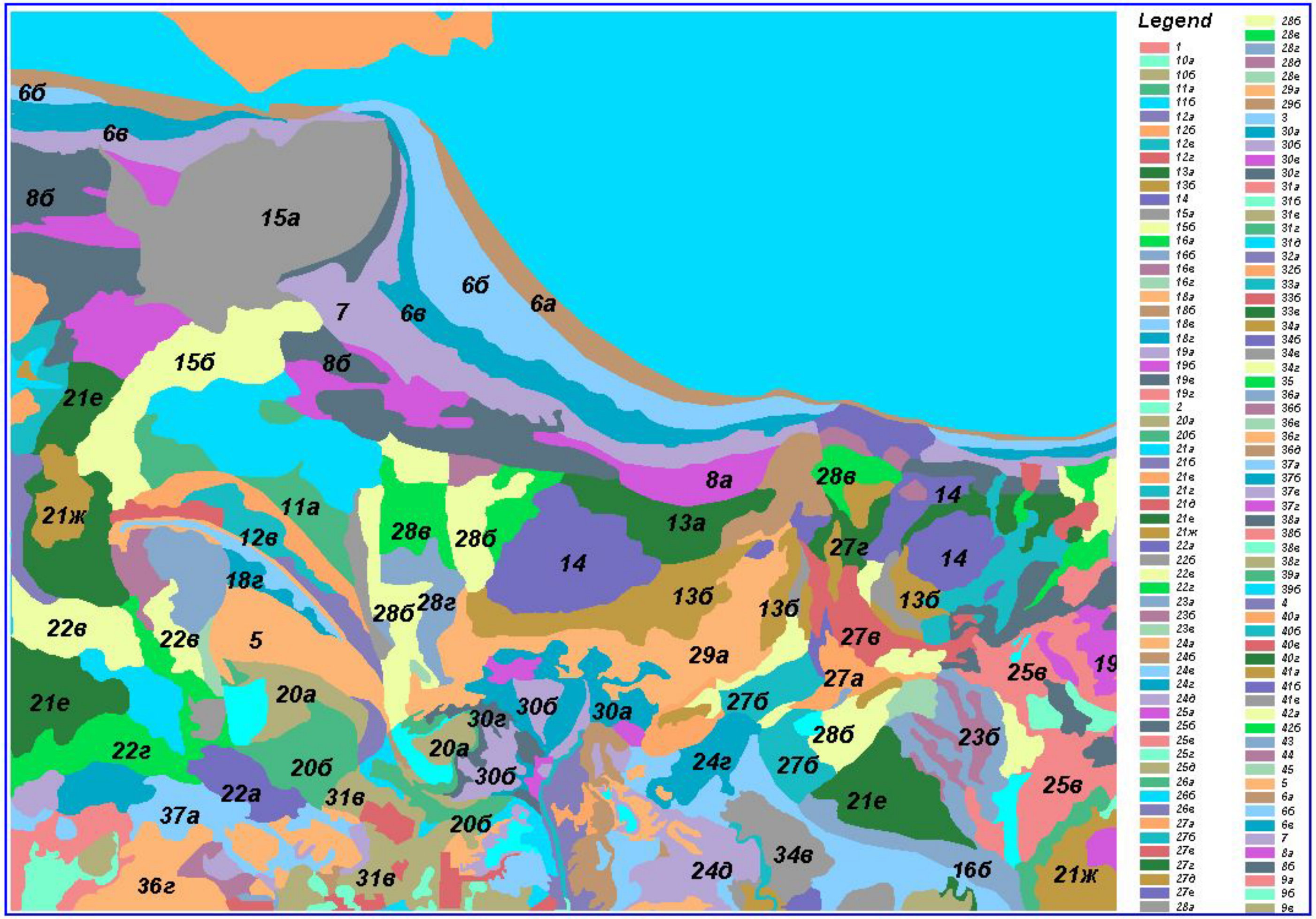


Fig. 7: “Landscape Map for the year 2000”, provided by NATO SFP 974101 Project

Legend for landscape map of the south Prearalie scale 1:500 000

Structural-denudation plains

Arid-denudation plateaus and isolated hills

1. Sloping-undulating plains composed of loamy-rubbly sediments, underlaid by limestone with complex of Saxaul, gray land wormwood and keireuk associations including goat's-wheat on gray-brown plastered soils.
2. Steep- and gentle-sloping plains composed of sandy loam and loam sediments with crushed rock inclusions and all-round outcrop of limestone and marl, with groups of petrophyte and hydrophyte at discharge points of temporary springs.
3. Flat, more rarely undulating plains composed of loamy-clay sediments, underlain by clay with complex of biyurgun, white land wormwood and keireuk associations on brown gypsumed soils.
4. Hilly-ridgy sands with takyr and solonchak underlaid by clay, with associations of white and black Saxaul, psammophile shrubs - on hillocks and tamarisks and wormwood - on lowlands.
5. Hilly-ridgy sands in comlex with takyr and solonchak underlain by sandstones, with complex of black Saxaul and Saltwort on hillock tops, Salsola arbuscula and wormwood on equiplanated areas.

Plains of deposition

Landscapes of marine plains

Landscape of the exposed seabed

6. Equiplanated gentle-sloping plain with marsh solonchak and pioneer groups of mezohalophyte prone to periodical flooding by sea piled-up water.
7. Equiplanated gentle-sloping sandy loam and loam littoral solonchak barren plain, with isolated specimen of annual mesohalophyte.
8. Pit-and-mount sandy loam and loam barren plain on littoral solonchak soil, with poorly processed relief during subaerial development process: a) with groups of halophyte on littoral solonchak soil; b) with annual psammophyte in halophyte groups on areas covered by thin sand layer on crust solonchak.
9. Hilly-cellular sandy and sandy loamy solonchak plain with processed relief during subaerial development process, with rare vegetation cover including galophilic shrubs on shor solonchak: a) gently-undulating with sarsazan and tamarisk; b) ridgy-hilly with Nitraria, Tamarisk and Sarsazan; c) Beaded-hilly with local ground water outlets marked by reed, Sarsazan and Karabarak on interhilly areas.
10. Hilly-ridgy sandy loam and sandy plain covered by red yellow medium sand layer om littoral solonchak soil with: a) phytogenous hillocks formed by Nitraria and tamarisk; b) fixed by partial associations of black Saxaul;
11. Pit-and-mount sandy loam and sandy plain with bad processed relief and poorly fixed by vegetation on littoral sandy soil, with solitary specimen.
12. Hilly-cellular sandy loam and sandy plain with littoral soil and yellow medium sand layer, with processed relief somewhere: a) without vegetation on residual solonchak; b) with groups of Black Saxaul and tamarisk on thin blown sands; c) with rare specimen of Zhuzgun, Tamarisk and black Saxaul on small-hilly sands; d) with Zhuzgun, Tamarisk and psammophilous grass on medium-hilly sands.
13. Pit-and-mount sandy plain poorly fixed by halo-psammophyte, with littoral sandy saline soil.
14. Massifs of high-hilly and barchan-ridgy blown sands unfixed by vegetation.
15. Hilly-cellular sandy plain referred to regional elevation composed of red yellow sands, with poorly Selin desert sandy soil and: a) poorly fixed by vegetation with solitary Saltwort and goose-foot; b) in combination with well fixed areas, with psammophilous shrubs and solonchak vast barren lands;

16. Pit-and-mount sandy loam and sandy plain with littoral soil including crust solonchak: a) barren with reed medallions at groundwater discharge points; b) fixed by psammophyte and halo-psammophyte shrubs; c) with sandy acacia.
17. Littoral plains with shortened zonal landscape chains referring to different drying-up periods, from pioneer groups with annual Saltwort up to park black and white Saxaul forests on forming desert-sandy soil under the Eastern Ustyurt chink.
18. Fossil landscapes of coast with fragments of sandy beach ridge and phytogenous hillocks of tamarisk on poorly developed desert sandy soil.
19. Combination of high sandy hillocks of former islands with degrading desert vegetation and overgrowing deep solonchak depressions of dried sea strait.
20. Landscapes of formed lakes with running water, with long-term availability of clarified water and massifs of high reed.
21. Gentle-sloping pit-and-mount sandy loam and loam lacustrine plain with a) regular and long-term flooding, high reed timbers, flow paths, areas of died reeds, tamarisk; b) short-term regular salt water flooding and stagnating, covered by tamarisk, Sarsazan, fleshy Saltwort in complex with puffed solonchak; c) with salt water flowing on surface like flat flows (within 60% of surface) accompanied by rare reeds.
22. Sandy loam and loam, pit-and-mount solonchak plain with blown sandy layer flooded by river water a) relatively regularly flooded areas, with heavy tamarisk and closed grass cover of azhrek, including rare reed; b) Karabarak Saltwort, including Nitraria and Climacoptera on sandy and saline soil and on bog of former bays.
23. c) broken by numerous end flows, with wilting reed

Landscapes of lacustrine-alluvial plains

24. Landscapes of lacustrine plains formed mainly by river water in small lake hollows a) reed timber in shallow-water area; b) regularly flooded reeds, with Tamarix; c) Tamarix with inclusions of reed, periodically flooded d) sites of sparse Tamarix and reed, periodically flooded; e) barren area of dried bottoms; f) reed timber on margins of dried lakes.
25. Landscapes of lake systems formed by collector-drainage water a) reed timber in shallow-water area; b) low reed, with plenty of dried old plant; c) Tamarix, with halophytes and isolated reed; d) puffed and crust-puffed solonchak on margins of lake hollows.
26. Landscapes of dried lake systems, periodically filled with river water a) reed timber on margins of dried lake hollows; b) bottoms overgrown with Tugai shrubs and grass, young trees.

Landscapes of alluvial-deltaic plains

Emerging deltaic landscapes on the dried seabed

27. Gentle-sloping sandy loam-loamy plains broken by channels of long-term active watercourses a) young growth of tree and shrub Tugai specimen along numerous watercourses; b) restoration of tree and shrub Tugai specimen and reeds; c) reed timber; d) set of flow paths surrounded by reed and loamy spaces without vegetation;
28. Gentle-sloping sandy loam and loamy plains broken slightly by watercourses a) tamarisk-herb communities on solonchak soil; b) channels surrounded by Tugai trees and reed and near-channel plantations of black Saxaul and Saltwort; c) inter-channel spaces with sparse Tamarisks, barren takyr and solonchak spaces.

Fore-delta (advancement delta) of 70s-80s

29. Flat, rarely slightly undulating, composed of loam and sandy loam deposits/
30. Gently-undulating plains, composed of sandy loam and loam deposits a) barren b) Black Saxaul and Saltwort plantations c) fragments of dried Tugai and shrub communities and alive salt trees d) tamarisk on waterlogged sites

Modern drying alluvial-deltaic plain

31. Gently undulating plains of near-channel banks and breach deltas periodically watered and sites of dried channels with young Tugai.

32. Elevated flat plains of near-channel banks, composed of sandy loam and loam deposits, non-watered since early 90s, under automorphic development stage
33. Elevated flat inclined sandy loam and loamy plains of near-channel banks, non-watered since 80s. a) practically no vegetation, crust alluvial-meadow-Tugai soil b) sandy salinized depressions, with salt tree and dog-bane
34. Elevated flat inclined sandy loam and loamy plains of near-channel banks, non-watered since 70s, passed solonchak stage a) tamarisk and Karabarak on residual solonchak b) Karabarak communities and suffozive subsidence.
35. Gently undulating elevated loamy plains of inland deltas, with sparse tamarisk and fragments of turang Tugai along dried plow paths and canal banks
36. Flat rolling sandy loam and loamy inter-channel depressions, periodically watered or flooded a) reed and tamarisk in hydromorphic conditions b) wet solonchak with tamarisk c) crust solonchak with tamarisk and Karabarak d) tamarisk, Karabarak and tree-like Saltwort on solonchak transforming into takyr e) solonchak with Sarsazan.
37. Flat sandy loam and loamy littoral plain a) residual bog soil, covered with sand b) secondary hydromorphic with tamarisk and reed c) dead reed on periodically watered sites.

    Alluvial-deltaic plain dried by 60-s of XX century

38. Gentle-sloping surfaces of inter-channel depression slopes composed on loam and clay, watered during high-water years a) reed timber on dry land b) annual weeds on wet surface of long-term watered sites c) no vegetation d) tamarisk, Tugai herb and reed.
39. Gentle-sloping sandy loam and loamy elevated water-division plains a) isolated tamarisk specimen b) Turanga and young Black Saxaul and Kargan
40. Flat inland delta composed of sandy loam and loamy deposits, with tamarisk and annual saltwort and fragments of tugai a) reed on shallow groundwater area b) isolated tamarisk c) barren takyr surface d) desalinated residual solonchak with Karabarak and black Saxaul

    Plains of Holocene delta

41. Gentle-rolling, rarely flat inland delta composed of sandy loam and loamy deposits: a) Black Saxaul with Karabarak, sand massifs with Zhuzgun in automorphic conditions b) sparse tamarisk and meadow-solonchak herbs under additional wetting conditions c) reed and tamarisk on margins of oases
42. Complex loamy solonchak-takyr pit-and-mount plain

    Poorly transformed fragments of natural landscapes preserved in oases

43. Isolated fixed barchans, with filtration small lakes
44. Zone of groundwater discharge in inter-channel depression, with solonchak vegetation
45. Fragments of Tugai forest

Using spatial analysis of all materials available in SIC ICWC, the two most risky zones were identified (Fig. 8) as of 2000:

1st zone - "environmentally critical zones" - areas of South Prearalie characterized by dynamically unstable landscapes (shifting sands in form of barchans and dunes), which have remained without changes for the last 10 years;

2nd zone - "environmentally unstable zones" characterized by potentially unstable landscapes (sandy soil, with groundwater depth of more than 5 m, poorly developed vegetation); posing risk over the last 8-20 years.

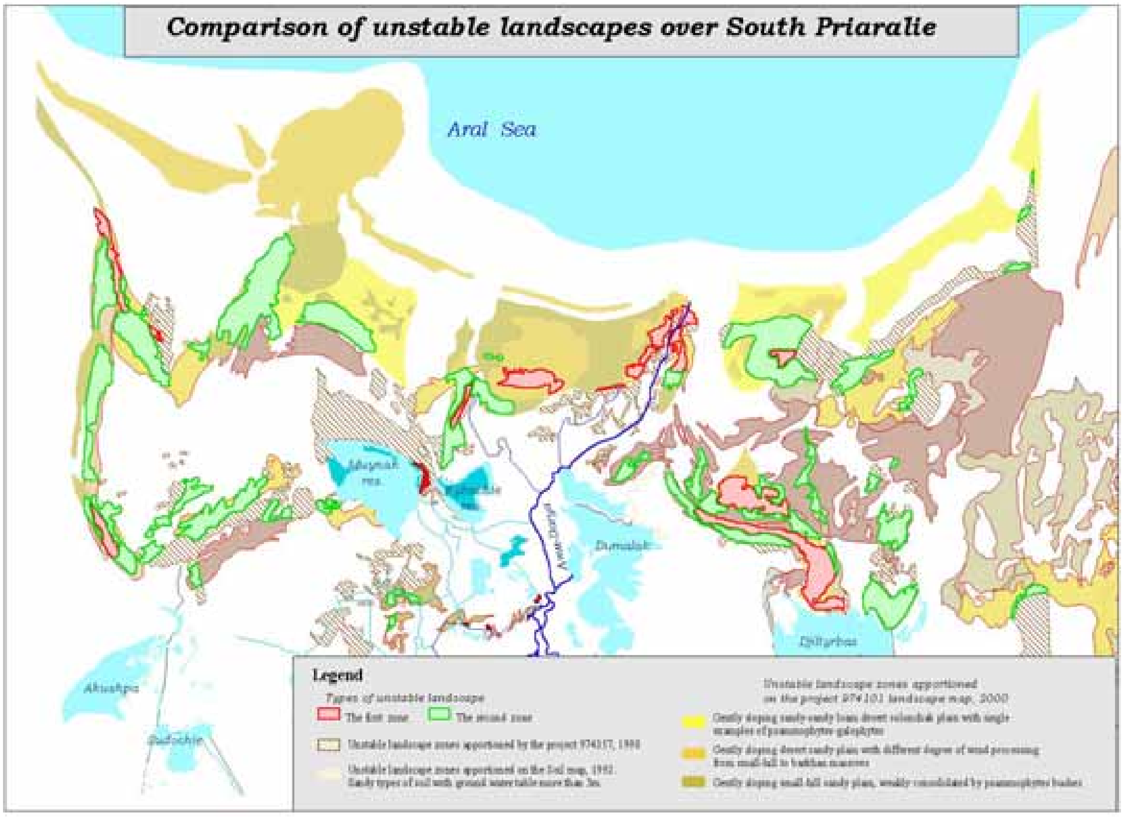


Fig. 8: Distribution of unstable landscapes over South Prearalie – Amu Darya river delta(zone 1 - green color; zone 2 - red color)

Later on, Novikova (2005) developed a further division into stable and unstable landscapes, based on genetic and hydrological forecasts, and also identified their tendency towards stabilization or destabilization. A more complete division into taxons for the map of “Lithological structure of overlying strata (Quaternary) layers on the dried bed of the Aral Sea”, as of 1993-1996 (Fig. 9) by Pinkhasov, defined a number of ecosystems, which are understood as genetically homogeneous areas: uniform in relief, composed of even-aged quaternary deposits, uniform in their origin and composition, with the same dominating exogenous geological processes and similar vegetation.

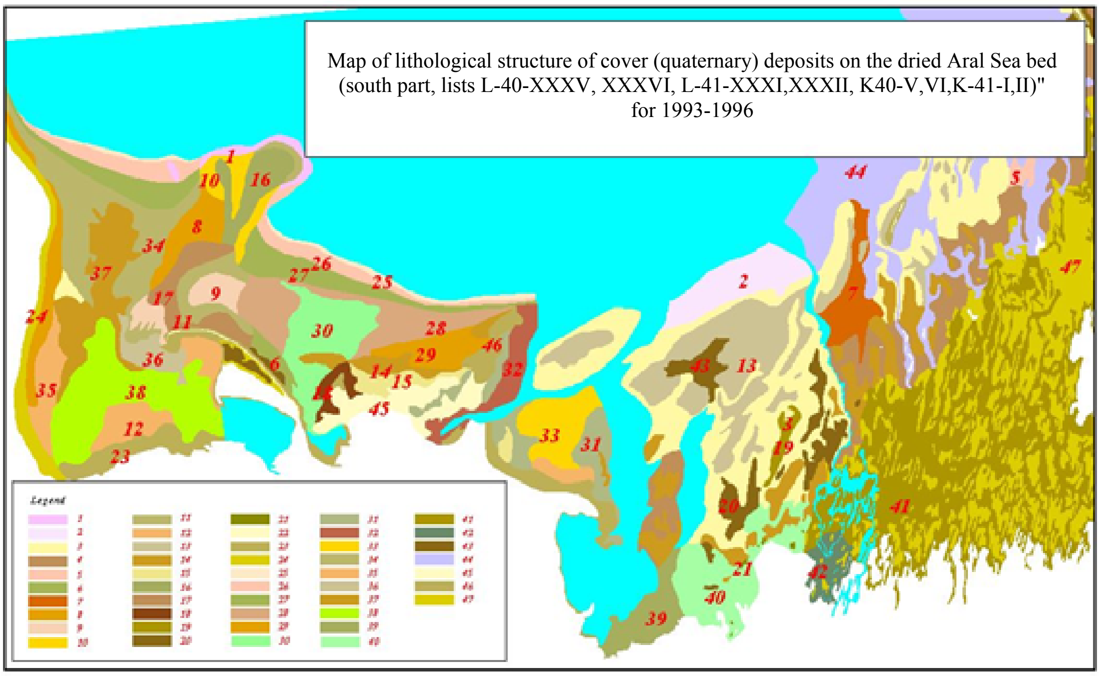


Fig. 9: Lithological structure of overlying strata (Quaternary) layers on the dried bed of the Aral Sea, as of 1993-1996

By typological zoning and mapping, the authors proceeded from the main project goal, which was to identify areas subjected to wind erosion and requiring afforestation. 48 natural complexes were identified on the dried bed, of which 21 are characterized by different degrees of overgrowing, both natural and artificial; one natural complex is water surface and more than 10 are unstable and subjected to severe desertification (Pinkhasov et al. 1999). A detailed description of the different types is given in the Annex, Table A3.

Taking into account significant differences in classification approaches of individual researchers, the recent dynamics of the soil cover conditions will be explained here, using research results.

2.5. Soils

At present, the exposed Aral Sea bed is more than 150 km wide. It represents limnic, riverine and mixed deposits. Can those sediments be classified as soils?

According to local soil scientists, the exposed ground can be regarded as soil, which differs from zonal soil in specific features. Those features consist of dynamic soil formation processes in space and time, underdeveloped and poorly differentiated soil profile, low biogenity, prevalent organics destruction processes and almost lacking organics accumulation, and consequently specific water and salt regime of young soils. These peculiarities enable the soil cover on the dried bed of the Aral Sea to pass a usually century-lasting development cycle over a short time (Sektimenko 1991; Stulina & Sektimenko 2004).

In the first stage of the studies on the dried bed, the area emerging from under water was only characterized by salinity degree.

Having examined the salt-accumulation conditions on the exposed coast and in lagoons, Bogdanova & Kostyuchenko (1977) have noted major differences between them. During the sea recession, the majority of the salts is taken away with the seawater, while the exposed ground starts to get saline later, mostly due to capillary rise of vadose water. At the same time, the lithology of deposits plays a crucial role in the process. During the drying up of closed lagoons and bays, all salts contained in the seawater remain in the ground. In this case, salt is accumulated due to capillary rise of vadose water and salt deposition directly from solution. Therefore, the lithology of deposits is of less significance here.

In 1978, Bogdanova and Kosyuchenko produced a salinity map of the dried bed of the Aral Sea at an elevation of 49-53m a.s.l. Four categories of soils differing in character and salinity were selected on the map: non-saline (less than 0.3% of salt), surface-saline (3% in the crust, 0.2-0.6% below), saline to vadose water (up to 10% in 0-5 cm layer) and solonchak of drying bays, lagoons, and filtration lakes.

The reasons for strong salinization are salt deposits on the bed of the Aral Sea under thin (0.5-1.5m) silt layer (Rubanov 1977). The first data on presence of salt on the bed of the Aral Sea were obtained by Chalov (1968) and later by Veinsberg (1972). The formation of a sub-surface salt layer is related to salt deposition from sea water due to increase in salinity of the latter. The seabed sediments laying under the sea water at a depth of 1 m and being a soil-forming rock (Brodskaya, 1952) are represented by marl in the central and western parts, and by sand and siltstone in the peripheral parts.

The plain relief of the dried bed (which actually causes a lack of drainage of the area) and shallow groundwater facilitated intensive soil salinization. Therefore, the main part of the dried area is occupied by solonchaks.

In further studies of the dried bed, the soil conception was supplemented and detailed.

At the initial stage of the sea desiccation, when the desiccation strip was only 10-12 km wide and even less at fore-deltas, three soil groups were distinguished: solonchaks, desert-sandy soils, and sand (Rafikov 1982; Kostyuchenko 1984).

The area of fore-deltas emerging from under the sea level is regarded as underwater soil. They consist of elements earlier exposed to delta soil formation processes, enriched with humus and nutrient elements, and having high absorption capacity. The remaining area undergoes primary soil formation processes as desiccation goes on.

Following the formation of primary soils and their evolutionary transformations, the next types of coastal soils have formed on the dried bed of the Aral Sea: hydromorphic solonchak, semi-hydromorphic solonchak, semi-automorphic solonchak, automorphic solonchak, desert-sandy soils and various sands. Moreover, combinations and complexes of these soils are often found here, reflecting the diversity of soil cover on the dried seabed (Sektimenko et al. 1991).

Specific soil formation conditions on the dried bed predetermined the appearance of a special subtype of solonchak here such as *coastal solonchak.*

The Institute of Soil Science conducted the most recent soil research on the dried seabed in 1990, based on which a soil map was produced (Fig. 10).

By the 1990s, the groundwater level in the studied areas lowered to 4-7m and below, and groundwater salinity was very high (up to 50 g/l). Hydromorphic and semi-hydromorphic solonchak was transformed into semi-automorphic and automorphic solonchak here. The emerging hydromorphic soils followed the receding shoreline.

The initial stage of soil cover formation on all types of the Aral Sea coast is the same. It is related to the intensive salinization of grounds emerging from under water as well as to the formation of marshy and coastal solonchak, with chloride, sulfate-chloride and chloride-sulfate salinization type in the active beach zone. The equal salt distribution along the profile gives place to intensive salt accumulation in the upper horizons under continental conditions by the end of the first year of young soil formation. The periodical washing regime changes into an exudative one, while the initial chloride type of salinization changes into chloride-sulfate and sulfate-chloride types, with solid residue being as much as 15%. The transformation of marshy solonchak into coastal solonchak lasts about 3-4 years, and is related to a salt distribution pattern change in the soil profile and to salt accumulation in the upper 1 m layer. At the same time, the groundwater level decreases from 0.5 to 1.5 m.

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

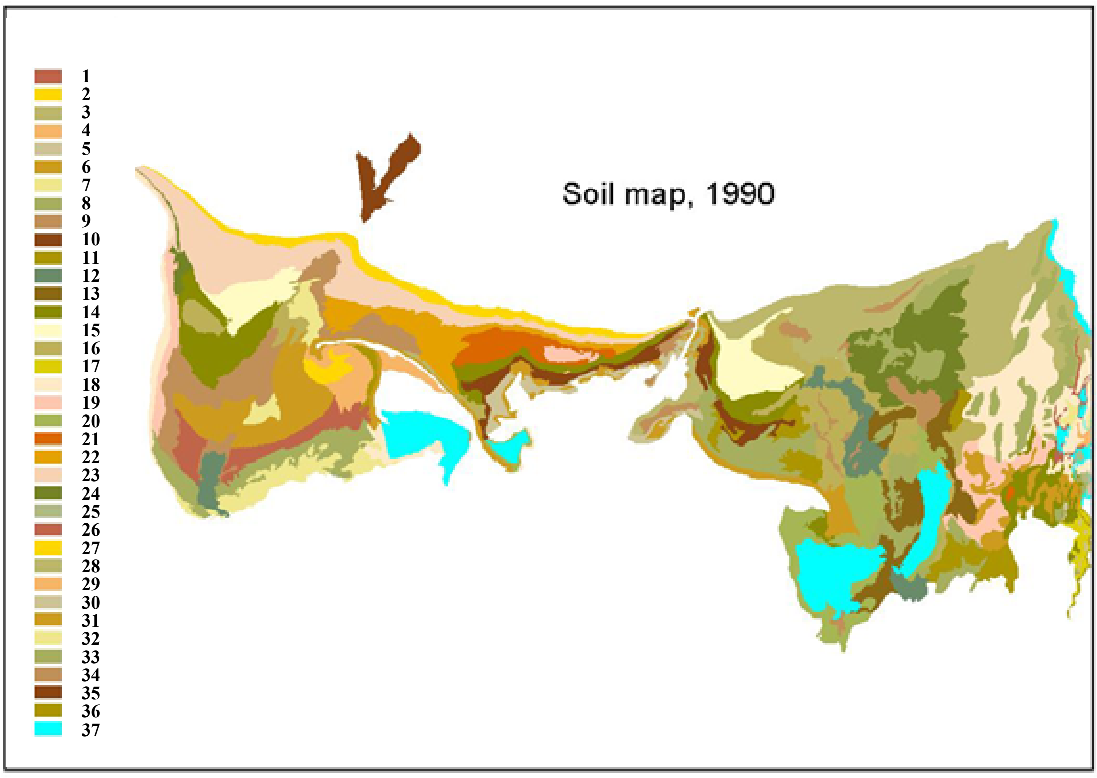


Fig. 10: Soil map as of 1990 (author: Sektimenko*)*

Soil types

1. Coastal solonchak, automorphic, crust Very strong solonchakous, very strong and strong solonchakous-deep saline Clayish and heavy loamy (sand covered)
2. Coastal solonchak, automorphic, crust Very strong solonchakous, very strong and strong solonchakous-deep saline Heavy- and medium loam (poorly sand-covered in places) on stratified loam, with sandy loam and sand layers
3. Coastal solonchak, automorphic, crust-puffed, takyr-formation in places (under Tamarix tousle) Very strong solonchakous, very strong and strong solonchakous, deep medium- and heavy saline Heavy- and medium loam on stratified deposits of clay and loam, with rare layers of sand

4. Coastal solonchak, automorphic, crust-puffed and crust Very strong solonchakous-solonchakous, deep medium- and very heavy saline Heavy- and medium loam (often strongly sand-covered) on stratified deposits of clay and loam, with layers of sandy loam and sand
5. Coastal solonchak, automorphic, crust and crust-puffed (overgrowing with Tamarix) Very strong solonchakous, very strong and rarely medium solonchakous, deep strong-, medium- and rare very heavy saline Clayish and heavy- and medium loam (sand-covered) on poor-stratified deposits having different textures
6. Coastal solonchak, automorphic, crust-puffed and puffed Very strong solonchakous-solonchakous, deep strong- and very strong saline Clayish and heavy- and medium loam (surface lightened), with rare layers of sandy loam in lower horizons
7. Coastal solonchak, automorphic, polygonal-hillocky Very strong solonchakous-solonchakous, deep strong- and rare very strong saline Clayish and heavy- and medium loam, with layers of light loam and sandy loam in lower horizons
8. Combination of sandy automorphic soil, with semi-fixed small-hilly sand (subjected to wind erosion) Strong and very strong solonchakous (rarely non-saline and slightly saline), medium-very strong solonchakous, deep saline Sandy loam and sand with thick layers of clay and heavy loam in lower horizons
9. Coastal solonchak, semi-automorphic, crust-puffed and puffed (overgrown by Tamarix in places) Very strong solonchakous, strong and medium solonchakous, deep medium-strong saline (rarely very strongly saline and non-saline) Clayish and heavy- and medium loam (surface lightened), with layers of sandy loam and sand in lower horizons
10. Coastal solonchak, semi-automorphic, crust-puffed and puffed, deflated, with small hillocks Very strong solonchakous, strong solonchakous, solonchakous, deep strong saline, rarely very strongly saline Clayish and heavy- loam, with layers of sandy loam and sand in lower horizons
11. Coastal solonchak, semi-automorphic, puffed and crust-puffed (subjected to wind erosion), with small sandy hillocks Very strong solonchakous, strong solonchakous, solonchakous, deep saline at different degree Sandy and sandy loamy on stratified deposits having different textures (from clay to sand)
12. Coastal solonchak, semi-hydromorphic, crusted, getting takyr properties in places (flooded at times) Very strong solonchakous, strong solonchakous, solonchakous, deep saline Heavy-, medium- and light loam on heavy loam and clay, with rare layers of sandy loam and sand in lower horizons
13. Coastal solonchak, semi-hydromorphic, crusted Very strong solonchakous, solonchakous, solonchakous, deep strongly saline and very strongly saline Clayish, in some places with layers of sandy loam
14. Coastal solonchak, semi-hydromorphic, crusted and crust-puffed Very strong solonchakous, very strong and strong solonchakous, deep saline Medium and heavy loam and clay (sand-covered), lightened on the surface
15. Coastal solonchak, semi-hydromorphic, gypsum-crusted, with spots of puffed solonchak Very strong solonchakous, very strong and strong solonchakous, deep saline Stratified complex of clay, loam, sandy loam and sand (sand-covered in places)
16. Coastal solonchak, semi-hydromorphic, crust-puffed, with small sand hillocks (subjected to wind erosion) Very strong solonchakous, solonchakous, deep very strongly and strongly saline Sandy loam - sand with layers of loam and clay
17. Coastal solonchak, semi-hydromorphic, crust-puffed and puffed Very strong and strong solonchakous, solonchakous, deep very strongly, strongly and medium saline Mainly sandy loam and sand with layers of loam and clay (sometimes thick)
18. Coastal sandy semi-hydromorphic and hydromorphic soil, with small erosion-accumulative relief and solonchak in dishes Mainly medium-solonchakous, medium-strong solonchakous, deep Sandy with layers of sandy loam and very rare loam in lower horizons medium saline

19. Coastal sandy semi-hydromorphic and hydromorphic soil, with small erosion-accumulative relief Poor-strongly solonchakous, medium-very strong solonchakous, deep saline Sandy with layers of clay and loam in lower horizons
20. Coastal solonchak, hydromorphic, crust-puffed, with spots of leached soil under reed-Tamarix tousles (sometimes flooded) Very strong- (rarely poor-) solonchakous, strongly solonchakous, medium- strongly deep saline Sandy loam and sand, with clay and loam layers in places
21. Coastal solonchak, hydromorphic, crusted Very strong- solonchakous, strongly and very strongly solonchakous, strongly deep saline Clayish and loamy (heavily sand-covered) with sandy-loam and sand layers
22. Coastal solonchak, hydromorphic, fragile-crusted, with small sandy hillocks Very strong- solonchakous, very strong-, strong- and medium solonchakous, deep saline Stratified complex with dominant sandy loam and sand over loam and clay
23. Coastal solonchak, hydromorphic, crusted Very strong- solonchakous, very strong- and strong solonchakous, deep heavily and medium saline Clayish and loamy, with sandy loam and sand layers in lower horizons
24. Coastal solonchak, hydromorphic, fragile-crusted Very strong solonchakous, solonchakous, deep saline Sand with thick clay layers, mainly in middle horizons
25. Combination of coastal hydromorphic and excessive-hydromorphic (lacustrine) solonchak and residual-boggy soil in former shallow-water areas Very strong and strong solonchakous, solonchakous, deep saline Sand, silted in dishes and with organogenic horizons
26. Combination of coastal hydromorphic and excessive-hydromorphic (lacustrine) solonchak, sand-covered in places Very strong solonchakous, very strong- and strong solonchakous, deep saline Sandy and sandy loamy on stratified deposits, with spots of clay and sandy loam (often with organogenic horizons)
27. Combination of coastal hydromorphic and excessive-hydromorphic (lacustrine) gypsum-bearing solonchak and flat- small hilly sand Very strong solonchakous, solonchakous, deep saline Sand mixed with crystalline gypsum
28. Complex of coastal hydromorphic and excessive-hydromorphic (including marsh) solonchak Very strong solonchakous, very strong and strong solonchakous, deep very strongly saline Stratified complex of loam, sandy loam and sand
29. Complex of coastal hydromorphic and excessive-hydromorphic (including marsh) solonchak Very strong solonchakous, solonchakous, deep saline Sandy loam and sand
30. Combination of coastal hydromorphic and excessive-hydromorphic (lacustrine) solonchak and flat- small hilly sand Very strong solonchakous and non-saline, from very strong to poor Sandy; light loam and sandy loam in lake-like dishes solonchakous deep saline
31. Ridgy-cavernous and hilly fixed and semi-fixed sand with desert sandy soil in slopes Non-saline and poor solonchakous, solonchakous, deep slightly, medium and strongly saline Sandy
32. Barchan-hilly-flat sand, unfixed and semi-fixed, deflated Mainly non-saline and poor solonchakous, solonchakous, deep slightly-strongly saline Sandy (loose) with clay and loam layers in lower horizons
33. Medium-barchan and hilly sand, unfixed, deflated Medium solonchakous, poor and medium solonchakous, deep very strongly and strongly saline Sandy (loose) with sandy loam and loam layers in lower horizons
34. Small-barchan and hilly sand, poor fixed and unfixed, deflated, sand-covered solonchak in depressions in some places Non-saline, as well as poor and medium solonchakous, medium and strongly solonchakous, deep very strongly and strongly saline Sandy (loose) with sandy loam layers
35. Flat-small hilly sand, unfixed, deflated, with sand-covered solonchak in dishes Mainly strong-solonchakous, strong- and medium-solonchakous, deep strongly saline Sandy (loose), crusted in places, with rare sandy loam layers
36. Flat-small hilly sand, unfixed, deflated Strong-solonchakous, strong- and very strong solonchakous, deep saline Coarse skeletal sand overlaid with blown sands

37. Channel solonchak, deflated Very strong solonchakous, strong- and very strong solonchakous, deep saline Loose sand with clay and loam layers in lower horizons
38. Water

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

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

Automorphic and semi-automorphic soils, especially their crust-puffed types, become a source of dust and salt.

Under the conditions of insufficient watering, the hydromorphic delta soils degrade and change into deserted types, the swamp-boggy soils are transformed completely and the drying types of meadow-boggy and alluvial-meadow soils with very high salinity prevail, and the areas of takyr soil, sand and solonchak increases.

Before flow regulation, under the conditions of periodical flooding, the hydromorphic soils had minimum salinity. With the termination of flood flows and the development of desertification processes, the soil water-salt regimes changed. Replacement of washing regime by exudative one led to significant salinization of all hydromorphic soils. The intensity of this process is determined by features of meso- and macro-relief and regional ecological conditions. During the period of flow regulation, almost all hydromorphic soils became highly saline. This process is especially typical for initial stages of soil desertification.

Sulfate and chloride-sulfate types of salinization changed into sulfate-chloride and chloride types, and the salt content in the 1-m layer increased from 0.23-0.45 to 0.31-1.25% for boggy soils, and from 0.23-0.53 to 0.57-0.82% for meadow soils. This tendency poses a risk of secondary salinization in hydromorphic soils.

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

Unfortunately, at present the process of deep genetical transformation and development of soils is not studied. Microbiological research, which is crucial for studying primary soil formation process has not been carried out.

2.6. Hydrogeology of South Prearalie

In geological terms, the research area is a part of the Turan lowlands and refers to the western half of the Syr Darya artesian basin of the first order, complicated by folded strains. As a result, the basin is characterized by a complex and polytypic structure, associated with a varying hydrological profile and chemical composition of ground and confined waters (Pinkhasov 1984, 1997, 1999, 2000; Rubanov et al., 1987).

The study area is delimited by the Ustyurt plateau vault in the west and the Amu Darya river delta and irrigated zone in the south. The groundwater dynamics related to the upper hydro-geological stage is studied further in this area under the setting of desertification and dynamic development of harmful exogenous-geological processes in the South Prearalie region. This hydro-geological stage is situated above the regional Senonian-Paleogene confining layer and is characterized by free water exchange with surface and atmospheric waters. The specificity of distribution of its aquifers consists of direct relationships with natural factors developed intensively in the research area.

According to groundwater depth and recharge, distribution and discharge as well as on the geological and lithological structure of water-storing rock, “Gidroingeo” Institute defined 2 aquifers.

The upper aquifer system is mostly represented by grey, reddish brown and red-brick sandy loam, sand, loam and clays, which are interstratified by benches and lenses of channel grey, micaceous-clay and fine-grained sands 7-10m thick. The thickness of loam and clay reaches 10-12 m. The overlying modern formations of the Amudarya complex, up to 12-15 m thick, are comprised of grey sandy loam, loam and sand.

The aquifer of quaternary modern alluvial-lake deposits is situated at depths of 2.4-2.5 m to 2.6-2.65 m. The salinity in this stratum varies from 8.0-12 g/l to 35.8-38.5 g/l in the delta zone and from 40-42 g/l to 63.0-71.5 g/l in the dried seabed.

In the area where the former Amu Darya river delta is connected with the Aral Sea (53 m altitude), the modern alluvial-lake formations of the Amu Darya complex are replaced by modern alluvial-marine and underwater-delta deposits of the Aral complex. In contrast to them, the underlying water-storing layers of alluvial-lake formations can be found further in the sea or to the north from shoreline at the altitude of 53 m.

These deposits of given aquifer system have their spatial extent within the former bays of Akbulak, Adzhibay, Muinak, Rybachie, Akkala and Dzhiltyrbas deeper than the sea, in the dried and plain areas of the sea to shorelines at 39-38m (1989-1990).

The upper part of this system, which corresponds to the alluvial-marine profile of the Aral complex, is formed by unevenly interstratified marine sandy loam, silt sand and light and medium loam, grey-brown alluvial and underwater-delta sandy loam, loam and clay, with very low filtration parameters and highly saline groundwater.

Systematical observations on groundwater depth and salinity on the Aral Sea bed have not been conducted. The last observations have been generalized by “Gidroingeo” Institute based on data for 1993-1996. They show that the decrease in sea level results in a decrease in groundwater depression curve, preserving its values within 5 m from the surface. Higher groundwater depths refer to the channels of former watercourses and the points of current releases from lake complexes towards the dried seabed. Groundwater salinity of less than 10 g/l can only be found in former channels and waterways. Salinity exceeds 30g/l on the major part of the dried bed.

A sharp prevalence of capillary moisture rise leads to a concentration of chlorine and sodium ions in groundwater, thus making them sulphate-chloride with increased sodium content. The chemistry of groundwater is similar in general to that of sea water, despite a large percentage of some ions.

Incision of the riverbed bottoms resulted in disappearance of previously existing channels and to GWL lowering (Kipchakdarya, Taldyk and Arkindarya channels, and Inzsheneruzyak and Akkay low branches). During the last years, the Amu Darya flows along the rectified Udrubay branch. Incision influence is traced from 100 to 20 km from the shore line. Along Temirbay hydrological station, the river bottom lowered 3.8 to 4.5 m. Presently, water is supplied to the branches by pump stations. Simultaneously with the incision, a general lowering of ground water level, head and output of artesian wells occurs in Prearalie. According to forecasts of 1990, the pressure water level will lower 20 to 22 m at a distance of 60 to 100 km from the coastline (presently 4 to 20 m), and ground water level will go down 3 to 5 m. Groundwater inflow to the sea is 0.2 km³, but 6.2 million tons of salts are leached due to high concentration.

The thickness of water-storing layer varies from 1.0-3.0 m to 3.0-7.0 m. Groundwater is situated at 3-4 m to 4-6 m. The aquifers are highly saline, with solid residue varying from 17-34 g/l to 200 g/l and over. Permeability coefficient changes from 0.3-0.6 m/d to 0.8-3 m/d.

The least saline water (17-34 g/l) is found in Sudochie-Adzhibay, Muinak and Rybachie parts of the dried seabed.

2.7. Afforestations for erosion prevention – history and current situation

The outstanding scientist V.A. Obruchev conducted the first fundamental studies of unfixed sands in Central Asia when he assisted the constructors of the Trans-Caspian railway in developing methods for sand drift control. In 1886-1888, an expedition to the Central Asian deserts was organized and first recommendations were developed on methods for fixing loose sands along the railway.

Further work on methods for protection of railroads from sand drifts was undertaken by famous forestry specialist V.A. Paletskiy. He continued the work of V.A. Obruchev and developed and implemented a number of recommendations on methods for protection of railroads from sand drifts. Under the direction of Paletskiy and according to his methods, loose sands from both the sides of the Trans-Caspian railroad were fixed (Paletskiy 1956; Petrov 1963).

Another valuable contribution to development of methods for unfixed sand control in Uzbekistan was made by the head of forest-reclamation activities of Uzbekistan, S.G. Zaozersky. Upon requests of Paletskiy and Zaozerskiy, specific scientific and production organizations were established in Uzbekistan and Turkmenistan: the sand fixing field parties of Amu Darya, Bukhara, Khorezm, Chardjou and Syr Darya. In the subsequent years, Petrov. (1950), Koksharove (1985), Korovin (1961), Nikitin (1969), Novitskiy (1984, 1986) and others made a great contribution to the development of forest-reclamation science and practice in Central Asia.

Many nations have gained extensive knowledge in the control unfixed sands. Sand fixing work in the desert areas of the CIS countries have been running for centuries. The first evidences from official sources on unfixed sand control are found in the 1880s. The accumulated national experience in forest reclamation work is successfully used in other countries such as Iran, Afghanistan, India, Africa and others (Niknam & Ahraniani 1977).

Forest plantations in arid zones play a crucial role in erosion prevention. They protect light desert soils from wind erosion, guard national economic objects from sand drifting and deflation, improve microclimate, and ensure favorable conditions for better growth and development of grass and sub-shrubs, thus increasing the productivity of desert and semi-desert pastures.

In the late 1940s, forestry specialists of Central Asia faced a challenge to create fire wood bases to meet the needs of the local population, using desert tree species on loose sands. To accomplish this task, a project was prepared in 1949 for the afforestation of Shafirkuduk sand massif, with an area of 47,000 ha, situated in the Shafirkan district, Bukhara province.

Most part of this massif was occupied by barchans, 2.0-2.5 m high. In the south, barchans joined into chains up to 10-15 m high and occupied 80-90% of given territory. Those sands were formed on takyr soils of the ancient irrigation land (Nikitin 1969).

It was planned to afforest barchans and barchan-hilly sands occupying an area of about 20,000 ha. The plan was to fix the massif by planting seeds of Black Saxaul in inter-barchan depressions. The first attempt to fix the dunes was made in autumn 1954. Saxaul seeds were sown manually without tillage and embedded into the soil using sheep herds running over it after sowing. In spring, sprouts came up in an area of 5,000 ha. This procedure was continued in the two subsequent years. A great number of plants were covered with sand, but the majority in an area of 15,000 ha remained standing and survived (Petrov 1950). In the following years, sowing was performed using a mechanical protection method for sand fixing.

A mixture of Saltwort and *Calligonum sp.* seeds were sown along the mechanical protection area in autumn, while cuttings of these species were sown in early spring. Few years later, after sand fixing in inter-barchan depressions, Black Saxaul (*Haloxylon aphyllum*) was sown. Thus, the southern part of Shirinkuduk massif was afforested. In areas occupied by poorly overgrown hilly sands, sandy takyrs, free broadcasting of Black Saxaul seeds was performed. As a result, the whole territory of Shirinkuduk massif was afforested during 5 years. After 25-30 years, the complete stands of Black Saxaul mainly were formed and the standing volume ranged in 15 to 30 m^3/ha.

Since 1980, the Central Asian Forestry Research Institute (SredazNIILKh) together with Karakalpak specialists has been conducting experiments on unfixed sand control in the territory of Nukus and Muinak forestries. First of all, a standing, cellular and reedy and high-stem plant mechanical protection was arranged, in order to stop sand movement. The inputs varied from 150 to 500 m^3/ha from the direction of barchan slopes exposed to wind. Afforestation of sands was implemented on preliminarily arranged mechanical protection, with subsequent sowing of cuttings or seedlings of Kandym (*Calligonum sp.*) and Saltwort.

The first successful forest-reclamation activities of desert pastures in Central Asia were implemented in 1948-1949 in the territory of “Karnab” state breeding farm in Uzbekistan under the direction of G.A. Sergeyeva. In the following years, Central Asian scientific organizations developed and introduced narrow-band, broad-band, coulisse and other methods for forest reclamation in desert pastures (Sergeyeva, 1954).

The narrow-band method for forest reclamation in desert pastures was developed by KazNIILKh. Later on, it was improved by SredazNIILKh with the aim to make a forage area of Black Saxaul plants, under typical conditions of sandy deserts, with groundwater inaccessible for the roots of this species and the average annual precipitation being within 80-120 mm.

In 1985, a base station of SredazNIILKh was created in Karakalpakstan (Novitskiy 1984). The primary task was to develop and introduce methods for phytomelioration on the exposed Aral Sea bed. The aim was to prevent negative ecological consequences of the Aral Sea disaster and form artificial desert pastures through phytomelioration (Koksharova 1985).

During the experiments it was found that one of the ways for reducing the negative effects of the sea desiccation is to plant shelterbelts of big shrubs on the exposed seabed. They will be an obstacle to wind, sand, dust and partial salt transport, and further on will compensate, to a certain degree, the loss of pastures in Prearalie.

Due to cuts in the national budget, the UzNIILKh Institute together with the Karakalpak base station and specialists from the Academy of Sciences of Karakalpakstan had to reduce the scale of forest reclamation experiments on the dried seabed.

Based on the recommendation developed by the SredazNIILKh Institute (Novitskiy 1986), foresters of Karakalpakstan undertook forest reclamation in an area of about 225,478 ha over the last 15-20 years on the dried seabed, according to data from the Forestry Authority. Besides, international organizations as IFAS (about 10,000 ha) and GTZ (about 30,000 ha) are actively involved in forest reclamation measures.

3. DATA AND METHODS

3.1. Field studies

3.1.1. Objectives and scope

Based on the requirements set by GTZ, the objectives for the first research stage were determined. The first task was to collect ground-truth data for the classification of satellite images by conducting a field survey on the desiccated seabed. With this data at hand, the potential of satellite imagery for landscape monitoring in the territory was to be assessed. Furthermore, the results from the remote sensing survey should be compared with earlier investigations on the dry seabed with regard to landscape, hydrogeology, soil and vegetation.

Hence, two expeditions were organized with the following team members: leader-ecologist, soil scientist, geobotanist and hydrogeologist, as well as workers, technicians and guides.

The customer GTZ determined the periodicity of expeditions. Thus, initial work was conducted in the southeastern part of the dried seabed within the former Akpetki archipelago and along the coast to the border with Kazakhstan in autumn 2005. The second expedition (Spring 2006) completed the ground truth data collection in the central part of the southern dried seabed.

In autumn 2006 and spring 2007, three additional expeditions were undertaken, with geobotanical focus to specify the plant establishment rate in the afforestation areas: the third expedition - within Muinak region with a survey area of about 30,4 thousand ha; the forth one - within Dzhiltyrbas region in an area of 58 thousand ha; and, the fifth one - in the western part of the dried seabed within Sudochie lake, northward of the “Tiger Tail” and along the Ustyurt chink.

Simultaneously, the GTZ project conducted detailed assessments on the impact of afforestation measures on wind speed and aeolian erosion. These experiments were arranged through the whole 2006 season. High resolution measurements on wind speed and direction were made on 5 weather stations in the Dzhiltyrbas region. These measurements were supplemented by sand transport assessments at 23 spots in the area on a monthly basis.

In order to negotiate a future contract, the key project participants studied a possibility of involving local staff, the availability of soil (Institute of Soil Science) and hydro-geological (Gidroingeo) reports and maps in associate organizations. The materials were discussed with the customers from the GTZ Project and the Ministry for Agriculture and Water Resources (Novitsky Z.B., Obidov K., Ganiev M.).

After the preparation of the above-mentioned materials and their analysis, SIC ICWC started to organize and conduct field studies.

3.1.2. Field study methods

The principal methods for studying the exposed area of the Aral Sea were en-route (pedestrian, car and visual) and semi-stationary surveys in combination with large-scale profiling and schematic description.

Based on the results of unsupervised and supervised classifications of IRS-1D satellite images acquired by GTZ, the expedition team together with GIS experts determined sites for detailed field studies.

The tasks of the first and second expeditions included:

1. Describing the current environmental status of the dried bed of the Aral Sea: relief; main landscape types (with determination of position by GPS).
2. Describing plant associations on the dried seabed.
3. Assessing the current soil cover state of the dried seabed.
4. Assessing the current hydro-geological state (groundwater level and quality measurements).

The tasks of the third, fourth and fifth expeditions were to survey the sites for phyto-reclamation (afforestation): planting of Saxaul and other plant associations within Muinak and Dzhiltyrbas on the dried seabed. The survey included the assessment of the environmental and soil conditions in the study area and of the state of trees and shrubs.

3.1.2.1. Soil research techniques

Soil research consists of:

1. field study of soil cover along the routes of five expeditions
2. laboratory analysis of soil samples
3. analysis of resulting data, soil mapping

The field study includes description of locality, selection of key sites, arrangement of soil sections, morphological description of soil profile over genetic horizons, and soil sampling. The soil was described using a standard model. Soil samples were passed to SANIIRI laboratory to analyze soil chemical and physical properties, salt content in full water extract, its anionic and cationic composition, organic substance content, gypsum and carbonate content, and soil texture (granulometric composition).

Soil research was conducted during the five expeditions and had several objectives:

1. Studying soil cover of the dried seabed and producing a soil map as for 2006.
2. Analyzing soil cover in the context of vegetation cover and selecting zones suitable for planting.

Each key site was geolocated by GPS. The information related to it was included into a summary table of field observations.

133 soil sections and small trenches were arranged in total during the expeditions. Since numeration of the soil sections was always started with the digit one, in order to avoid number repetition, a three-digit number was given in description in the report. Soil section number is started with a serial number of expedition.

3.1.2.2. Vegetation cover study technique

Natural vegetation cover characteristics are given in the geobotanical description of the area, taking into account plant features and soil conditions for determining the areas prone to salinization and desertification.

Description of vegetation cover starts with a preliminary survey of the study area for general terrain orientation, as well as with identification of environmental links between plant associations and local conditions: relief, soil, soil salinization and moisture features, etc. After a detailed survey, the most representative phytocenosis sites are selected, with homogeneous floristic composition and habitat conditions.

A phyto-reclamation land survey, particularly, of Saxaul plantings, as well as shrubs and semi-shrubs for potential pastures was of great importance. Based on route survey, the state of Saxaul and other vegetation, a few sites are selected for geobotanical description of soil sections. The geobotanical description is made simultaneously within three sites in three replications: a) best establishment of Saxaul; b) medium establishment of Saxaul; c) bad establishment of Saxaul (Form 1).

Form №1

The Scientific-Information Center of the Interstate Commission for Water Coordination (SIC ICWC)

“_27_”_October_2006

Forms for vegetation description

1. Researcher_ **Saparniyazov Zh., Kosnazarov K. A.**_________________________
2. № **1**_of site (coordinates________________________).
3.Site dimension_**100x100**____
4. Plant group_**Saltwort and grass association** _______________________________
5. Geographical point_ **3-4 km from drill tower to the north-east on dried seabed _**
____
6. Topography of described locality **uneven hilly** sand barchans, barkhan height up to 2-3 m ____
7. Exposition and slope_______ ____
8. Water body depth and water clarity
9. Brief soil characteristic (horizon thickness, color, moisture, texture, structure, root zone, animal activity, new formations, inclusions, character of transition to the next horizon).
10. Landscape plants:
I. Layer_ **grass**
II. Layer_**saltwort, height up to 1.5 cm., age 3-4 years _**
III. Layer
11. Landscape within this locality (homogeneous complex area). **Grass on solonchak surface**
12. Aspect_ **brown-suppressed state**
13. Total soil cover degree in % %_**60-65**
14. Contribution of each landscape’s plant to soil cover **grass covers the soil by 50 % with sparse 10-15% cover by saltwort**
15. List of plants

Plant name or № of herbarium leaves	Height (m)	Abundance in Drude	Distribution	Life state	Phenological phase
Saltwort	1,5	Sol	Uneven	Normal	Beginning of fruitage
Dzhuzgun	2,0	Sol	Uneven	Normal	Vegetation
Thorn kanbak	0,3	Cop_1	Even	Normal	Vegetation
Goose-foot	0,45	Sp^2	Even	Suppressed	
Grasswort	0,25	Sp^1	Even	Normal	Vegetation
Fish eye	0,3	Sp	Uneven	Abnormal	Vegetation

3.1.2.3. Hydro-geological studies

Types, volumes, sequence and technique of studies under hydro-geological survey should be based on geological and hydro-geological conditions of the study area and on basic and additional tasks set for the survey (Klimentov et al. 1978). The studies include collection of data from the earlier conducted geological, geomorphological, hydrological, and hydro-geological observations. Various ground-based visual observations being one of basic components of the hydro-geological survey are made during field surveys of the mapped territory. The data collected during the field surveys are important for study and assessment of upper aquifers (uncovered by erosive pattern, shaft wells and shallow wells) and for production of a hydro-geological map. Pits were drilled in some points along the route to determine groundwater level and salinity.

3.1.2.4. Landscape assessment

The main natural landscape-forming factors are divided into zonal (climate, water, soil, vegetation, fauna) and azonal (geological structure and relief) ones (Chupkhin & Andryuishin 1989). All of them are the basic elements contributing to general landscape pattern as a natural-territorial habitat (NTH). The internal structure and development of the landscape are basically determined by relief-forming (geomorphologic), climatic, soil and other processes.

Elementary association is the simplest, lowest morphological unit of a landscape, within which the character of interrelations between natural components remains constant. It is a part of the natural system, along which lithology of surface strata, character of relief and moistening, microclimate, soil types and biocenosis are identical. The elementary association usually occupies microform of relief or its part, keeping its own basic quality - composite nature.

As there is a great number of elementary associations on the earth, it is practically impossible to study each of them individually. Therefore, they are usually studied comprehensively in typical sites of landscape. This makes it possible to integrate them in groups or types, i.e. classify them according to similarity in origin and biocenosis.

Combinations of two or several elementary associations form more complex natural systems - tracts formed within the limits of relief's mesomeride. Elementary associations and tracts characterize fully the natural properties of specific piece of land.

Various classifications of landscape's morphological parts form medium and higher typological complexes of ground variant of Earth landscape sphere: sort, subtype, type, subclass and class.

Our methods of landscape observations are based on the following considerations:

- relief description of locality
- climatic conditions of locality
- soil cover of locality
- vegetative cover of locality
- geological structure of locality
- fauna
- water surface of locality

Based on the above-mentioned data, we described geomorphological conditions and vegetation, i.e. landscape description of the south-eastern part of the dried seabed.

3.1.2.5. Wind and erosion measurements

Another component of the present study was the assessment of the wind conditions (speed and direction) and a quantification of the soil erosion processes taking place on the desiccated sea bed. Therefore a system of meteorological stations equipped with data loggers combined with a set of BNSE saltation sampler clusters was established in the project area of the GTZ-Project.

Fig. 11 shows the spatial layout of the measurements. A total of 5 meteostations were installed on different land cover types, equipped with anemometers (Thies Clima Windgeschwindigkeitsmesser Compact) in three measurement heights (0,5m, 2m and 10m) and one wind vane (Vector Instruments W200P). The stations were equipped with Delta-T GP1 data loggers which were programmed to log the sensor measurements in a 10 sec interval. The power supply was realized by 12V lead-acid batteries, which granted a 6 week measuring cycle until a data readout and battery change were necessary. In order to maintain a security buffer and prevent data loss, the actual read-out interval was 4 weeks.

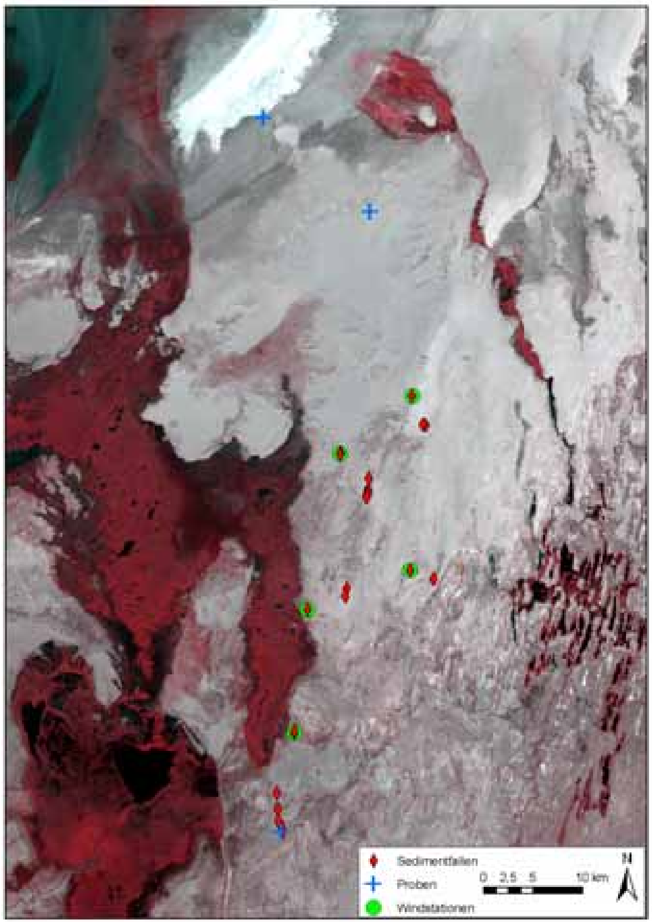


Fig. 11: Location of the wind stations and sediment traps

The 23 saltation samplers were designed in the concept of the BSNE (Big Spring Number Eight) sampler as described by Fryrear (1986), Zobeck et al. (2003) and Zobeck &Van Pelt (2006) (Fig. 12). These samplers were installed on posts into sampler clusters, with measurement heights 0,1, 0,4, 0,65 and 1,5m. The locations were also spread over the project territory, covering all kinds of surface types and vegetation covers.

Sediment traps
Samples
Wind stations

Fig. 12: Wind and erosion measurement stations

The samplers were emptied on a monthly basis, and the collected sediment was characterized by weight (quantity) and texture where possible (dependent on sufficient quantity collected).

Apart from the characterization of material transport on the different surface types, one central objective of this investigation was the impact assessment of afforestation measures on soil erosion. Therefore, some of the 23 samplers were set-up in north-south transects (aligned with the dominant wind direction) covering individual plantations of *Haloxylon aphyllum* or *Aristida karelini*). A comparison of the quantity of the caught sediment allowed an impact estimation of the afforestations on material transport.

A similar strategy was chosen in order to estimate the influence of *Haloxylon aphyllum* plantations on wind speed. Therefore, the measurements for one month (July 2006) on an unvegetated surface were compared to the measurements from a station located within a 5 year old afforestation.

The results will be presented in chapter 0.

3.1.3. GIS and remote sensing based preparations of the field campaign

For the investigations on the desiccated Aral Sea bed, two types of satellite images were used: IRS-1D LISS-III (acquired in September 2005) and Landsat-5 TM (acquired in August 2006). Spatial (geometric) data resolution, which is characterized by minimum size of objects distinguishable on images, is 23.5 m for IRS, and 30 m for Landsat. The software product “ERDAS Imagine 8.4” is used for work with satellite images in SIC ICWC.

Since all the images had 1G processing level, they were already converted to UTM projection on the WGS84 ellipsoid. Residual geolocation error for Landsat images of level 1G is a systematic shift of no more than 90 m over each of coordinate axis. The geometric correction of images was validated by the use of check point coordinates (crossroads, bridges, etc.) collected by handheld GPS receivers.

For the environmental monitoring tasks, SIC ICWC used the following main stages of initial remote studies, as described in Vostokova Ye.A., Suschenya V.A., Shevchenko L.A. («Environmental mapping on the base of space information », M. Nedra, 1988).

Pre-survey preparation:

- Selection of source cartographic information for studying the territory.
- Preprocessing of satellite images.
- Selection of sites for control and detailed study.
- Determination of routes for field studies.

Pre-survey preparation. At the first stage of activities in 2005, SIC ICWC together with specialists from GTZ determined primary routes for field studies throughout the territory, i.e. general layout for the field studies on the dried bed of the Aral Sea. For the determination of the expedition routes, ancillary map material available at SIC ICWC was used.

The primary objective of the field surveys was to collect ground truth data for the classification of the satellite images. Additionally, information about soil texture and groundwater tables in areas with high and low projective cover was collected. This was necessary in order to assess changes in soil cover and to identify sites for future phyto-reclamation measures.

Fig. 13 shows the comparison of the route developed in GIS with the actual field routes. The changes were necessary due to terrain accessibility. Since virtually the whole study area was covered by the field surveys, a good spatial distribution of test sites for image classification was possible.

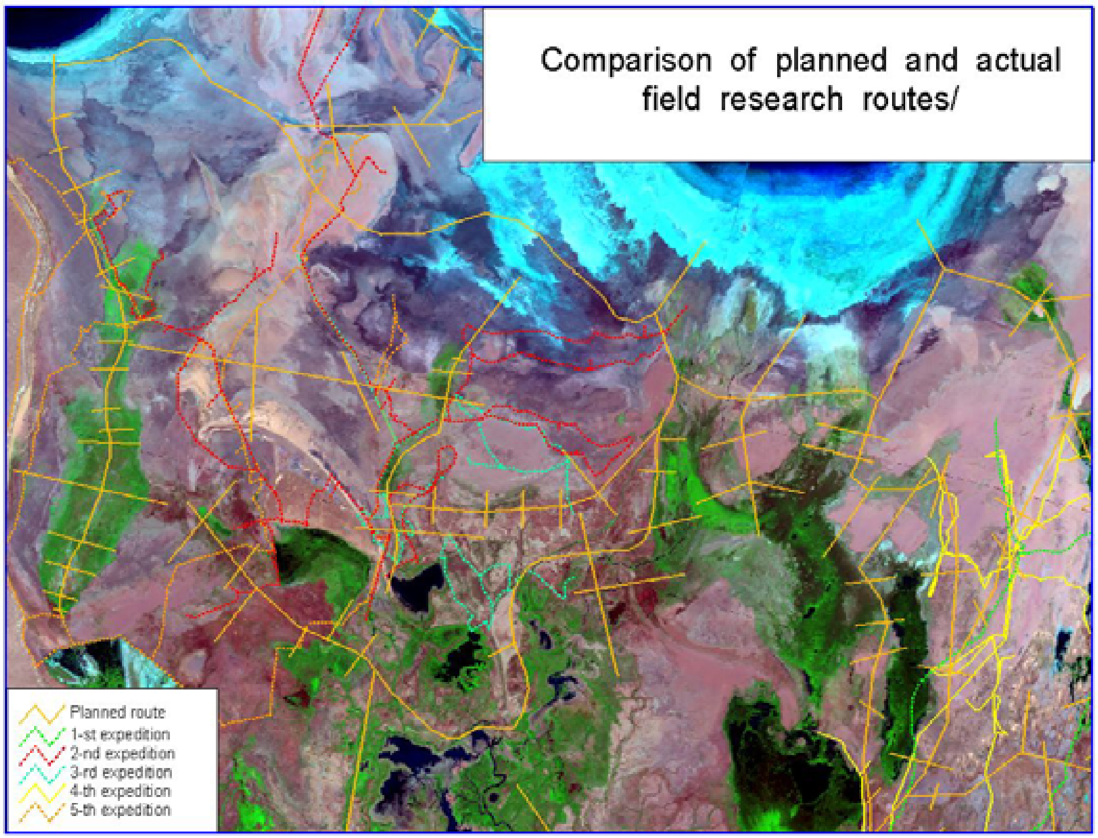


Fig. 13: Comparison of planned and actual field survey route

Previous RS & GIS studies in the territory of Southern Prearalie. Remote sensing (RS) can be regarded as a process through which information on an object, territory or phenomenon is gathered without direct contact. This is especially important for hard-to-reach areas. Identification and subsequent classification of remote sensing data are practically impossible without field studies. This excludes the territories studied well enough, on which a large quantity of cartographical and field data is available, for example, evaluation of changes in wetland areas in Prearalie.

The application of remote sensing data for ecological monitoring tasks is necessary since satellite images have some advantage over topographical materials. From the perspective of acquisition of information on earth surface, these are uniform generalization of images, integrated mapping of all geosphere components and regular frequency at certain intervals, i.e. capability for regular data updating. SIC ICWC used remote sensing data for a set of tasks, for example:

- target landscape mapping;
- evaluation of changes in the area of wetlands;
- evaluation of dynamics of open water surface;
- allocation of territories subjected to erosion, etc.

For more than ten years SIC ICWC has been carrying out studies within Amu Darya river delta and the exposed Aral Sea bed, and since 2005 has been performing systematic monitoring over the dried seabed together with GTZ. The appearance of desertification processes in the Amu Darya and the Syr Darya river deltas started in the 1960s, which created a need for monitoring these areas in order to assess the possibilities of mitigating the negative consequences of the ecological disaster caused by the Aral Sea desiccation. One possible way of mitigation is the creation of artificial water bodies on the exposed bed; furthermore, it is necessary to identify areas for phytoreclamation (afforestation).

3.1.4. Expeditions and routes

The expeditions were undertaken in Autumn 2005 - Spring 2007. The total length of route was more than 7 thousand km, 430 testing representative sites were selected and described and 133 soil profiles were cut. The expeditions covered a part of the dried Aral Sea bed located within the boundaries of Uzbekistan.

The expedition routes were marked by sections or individual parts of the general path to describe typical forms. Since two expeditions were focused on description of vegetation cover, a spatial description of massifs was made. A brief description of the routes is given below.

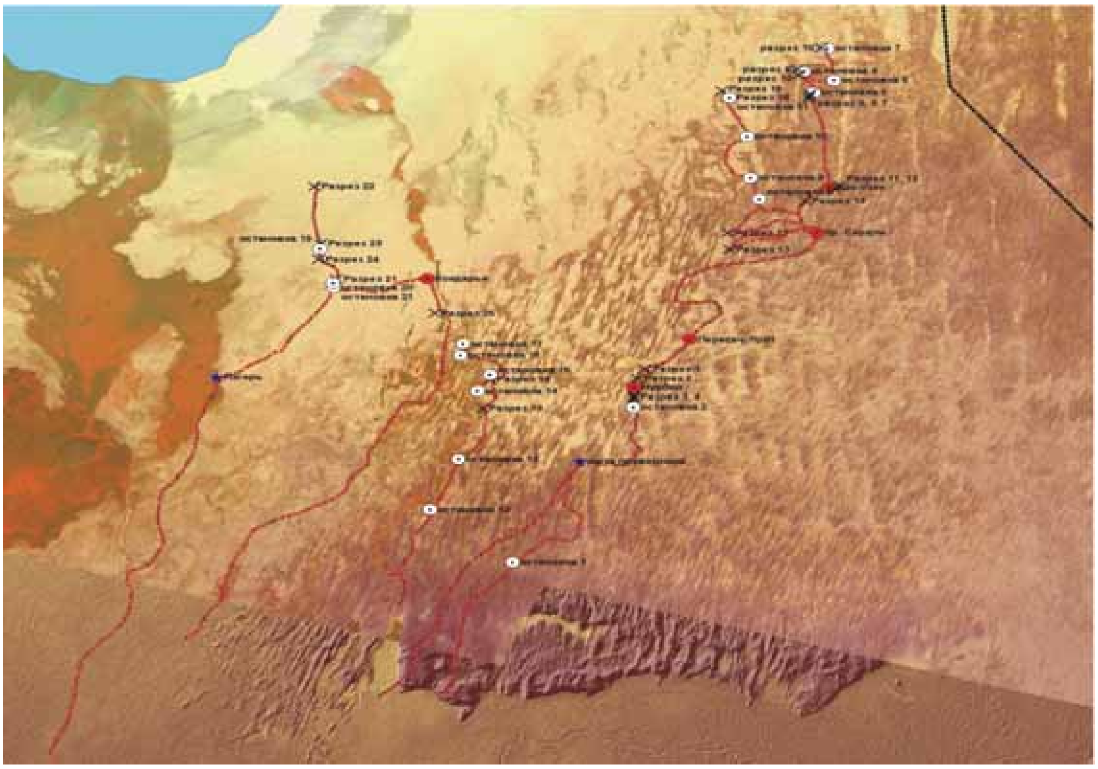


Fig. 14: Expedition route of the first expedition

First expedition

First section - from the side of Takhtakupyr district via Beltau towards the Akpetki archipelago to the border with Kazakhstan, with maximum approach to water edge of the Aral Sea (stop 1 - stop 22) (Fig. 14).

Second section - from the side of lake Karateren along the right bank of Kokdarya, with maximum approach to water edge of the Aral Sea (stop 22 - stop 26).

Third route - from the direction of Karauzek district between Dzhiltyrbas bay and Kokdarya channel, via GTZ objects, with maximum approach to water edge of the Aral Sea (stop 26 - stop 44).

The study was planned to include polygons in the south-east of the dried seabed as selected in processing of satellite images.

The expedition was undertaken in the period from October to November 2005.

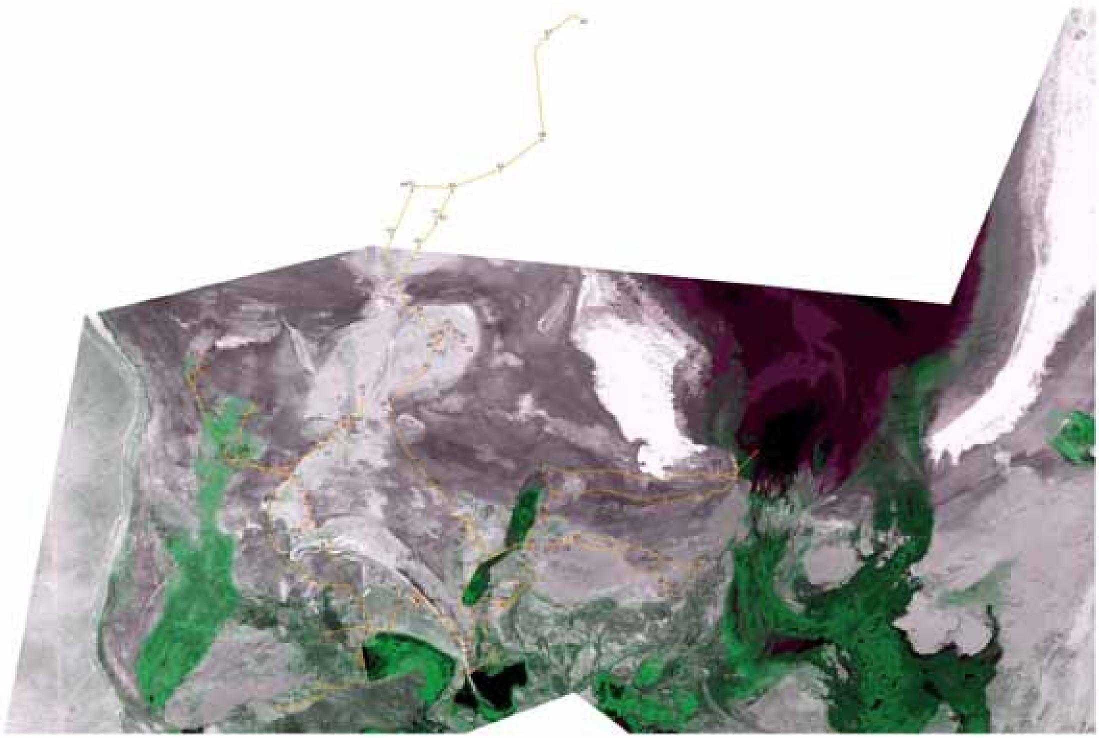


Fig. 15: Route of the second expedition

Second expedition

The route of the spring expedition covered the south-western part of the dried seabed. The duration of the field studies was from 14 May to 4 July. The field studies were carried out according to the earlier planned and approved route (Fig. 15).

First route - from Muinak town through gas-condensate station to Uch-Say (stops1 -25)
Second route - from Uch-sai to Lazarevo island, drill tower Kabanbai-2 and from drill tower Kabanbai (1- to stop 43).
Third route - from Lazarevo island to oil-rig Bakyt (stop 44-stop 52)
Fourth route - from oil-rig Bakyt to watercourse (stop 53 - stop 59)
Fifth route - from watercourse eastward, round-route towards the delta (stop 59- stop 70)
Sixth route - from watercourse northward and north-eastward to Amudarya delta (stop 70- stop 82)
Seventh route - from Rybachie through Tigrovy Khvost, Muinak dam to Adzhibay bay (stop 83- stop 104)
Eighth route - from Muinak town to the last ship graveyard (stop 105- stop 126)

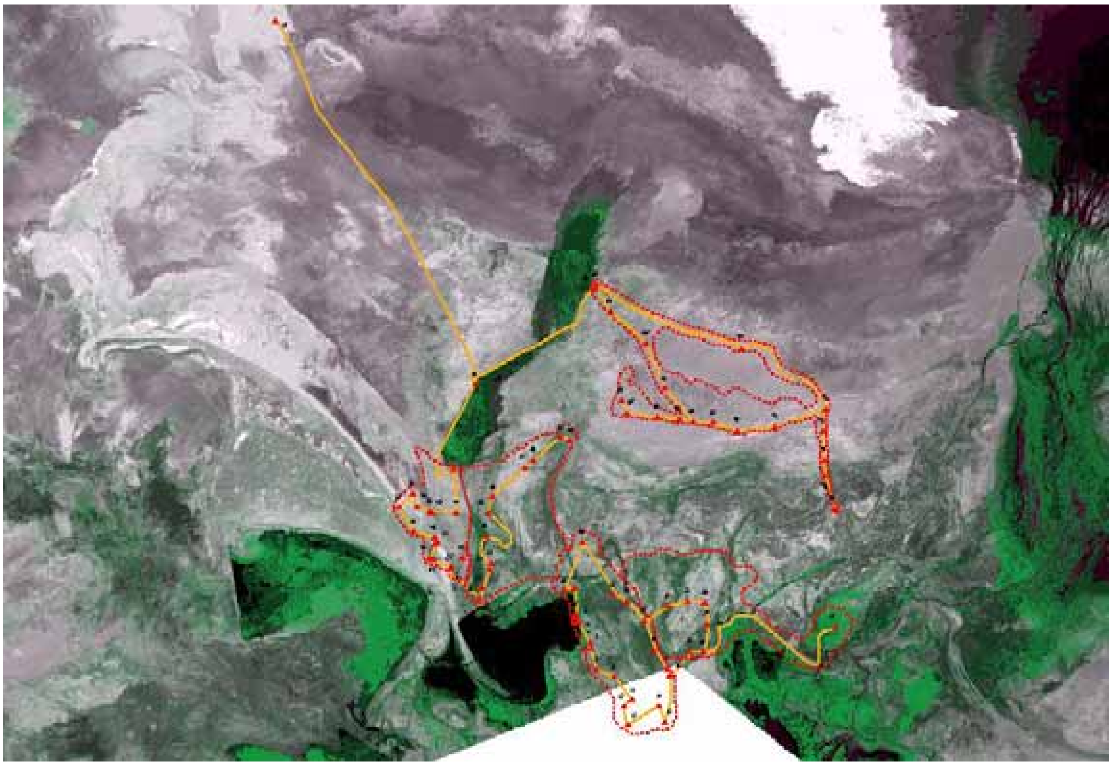


Fig. 16: Route of the third expedition

Third expedition

Due to the vast extent of the study area and its heterogeneous composition, the survey was divided into separate massifs linked to routes (Fig. 16).

The study area was conditionally divided into 6 massifs:
1st massif - territory between Rybachie bay and Inzheneruzyak canal (stop 1 - stop 22)
2nd massif - territory between Inzheneruzyak canal and main channel of Amudarya (stop 23 - stop 31)
3rd massif - territory between Inzheneruzyak canal and Motornaya track (stop 32 - stop 40)
4th massif - territory of the Aral seashore (stop 41 - stop 56)
5th massif - territory of plantations in area of Bakhyt drill site (stop 57 - stop 61)
6th massif - territory between watercourse and delta (northern part of the study area) (stop 62 - stop 78).

The expedition was conducted in September-October 2006.

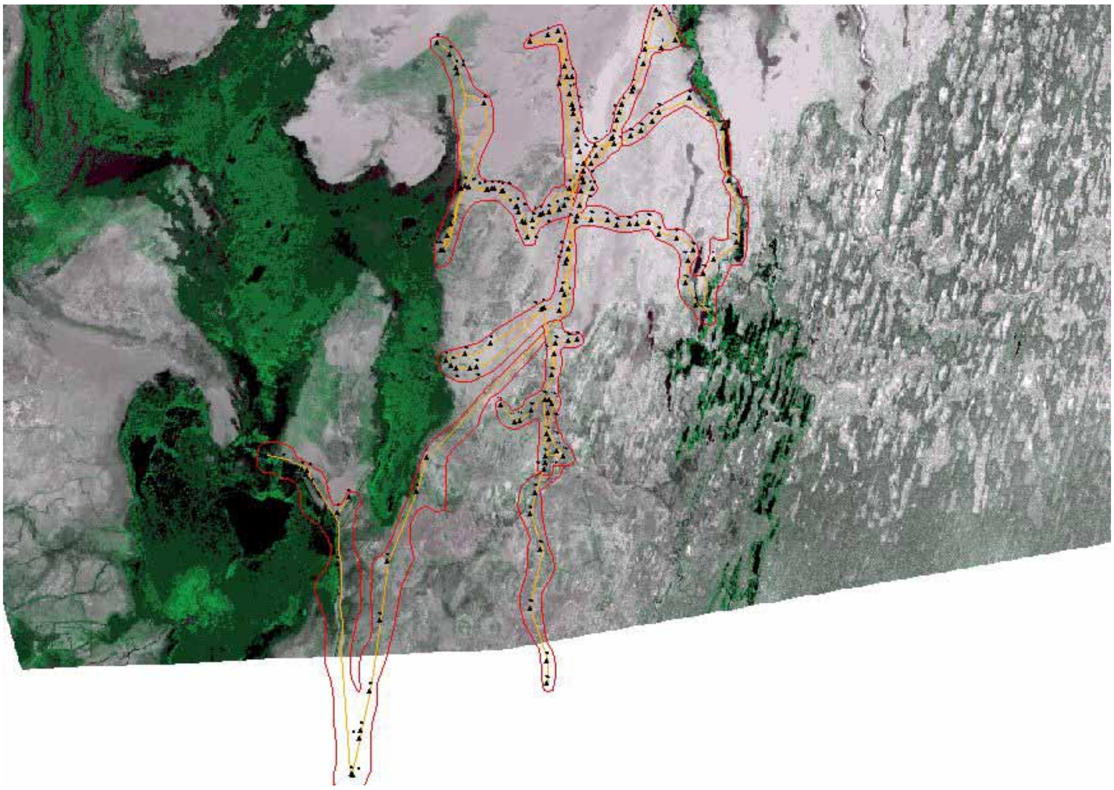


Fig. 17: Route of the fourth expedition

Fourth expedition

Since the study area is large and heterogeneous, it is useful to make its description by separate massifs related to routes (Fig. 17).

Massif 1: (stop 4 - stop 18) from well #2 (of new GTZ camp to water edge).
Massif 2: north-eastward of new GTZ camp to Kokdarya (from 40th to 50th point)
Massif 3: (stop 20-38) (stop 55-68) from new camp towards south-west to Dzhiltyrbas bay.
Massif 4: (stop 103-111) from new GTZ camp to Kokdarya
Massif 5: (118 -130 points) from Rybakov camp (Kokdarya) to Takhtakupyr District Forestry Administration.
Massif 6: from the well of new camp to old GTZ camp (stop 69-84, 130-131).
Massif 7: from Takhtakupyr District Forestry Administration (stop 130 to 158 towards the cultural zone in Karauzyak district) to Karauzyak state farm.
Massif 8: from Chimbay District Forestry Administration to Aral bridge on KS-3 and from the bridge to Kazakhdarya site of the District Forestry Administration.

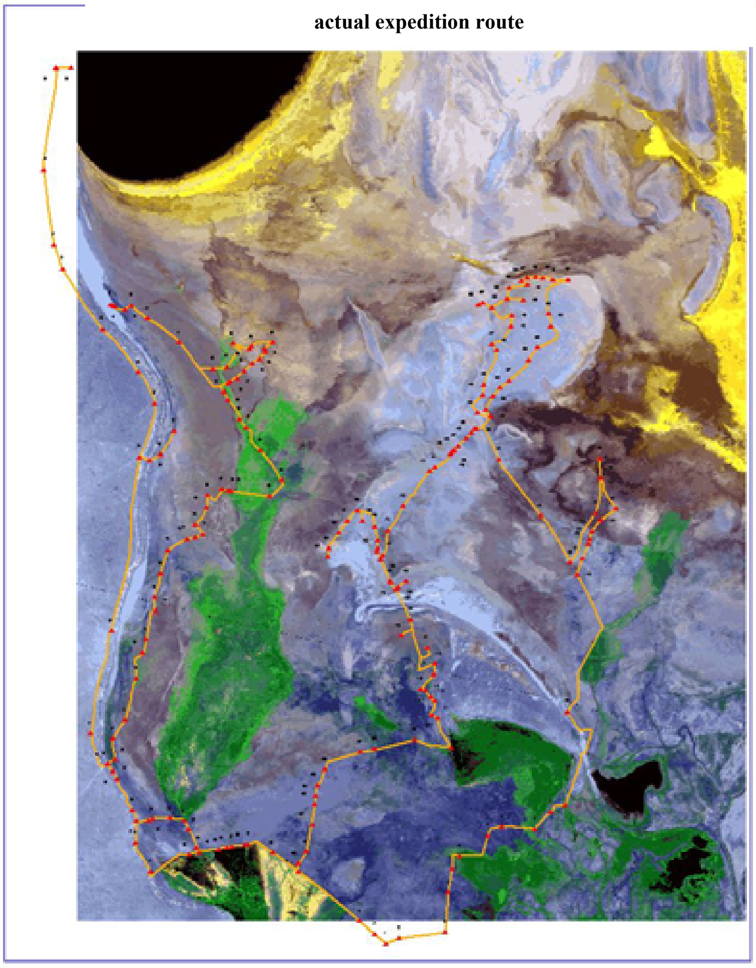


Fig. 18: Route of the fifth expedition

Fifth expedition

Route of the (5th) spring field expedition covered the south-western part of the dried seabed. The duration of the field studies was from 4 May to 25 July 2007. The field studies of the territory were conducted according to earlier planned and approved route, with account of local conditions.

First route - from Muinak town along Ustyurt chink to Western Sea (stop 1 -29)

Second route - from Ustyurt chink to drill tower Kabanbai-2 and from drill tower Kabanbai 1- to stop 49.

Third route - from drill tower Kabanbai 1 to Sudochie lake (stop 50-stop 100)

Fourth route - from Sudochie lake to Muinak bay (stop 101 - stop 118)

Fifth route - from Muinak bay through well Saule to oil-rig Bakyt (stop 119-stop 132)

Sixth route - from oil-rig Bakyt to Lazarevo island (stop 132- stop152)

Seventh route - from Lazarevo island to Muinak town through Tigrovy Khvost, Surgul lake (stop 153- stop 194)

3.2. Remote sensing based land cover mapping

3.2.1. Satellite data and required data preprocessing

The remote sensing data sets used in this study are described in Table 5.

Table 5: Characteristics of the satellite images used in this study

Satellite	Sensor	Acquisition date	Spatial resolution	Spectral properties	Processing level
IRS-1D	LISS-III	23.09.2005	23,5m	4 bands	
Landsat-5	TM		30m	7 bands	1G
SPOT-5	PAN	21.07.2005	2,5m	1 band	2A
SPOT-5	XS	21.07.2005	10m	4 bands	2A
SPOT-5	PAN	05.08.2006	2,5m	1 band	1A
SPOT-5	XS	05.08.2006	10m	4 bands	1A

These datasets were utilized for a different set of applications in this study. The IRS data was used primarily for the preparation and planning of the first two field expeditions in autumn 2005 and spring 2006. Due to problems with the LISS-III sensor aboard the IRS-1D satellite, only the data of the red and NIR band were available. The native green and SWIR bands were missing in the datasets which seriously limited data quality and thereby the value of the data for a reliable land cover classification. This is why the IRS data was not used for further land cover mapping and Landsat-5 TM data was used as a substitute, as soon as it was available in summer/autumn 2006. This dataset showed itself very suitable for an accurate mapping of the desiccated Aral Sea bed, due to it's increased spectral resolution in comparison to the IRS data.

Very high resolution SPOT-5 data was used for high detail mapping of afforestation areas in the eastern part of the study area. The aim was to estimate growth success and several other properties of large scale *Haloxylon aphyllum* ("Black Saxaul") plantations.

Due to differences in the preprocessing level of the datasets, different preprocessing steps had to be applied. The LISS-III and TM data were delivered already in Level-1G format, which means that radiometric and geometric corrections had already been applied by the vendor. Therefore, the only further preprocessing to be done was mosaicking the individual scenes into a single dataset, covering the whole study area. The mosaicking was done by TERRA, Almaty.

The SPOT-5 datasets had to undergo a different preprocessing. The datasets of 2005 was already available at GTZ. The initial preprocessing level was 2A which means radiometric and basic geometric correction. In order to improve spatial accuracy, the data was geometrically corrected by the use of GPS-measured ground control points (GCPs) and a pan-sharpening procedure was applied in order to generate a high-spatial resolution multispectral image out of the input PAN and XS images. Additionally, the datasets underwent atmospheric correction (Navratil 2007).

The 2006 SPOT-5 data was delivered again in a different preprocessing format, level 1A. This means that only sensor-specific radiometric calibration has been applied by the vendor. By the use of a DEM (digital elevation model), the data had to be geometrically orthorectified. This task was done at the German Aerospace Center (DLR) with a special rectification software tool (xDibias ortho). In addition, atmospheric correction was applied and the data was pan-sharpened in order to fit the quality of the 2005 SPOT data.

3.2.2. Unsupervised classification technique

The earth surface consists of numerous elements which absorb and reflect the electromagnetic energy from the sun in different ways i.e. every type of land cover has a unique surface reflectance. The spectral characteristics of a surface show the degree of reflectance of electromagnetic energy in spectral ranges. The reflectance properties of desert and semi-desert landscape elements are formed by joint effects of soil and vegetation. Due to the usually sparse vegetation cover in these areas, it is often difficult to obtain clean vegetation signals or clean soil signals. Image classification methods are based on detection and separation of the individual spectral responses of different land cover types. They can roughly be separated into unsupervised and supervised classification procedures.

In order to explore the satellite images and prepare the field surveys, unsupervised classification was conducted by the use of the ISODATA algorithm. The ISODATA algorithm is a statistical clustering of the image into a predefined number of clusters based on the spectral characteristics of the input bands. (ERDAS IMAGINE 8.4. Tour GUIDES Inc., 1999). The objective of this preliminary classification was to delineate the boundaries of spectrally homogeneous regions, representing homogeneous landscape types in reality.

For the clustering of the IRS images, various quantities of output classes were tested. The results were discussed with the members of the field expeditions - soil scientist and ecologist in order to determine the optimum number of classes. These varied from 12 to 200.

For the preparation of the autumn 2005 and spring 2006 field expedition route maps, the soil scientist determined a quantity of 200 classes as best suitable (Fig. 19). This considerably large number of classes allowed an accurate determination of the boundaries of homogeneous site conditions.

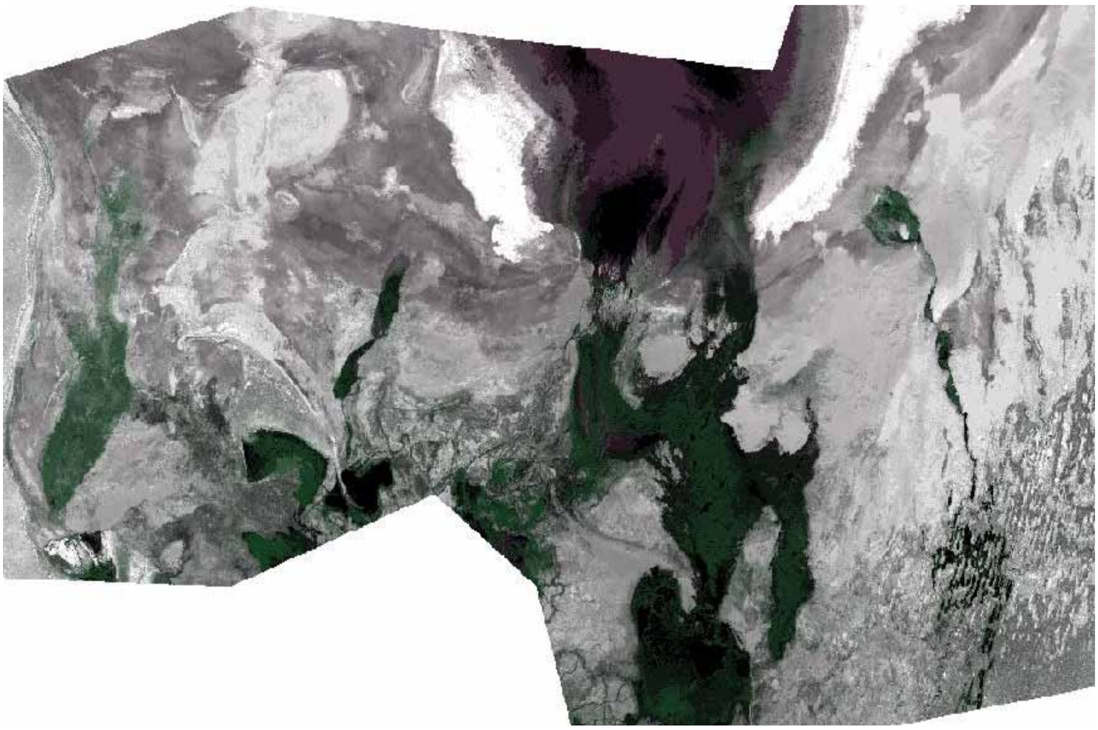


Fig. 19: Results of unsupervised classification (200 classes; prepared for field expedition)

For the second expedition, results of a supervised classification with 40 classes (minimum distance classifier) were used additionally (Fig. 20). This map was used for the detailed description of plant communities in the study area. The following input information was used for the supervised classification:

- Materials of autumn expedition conducted by SIC ICWC
- Maps
- Results of unsupervised classification

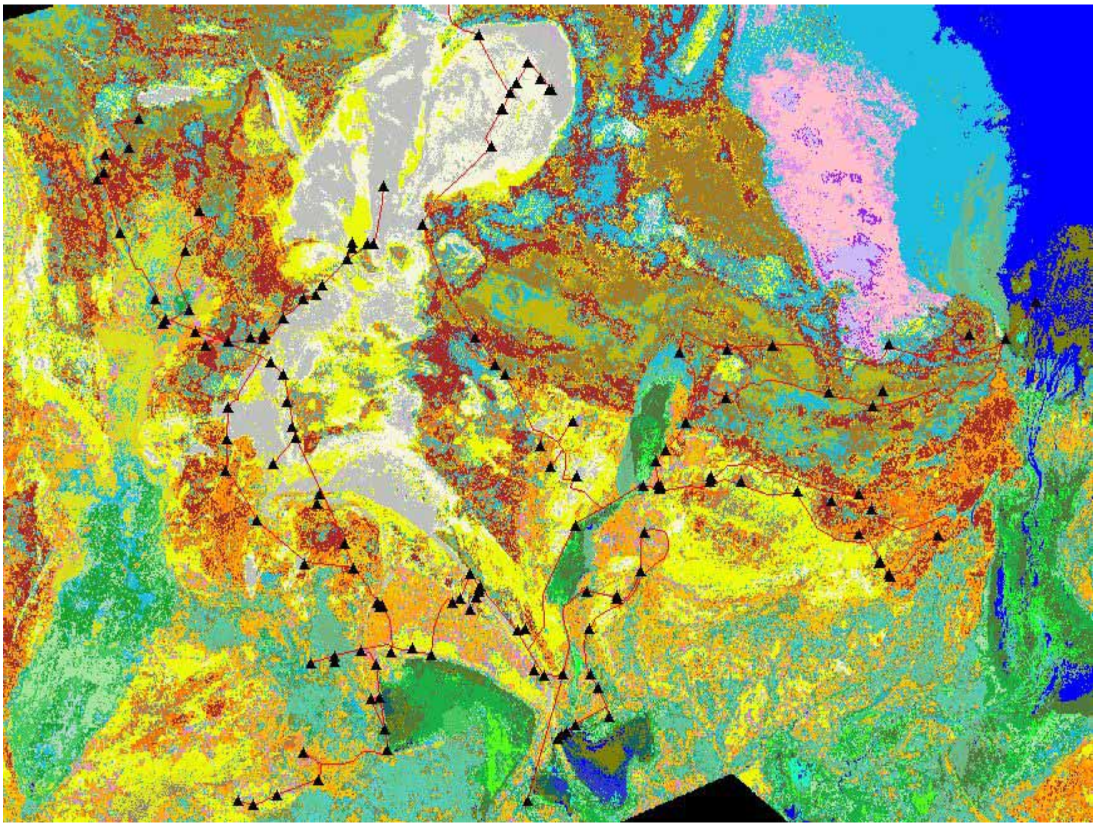


Fig. 20: Results of supervised classification of IRS data and actual route of the spring expedition

For the preparation of the follow up field studies (three expeditions with geobotanical focus), the Landsat images were used. Since the primary objective of the next expeditions was to investigate vegetation features in South Prearalie, a high number of classes was chosen in unsupervised classification, since the vegetation composition of large parts of the study area was unknown. Fig. 21 shows the results of the ISODATA classification of the Landsat data and the recommended expedition route in the western part of southern Prearalie (70 classes).

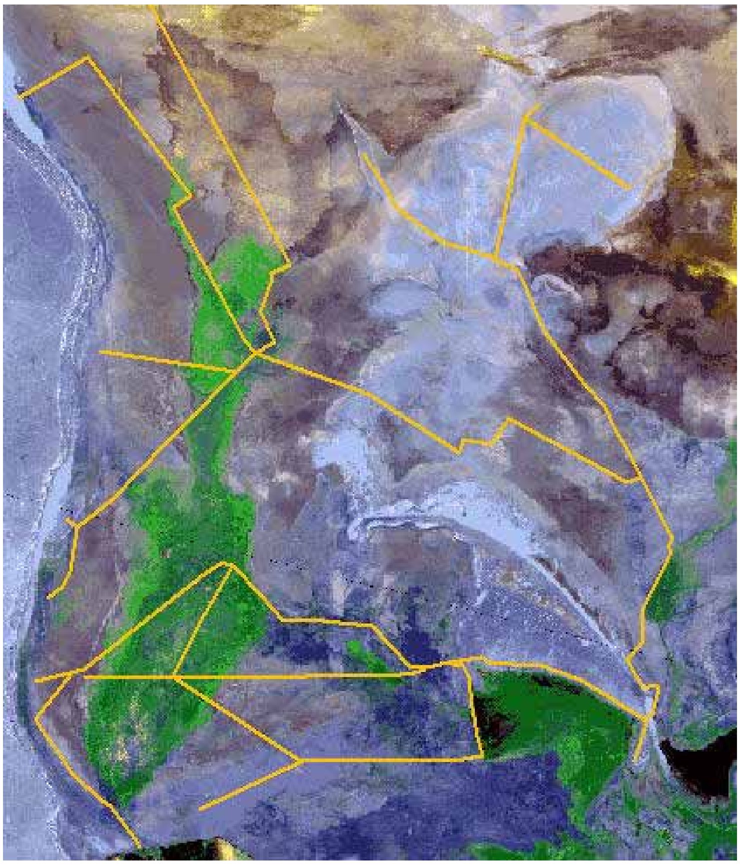


Fig. 21: Recommended expedition route

Proceeding from the previous expeditions, it was concluded that this number of classes was optimal for field observations on the exposed bed of the Aral Sea since changes in soil cover, plant communities and relief could be traced optimally.

3.2.3. Development of the land cover classification scheme

The last preparation step before the actual image classification was the generation of an appropriate classification scheme. This step included the analysis of available map material of the study area. The maps listed below were used as input information for identification of thematic classes:

- Landscape map of 2000 - produced under the NATO Project SFP # 974101 (authors: Ptichnikov A., Novikova N.M., Reyimov P.)
- Map of South Prearalie landscape as of 1990 (SANIIRI, author: Chernishyev A.K.)
- Map of lithological composition of cover (quaternary) deposits on the dried bed of the Aral Sea for 1993-1996 (source: GIDROINGEO Institute)

As a result of the analysis of the thematic maps and field observations, also considering the relationships between major natural components such as relief, soil, and vegetation, the following basic landscape types of natural-territorial systems were selected (as in Novikova's Landscape map and others):

1. Arid-denudation plateaus and isolated hills
2. Plains of deposition

2.1. Landscapes of marine plains

2.1.1. Landscapes of the exposed seabed

2.1.2. Landscape of lacustrine-alluvial plains
2.2. Landscapes of alluvial-delta plains
2.2.1. Emerging delta landscapes on the exposed seabed
2.2.2. Fore-delta (advancement deltas) of 70s-80s
2.2.3. Modern drying alluvial-deltaic plain
3. Holocene delta (former islands, straits and bays of the Akeptkin archipelago).

Furthermore, the results from the field expeditions were analyzed, particularly the landscape descriptions. The analysis of information, map legends and classifications found more than 40 conditions of different landscapes.

1. Arid-denudation plateaus and isolated hills:
- Hilly sands;
- Hilly and hilly-ridgy sand, with vegetation;
- Hilly-ridgy sand in combination with solonchak

2. Plains of deposition:

2.1. Landscapes of marine plains:
- Water surface;
- Shallow water with reed.

2.1.1. Landscapes of the exposed seabed:
- Marsh solonchak;
- Wet-coastal;
- Crust and crust-puffed solonchak, in initial stage of wind transformation;
- Sandy plain with poorly processed relief (solonchak with blown sandy cover);
- Pit-and-mount sandy loam-sandy plain (dunes);
- Hilly-cellular plain;
- Hilly and hilly-ridgy sand;
- Relic landscapes of the seashore (hilly and hilly-ridge, with vegetation);
- Pit-and-mount sandy loam-loamy plain, with long-term or periodical watering (hydromorphic soil subjected to desertification);
- Landscapes of lacustrine plains (meadows on alluvial plains).

2.1.2. Landscape of lacustrine-alluvial plains
- Meadows on alluvial plains;
- hydromorphic soil subjected to desertification, with grass-halophite, herbs and shrubs;
- Gentle-sloping plain, with brakes (halophyte: Tamarisk, Karabarak).

2.2. Landscapes of alluvial-delta plains:

2.2.1. Emerging delta landscapes on the exposed seabed:
- Gentle-sloping plains, with long-term active watercourses (meadow on alluvial plains);
- Hydromorphic soil subjected to desertification, with grass-halophite, herbs and shrubs;
- Hilly sand, with brakes (halophyte: Tamarisk, Karabarak).
- Hilly and hilly-ridge, with brakes;

2.2.2. Fore-delta (advancement deltas) of 70s-80s:
- Gentle-sloping sandy loam-loamy plains;
- Gentle-sloping sandy loam-loamy plains, in combination with solonchak;
- Hilly and hilly-ridgy sand;

- Relic landscapes of the seashore (hilly and hilly-ridge, with vegetation);
- Solonchak with blown sandy cover.

2.2.3. Modern drying alluvial-deltaic plain:

- Gentle-sloping plains, with long-term active watercourses (meadow on alluvial plains);
- hydromorphic soil subjected to desertification, with grass-halophite, herbs and shrubs;
- Crust and crust-puffed solonchak;
- Plain sands;
- Dunes;
- Hilly sand, with shrubs and herbs;
- Hilly and hilly-ridge, with isolated plant specimen;
- Brakes - artificial plantations;
- Hilly and hilly-ridgy sand;
- Relic landscapes of the seashore.

3. Holocene delta (former islands, straits and bays of the Akpetki archipelago):

- Hilly sand, with shrubs and herbs;
- Hilly and hilly-ridge, with isolated plant specimen;
- Brakes - artificial plantations;
- Shor solonchak of closed sinks;
- Solonchak with blown sandy cover.

In order to adjust this multitude of landscape classes to the potentials of the used RS data, experts from GTZ, TERRA and SIC ICWC agreed on the list of the thematic land cover classes listed below. This cutback enables an assessment of the erosion risk degree and track desertification dynamics whilst ensuring a satisfying separability of classes in the satellite image. This classification scheme was finally applied to the Landsat-TM data of 2006.

1. WATER
1.1. Water surface
1.2. Shallow water, sometimes with reed

2. SOLONCHAK
2.1. Marsh soil, without vegetation or with Saltwort community
2.2. Wet-coastal, with cockle-shell, spots of Saltwort and Sarsazan
2.3. Desert crust-puffed and crust soil, without vegetation, spots of bushes (Karabarak, Tamarisk)
2.4. Solonchak with blown sand cover, sparse Orach and Selin communities
2.5. Shor solonchak of closed sinks, without vegetation, sometimes in Sarsazan setting

3. SANDS
3.1. Plain (with shell rock), without vegetation or sparse bushes (Saxaul, Tamarisk)
3.2. Dune, without vegetation
3.3. Pit-and-mount (poor fixed) with sparse wormwood, bush communities and Selin plantings.
3.4. Hilly, hilly-ridge, without vegetation and poor fixed.
3.5. Hilly, hilly-ridge, poor-fixed with ephemeral-wormwood-bush communities.

4. PLAINS DELTAIC AND OF DEPOSITION
4.1. Meadow on alluvial plains (reedy, forb-Gramineae) on alluvial-meadow, bog-meadow and meadow-bog soils.
4.2. Subjected to desertification, hydromorphic Gramineae -halophyte-forb, with bushes.

4.3. Shrubs (halophyte: Tamarisk Karabarak).
4.4. Subjected to desertification, shrub.
4.5. Shrub-Saxaul (desert forest/artificial plantations).

The reduction to 17 classes was performed by a grouping of spectrally similar items. For example, the class “hilly and hilly-ridge sands”, which is present practically in all landscapes of the exposed Aral Sea bed, was initially represented by the seven different subclasses shown in Fig. 22. Due to the very high similarity of the spectra, these seven subclasses could easily be combined into a single class. The spectral profiles were determined on the basis of field observations.

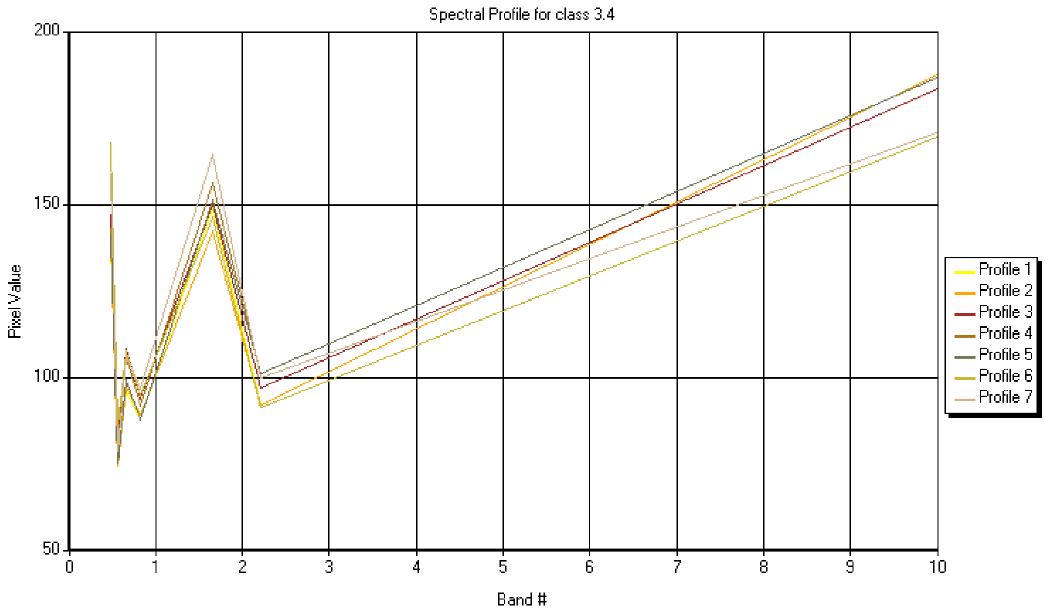


Fig. 22: Spectral characteristics for class 3.4 for the whole work site

Legend:

- Profile 1. - Hilly and hilly-ridgy sand on arid-denudation plateaus;
- Profile 2. - Hilly and hilly-ridgy sand on landscapes of the dried seabed;
- Profile 3. - Hilly and hilly-ridgy sand on landscapes of lacustrine-alluvial plains;
- Profile 4. - Hilly and hilly-ridgy sand on fore-delta - advancement delta of 70s-80s;
- Profile 5. - Hilly and hilly-ridgy sand on modern drying alluvial-deltaic plain;
- Profile 6.7. - Hilly and hilly-ridgy sand on Holocene delta - former islands, straits and bays of the Akeptki archipelago.

The described procedure was applied in the same way to all the other classes, leading to a semantically meaningful classification scheme with spectrally homogeneous and separable classes.

3.2.4. Supervised classification technique

While unsupervised classification divides the input data into a user-defined number of clusters, which are assigned (or labeled) by the interpreter to the respective class afterwards, supervised classification procedures directly separate the image into the target classes by the use of predefined reference data (samples or training areas). Based on the spectral characteristics of the reference samples, each pixel of the image is assigned to the class of the most similar samples. There are numerous algorithms to accomplish this task, like *Minimum Distance to means*, *Mahalanobis Distance* or *Maximium Likelihood*, to mention only a few. The mechanism of class assignment of these procedures can be looked up in standard remote sensing literature (Lillesand and Kiefer 1994, Richards 1998).

For the supervised classification, training samples for all above-mentioned classes were collected in the Landsat image. For each class, the histograms of the training samples were analyzed in order to reach a normally distributed set of samples. The closer the histogram is to normal distribution, the better the training set described the target class. While collecting the training sites (signatures) on the image, all samples were checked for their suitability for separating the classes. Fig. 23 shows examples of the histograms of the reference samples for some selected classes.

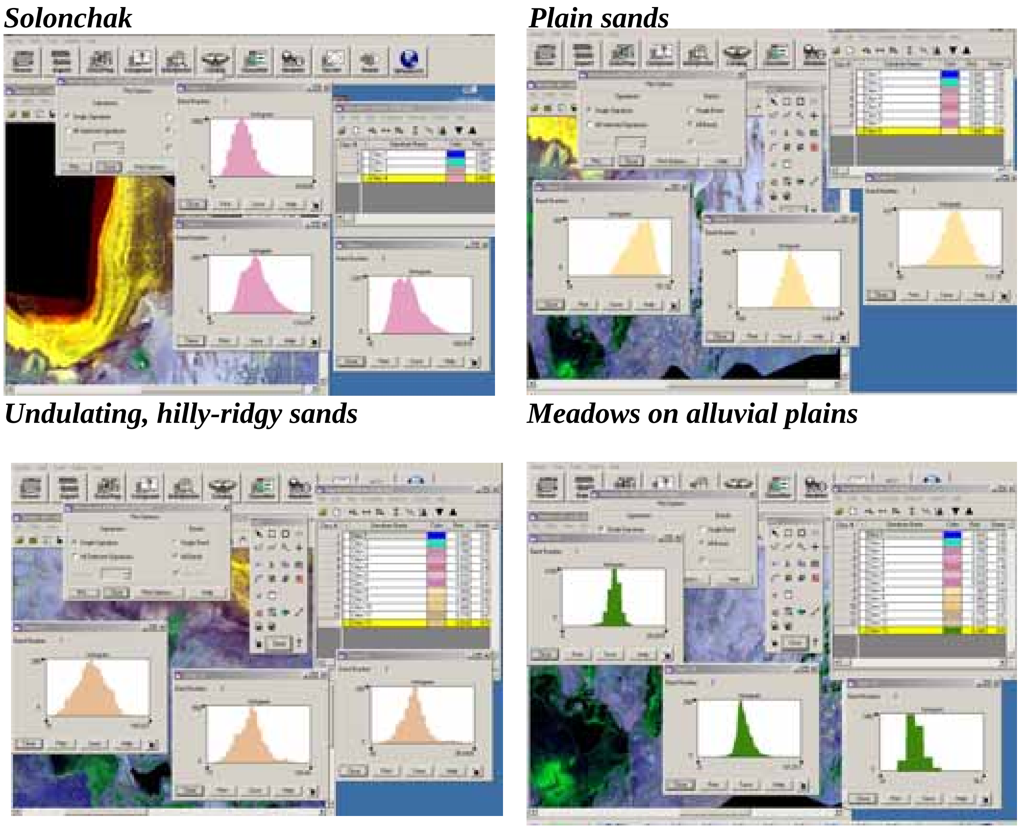


Fig. 23: Histograms of the reference data for the classes „Solonchak", "Plain sands", "Undulating, hilly-ridge sands" and "Meadows on alluvial plains"

The analysis of the spectral profiles of the individual classes revealed their unique reflectance characteristics. Field data was used for the selection of reference sites in the images, while the quality of the selected reference sites was estimated on the basis of spectral profiles. The next paragraphs show the spectral signatures of selected land cover types as well as a short interpretation.

Water is characterized by the highest reflectance in the blue band, strongly dropping towards zero in the infrared bands (

Fig. 24). The highest values in visible spectrum are observed on the surface of the Aral Sea (shallow areas in the eastern part). Since the classes "drying bays" and "Aral Sea" have very similar spectral properties, they were merged for supervised classification. A separate treatment of those two classes would be advisable for the analysis of wetland change dynamics, but is not necessary in the context of this study.

Legend for data shown in the Figure 24:
1.1. Drying bays
1.2. Aral Sea
1.3. Reservoirs and rivers with freshwater

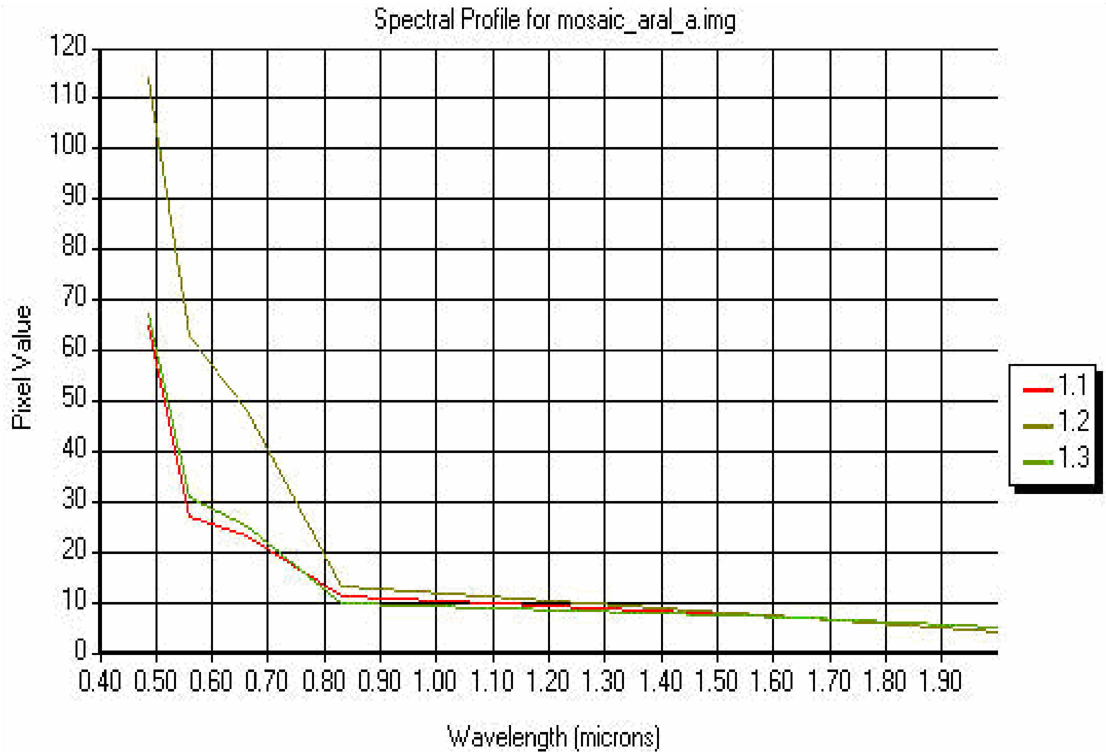


Fig. 24: Spectral profiles of water surface (Landsat data)

After the comparison of the signatures, only two classes were retained due to the high degree of similarity of Classes 1.1 (Drying bays) and 1.3 (Reservoirs and rivers).

Solonchaks (Salt soils) vary greatly in their reflectance values but are characterized by the following commonalities: high reflectance in the visible spectrum, and relatively low brightness in infrared spectrum (

Fig. 25):

Legend:
2.1. Marsh solonchak
2.2. Salt marsh-coastal solonchak
2.3. Crust-puffed and crust solonchak
2.4. Solonchak with blown sandy cover
2.5. Shor solonchak of closed sinks

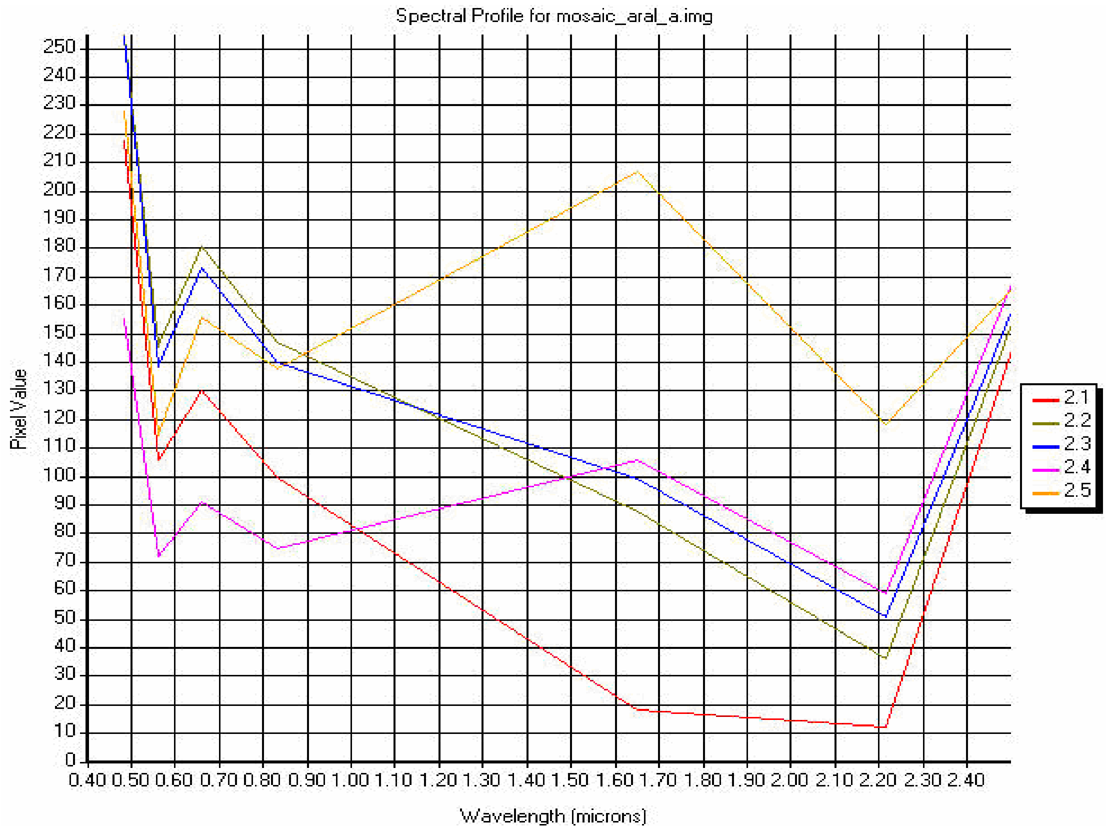


Fig. 25: Spectral profiles of solonchaks (Landsat data)

Sands are characterized by quite great differences in reflectance, which is determined by their mineral composition and physical properties. They have the lowest reflectance in the visible spectrum and the highest one in infrared spectrum.

Fig. 26 illustrates spectral profiles for various sand types.

Legend:
3.1. Plain sand (with shell rock)
3.2. Dune sand, without vegetation
3.3. Pit-and-mount sand (poor fixed)
3.4. Hilly and hilly-ridgy, poor fixed sands, without vegetation.
3.5. Hilly, hilly-ridgy fixed sands

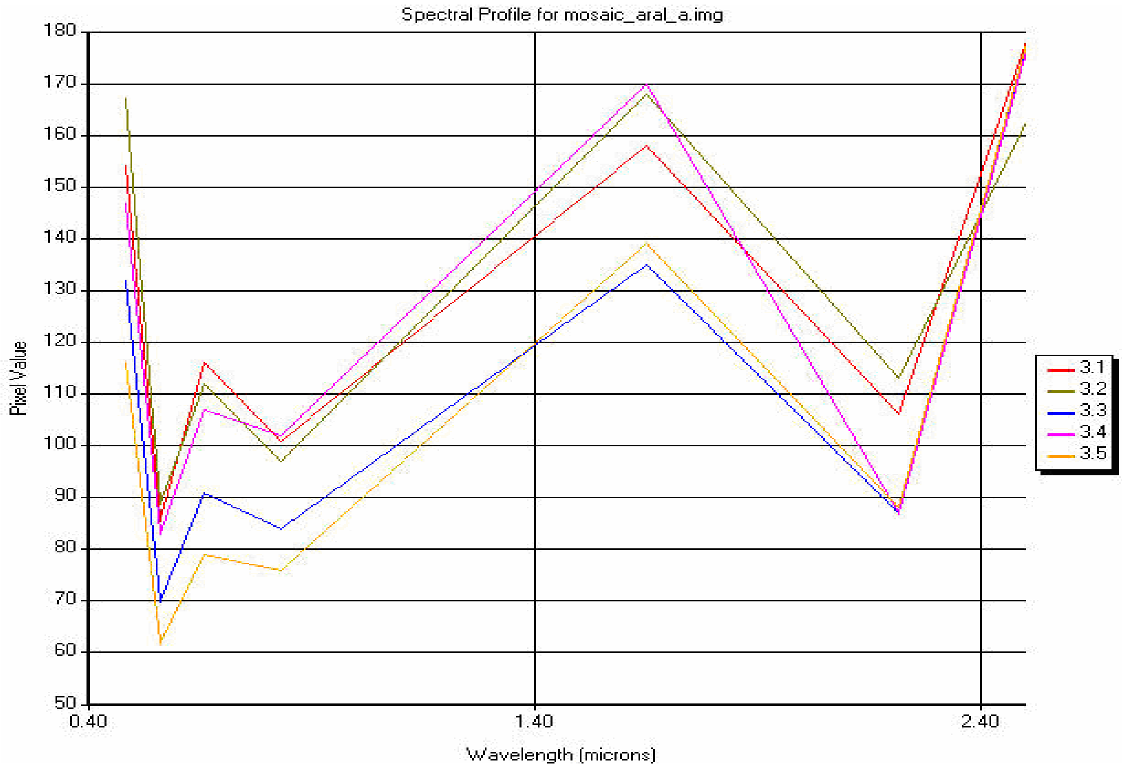


Fig. 26: Spectral profiles of sands (Landsat data)

Delta and deposition plains. Reed beds (*Phragmites australis*) feature a typical vegetation signal with a high reflection in the green and near-infrared bands and absorption in the red band. Shrubby-Haloxylon associations have higher reflectance in visible and infrared spectrums, since they are characterized by a mixed signal of the underlying soil and the vegetation due to relatively low surface cover. Therefore, the intensity of the red-absorption diminishes.

Fig. 27 illustrates spectral profiles for deltaic plains.

Legend:

4.1. Meadows on alluvial plains (reed, herb, cereals on alluvial-meadow, swampy meadow and meadow-bog soils)
4.2. Hydromorphic soil subjected to desertification
4.3. Shrubs (halophytic vegetation: tamarix, karabarak)
4.4. Shrubs subjected to desertification
4.5. Shrubby-haloxylon

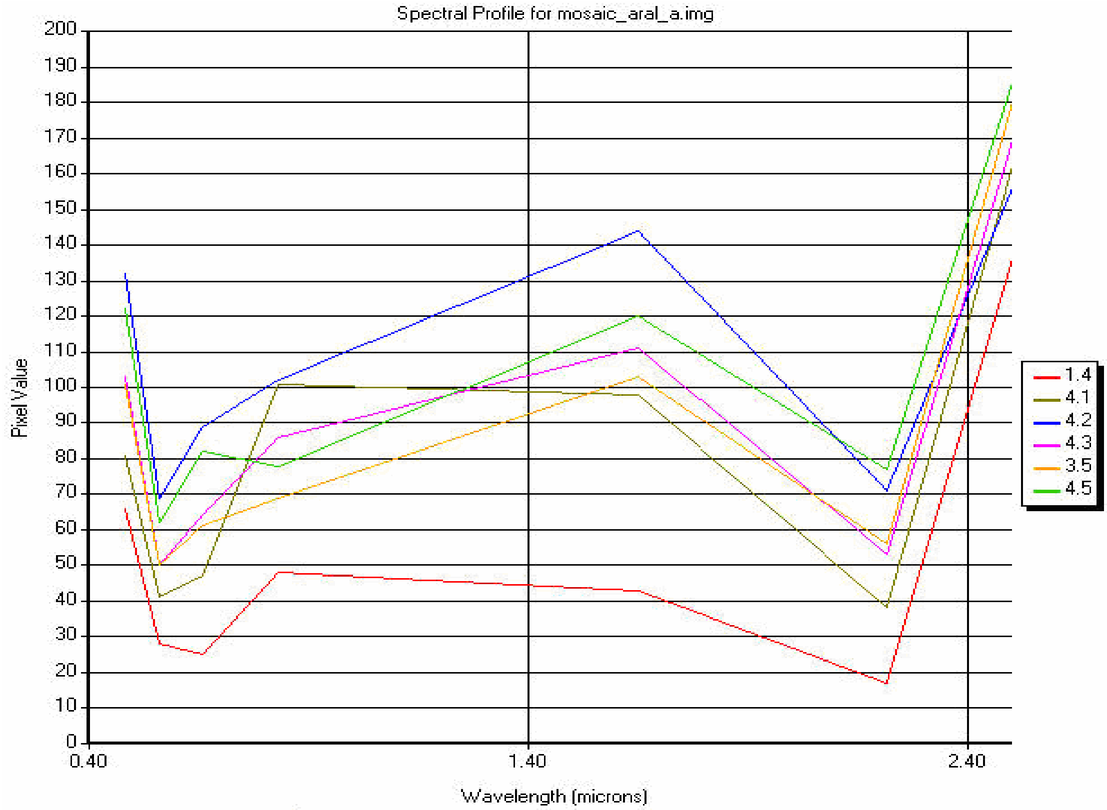


Fig. 27: Spectral profiles of deltaic plains (Landsat data)

Several image classification techniques were tested on the created training dataset. Finally, the *Minimum distance to means* classifier (Lillesand and Kiefer 1994, p.590f) was selected as the most suitable, because it yielded the highest classification accuracy under the given circumstances of this study. The results are presented in chapter 0.

3.2.5. Erosion risk assignment to the land cover classes

A further objective of this study was the assessment of the ecological risk degree of the landscape types on the desiccated Aral Sea bed, in the means of desertification and soil erosion risk. At a workshop in Tashkent 2006, local and international specialists agreed on the assignment of 4 risk levels to the classes resulting from the land cover mapping. These "risk levels" inversively coincide with the degree of landscape stability, i.e. level 1 being safe/stable up to level 4 showing maximum area instability and high ecological hazard. Each of the land cover class was assigned to one of the four hazard levels shown in Table 6, and explained below. During the assignment of the ecological hazard degree, the future development of the land cover classes by exogenic processes was also taken into consideration.

Table 6: Rating scale of ecological hazard for classification results

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

1. <u>No risk (practically absent), given to the following classes:</u>

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

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

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

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

2. <u>Low ecological risk:</u>

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

The existence of the classes assigned to risk level 2 depends on water supply to the delta, i.e. on available river runoff during a year. When the water surface area decreases considerably in low water years, lake beds are being exposed, reed stands (*Phragmites australis*) dry out and may subsequently be subjected to fire. This puts both land cover classes into a potential risk class, but only during drought periods.

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

3. Moderate ecological hazard.

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

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

4. High ecological hazard.

- 2.4 Solonchaks with blown sandy cover and sparse communities of Orach and Selin;
- 3.1 Plain sands (with shell) without vegetation or with sparse shrubs (Saxaul, Tamarisk);
- 3.2 Dune sands without vegetation;
- 3.3 Pit-and-mound sands (poorly fixed) with sparse communities of wormwood, shrubs and Selin plantings.

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

After the assignment of the risk levels to the land cover classes, the land cover dataset was recoded in ERDAS Imagine image processing environment into the risk values. This enables the calculation of the spatial extent of the different risk classes. The results will be presented in Chapter 0.

3.3. Satellite based assessment of afforestation measures

The GTZ-Project "Stabilization of the desiccated Aral Sea bottom" was established in 2000. The project objectives are the improvement of the existing afforestation techniques in Uzbekistan and Kazakhstan by the large scale use of machinery and new planting techniques. Thereby, it should be shown that an afforestation of the desiccated Aral Sea bed is feasible on a large scale. Since there has been a lack of information on the afforested areas for a long time, remote sensing techniques were used in 2006/2007 to gain certain necessary information on the areas afforested and the general features of these afforestations.

Very high resolution satellite data was used for an accurate mapping of the land surface within a short time and with comparably little cost efforts, considering a similar survey with only field based methods.

The project area was assigned to GTZ in 2000, situated north-east of the Dzhiltyrbas wetland, between the collectors KS-3 and Kok-Darya (see Fig. 28).

As the afforestation areas as well as the planted trees (mainly "Black Saxaul", *Haloxylon aphyllum)* on the desiccated Aral Sea bed have only a small spatial extent, satellite images with a very high spatial resolution are required.

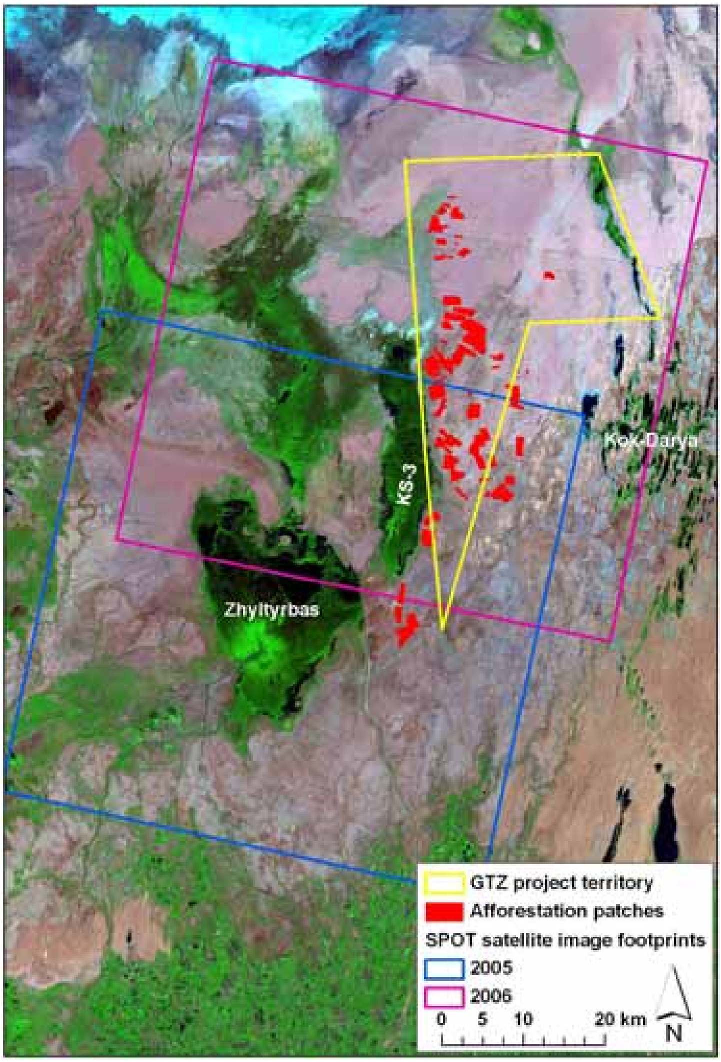


Fig. 28: GTZ project territory and afforestation patches

These afforestations consist of individual patches, with the trees planted in lines. The spacing between the trees is approximately 1.5-2 m, with a spacing of approximately 10m between the lines. Fig. 29 illustrates a typical example. In this study, data from the French SPOT-5 satellite (Systeme pour l'observation de la terre) were being used, with the characteristics described in chapter 0.

Fig. 29: Saxaul afforestation as seen from the ground, from the air and in the satellite image

The principal objective of this survey was an inventorization of the planted and natural vegetation in the study area. This was achieved by a visual interpretation of the satellite image and GIS techniques.

After the pre-processing (atmospheric correction, geometric correction, pan-sharpening), the SPOT data was visually interpreted. The first step was the establishment of a GIS database which contains the acquired information. Table 7 shows the created datasets and their attributes:

Table 7: Attributes of the GIS-layers for the inventorization study

Name	Content	Type	Attributes
plant_area	Afforestation patches	Polygon	center coordinates [UTM], area [ha], plantation line length [m] total, plantation line length [m] succesfull, plantation line length [m] not successful, planting direction mean [°], planting direction std_dev [°], natural shrubs [count, count/ha]
plant_line	Afforestation lines	Polyline	Length [m], growth [successful/not succesful], planting direction [°]
Natural_shrubs	Natural shrubs	Point	
plant_shelter	Area sheltered by vegetation	Polygon	area [ha], buffer size [m]

These datasets were created by on-screen digitizing of the satellite scenes. First, all afforestation patches were demarcated, which can only be done by visual analysis. All in all, 70 patches could be identified, covering a total area of 9188 hectares. These patches are not aligned to the exact extent of the visible planting lines as the assumption is that patches were originally planned in a more or less rectangular shape.

The plantation lines were considered as one afforestation patch if the criteria direction, spacing and planting pattern were homogeneous. The planting lines were digitized and attributed with planting success.

The natural shrubs were captured in a point dataset, with no additional attributes. The criteria for an object to be considered as a naturally grown shrub were the size and spectral value of the object differing from those of the planting lines or a location outside the typical planting line pattern. This survey was, by now, only conducted for the coverage of the 2005 SPOT scene.

After all afforestations were digitized and quality checked for errors of omission and commission, a statistical analysis was applied to the planting line dataset.

Line segment length was captured and statistics for successful and unsuccessful line segments were calculated (sum, mean, standard deviation of segment length). Planting direction was measured and the arithmetic mean and standard deviation were calculated for each afforestation patch. Additionally, a growth success rate was calculated by

[length of successful line segments]/[total line length]

The results will be presented in chapter 0.

4. RESULTS

4.1. Summary of the field data collected

The main objectives of the 5 expeditions differed in some aspects. **The 1st and 2nd expeditions** aimed to collect data on actual status of the dried bed of the Aral Sea, mainly for the collection of ground truth data for the classification of satellite images. The investigation consisted in studying hydro-geological, soil, botanical conditions in the study area and assessing the environmental situation. **During the 3rd and 4th expeditions,** assessments of the afforestation areas (tree and shrub plantations) in the deltaic part and on the dried seabed were conducted. **The 5th expedition** was organized in order to refine the field data and collect additional information on afforestation measures as well as data required for image processing. This chapter serves as a brief summary of the data collected, followed by a detailed presentation of the results of this study.

1st expedition - description of 45 geolocated points.

25 soil sections were cut on typical soil covers, a morphological soil description was made, soil samples were taken from genetic horizons for the analysis of soil texture, soil salinity and organic matter content. Geobotanical investigations included the description of plant formations, species composition, and projective cover. Furthermore, the hydro-geological situation was described.

2nd expedition - description of 157 geolocated points (including 31 soil sections), similar to the 1st expedition. Additionally, the expedition was video- and photo-documented.

3rd expedition – description of 78 geolocated points, 17 soil sections and 23 testing sites of artificial afforestations, distributed over 6 massifs (landscape units). Geobotanical surveys were conducted as described above. The indicator of mean coverage density of the studied sites was added, because artificial afforestations were accompanied by natural succession everywhere. The hydro-geological situation was described as well.

The exposed seabed and delta were studied on an area of 30,400 ha, of which, according to our estimates, 20996 ha is covered with vegetation.

4th expedition – description of 158 geolocated points, 34 soil sections and 30 testing sites of artificial afforestations, distributed over 8 massifs. Soil, geobotanical and hydro-geological surveys were conducted as described above. Additionally, 50 soil sections and small trenches were cut in the testing sites of the afforestations.

The territory of the exposed seabed (at Dzhiltyrbas) and delta was studied on an area of about 50,000 ha, of which, according to our estimates, 37,200 ha is covered with vegetation.

5th expedition - description of 194 geolocated points, 27 soil sections and 12 testing sites of artificial afforestations. Soil and geobotanical survey as described above.

Soil cover of the studied territory

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

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

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

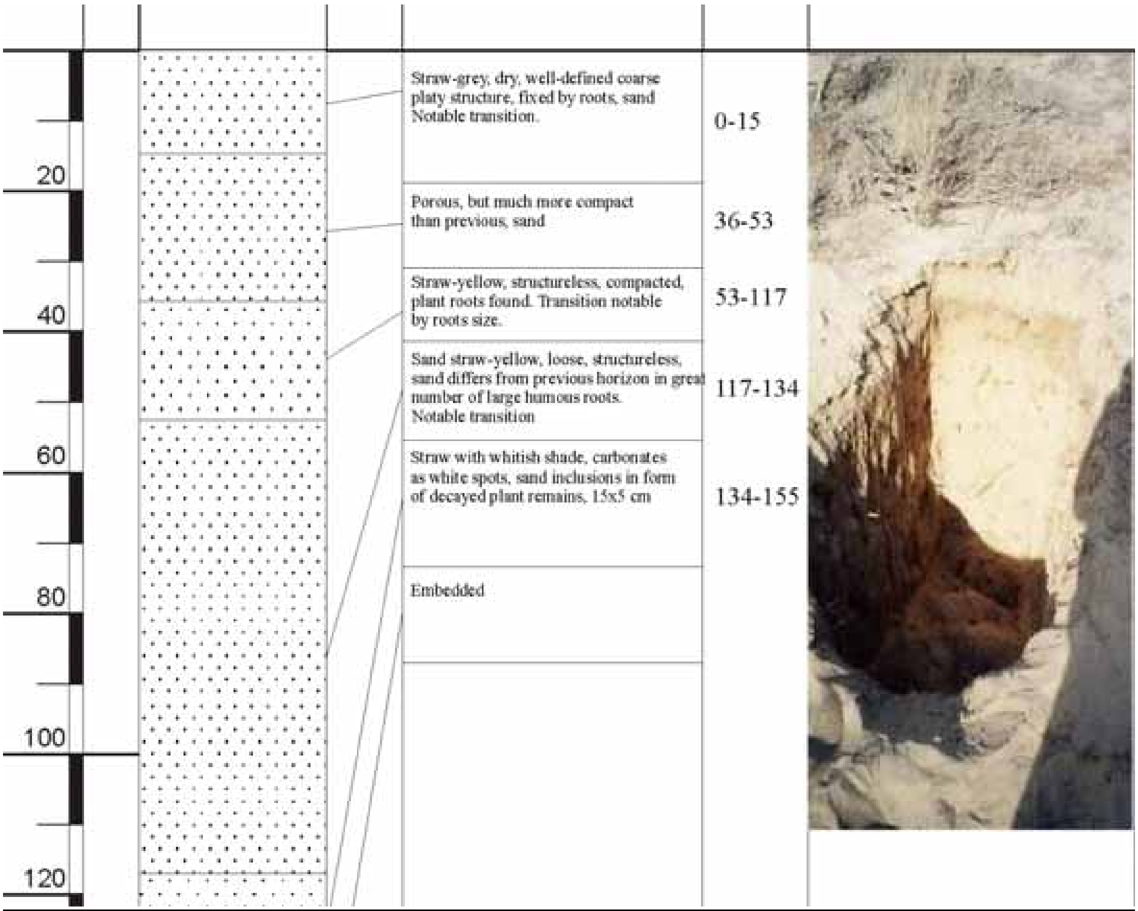
4.1.1.1. Soil cover in the eastern part of the dried bed of the Aral Sea

The eastern part of the dried seabed is occupied by the vast Akpetki massif, which is a former island system, characterized by considerable elevation shifts. The complicated relief of the seabed within the island system caused a long-term drying process, stage-by-stage appearance of its different elements from under water that created the preconditions for the formation of a heterogeneous soil cover. Old sand deposits, i.e. former islands reaching 10-15 m in height, are covered by Saxaul and desert sedge (31). Large sources of aeolian soil deflation are rare nowadays, in contrast to the situation in 1990. Unfixed deflated sands can be considered as absent at all in this area. Desert-sandy island soils covered by sand can be found in some places formed on slopes (Fig. 30).

Fig. 30: Combination of islands and drying lakes in Akpetki

Section 2 was cut into a hill slope, the profile constitutes desert-sandy soils overlain by fixed sands.

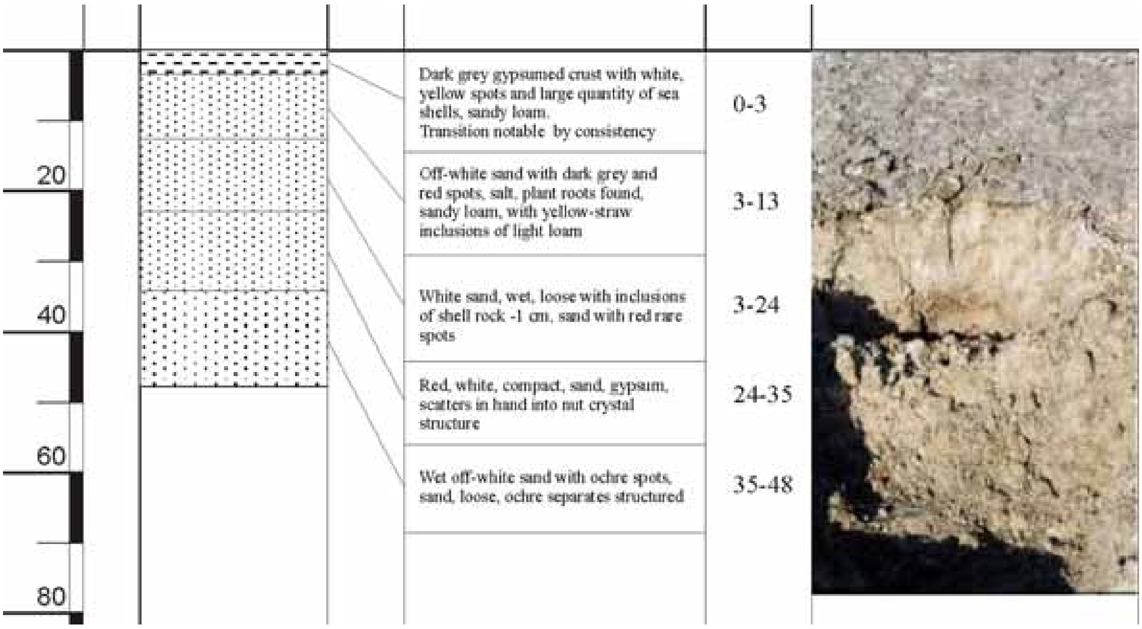
Description of section 2 (102)



Groundwater table (GWT) >10m

The upper part of the profile is sandy non-saline; medium and high salinity is only observed in a depth lower than 120 cm. In the Akpetki massif, there are a lot of large channel-shaped and inland depressions, in which small lakes were located. Vast depressions around such lakes are characterized by specific hydro-geological conditions, under which tense solonchak-formation processes take place. At present, practically all lakes have dried up, and solonchaks have been formed in their place. Hydromorphic and, in periphery of depressions, semi-hydromorphic solonchaks dominate. The salinity type is chloride. Section 4 (104)- hydromorphic solonchak (GWT 0.5m) in the center of deep depression, and section 3 (103)- semi-hydromorphic solonchak (GWT 0.9m) at a distance of 70 cm from the center of the shor (depression) to periphery are representative for this soil type.

Description of section 4



The soil texture is sandy down to the groundwater table. The interesting peculiarity of young solonchaks is the availability of a large quantity of organic substance not apparent morphologically, being in bound state with salts, constituting coarse humus, as semi-decayed organic matter remains. High evaporation and upward capillary fluxes cause salt accumulation in the upper part of the profile. Dissolved solids account for 7-12%, EC 28-35 dS/m. The gypsum content reaches 75% in the whole profile. The bottom of some hollows is of columnar-residual nature due to weathering of gypsiferous soils.

The soil cover below an altitude of 53m a.s.l. (1960 sea level) to Togyzarkan flow path comprises a set of solonchaks and desert-sandy soils, mostly overlain by sand from the surface. The solonchak complex consists of brine and mainly crust solonchaks. Puffed solonchaks are rarely found in less deep hollows of former lakes, but are frequent at the periphery of solonchak channel depressions. The relief forms are typical for the territory along Togyzarkan flow path and northward, where depressions are gentler in general. Desert-sandy soils in plains are more saline than their analogues on ridgy-hilly sands. Overall, the territory is characterized by self-overgrowing vegetation which leads to poor deflation. Water surfaces were observed around self-discharging wells. Along Togyzarkan flow path, a vast massif of solonchaks on alluvial deposits, section 1(101), was formed. The upper 15 cm consist of fixed sand with a large quantity of sea shells with medium salinity (EC 2 dS/m). Down to 30 cm the texture is medium loam of blue-gray color with very highly salinity (EC 17 dS/m). Below, ochre heavy loam with a very highly salinity (EC 14 dS/m) was found. Towards the periphery of the territory, crust solonchaks give place to puffed solonchaks. Surface water is observed in the flow path. This complex of solonchaks with its different degrees of hydromorphy is considered as a source of salt-dust transport if they dry up, and therefore needs to be fixed by anti-deflation measures.

After crossing Togyzarkan flow path towards north and north-east, hills overgrown with Saxaul are covered by semi-fixed sands. The territory features a set of depressions and hills in various proportions. Even though the depressions are of plain nature, they are large shors. The soil cover pattern of these shors is unique (Fig. 31). Excessively hydromorphic solonchaks, found in the center of the shors (section 5(105), GWT 0.3 m)) are succeeded first by hydromorphic (section 6 (106). GWT 0.7 m) and then semi-automorphic and automorphic ones towards the periphery (section 7 (107), GWT 1.8 m).

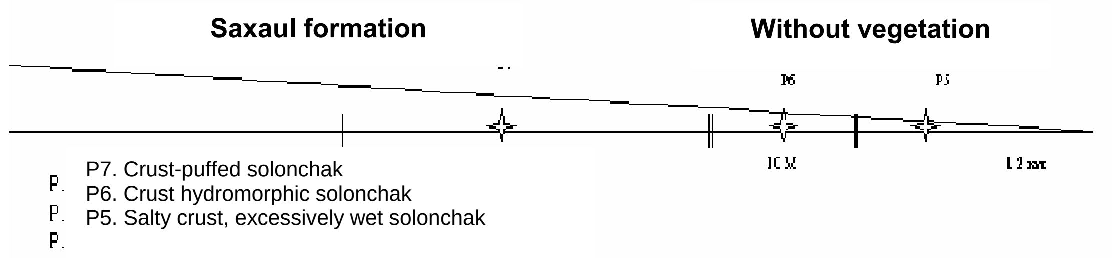


Fig. 31: Solonchak overgrowing pattern

Automorphic crust and puffed solonchaks are overgrown by Saxaul, semi-hydromorphic and hydromorphic ones with Saltwort. The salty crust in the very central part of the shor is not covered by vegetation; its basic color is white, but more frequently it appears dark gray or dirty yellow, as it is overlain by sand or silt particles which are kitted into the salt structure. From a depth of 30 cm downwards, the clay has a smell of hydrogen sulfide. The salinity in the upper horizons amounts to 15-45 dS/m.

Fig. 32: Typical process of shor overgrowing and transformation

Section 6 features a sandy profile with a salty expanded crust in the upper part. Salinity is 39 and 26 dS/m in the layers 0-10 cm and 10-30 cm, respectively. The location of salty horizons in the middle and lower parts of the profile is characteristic for automorphic solonchaks. In section 7, a maximum salt content of 17-29 dS/m is observed at a depth of 12-44 cm. The shift of the salty horizon is related to salt wash-out through precipitation. The lower salt horizon (EC 15 dS/m) is fed by saline groundwater. Section 9(109) is located at the border with deflated sands, described in section 8(108). Morphologically, section 9 can be attributed to desert-sandy soils. The vegetation cover consists of Saxaul and ephemers; the soil surface is covered by mosses. The soil profile is saline along the entire depth: the upper 30 cm are medium to highly saline (EC 1-3 dS/m), which indicates that the soil formation processes (transformation, translocation) have only recently started. Due to the large quantity of plant residue, the soil is enriched with humus (1.5-1.8%) from a depth of 50 cm. Deposited sands (section 8 (108)) form hillocks around vegetation patches.

Another complex of solonchaks and desert sands bordering with unfixed sands is described by sections 15 (115) and 16 (116). Puffed sandy solonchak, very highly saline (EC 5-20 dS/m) along the entire profile, except for the upper crust of 2 cm is found at section 16 (116). The site is located around large shor. The soil surface is not overgrown yet. This and the undefined horizons indicate that soil transformation processes have just started. The semi-fixed sands at section 15 (115) are slightly saline (EC 0.6 dS/m), with a thickness of 30 cm. They overlie solonchak horizons, with medium salinity (EC 0.8 dS/m). The crust on the surface is unstable and destroyed by abrading sand grains transported by strong wind.

The territory to the west and east from Serali tract to Boz-Uzyak tract and to the north features a landscape combined of solonchak depressions and small hillocks. The hillocks are covered by fixed sands and desert-sandy soils (section 13 (113)) not requiring artificial fixation. Section 13 (113) was cut in the center of a slope: the texture is sandy, non-saline in the entire profile (EC 0.2-0.5 dS/m) and enriched with humus by 1.37%. Vegetation cover includes Saxaul, ephemers and mosses. The samples taken from the upper horizon along the slope to the border with solonchaks are non-saline. The territory is relatively well accessible, in contrast to the landscapes of deep hollows with solonchaks (section 17 (117)) and high hills, where the solonchak area is smaller and self-overgrowing appears to be more intensive. The belt of deflated sands and dunes northward of E 60°54’ and N 44°14’ until the bordering marsh coastal solonchaks needs to be fixed by afforestation measured, since it is a territory of intensive erosion (Fig. 33).

Fig. 33: Loose and poorly fixed sands

The territory east and north from Boz-Uzyak tract is described by the following representative points: section 11(111) of desert-sandy soil with Saxaul-Wormwood vegetation formation, section 12 (112) of hydromorphic solonchak with reed vegetation, and section 14 (114) of desert-sandy soil with wormwood formation. The desert-sandy soil of section 11(111) is slightly saline in the upper part of the profile with EC 0.6 dS/m down to 70 cm. Humus content is 0.5-0.7%. The horizons below that are medium and highly saline (EC 1.4 5 dS/m), which is a typical pattern of salt distribution in the profile of desert-sandy soils (section 2 (102)). The profile of section 14 (114) has a distinct feature among all described soils. It is non-saline soil of EC 0.1-0.5 dS/m in the upper layer, and has a very compacted cemented horizon from the depth of 30 cm.

The solonchak described in section 12(112) has a very high salinity with an EC up to 43 dS/m and an increased organic content of up to 3% organic remains in the salt crust. This part of the territory up to the belt of semi-fixed sands in the north is not critical from the perspective of aeolian erosion.

The territory along the Kokdarya river channel needs afforestation (especially a site near the Karateren pumping station). Hillocks are covered with deflated sands (section 18(118)), lowlands are covered with solonchaks (section 19 (119)).

The dried bed of the Aral Sea between Kokdarya and Dzhiltyrbas bay represents an inclined plain, formed under the influence of desiccation and aeolian processes. Most of the territory has been afforested. An area near a massif of loose barchans (Fig. 34) was investigated. The plain part is occupied by solonchaks of different hydromorphic degree and highly active barchans without vegetation, stretching from north-east to south-west.

Fig. 34: Barkhans, loose

Section 22 (122) was cut in a territory with undulating sands. In this part of the dried sea bed, the bottom sediments have a heavy texture, sticky, red, and overlain by sand. The soil - hydromorphic solonchak on sea bottom sediments - is highly saline (EC 2-8 dS/m) among the entire profile. Texture is heterogeneous with alternating sand and heavy loam layers. The salinity in the blown sands and barchans is lower than in the sand deposits on the seabed. During aeolian formation, sands lose up to 70% of their salt content, which can lead to a salt content of only 0.05% in old barchans. Soil sections from the massif of barchans northwards show a sequence of different solonchaks as the groundwater table changes from 1.57 m (section 22(122)), 1.3 m (section 23(123)), 1.0 m (section 24(124)), 0.57 m (section 21(121)). The whole territory needs to be afforested.

4.1.1.2. Soil cover in the western part of the dried bed of the Aral Sea

Coastal automorphic and semi-automorphic solonchaks

Automorphic (sections 13(213), 22(222), 23(223), 24(224)) and related semi-automorphic (section 2(202), 3(203), 15(215), 16(216), 17(217), 18(218),19(219)) coastal solonchaks are widespread in the southern part of the dried bed. In the relic and coastal zone, they are related to flat surfaces of the fore-deltas.

The sediment load of the Amu Darya river runoff was deposited not only in the continental part of the delta, but also in the delta’s fore-set bed. Large fractions of the rivers sediment runoff are deposited as river flow lost its speed when discharging into the sea. Smaller parts of the suspended material were brought further into the sea and deposited on the seabed further away from the shoreline, onto the so-called bottom-set bed.

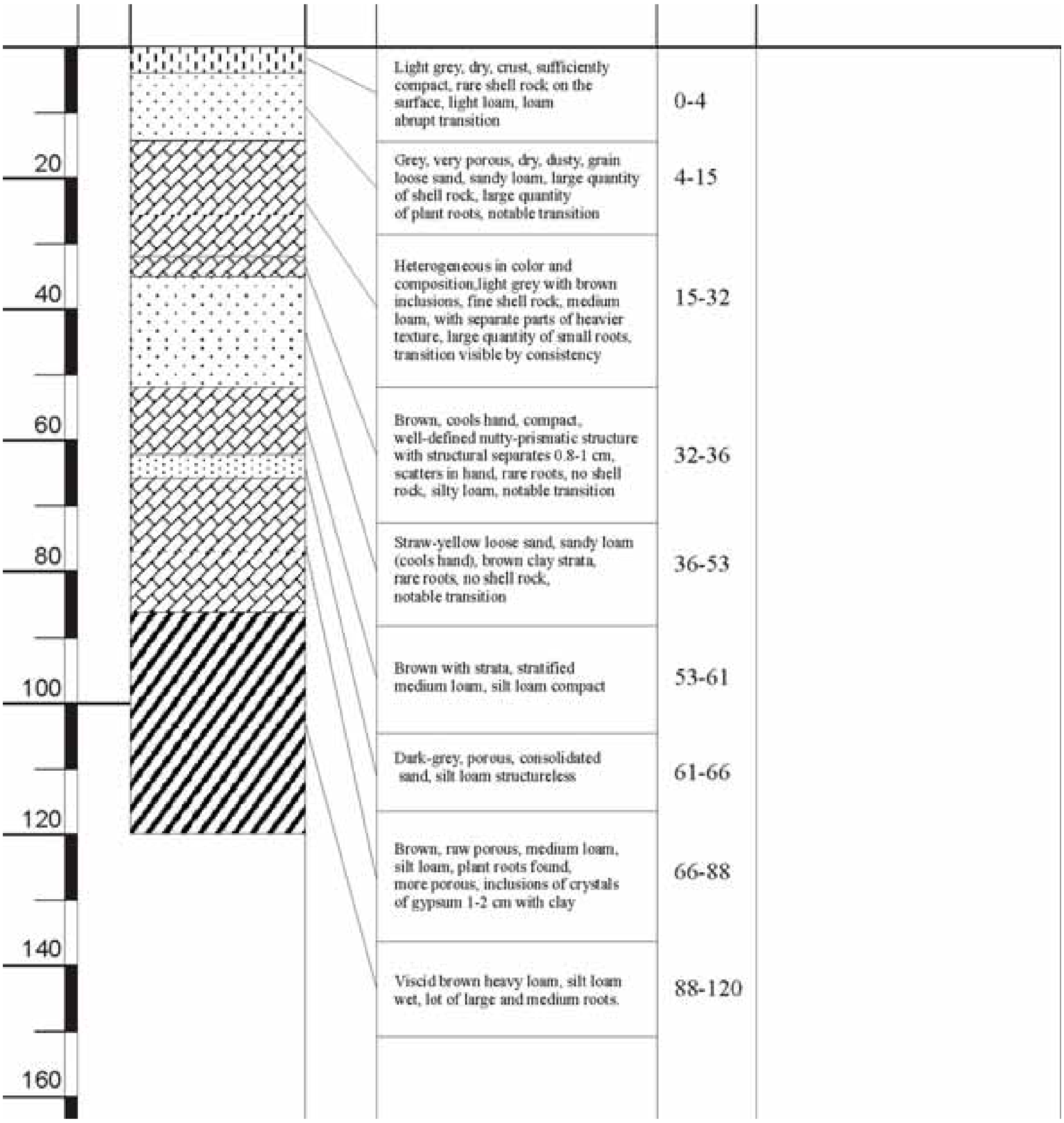
Thus, while forming under water on the seabed, fore-deltas are the natural extension of alluvial-deltaic continental plains. Therefore, while they possess many similarities to the continental part of the delta in their lithological structure, they differ from them in many respects.

Fore-deltas, like deltas, are formed of suspended solid material. A clearly stratified lithological profile is formed during the delta formation, due to different periods of deposition; while different alluvial layers alternate in deltas, they mix with sea sediment layers in fore-deltas.

After the sea desiccation, a part of the bed was watered through temporary flows that also had an effect on lithological profile.

Representative for the lithological-morphological soil structure in the upper part of fore-delta, section 15 (215) is described here. The section was cut on a slope with western exposition to Rybachie bay. The soil surface is covered with Karabarak (*Halostachys caspica*) and Tamarisk (*Tamarix hispida*) associations. The relief is of the pit-and-mount type. The solonchak is crust-puffed and semi-automorphic. Groundwater table is at a depth of 3 m.

Description of the section 15 (215)



As shown in the section description, the soil consists of a mixture of alluvial-marine sediments.

Alluvium of clayey, heavy-loam and rarely medium-loam texture dominates in the sediments. Mostly, the sandy loam and sand layers are only thin. The role of the marine sediments is poorly notable in profile formation. Sands with marine fauna are found only in the upper 30-40 cm layer. Organic inclusions in form of large plant residue (tree stems, branches, etc.) are often found in the lower layers. Dusty particles with a considerable admixture of silt prevail in fractional soil composition.

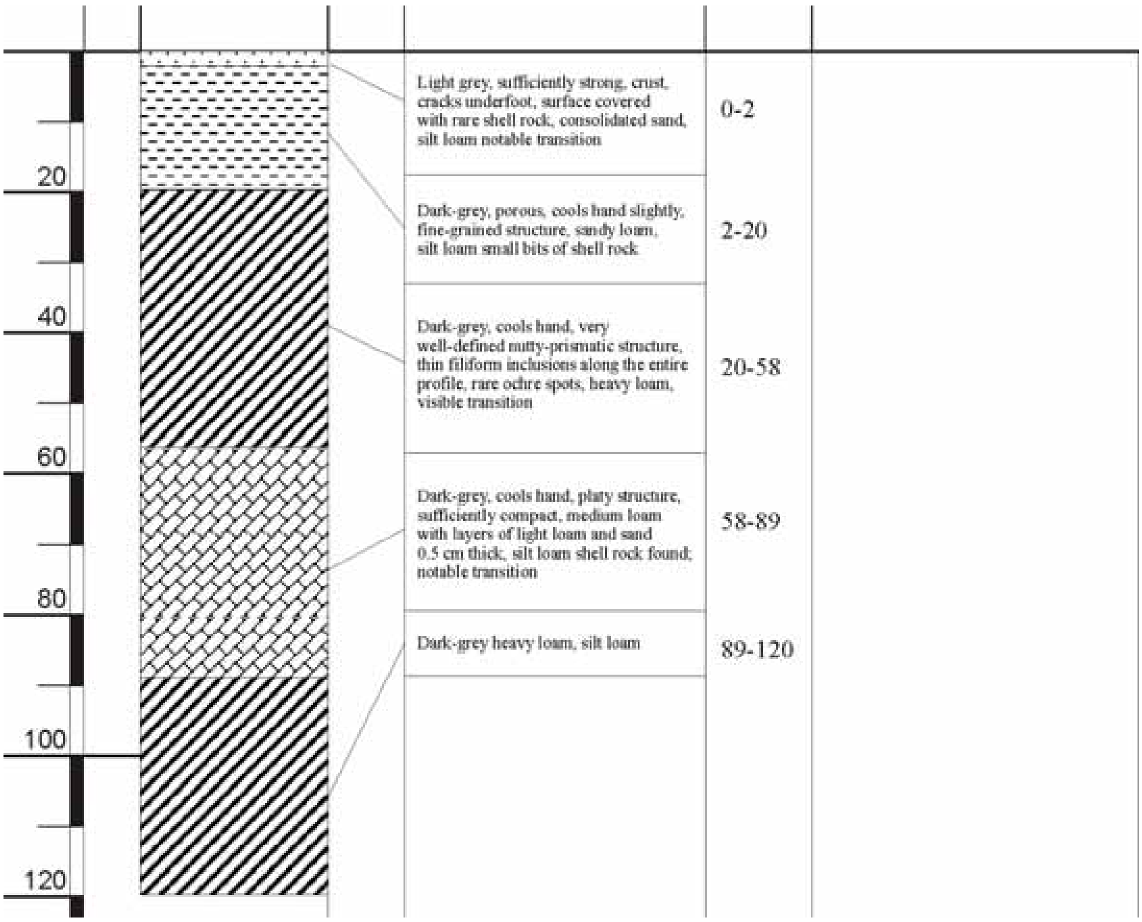
Moving to the north, marine sediments of light loam - sandy loam texture with inclusions of sea shells are found in the profile more frequently. Nevertheless, heavy loam and clay dominates the upper horizons (50-100 cm) as well as the underlying layers.

Loamy-clayey layers (usually of alluvial genesis) are, as a rule, very compact in dry condition, and become sticky and increase their volume in wet condition. This is why large cracks appear in the profile during soil desiccation, due to a compacting (shrinking) of the soil. Precipitation and surface water falls into these cracks and washes them out. Funnels, similar to Karst formation appear. Sometimes they can grow to a considerable size.

The cracks also appear during desiccation in the peripheral parts of the fore-delta, but are often hidden under sand - sandy loam marine sediments.

The typical lithological-morphological structure of automorphic solonchak is described at section 22 (222). The section was cut in the south of Tigrovy Khvost. GWT is 4 m. There is a gully (okopan) along the profile. Vegetation consists of a Tamarisk association with dried ephemers. The soil type is crust automorphic solonchak with signs of suffusion processes.

Section 22 (122) was cut between sandy hills.



Automorphic solonchaks are mainly represented by crust and crust-puffed types. The silt-salt crust strongly armors the soil surface and protects the underlying powdery puffed solonchak horizon from wind erosion. Dried vegetation cover, sometimes covering the ground surface very densely, facilitates it as well. The destruction of the crust and plant remains leads to an activation of aeolian erosion processes.

Semi-hydromorphic and hydromorphic coastal solonchaks

Hydromorphic coastal solonchaks occupy more than half of the area of the dried seabed. They are located between the semi-automorphic solonchaks and the current sea shore. They are also found near off-stream water bodies, in depressions of the sea bed and around numerous filtrations and residual small lakes.

Semi-hydromorphic coastal solonchaks (section 1(201), 5(205),10(210), 11(211), 12(212), 21(221)) are formed when saline groundwater lies within a depth of 2-3 m. The groundwater salinity is about 20-80 g/l, the salinity type is mainly chloride magnesium-sodium. The landscape relief is mainly a pit-and-mount type and sandy loam - loam plain (Fig. 35).

Fig. 35: Surface of hydromorphic solonchaks, overlain by shell rock in some places

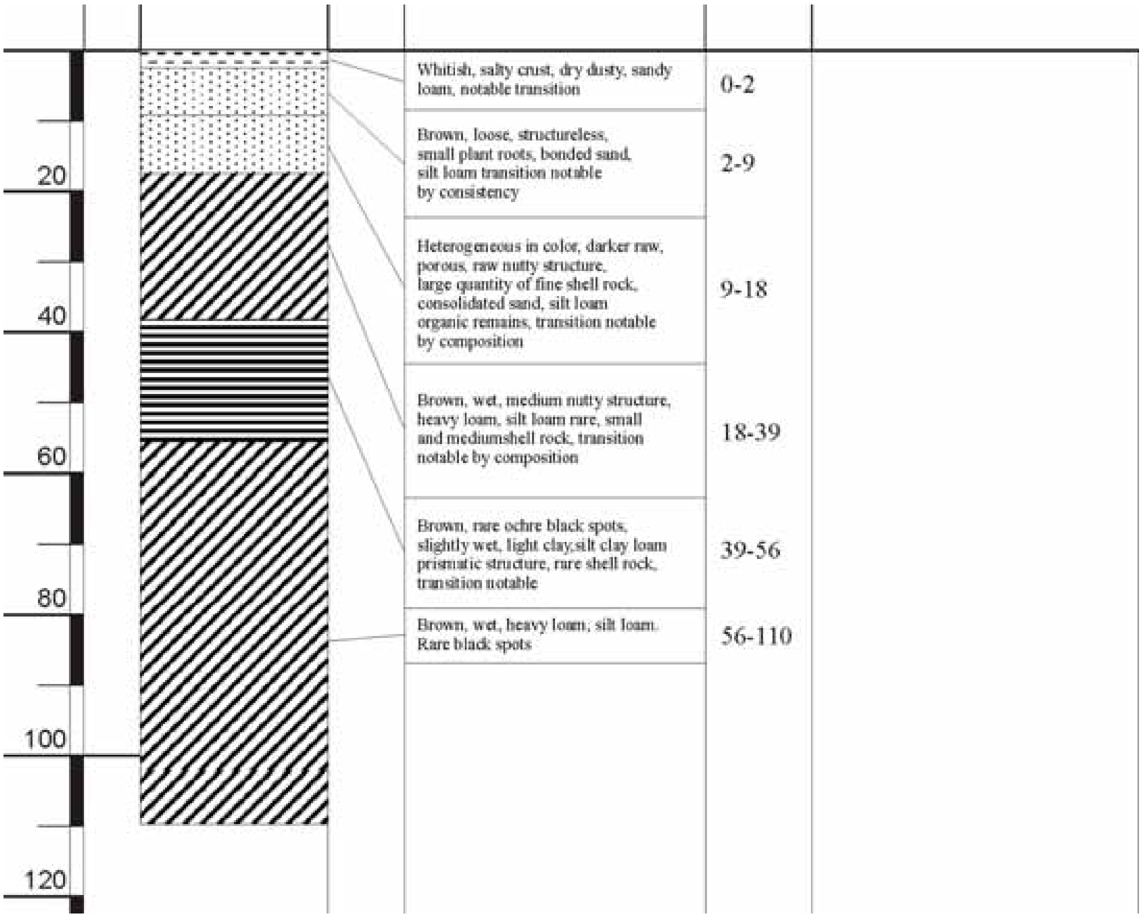
The soil surface is often enriched with shell rock. Semi-hydromorphic soils are represented by crust and crust-puffed types. Sometimes, spots of easily deflated puffed solonchaks slightly whitened by salts are found. In some places, where the surface horizons are represented by sandy loam and sand deposits, traces of wind erosion are visible.

These solonchaks are formed on deposits with a wide variety of textures; they often have stratified profile, sometimes of mixed alluvial-marine genesis.

Various vegetation associations are present, depending on the location to the semi-hydromorphic solonchak border: Karabarak-Tamarisk, Tamarisk vegetation, Saltwort, remains of reed vegetation and open surface without vegetation.

The lithologic-morphological structure of semi-hydromorphic coastal solonchaks are described in section 1(201). The soil surface is flat, with a sparse vegetative cover of scattered Karabarak and Tamarisks. The groundwater table is at a depth of 2.5 m.

Description of section 1 (201)*



Overall, the soil profile is very saline, with a maximum salt content in the upper salt crust, reaching up to 25%. The remaining part of profile consists from 1 to 9% of salts, with a declining salt content in deeper layers. That means that salt redistribution downside the profile is still absent. Soil salinity anions is mainly chloride, while the salinity close the surface is chloride-sulfate and sulfate. The dominant cation type is mainly sodium.

Among the semi-hydromorphic solonchaks, puffed solonchaks, with a surface of powdery silt-salt layer, and solonchaks formed on sandy loam-sand deposits are most subjected to wind erosion. On the surface of the latter, a very weak sandy-salty crust is formed that is easily destroyed by wind. The soil surface is covered by flat (stratal) deflation sources (Fig. 36). These solonchaks are active sources of deflated salts which are transported by the wind far outside the basin of the former sea area.

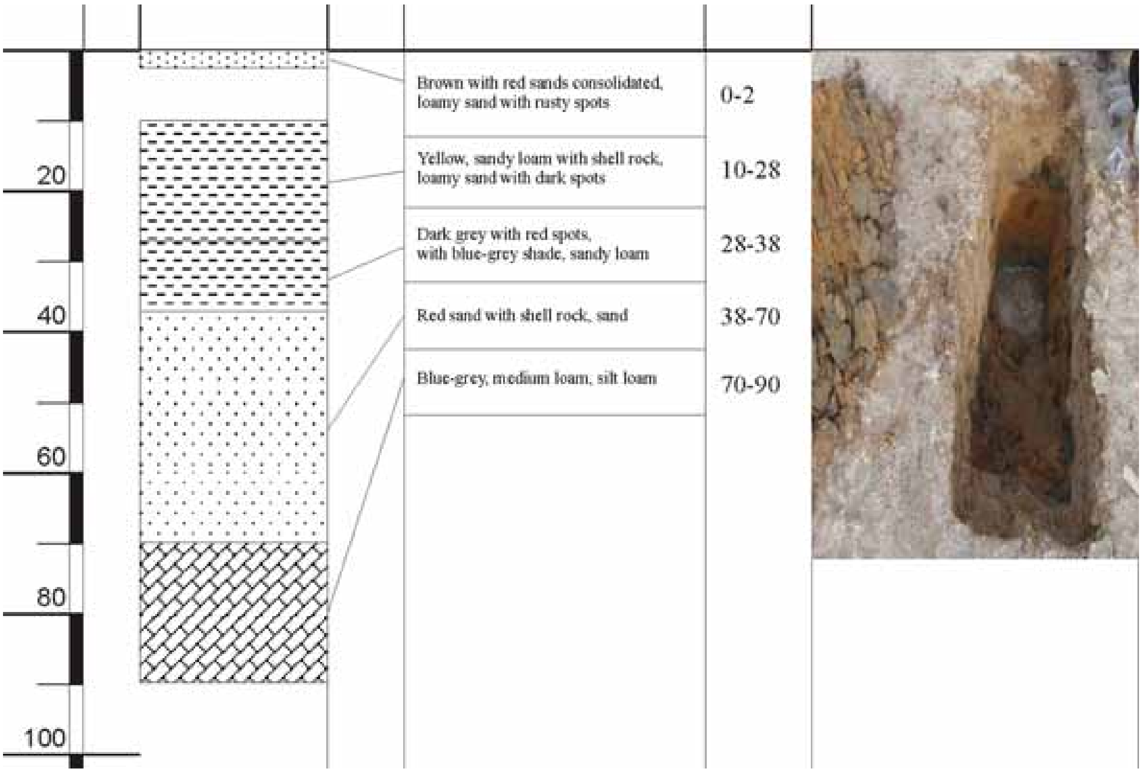
Fig. 36: Crust-puffed solonchaks with deflation sources

Along the current shoreline of the Aral Sea, under the influence of a shallow groundwater table (from 0.5 to 1 m), moderately and excessively hydromorphic solonchaks are formed. Groundwater salinity varies from 30 to 60 g/l, the salinity type is sulfate-chloride magnesium-sodium.

The lithologic-morphological structure of hydromorphic solonchaks, is outlined in the description of section 7(207), cut in the current coastal zone in the east from Takmak peninsula.

Excessively wet hydromorphic solonchaks cover a wide strip of the seacoast. Groundwater table is at 0.5-0.8 m. The surface of these solonchaks is covered by a compact salt crust. The surface color depends on the degree of sand coverage. White massifs with solonchak spots, dark sand-covered and mixed massifs are found. The soil profile of hydromorphic coastal solonchaks is strongly moistened. Only the uppermost horizon dries during the hot summer season. Here, the formation of a thin but strong salt crust is typical. A strongly gleyed horizon lies directly beneath the crust.

Description of profile 7 (207)*



In the part of coastal zone itself which is still flooded by sea water during storm events, marsh solonchaks are formed. A specific leaching (or washing) water regime is developed in these solonchaks, which are periodically flooded. Therefore, a permanent salt crust is not formed there.

When hydromorphic solonchaks dry up, they represent a great hazard, as they become a source of salts and dusts ready for aeolian transport.

Sandy formations with aeolian erosion-accumulative relief

During the desiccation of the sea, a vast area of sands emerged from underwater. As a result of wind processing, transport and redistribution of sand material, abundant aeolian-accumulative landscapes were formed (Fig. 37).

Fig. 37: Eolian erosion-accumulative relief

Several sand massifs with different levels of stability have formed by now. There are two massifs at a joint point with the alluvial-delta plain of Amu Darya river and Adzhibay bay. The eastern part of the dried seabed is of partially ridged-barchan character. Advancing to the west towards the water flow path, the accumulative relief changes into the pit-and-mount type with unfixed sands. The northern part of those massifs has the typical relief of deflating surfaces: undisturbed sand-covered surfaces alternate with multiple sources of deflation. Despite deflation, the southern part is partially covered by relatively healthy grassland. Here, desert sand soils are formed under an automorphic regime of moistening.

In the area between Adzhibay bay to the western reaches of Muinak bay, the relief of the sand massive is hillocky. A great diversity of shrubs and herbaceous plants grows here. Ordinary desert sandy soils are formed on surfaces fixed by vegetation.

A chain of moderately high and high semi-fixed hillocks and barchans stretches along the "Tiger tail" peninsula. In some places, desert sandy soil can be found.

A massif formed by marine sediments and pieces of tertiary deposits is situated near the western coastal area of the peninsula. It stretches from south to north along the coast. At present, the relics of tertiary deposits are exposed or partially covered by coarse debris-sandy material mixed with sea shells. A part of the territory is buried under individual low hillocks of blown sands. Ridgy barchans, 5-7 m high, oriented from the north-east to south-west, are not overgrown. They stretch along the alluvial cone, sandspit in the middle part of the massif. The eastern part of this regional elevated bank is occupied by plain unfixed sands with deposits of the parent rock.

Desert sandy soils

There are two types of desert sandy soils in the study area.

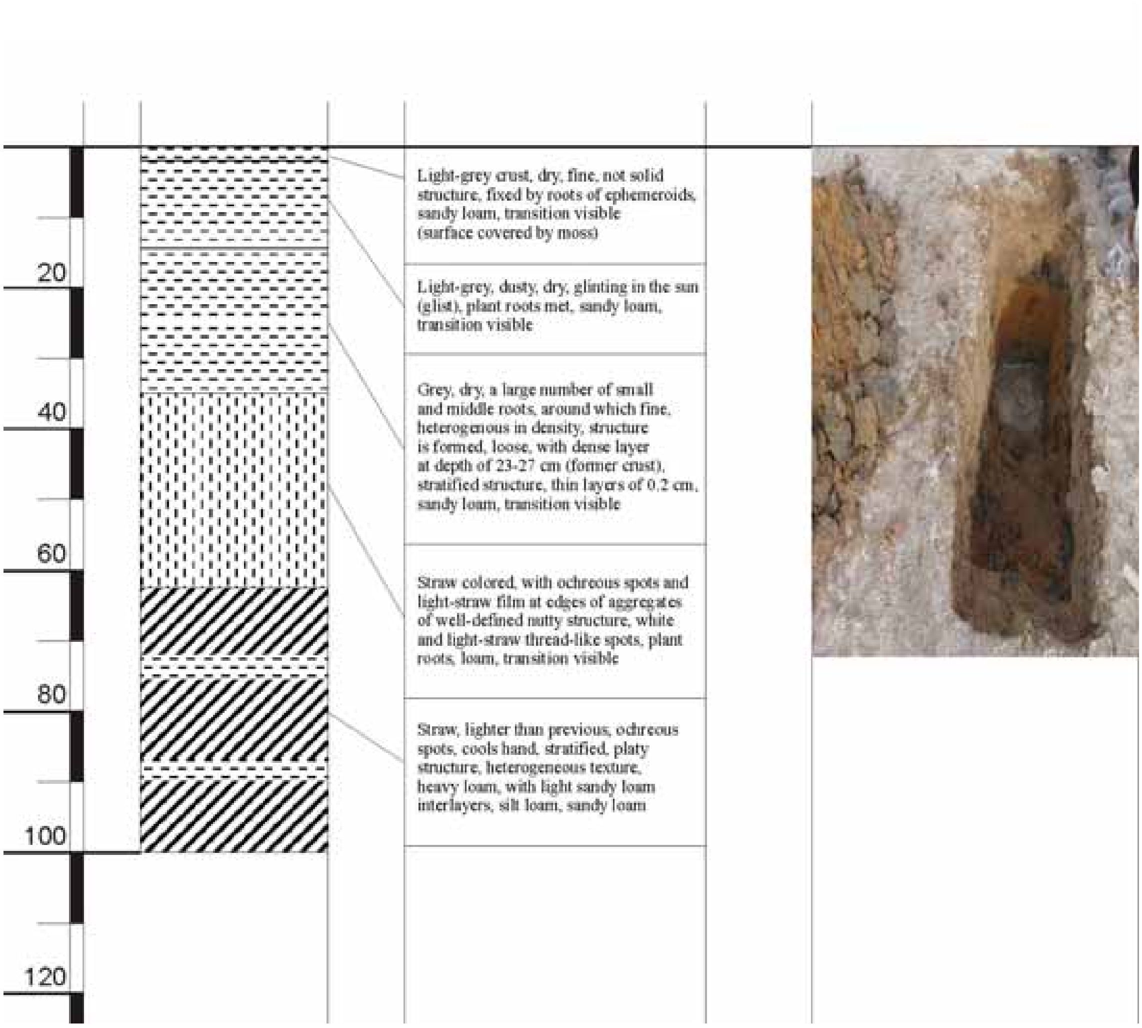
The first type is the genetically formed old soil under long lasting soil-formation processes. Those soils refer to insular landscape. As a result of aeolian activity, they are often covered by sands. Their profile can have two humus horizons. The upper horizon is secondary, as a result of overgrowing and fixation of sand and the lower one is embedded (section2(102), 1st expedition, Akpetki). As a rule, these soils are either non-saline or slightly saline in the source profile.

The second type is a young primitive desert sandy soil (Fig. 38). One humus horizon is defined in the soil profile and it still keeps signs of salinization, specific to the solonchaks on which desert sandy soils are formed.

Fig. 38: Desert sandy soil under saxaul plantations

In order to characterize the morphological profile of desert sandy soils, the section 30 (230) cut in the area of a ten-year old artificial Saxaul plantation, northward of Rybachie bay, is described.

Section description 30 (230)*

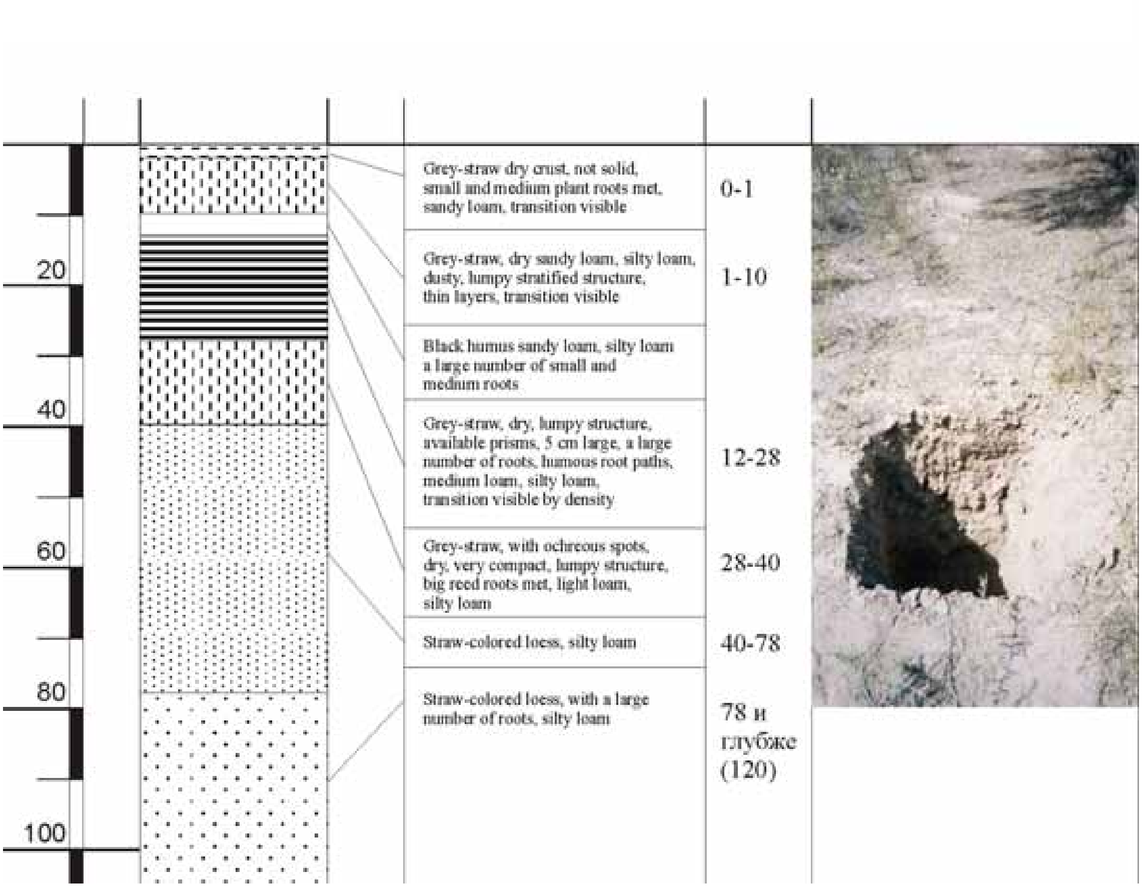


Desertification of meadow alluvial soils

Meadow-alluvial soils subjected to desertification are mainly found within the Amu Darya river delta. The drying up of the river-bed, a decrease of erosion base level, and a decrease of the ground water table bring changes into genesis of meadow soil and cause their desertification.

Salts in the upper layer are chloride-sulphate and sulphate-chloride. They are medium and lowly saline along the profile. The soils are formed on alluvial deposits; therefore they have an extremely heterogeneous soil texture. A great number of plant residue can be found in the profile, including reed. A humus horizon is well-defined in color and structure, while the upper 10cm layer is unstructured. Description of the section 6(306) is given below. The section was cut on within a Saxaul plantation massif in the area of Rybachi bay.

Section description 6 (306)*



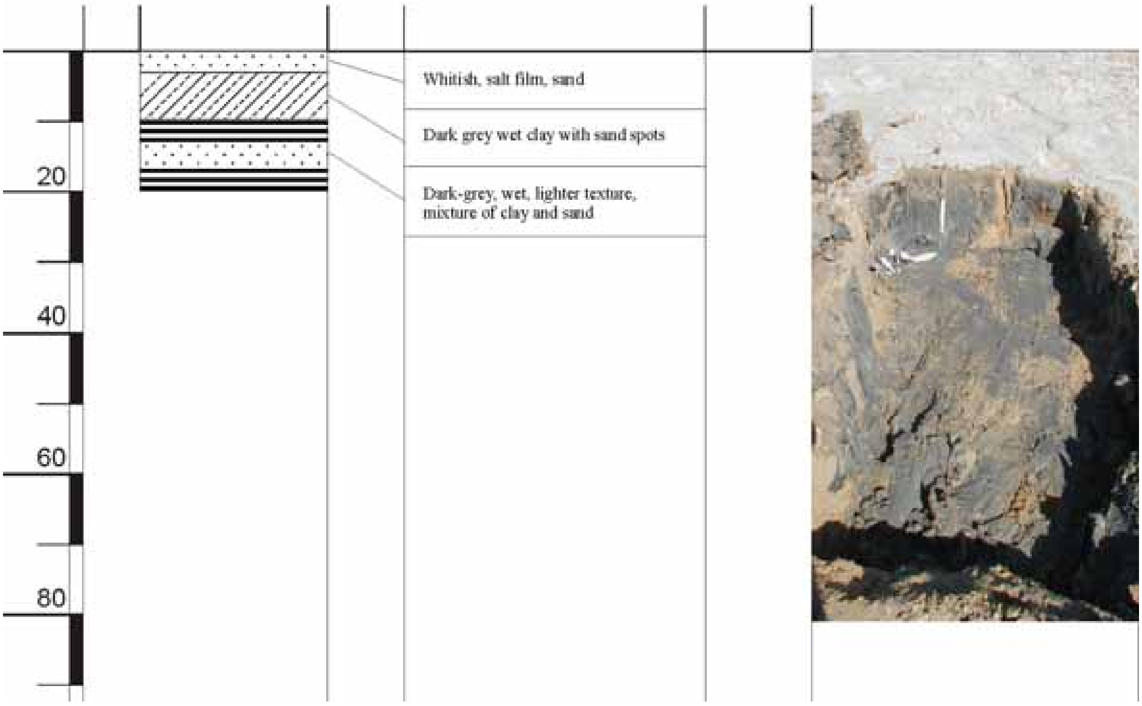
The general relief of the territory is plain, slightly sloping the towards current water edge and the slope from chink to Adjibay bay. The sea recession here is observed in two directions. The sea receeded from the original steep shore of Ustyurt eastwards and simultaneously moved away to the north. The steep chink of Ustyurt became exposed, representing a vivid picture of stratified quaternary deposits. (

Fig. 39).

Fig. 39: Ustyurt chink

Well-defined borders of hydromorphic solonchaks changing into their dry types can be observed from Ustyurt plateau.

Description of section #501, marshy solonchak



In a transect from the chink to the sea shore, we observed the shift from beach sands to marshy solonchak, with a following drying up and crust formation on the surface (sections 501, 502, 503) (Fig. 40).

Fig. 40: Aral Sea. Coast (Western Sea)

Even here the dried seabed has a complex lithological and geomorphological structure. Slump grounds are typical for that part of dried bed. This is expressed in an alternation of sand covered by silt. Washing out of the latter and settling of the underlayer leads to the formation of holes reaching 1 meter in diameter.

A big massif of almost unfixed sand (Fig. 41) stretches from Sudochie lake and covers a road and the lake. The second risk area is a dried lake bed covered with unfixed sands. The soil cover is presented, as in the whole dried area, by solonchaks of different types, depending on groundwater table. Process of desert sandy soil formation can be observed in the Haloxylon desert (section 515).

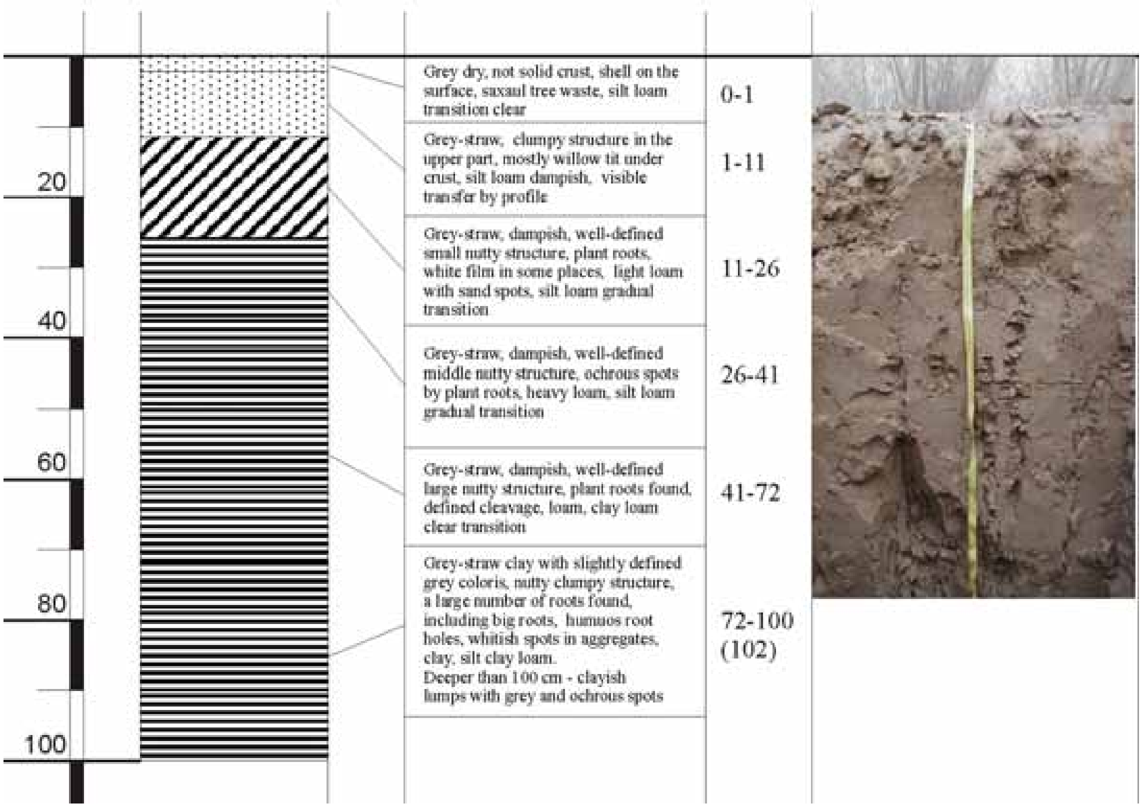
Fig. 41: Unfixed sand along Sudochie lake

The main part of the described massif is formed by crust-puffed (section 504-506) and crust solonchak, which are excessively hydromorphic northward of Adzhibay (section 507). The territory is characterized by active salt and dust transfer (Fig. 42).

Fig. 42: Dust storm

The major part of the solonchaks is covered with sands. Aeolian abrasion destructs the crust, and sand covers the external surface of the soil as well as cavities under it, forming a rampant mesorelief in combination with sand hillocks and non-solid crust solonchaks (section 512-513). Solonchaks with holes stretch from the western and eastern parts along Adzhibay, as described in section 511. Vertical cracks can be clearly seen in the soil profile.

Description of section # 511; solonchaks with unsolid crust, at the beginning of desert-sandy soil formation.



The observations showed that this soil type is a considerable source of dust. The fine fractions of the substrate can be transported over long distances. The photo demonstrates a well-defined border of dust storm formation. This picture is very representative as it demonstrates the effect of plantations that end 1.5 kilometers before the eye of storm.

Based on these field investigations, a soil map was produced for 2005 (Fig. 43).

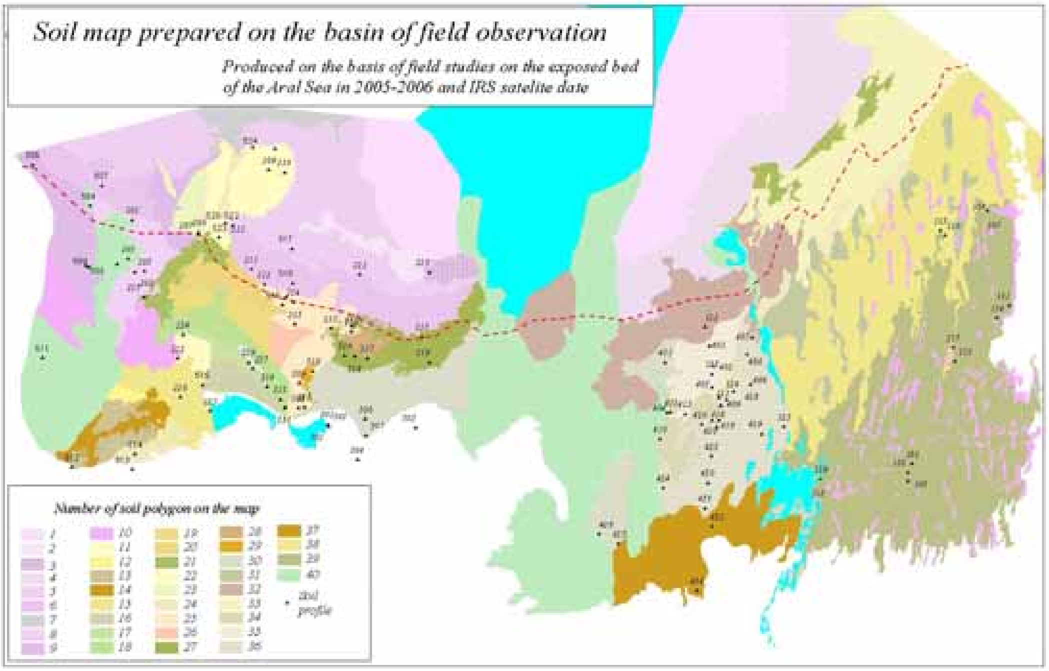


Fig. 43: Soil map generated on the basis of field studies

Legend to the soil map

1	Littoral solonchak, excessively wet, takyr-like	Stratified complex of loam, sandy loam, and sand
2	Littoral solonchak, excessively wet, unstable crust	Stratified complex of loam, sandy loam
3	Littoral solonchak, excessively wet, unstable crust	Stratified complex of loam, sandy loam, and sand, with prevalent loam
4	Littoral solonchak, excessively wet, unstable crust	Stratified complex of loam, sandy loam, and sand, with prevalent sand
5	Littoral solonchak, moderate hydromorphic, unstable crust, sand-covered in places	Stratified complex of loam, sandy loam, and sand
6	Littoral solonchak, semihydromorphic, unstable crust, sand-covered in places, with spots of shell	Stratified complex of loam, sandy loam, and sand
7	Salty barren land	
8	Littoral solonchak, moderate hydromorphic, crust-puffed, periodically watered	Stratified complex of loam, sandy loam, and sand, underlain by heavy and medium loam
9	Littoral solonchak, moderate hydromorphic, crust-puffed, sand-covered in places	Stratified complex of loam, sandy loam, and sand, underlain by heavy and medium loam
10	Littoral solonchak, moderate hydromorphic, crust-puffed, sand-covered in places	Sandy loam-loam, with marked upkans
11	Littoral solonchak, moderate hydromorphic, crusted, sand-covered in places	Heavy and medium loam (slightly sand-covered in places) on stratified loam with layers of sandy loam and sand
12	Littoral solonchak, automorphic, crusted, hummocky	Clayish and heavy loam (sand-covered)

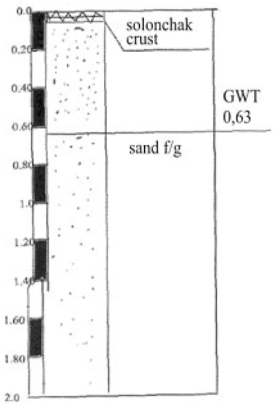
13	Automorphic solonchak, with blown, slightly overgrown hilly sand	Sandy loam-sand, with thick clay and heavy loam layers in lower horizons
14	Automorphic solonchak, with blown, overgrown hilly sand	Sandy loam-sand, with thick clay and heavy loam layers in lower horizons
15	Desert-sandy soil	Light loam, heavier downward
16	Continental part	
17	Combination of littoral solonchaks, hydromorphic and excessive hydromorphic (lakeside) and plain-small hilly sands	Sandy, in lake-like hollows light loam and sand loam
18	Littoral solonchak, moderate hydromorphic covered with sand	Sandy loam-sand
19	Littoral solonchak, moderate hydromorphic	Sandy loam-sand
20	Littoral solonchak, semi-automorphic, with sand massifs	Stratified complex, with prevalent sandy loam and sand over loam and clay
21	Littoral solonchak, semi-automorphic, with sand massifs	Clayish and loamy, with sandy loam and sand layers in lower horizons
22	Unfixed sand in combination with solonchaks	Stratified complex, with prevalent sandy loam and sand
23	Littoral solonchak, semihydromorphic, unstable crust, covered with unfixed sand, with outcrops of parent rocks in form of rubbles	Stratified complex, with prevalent sandy loam and sand
24	Sand with sea shell	sand
25	Barkhans	sand
26	Desert-sandy soil	Stratified complex of sandy loam, sand and loam
27	Desert-sandy soil in combination with solonchak	Clayish and loamy in lower horizons
28	Solonchak semi-automorphic and automorphic, crust-puffed and unstable crusted	Clayish and loamy in lower horizons
29	Sand	sand
30	Solonchak automorphic in combination with unfixed sand	Stratified complex of sandy loam, sand and loam
31	Meadow subjected to desertification	Clayish, heavy- and medium loam (sand-covered) on poor-stratified deposits of different textures
32	Solonchak, excessively wet	Mainly sandy loam-sand with loam and clay layers
33	Dunes	sand
34	Unfixed sand	sand
35	Plantations	
36	Solonchak, moderate hydromorphic, covered with loose sand in places	On heavy and medium loam deposits
37	Complex of semi-automorphic and semi-hydromorphic solonchaks with sand hills and barchans	Stratified complex of various textures
38	Solonchak automorphic, covered with sand in places (plantations)	Sand-sandy loam on stratified deposits of different textures (from clay to sand)
39	Littoral solonchak, semihydromorphic covered with thick cover of loose sand	Sandy loam-sand
40	Complex of solonchaks lacustrine-rap (shor) with desert-sandy soil of relic islands	Sandy loam-sand

4.1.2. Hydro-geological research results

During the expedition, wells were drilled in order to estimate geological section and groundwater salinity, as well as to take water samples for comparing with salinity of water samples taken from monitoring observation wells situated in the study area.

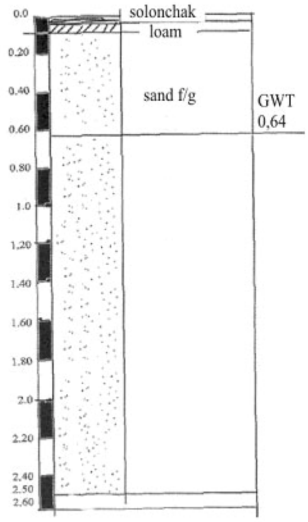
Drilled well 1 is located at the “Nurbay” well coordinate position in the south-east of the Aral Sea. Lithological section is presented up to 2 m. It is fine-grained sand, groundwater table is 0.63 m. The salinity is 42.0 g/l. Water samples were taken from monitoring observation well No. 4, the well depth is 6 m, groundwater table is 1.87 m and salinity is 47.2 g/l.

Well #1



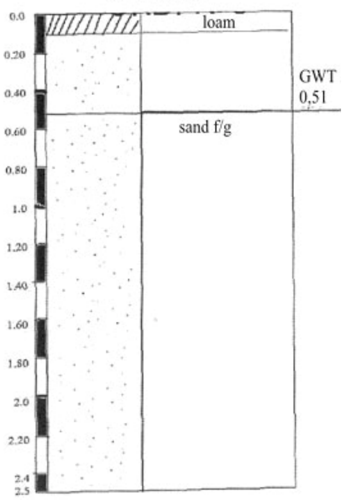
Well 2 was drilled in “Bozuzyak” area. Lithological section consists of solonchak crust at 0.0 - 0.5 m depth, loam with soil-vegetation layers at 0.05 - 0.5 m depth, and fine-grained grey-yellow sand at 0.5 m - 2.5 m depth. The groundwater table is 0.64 m and salinity is 46.0 g/l.

Well #2

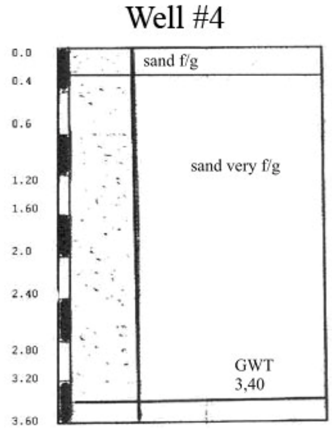


Well 3 (2.5 m deep) was drilled at “Seleule” tract. Lithological section is presented by 0.0 - 0.10 m of brown loam and 0.10 - 2.5 m of sand. The groundwater table is 0.51 m and salinity is 52.4 g/l.

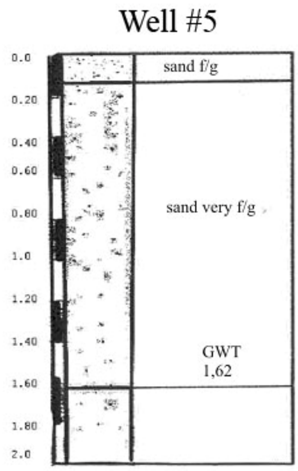
Well #3



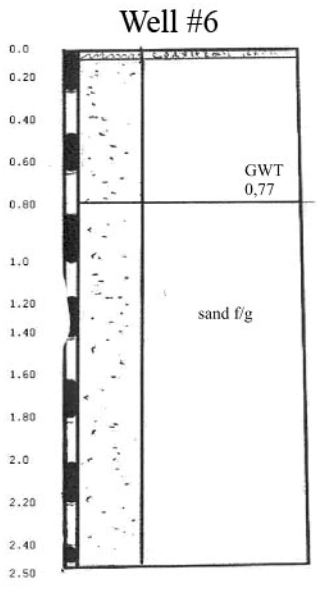
Well 4 was drilled at the border of Kazakhstan. Lithological section is presented by very fine-grained gray sand at a depth of 0.0 - 0.25 and fine-grained gray-yellow sand at 0.25 - 3.58 m. Groundwater table is 3.40 m and salinity is 42.0 g/l.



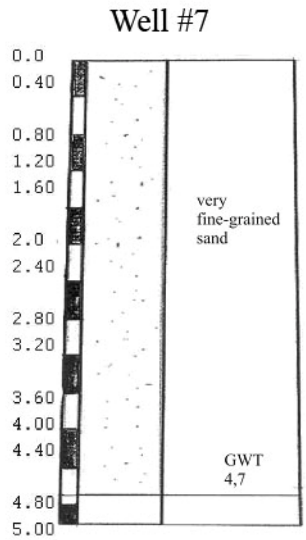
Well 5 was drilled 35 km far from "Sarsek" well towards the sea. In this area the lithological section is presented by very fine-grained gray sand at 0.0 - 0.15 m and gray silty drift sand, at 0.15 - 2.0 m. Groundwater table is 1.62 m and salinity is 36.0 g/l.



Well 6 was drilled on big shore. Lithological section is presented by solonchak crust at 0.0 - 0.05 m and gray silty sand at 0.05 - 2.5 m. Groundwater table is 0.77 m and salinity is 41.0 g/l.

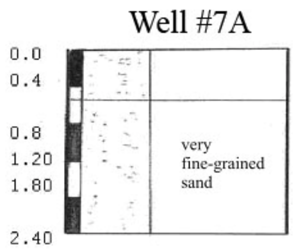


Well 7 was drilled 2 km far from "Sahabay" well. It is comprised of very fine-grained gray-yellow sand up to 5.0 m. The groundwater table is 4.7 m and salinity is 39.0 g/l.

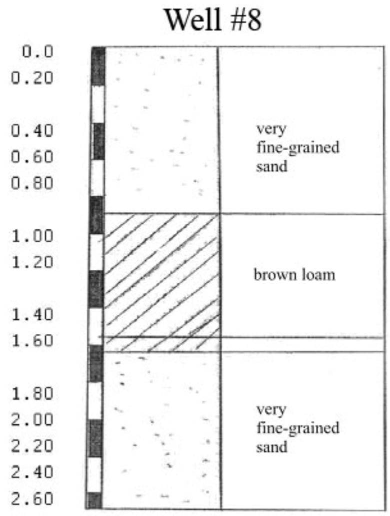


Operating well No.4 GHK-37, with salinity of 54.0 g/l and groundwater table of 3.75 m is located within "Togyzarkan" site. The same salinity and GWT are prevalent everywhere.

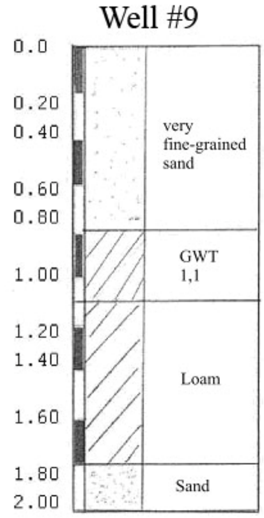
Well No.7A was drilled within Dzhiltyrbas site not far from the Dzhiltyrbas Bay. Lithological section is represented by 0.0-2.0 m of very fine-grained gray-yellow sand, with groundwater table of 0.58 m and salinity of 57.1 g/l.



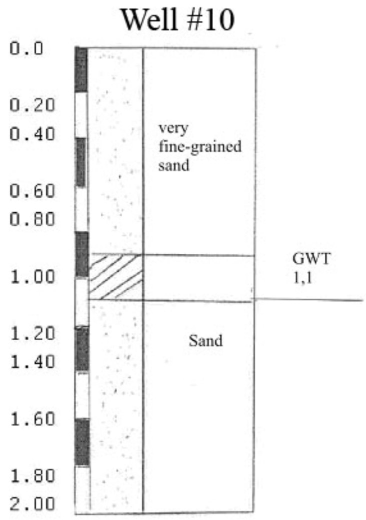
Well 8 was drilled along Kokdarya. Lithological section is represented by 0.0-0.90 m of gray sand, 0.90 up to 1.70 m of brown loam, and 1.70 up to 2.5 m of gray-yellow quicksand. groundwater table is 1.57 m and salinity is 42.0 g/l.



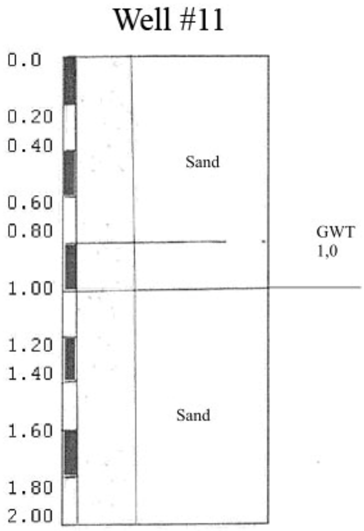
Well 9 was drilled close to an abandoned drill tower. Lithological section is represented by 0.0 to 0.80 m of grey sand, 0.80 m to 1.80 m of brown loam, and 1.80-2.0 m of gray-yellow quicksand. Groundwater table is 1.10 m and salinity is 43.7 g/l.



Well 10 was drilled within IFAS work-site (new GTZ's site). Lithological section is represented by 0.0 up to 0.90 m of very fine-grained sand, 0.90 m to 1.10 m of loam, and 1.10 to 2.0 m of gray-yellow sand. Groundwater table is 1.10 m and salinity is 47.0 g/l.



Well 11 was drilled 11- 200 m far from an abandoned drill tower towards the sea. Lithological section is represented by 0.0 to 0.80 m of very fine-grained gray sand, 0.80 to 1.0 m of loam and 1.0 to 2.0 m of very fine-grained gray-yellow sand. Groundwater table is 1.0 m and salinity is 37.0 g/l.



Thus, seven wells located in the study area have groundwater table within 0.51-1.10 m, i.e. characterize hydromorphic conditions that are very suitable for growing tamarisk and other relic plants. Deeper wells are characterized by semi-hydromorphic conditions with the groundwater table of 1.57…1.82 m. Automorphic regime was found only in three wells drilled to a depth of 3.40-4.75 m. The comparison with Pinkhasov's map for 1993…96 did not show a considerable change in groundwater table. Salinity varies within 36…57 g/l everywhere. We tried to establish a certain relationship between salinity and a distance from the current shoreline. This comparison is shown in Fig. 44.

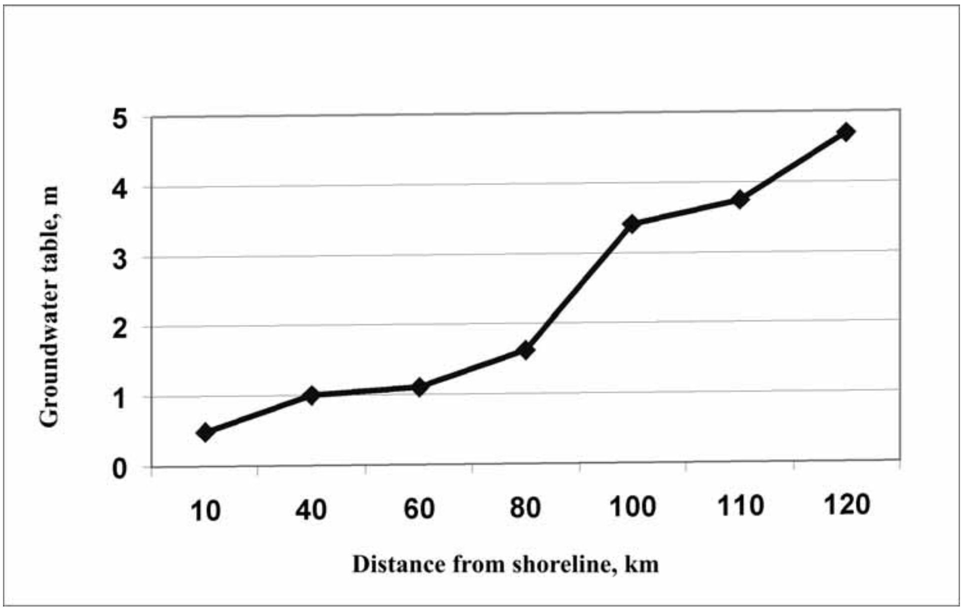


Fig. 44: Relationship between groundwater table and a distance from the current shoreline

There are a lot of operational self-discharging wells in the area of Akpetki (4) and Dzhiltyrbas (4). The majority of them are artesian wells, with highly saline and high-temperature water.

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

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

4.1.3. Vegetation cover (general)

The exposed sites of the seabed are heterogeneous in terms of their constituent sediments, and there is still a link with certain deltaic plain sites. As to modern processes (drying, salt accumulation, groundwater lowering, overgrowing), the sites such as Adzhibay, Muinak, Urdabay, and Kazakhdarya are good examples for new landscapes being formed. Kabulov

(1990) showed that during the aridization of dried bays, a natural change in phytocenosis takes place and expresses itself in modifications of species composition, quantity and other bioparameters of valuable population. The steering factors of such change are soil moisture and salinity.

The first pioneer in the zone of periodical floods is Saltwort (*Salicornia sp.*): 1-3 plants per 100 m^2. Saltwort abundance increases sharply at a distance of 60-80 m from the coastal line and Sea blite *(Suaeda salsa)* appears. These plants occupy mainly flat areas and interzones, and minor-saline micro-hills. Dense microstands of Saltwort and Sea blite are the most characteristic for the major part of active shore while Saltwort is prevalent in the zone close to the sea and sea blite is in the more distant zone. The common reed *(Phragmites australis)* is met along the border between hydromorphic solonchak and semi-hydromorphic one.

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

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

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

As a result of the sea-level lowering and an increasingly arid climate, desert-sandy soil-formation process became also more arid. This is characterized by the occurrence of saline silt crusts with desert moss on sandy ridges that deteriorates the physical properties of the soil. Salinity of desert-sandy soils increased in the zones close to the dried Akpetki archipelago, thus contributing to a suppression of the vegetation cover.

Hilly ridgy sands and solonchak medium extend from the north to the south and from the east to the sea on the dried bed of the Aktepinsky archipelago. This relief diversity has effect on vegetation character (Fig. 45).

Fig. 45: Towards Kazakh border

The landscape background in the hilly-ridgy sand complex is formed by tree, shrub and herbaceous plants such as: *Haloxylon aphyllum* (Black Saxaul), Kandym types (*Calligonum caput-medusae, Calligonum eriopodum, Calligonum junceum*), *Ephedra strobilacea, Astregalus villosiassmus*, including *Artemisia terraealbae, Heliotropium lasiocarpum, Carex physodes, Corispeormum lehenanianum*, etc. The dominant components in the lowest layers of the above mentioned complex are: *Bromus tectorum, Eremopyrum orientale, Poa bulbosoae, Stipagrostis pennata, Jsatis minima, Strijosella scorpioides*, etc. *Haloxylon persicum* and *Ammodendron conollyi* are characteristic for loose sandy massifs and ridgy sand slopes, while *Artemisia terrae-albae, Corispeenum lehmanianum, and Eeremopyrum orientale* are typical for compacted sands. Ephemers and ephemeroids are the elements of rich and diverse herbaceous vegetation on sands. All these species were dried at the time of the survey. However, we revealed dried stems of the following ephemers and ephemeroids: *Allium sabulosum, Tulipa sogdiana, Alyssum turkestanicum, Diptychocarpus strictus, Bromus tectorum*, etc. (Fig. 46).

Fig. 46: Near «Toguzarkan» flow path

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

Microrelief elements of biogenic origin are met along the eastern and the southern coast of the dried bed of the Aral Sea: vegetative hillocks, hummocks among disappearing reed beds (kupa laki) covered by sand. We disclosed sprouts of Saltwort, Sea blite, Tamarisk, etc. Coast vegetation of the receded sea is represented by a number of halophytes such as: *Atriplex dimirphostegia, Salicornia europea. Salsola micranthera, Suaeda, Tamarix hispida, T. laxa, T. Pentadra*, etc. Vegetation of fixed sand is distributed irregularly in some places. Sometimes there are 4-5 shrubs on one hillock or 10-15 shrubs in other case.

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

Grass - Black Saxaul association is disseminated in the eastern part of the dried seabed along old «Togyzarkan» flow path, with developed relief and with gentle slope towards the flow path in some places.

The relief in the area from the «Nurbay» well to the east is represented by barchan sands more or less fixed with motley grass. Vegetation cover is mainly composed of Black Saxaul and Tamarisk complex with motley grass. Grass-Karabarak-Saxaul associations are the main landscape plants 1.5 km further to the east in lowlands, among barchans on solonchak, with shells.

Mainly hilly barchan sands cover the central part of «Bozuzyak» tract. We have studied the territory towards the north in lowlands. The soil is a crusted solonchak and there is ground water in the center of the shor. The main vegetation is reed (*Phragmites australis*) in the central part. Tamarisk (*Tamarix laxa*), Urukh (*Calamogrostis dubia*), etc. are met along edges (Fig. 47).

Fig. 47: «Bozuzyak» tract

The area along the right bank of the Kokdarya river is also mainly covered by hilly barchan sands. Flat zones as well as solonchak lowlands are present as well. The main landscape background is formed by tree, shrub and herbaceous vegetation such as: *Haloxylon aphyllum* (Black Saxaul, Kandym species: *Calligonum caput-medusae*, *Calligonum eriopodum*, *Calligonum junceum, Ephedra strobilaceae, Astragalus villosiassmus* including *Artemisia terrat-albae, Heliotropium dasucarpum, Carex physodes, Corisporium lehenanianum, Phragmites australis* (this specimen is met closer to the bank), etc.

Ground surface is mostly plain, with artificial Black Saxaul plantations on the route of Karauzyak from the Aral bridge up to the key GTZ afforestation area. Afforestation is still under development. Vast unfixed barchans prone to intensive deflation process started at a distance of 5-10 km north from the GTZ area. Vegetation is sparse; however, we revealed some species such as: *Haloxylon aphyllum* (Black Saxaul, Kandym species: C*alligonum caput-medusae, Calligonumi eriopodum, Calligonum junceum, Ephedra strobilaceae, Astregalus villosiassmus* including *Tamarix laxa, Artemisia diffusa* (spreading wormwood), *Artemisia terrae-albae* (white land wormwood), *Ephedra strobilaceae* and rare Saltwort shrubs *Salsola richteri, Aristida pennata*, etc.

The return trip along the left bank of the Kokdarya river passed through hilly barchan and hilly sands. A great number of unfixed barchans with vegetation and prone to deflation process were found. There was a wide spectrum of vegetation among the barchans such as: *Haloxylon persicum*, *Haloxylon aphyllum*, *Salsola arbuscula*, *Salsola richteri*, *Artemisia santolina*, *Artemisia diffusa* (Spreading Wormwood), *Artemisia terrae-albue* (White land Wormwood), *Ceratocarpus arenarius, Carex physodes, Aristida pennata*, etc.

The current acute water deficit contributed to desertification process. High salinity and abrupt desalinization on the dried seabed and exposed zone in Amu Darya delta are represented by loamy and, in places, sandy sediments, with prevalent silt in bays (Brodskaya 1952; Petrov 1950).

4.1.4. The state of artificial plantations

The focus of the third expedition was on ground based assessments of the artificial plantations in the central part of the southern dried seabed. The territory was afforested at different degrees since 1977.

Investigations on the composition and status of plantings and seedlings enabled us to identify priority sites for future afforestation measures with a total area of 9.345 ha.

Table 8 shows an overview of the surveyed afforestations. The studies were conducted among 6 landscape units (massifs). An assessment of projective vegetation cover was conducted at three test sites per massif (Tables 9-11).

Table 8: Plantation survey results, 3rd expedition

Massif number	Massif area (ha)	Site 1 (%)	Site 2 (%)	Site 3 (%)	Mean coverage density (%)
I	6838	60 100	30 95	10 75	90
II	7273	50 95	30 75	20 50	73
III	6812	40	40	20	57

Massif number	Massif area (ha)	Site 1 (%)	Site 2 (%)	Site 3 (%)	Mean coverage density (%)
		80	60	30	
IV	3146	$\frac{60}{90}$	$\frac{30}{80}$	$\frac{10}{40}$	70
V	4,0				90
VI	6268	$\frac{20}{70}$	$\frac{60}{30}$	$\frac{20}{5}$	35
Total	30341				69.2 (20996 ha)

Note: numerator shows percent of the total massif area;
denominator shows projective vegetation cover in given area.

Table 9: Geobotanical description of selected sites with good vegetation status (the third expedition)

Site number	Moisture	Soil	Class	Cover	Degree of self-overgrowing	Age
1	+	Sandy loam	4.(4.5)	90-95 %	Intensive	1-15
6	+	Sandy loam	4.(4.5)	90-95 %	Poor	10-15
8	+	Takyr	4.(4.5)	80-90 %	Medium	1-15
4	-	Takyr	4.(4.4)	70-80 %	Poor	10-15
11	-	Sands	4.(4.3)	90-95 %	Intensive	1-10
14	-	Sands	3.(3.1)	80-85 %	Poor	3-4
18	-	Sands	3.(3.1)	75-85 %	Medium	1-20
19	-	Sands	3.(3.1)	85-90 %	Intensive	1-20
20	+	Takyr	4.(4.5)	75-80 %	Medium	1-15

Table 10: Geobotanical description of selected sites with medium vegetation status (the third expedition)

Site number	Moisture	Soil	Class	Cover	Degree of self-overgrowing	Age
2.	+	Solonchak	2.(2.4)	60-70 %	Absent	Up to 10
7	+	Sandy loam	4.(4.5)	60-70 %	Medium	1-15
9	+	Takyr	4.(4.5)	60-75 %	Medium	1- 20
12	-	Sands	3.(3.3)	55-65 %	Medium	1-10
15	+	Sands	3.(3.3)	65-65 %	Poor	3-4
22	+	Sands	3.(3.1)	60-65 %	Absent	Up to 10

Table 11: Geobotanical description of selected sites with bad vegetation status (the third expedition)

Site number	Moisture	Soil	Class	Cover	Degree of self-overgrowing	Age
3	+	Sandy loam	4.(4.3)	5-10 %	Absent	Up to 3
5	+	Sandy loam	4.(4.2)	30-40 %	Poor	10-15
10	-	Sands	3.(3.3)	30-45 %	Medium	1-10
13	+	Solonchak	2.(2.3)	5-10 %	Absent	Up to 5
16	-	Sands	3.(3.3)	15-20 %	Absent	2-3
17	+	Solonchak	2.(2.4)	10-15 %	Absent	Up to 5
21	+	Solonchak	2.(2.4)	20-25 %	Absent	Up to 5
23	+	Solonchak	2.(2.3)	30-40 %	Absent	Up to 5

The objective of the third expedition
was to survey the sites after implementation of phyto-reclamation measures: planting Saxaul and other plant associations in Dzhiltyrbas region (dried part of the Aral Sea).

A chain of barchans, up to 5 m high, crosses the area in the north-eastern direction. The lithological structure is stratified. The soil is alluvial-meadow, residually alluvial, and solonchak of different hydromorphic degrees.

The southern part is almost fully covered by plantations. The northern part is planted partially. The surveyed area is a polygon to implement afforestation programs of several organizations at once: Karauzyak, Takhtakupyr, and Chimbay District Forestry Administrations, IFAS in collaboration with Karauzyak Administration of GTZ Project. It was difficult enough to determine a mechanism for area allocation, their territorial division and belonging. Availability of tablets does not always make the situation clear. Discrepancy was found often between tablet content and plantation status over area, as well as plant age. Since the surveyed area was large and heterogeneous, its description was made by separate massifs linked to the routes.

Young tree and shrub associations are the predominant characteristic vegetation. Tamarisk brushwoods are prevalent. Fine-blown saline crusts with abundant broken sea shells are on soil surface are abundant. The components of Saltwort- Black Saxaul association are white boyalysh and salt sea blite. The next microzone is formed by Saltwort- Black Saxaul associations. The last zone is formed by mixed groups of shrubs, fine-leaved sea blite and Siberian slitryanka. According to the data presented by the Forestry Administration of the Republic of Karakalpakstan, since 1989 till 2006 their branches spread seeds and young plants in 8 regions, as well as implemented forest-reclamation measures to develop the dried bed of the Aral Sea (Table 12).

Table 12: Areas of artificial afforestation, data of Forestry Administration

No.	Years of planting	Seed planting	Spreading young plants	Total
1	1989	11260	83,5	11343,5
2	1990	12940	300	13240
3	1991	8768	447	9215
4	1992	6438	322	6760
5	1993	8374	355	8729
6	1994	10180	178	10358
7	1995	11012	341	11353

No.	Years of planting	Seed planting	Spreading young plants	Total
8	1996	14332	550	14882
9	1997	14131	734	14865
10	1998	14127	696	14823
11	1999	5036	715	5751
12	2000	14500	580	15080
13	2001	16281	893	17174
14	2002	16580	1050	17630
15	2003	15080	1009	16089
16	2004	15500	1762,5	17262,5
17	2005	15000	2223	17223
18	2006 (the II quarter)	3000	700	3700
	Total	212539	12939	225478

The region covers from the south a group of former sea's water bodies, lakes and bays (Abass, Sarybass, Dzhiltyrbas), and former Amu Darya channels (Taldyk, Inzheneruzyak, Baltabayuzyak, Merdibek, Urdabay).

The territory is characterized by the greatest development both regarding the general area and its close location to the shoreline. This can partially be explained by the conditions more suitable for plantations, since the most part of this territory is represented by alluvial sediments of the fore-delta. The northern part is more prone to erosion due to blown sands on the surface. Sand movement reaches up to several kilometers per year. Sands form the dune massif, up to 1.5 m high, stretched as continuous lines towards the sea (Expedition 4).

The 4th expedition.

The region covers from the south a group of former sea's water bodies, lakes and bays (Abass, Sarybass, Dzhiltyrbas), and former Amu Darya channels (Taldyk, Inzheneruzyak, Baltabayuzyak, Merdibek, Urdabay).

The survey of plantings and seedlings enabled us to identify massifs that need phyto-reclamation measures and the area of which amounts to 12,700 ha (Tables 13-16).

Table 13: Plantation survey results, 4th expedition

Massif number	Massif number (ha)	Site 1 (%)	Site 2 (%)	Site 3 (%)	Mean Coverage density (%)
I	2771.95	40/100	5/20	55/10	43.3
II	2734.47	10/100	20/50	70/10	60
III	7188.12	30/100	55/90	25/0	65.3
IV	1935.84	10/100	50/90	40/20	70
V	5452.11	5/30	25/90	70/20	46.6
VI	4941.75	50/100	40/100	10/10	70.0
VII	7354.85	80	20	10	80.0

Massif number	Massif number (ha)	Site 1 (%)	Site 2 (%)	Site 3 (%)	Mean Coverage density (%)
		100	80	60	
VIII	17.597.27	70 100	25 80	5 100	93.3
Total	50000				66.0

Note: denominator shows percent of the total massif area;
numerator shows percent of surface coverage in given area.

Table 14: Geobotanical description of selected sites with good vegetation status (the fourth expedition)

Site number	Moisture	Soil	Class	Cover	Degree of self-overgrowing	Age
1	+	Sands	3.(3.5)	70-75 %	Absent	Up to 4
5	+	Sand	4.(4.5)	65-70 %	Poor	7-10
8	-	Sands	3.(3.3)	65-70 %	Medium	1-8
9	-	Sands	3.(3.5)	70-75 %	Medium	Up to 5
13	+	Sands	3.(3.3)	75-80 %	Medium	10
14	-	Sands	3.(3.5)	75-80 %	Medium	Up to 10
16	-	Sands	3.(3.3)	60-70 %	Medium	Up to 5
17	-	Sands	3.(3.5)	75-80 %	Medium	Up to 5
18	-	Sands	3.(3.5)	65-70 %	Poor	Up to 3
19	-	Sands	3.(3.3)	65-70 %	Medium	Up to 3
23	+	Solonchak	3.(3.1)	75-80 %	Absent	Up to 3
24	-	Sands	3.(3.5)	75-80 %	Poor	Up to 4
25	-	Sands	3.(3.3)	85-90	Intensive	Up to 10
26	+	Sands	3.(3.4)	60-65	Medium	Up to 5
27	+	Sands	3.(3.3)	65-70	Medium	Up to 5
29	-	Sands	3.(3.3)	65-70	Medium	Up to 10
30	+	Sands	3.(3.3)	75-85	Intensive	1-15

Table 15: Geobotanical description of selected sites with medium vegetation status (the fourth expedition)

Site number	Moisture	Soil	Class	Cover	Degree of self-overgrowing	Age
3	+	Solonchak	4.(4.3)	50-60 %	Absent	Up to 2
4	+	Solonchak	4.(4.3)	50-60 %	Poor	Up to 5
6	-	Sands	3.(3.4)	40-50 %	Medium	Up to 2
10	-	Sands	3.(3.1)	60-70 %	Medium	Up to 5
11	-	Sands	3.(3.1)	40-50 %	Absent	Up to 3
12	+	Sands	3.(3.2)	60-70 %	Absent	Up to 4

Site number	Moisture	Soil	Class	Cover	Degree of self-overgrowing	Age
20	+	Sands	3.(3.3)	60-65 %	Absent	Up to 3
21	-	Sands	3.(3.4)	50-60 %	Medium	Up to 5
22	-	Sands	3.(3.3)	60-65 %	Medium	Up to 5
28	-	Sands	3.(3.5)	60-65 %	Poor	Up to 4
31	-	Sands	3.(3.1)	50-55 %	Poor	Up to 5

Table 16: Geobotanical description of selected sites with bad vegetation status (the fourth expedition)

Site number	Moisture	Soil	Class	Cover	Degree of self-overgrowing	Age
7		Sandy loam	3.(3.1)	10-20 %	Absent	-
15		Sandy loam	3.(3.2)	20-25 %	Absent	-

New solonchaks and dunes emerged within former Amu Darya River mouths near the sea, where various Saltwort species develop here and there. Mixed Saxaul forest starts from the Amu Darya River side. Black and white Saxaul were planted there since 1977 till 1997. At present, their height is from 1 m up to 5 m Thick scrubs stretch up to the Amu Darya River. We gave geobotanical description for three site types in three replications, similar to the above-mentioned descriptions.

Of 12 testing sites, 8 sites have good establishment of plants, 2 sites have average establishment, and 2 sites have poor establishment. Overall, according to the results of our visual observations, the surface coverage of the study area is about 60%, of which 25-30% is under tree and shrub plantings and seedlings.

The 5th expedition covered the south-western part of Prearalie, the Adzhibay bay, Western sea part (Aktumsuk), Tigrovy Khvost, Muinak Bay, former Sorkul lake, Sudochie lake, Bakhyt region, etc. The described territory is characterized as the most developed in respect to tree and shrub plantings. In particular, it concerns the western part of the Muinak Bay around Tigrovy Khvost, as well as the eastern part of Uch Say and the Rybachie Bay. Barchans are met on major part of the Adzhibay Bay and fill up Sudochie Lake. Solonchak areas without vegetation occupy mainly the territory between the Bakhyt and the dried seabed. Vegetation is mainly represented by grass-Saxaul-Tamarisk associations. Saltwort, Sea blite and goose-foot and suppressed annual herbage are found on hydromorphic soils (Tables17-19).

Table 17: Geobotanical description of selected sites with good vegetation status (the fifth expedition)

Site number	Moisture	Soil	Class	Cover	Degree of self-overgrowing	Age
1	-	Sands, stony	3.(3.1)	70-85 %	Absent	Up to 5
3	-	Sand	3.(3.5)	65-70 %	Medium	Up to 7
4	-	Sands	3.(3.3)	65-70 %	Medium	Up to 7
7	-	Sands	3.(3.5)	85-90 %	Medium	Up to 8
8	+	Sandy loam	3.(3.3)	80-90 %	Intensive	1-12
10	+	Solonchak	2.(2.4)	65-75 %	Medium	
11	-	Sands	3.(3.1)	60-70 %	Medium	Up to 5
12	-	Sands	3.(3.3)	60-70 %	Medium	Up to 7

Table 18: Geobotanical description of selected sites with medium vegetation status (the fifth expedition)

Site number	Moisture	Soil	Class	Cover	Degree of self-overgrowing	Age
2	-	Sand	3.(3.1)	40-50 %	Absent	
6	-	Sand	3.(3.1)	50-60 %	Poor	1-10

Table 19: Geobotanical description of selected sites with bad vegetation status (the fifth expedition)

Site number	Moisture	Soil	Class	Cover	Degree of self-overgrowing	Age
5	-	Sand	3.(3.3)	20-40 %	Absent	Up to 3
9	-	Solonchak	2.(2.4)	30-40 %	Poor	-

Thus, the surveys conducted in given region indicated to slow self-overgrowing, with various shrub and herbaceous vegetation species in some parts of the dried seabed. Tree and shrub vegetations were and are planted artificially in some sites. However, there are zones prone to deflation processes, where relevant measures should be undertaken to protect water bodies (Sudochie Lake) and populated areas around Muinak.

4.1.5. Impact assessment of the afforestation measures on wind speed and soil erosion

For the impact assessment of the afforestation measures on wind speed, data of two meteorological stations on the desiccated sea bed was compared. Station WIND02 (N43°49’25”, E60°05’50”) was installed in the center of a Black Saxaul (*Haloxylon aphyllum*) afforestation patch from 2001. This particular afforestation site was selected due to several reasons:

i. it was one of the first afforestations planted by the GTZ project (→ age verified)
ii. trees show very healthy growth (height > 2m)
iii. natural succession and development is already taking place

The station WIND03 (N43°52’25”, E60°11’27”) was located 9,3 km East-Northeast of WIND02, on a non-vegetated flat Solonchak surface. Due to the proximity of the two stations, the “input” wind conditions are assumed to be similar and therefore, the differences in wind speed between the two stations can be linked to the differences in vegetation cover (i.e. the afforestation). Detailed results can be found in Blasch 2007. Fig. 48 shows the profiles of the two wind stations in comparison.)

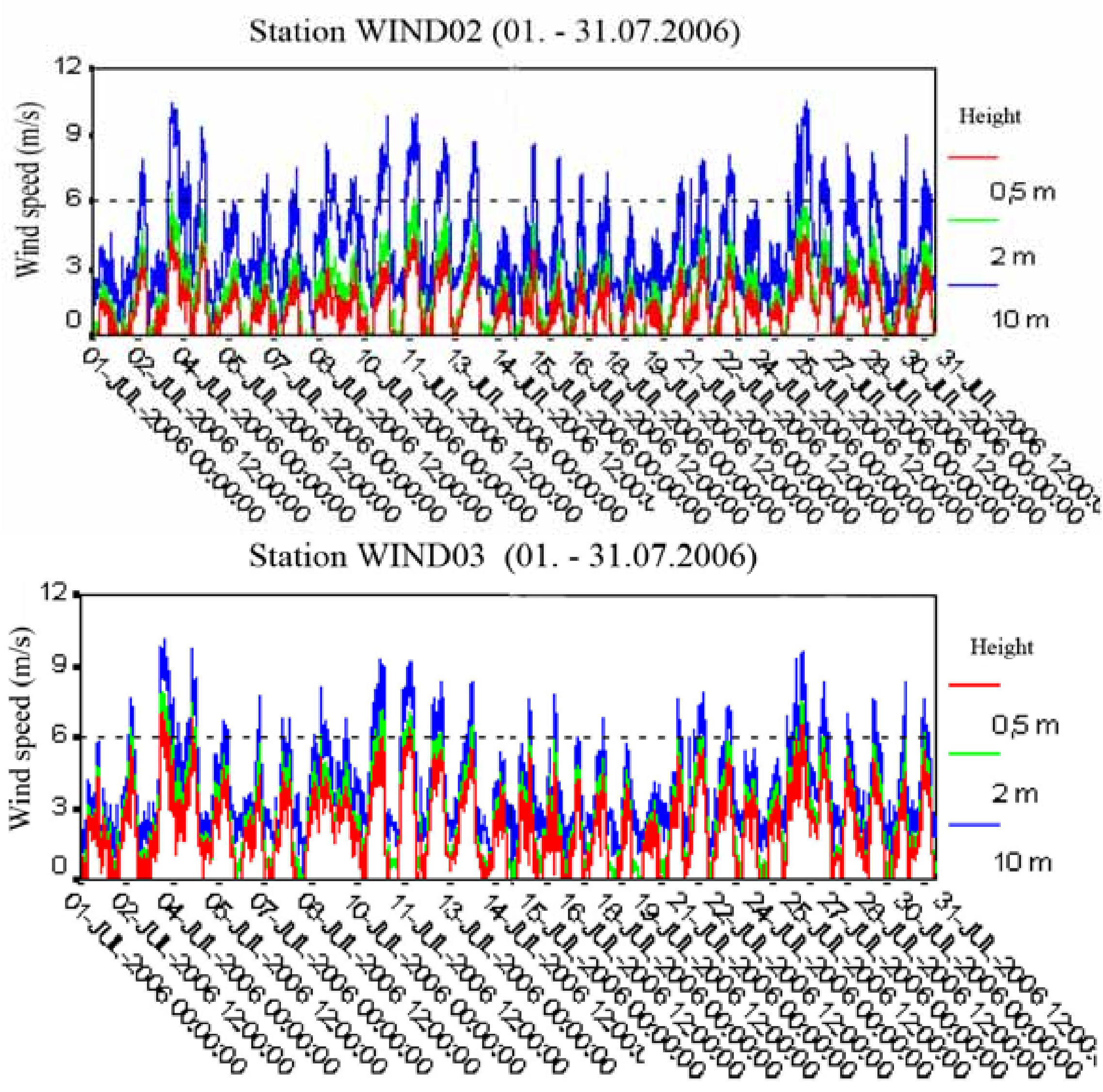


Fig. 48: Wind speed profiles for two stations on the desciccated Aral sea bed

The profile for station WIND03 (non-vegetated area) displays a very similar magnitude of the measurements in the three measure heights. Especially the plots for 0,5m and 2m overlay largely. It is also obvious, that even the close-to-surface winds (0,5 and 2m) reach the 6 m/s threshold for erosive winds during the peak times (July 03rd-05th, July 10th-12th, July 25th-27th).

In comparison to this, the profile for station WIND02 (vegetated area) differs in several characteristics. The plots for the different heights have a much smaller overlap, i.e. their wind speed magnitudes differ significantly. Furthermore, the surface near wind speed appears to be reduced in comparison to the measurements on the non-vegetated area.

These results are further underlined by the statistical measures shown inTable 20. While the mean wind speed at 10 m is almost identical among the two stations, it is significantly lower at 0,5 and 2m over the vegetated surface (WIND02). The surface near wind peaks also differ significantly: while the maximum values measured on the non-vegetated surface were 7 m/s (0,5m) and 8 m/s (2m), the peaks in the afforested area were 4,9 m/s (0,5m) and 6,4 m/s (2m), respectively.

Table 20: Wind speed characteristics on vegetated and non-vegetated surfaces in July 2006

	Height	Mean		Max	
		WIND02	WIND03	WIND02	WIND03
01st-14th	0,5m	1,2	2,3	4,9	7,0
	2m	1,8	2,8	6,4	8,0
	10m	4,1	3,9	10,5	10,1
15th-31st	0,5m	1,1	2,0	4,5	6,6
	2m	1,6	2,4	5,8	7,6
	10m	3,8	3,5	10,5	9,6

Assuming the general wind conditions to be similar in the two locations, these results indicate a positive (i.e. reducing) effect of the afforestation on wind speed. Thereby, it can also be assumed that the erosive impact of the wind is also reduced by the *Haloxylon aphyllum* trees. In order to underline this second assumption, a transect consisting of three BSNE sediment sampler clusters was established in a N-S orientation right next to the weather station. Fig. 49 shows the location of the three sand traps among the afforestation area.

Sampler 1:
North of afforestation
Active barchanoid dune field

Sampler 2:
Center of afforestation
2,5m Saxaul on flat dunes/ sand sheet

Sampler 3:
South of afforestation
Flat sand sheet with natural overgrowing

Fig. 49: Location of the three BSNE samplers

The afforested plants are supposed to reduce aeolian erosion in two ways: firstly, they fix the substrate by the development of an extensive root system and secondly, they increase surface roughness and thereby filter out aeolian sediment, which is transported in the air. The amount of the latter was measured in this study by the use of the BSNE samplers, in front of the afforestation, in the center and behind the afforestation, in reference to the dominant N-S wind direction. By collecting the transported sediment through a standardized opening, an estimation of the amount transported in one m² (vertical) was possible (Blasch 2007). Table 21 and Fig. 50 show the results of the measurements for the period May to August.

Table 21: Sediment amounts in three BSNE samplers May-August 2006

	Height (cm)	May	June	July	August
		kg/m²			
Sampler 1	15,0	272,5	1017,6	1055,4	N/A*
	40,0	120,0	286,5	333,8	238,5
	65,0	97,9	247,2	255,3	77,0

	Height (cm)	May	June	July	August
		kg/m²			
	150,0	48,4	85,2	74,0	29,1
Sampler 2	15,0	194,7	460,2	423,1	137,3
	40,0	62,4	228,1	223,6	67,2
	65,0	46,9	154,9	169,5	55,4
	150,0	30,9	115,4	114,7	38,0
Sampler 3	15,0	57,1	180,7	148,7	12,5
	40,0	28,6	99,4	118,4	18,1
	65,0	20,6	71,3	91,2	27,0
	150,0	15,2	55,4	76,0	45,0

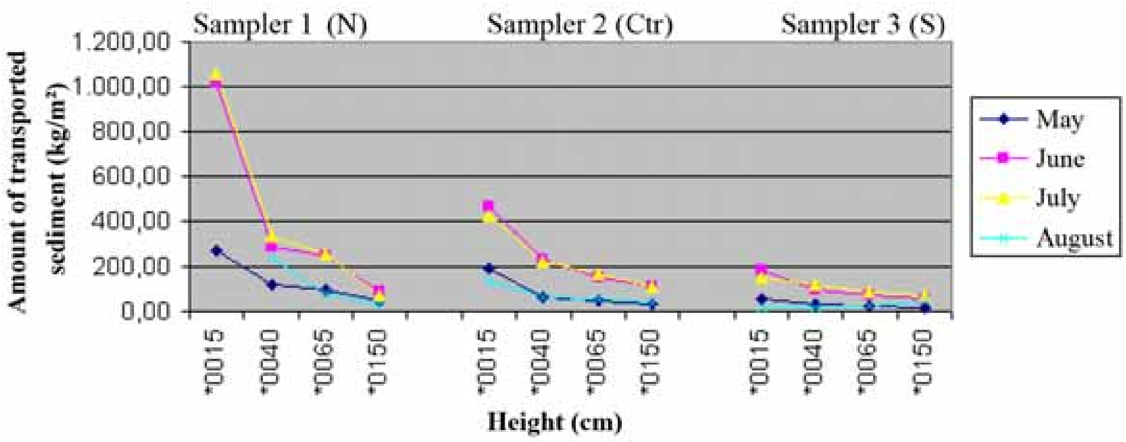


Fig. 50: N-S profile of sediment transport Haloxylon aphyllum afforestation of 2001

The table and figure show a clear N-S trend in the sediment transport: the more planting lines are passed, the less sediment is transported. This trend also is visible in the geomorphology in the area: while the northernmost sampler is situated in an active dune field (which indicates very high amounts of sand transport), sampler 2 (center of plantation) stands on a slightly undulating sand sheet. Finally, sampler 2 is situated in a flat terrain, which can be considered as a fixed sand flat.

Since the overall conditions on the three locations can be considered as similar, the factor which causes the decrease in sediment transport can only be the vegetation. This proves the positive effect of the Saxaul afforestation: on the long-term, a well-developed plantation is able to significantly reduce sediment transport and to transform a zone of active transport and erosion into a zone of accumulation and positive sediment balance.

Another interesting indicator for the impact of the plantation on sand transport is the fact that the lowest sand trap on sampler one was buried in the sand of an approaching dune by August 4th, while the other two samplers remained free of handicaps over the whole measurement period (Mai-November 2006).

Apart from the afforestation with *Haloxylon aphyllum*, another technique for moving sand fixation is the sowing of Selin (*Aristida karelini)* , a herbaceous psammophyte with very good sand fixation capabilities. These plants reach a height of up to 1,5m and up to 2m in diameter (including the underlying sand nebkha, which they accumulate over time). Due to its many fine leaves and stems, this plant filters large amounts of sediments out of the air and furthermore fixes the substrate over a large area with its extensive root system. Another very important fact about Selin is its potential use as a fodder plant for livestock. Thus, when an area is sustainably developed with Selin, it can also be taken into a (careful) economic use.

Similar to the experiment described above, the impact of a Selin plantation was assessed in a set-up of two sediment sampler, separated about 800m. Fig. 51 shows the situation of the samplers: Sampler 1 was set-up on a vegetation free sand flat covered with mussels, while sampler 2 was established on the very same sand flat, but featuring a 25% projective cover of *Aristida karelini* with a growth height of approximately 0.8-1m.

Sampler 1
Sand flat with mussels

Sampler 2
Sand flat with mussels and *Aristida karelini*

Fig. 51: Situation of the two BSNE sediment samplers for Selin impact assessment

Fig. 52 shows the plots of transported sediment for the period June-August 2006. The higher amount of transported sediment over the non-vegetated area is striking, especially right above the surface (15cm). Depending on the measured month, the sediment transport is 93-111 times (15cm), 16-41 times (40cm), 2,2-8 times (65cm) and still 1,7-2,3 times higher (150cm) than on the vegetated area. Even though the most obvious differences are found in the very surface-near layers, the sediment transport in 150cm height and above is also reduced by about 40-55%.

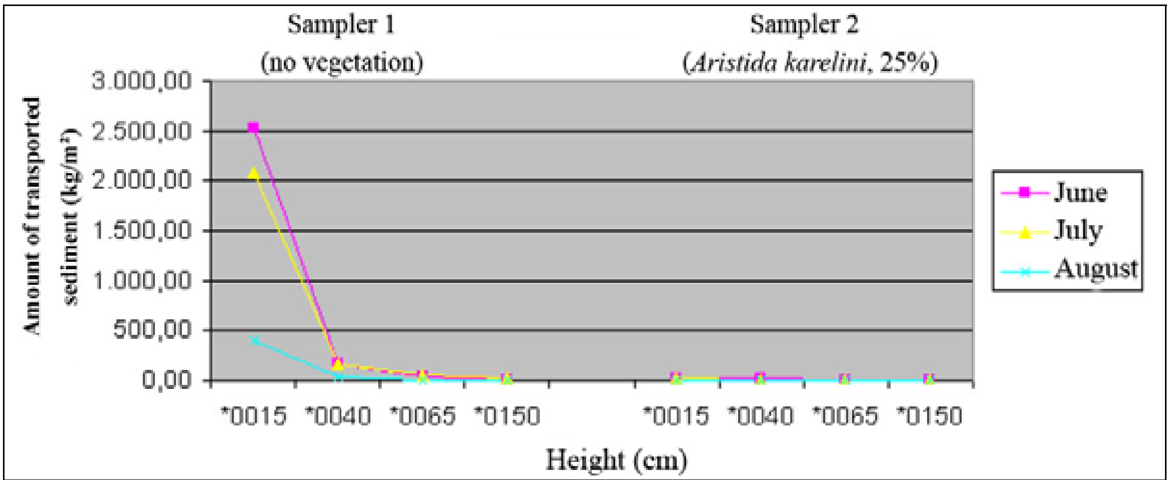


Fig. 52: Sediment transport profiles of a non-vegetated sand flat and a Selin plantation

These results underline the before mentioned characteristics of Selin as a formidable “sediment catcher”. This suggests that the use of Selin should be enforced in future phytomelioration activities. However, Selin is a typical psammophyte, and thereby will only grow on sandy substrate with low to moderate salinity. These conditions are typically found on sand sheets and moving sands, i.e. in moderately to highly dynamic landscapes. Therefore, mechanical fixation, like shown in Fig. 53, should be considered before the sowing of *Aristida karelini*, in order to stop the sand from moving and thereby improve the planting success and sustainability of the plantation.

Fig. 53: Mechanical fixation of sand sheets and dunes with reed cane

4.2. Remote sensing based landscape assessment

4.2.1. Results of the supervised land cover mapping

After the spectral characteristics of the reference sites were analyzed, the image pixels were assigned to the reference class, i.e. supervised classification has been performed. The Minimum distance to means classifier was chosen as the most appropriate, since it yielded the best map result and statistical accuracy.

The Minimum Distance method is based on a deterministic approach. Hereby, the reference class means are calculated for each band, leading to a mean vector in the multidimensional feature space. Each pixel is then assigned to the reference class, of which the Euclidian distance from the class mean is minimized. (Lillesand & Kiefer 1994). Fig. 54 shows the result of the Minimum distance classification.

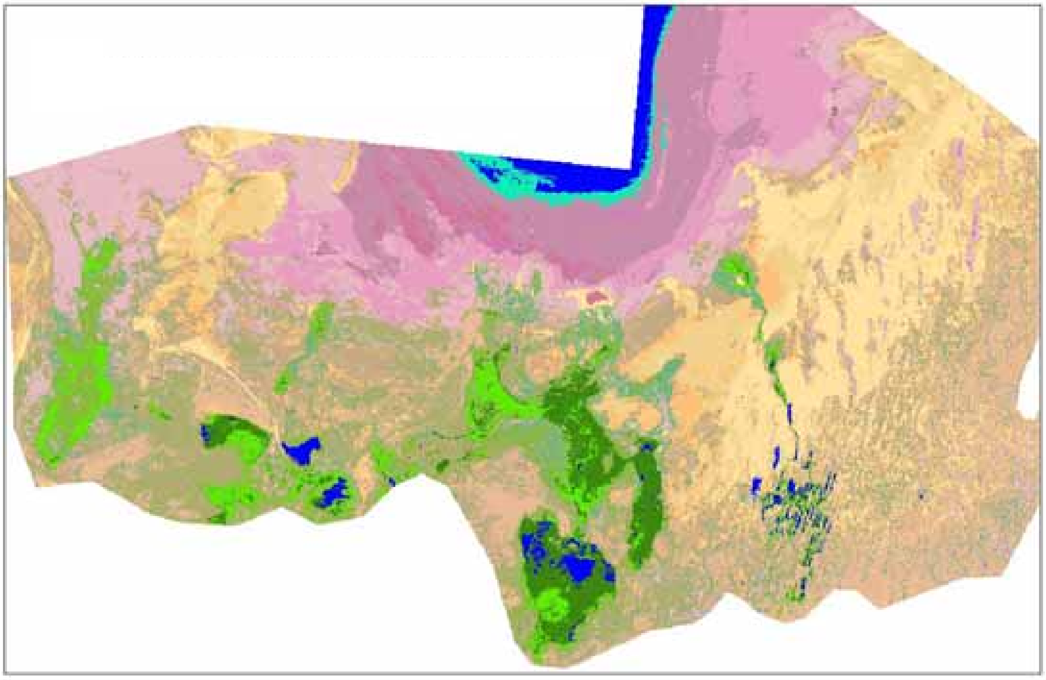


Fig. 54: Supervised classification results

Table 22 contains the legend of the land cover map as well as an area estimation for the classes. Fig. A1 in the appendix shows the classification result in a thematic map layout.

The thematic land cover classes extracted from the satellite image allow the evaluation of the erosion risk of the territory, as described in chapter 0. The results of this risk assessment will be presented in chapter 0.

Table 22: Legend of the land cover map

NN	*Class*	*Color*	*Area (ha)*	*%*
1	**WATER**			
1.1.	Water surface		72848,4	3,16
1.2.	Shallow water, sometimes with reed		25753,4	1,12
2	**SOLONCHAK**			
2.1.	Marsh soil, without vegetation or with Saltwort community		176185,0	7,63
2.2.	Wet-coastal, with cockle-shell, spots of Saltwort and Sarsazan		163604,0	7,09
2.3.	Desert crust-puffed and crust soil, without vegetation, spots of bushes (Karabarak, Tamarisk)		24252,0	1,05
2.4.	Solonchak with blown sand cover, sparse Orach and Selin communities		233747,0	10,12
2.5.	Shor solonchak of closed sinks, without vegetation, sometimes in Sarsazan setting		6461,0	0,28
3	**SANDS**			
3.1.	Plain (with shell rock), without vegetation or sparse bushes (Saxaul, Tamarisk)		231935,0	10,05
3.2.	Dune, without vegetation		161855,0	7,01
3.3.	Pit-and-mount (poor fixed) with sparse wormwood, bush communities and Selin plantings		157498,0	6,82
3.4.	Hilly, hilly-ridge, without vegetation and poor fixed		197222,0	8,54
3.5.	Hilly, hilly-ridge, poor-fixed with ephemeral-wormwood-bush communities		199462,0	8,64
4.	**PLAIN DELAIC AND OF DEPOSITION**			
4.1.	Meadow on alluvial plains (reedy, forb-Gramineae) on alluvial-meadow, bog-meadow and meadow-bog soils		121101,0	5,25

NN	Class	Color	Area (ha)	%
4.2.	Subjected to desertification, hydromorphic Gramineae -halophyte-forb, with bushes		111891,0	4,85
4.3.	Shrub (halophyte: Tamarisk Karabarak)		149354,0	6,47
4.4.	Subjected to desertification, shrub		59368,0	2,57
4.5.	Shrub-Saxaul (desert forest/artificial plantations)		216163,0	9,35
			2308700	100

4.2.2. Accuracy assessment

Classification accuracy assessment was conducted by the use of a confusion matrix. In this commonly accepted technique, the classification result is compared to an independent validation dataset (ground truth). In this study, the validation samples consisted only of field data, which has not been used for the training of the classifier in beforehand, in order to avoid bias in the validation procedure. Table A1 in the appendix gives an overview of validation samples used for each class and the expeditions on which the samples were collected.

For some classes, there were no validation samples available. These include the water classes (1.1, 1.2) as well as the marsh soil class (2.1). The reason for the missing validation data is the inaccessibility of these areas in the field. This has to be kept in mind when interpreting the accuracy results.

Analysis of the error matrix revealed the following measures:

- Overall classification accuracy = 77,90 %
- Overall Kappa index of agreement = 0,7509

Overall accuracy states the percentage of the validation samples classified correctly. Hereby, it is assumed that the validation dataset is true. The Kappa index of agreement differs in the underlying assumption: It is assumed that the tested classification and the validation samples are independent class assignments of equal reliability. It measures, how well the classification and the validation datasets match, taking chance agreement into account. This means that the match of a validation sample with a correct classified pixel can be merely incidental. A perfect match of classification and ground truth would lead to a value of 1. Both measures are well accepted for the evaluation of remote sensing classification results.

Table 23 shows the confusion matrix used in this study. The lines in the table represent the classes in the image classification, while the columns represent the classes in the ground truth data. The diagonal axis in the table show the samples classified correctly. It can easily be seen that the majority of the samples are situated in the diagonal axis. Table 24 shows the percentage of the correctly classified samples for each class.

Table 23: Estimation of classification reliability using field observations

Classes	1.2	2.2	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5	**Total**
1.1	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1.2	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
2.1	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
2.2	0	0	0	**7**	3	0	0	0	0	0	0	0	0	0	0	0	0	**10**
2.3	0	0	0	1	**14**	4	1	1	0	0	0	0	0	0	0	0	0	**21**
2.4	0	0	0	0	1	**26**	0	3	0	0	0	2	0	0	0	0	0	**32**
2.5	0	0	0	0	2	0	**4**	0	0	0	0	0	0	0	0	0	0	**6**
3.1	0	0	0	0	0	5	0	**22**	4	0	0	0	0	0	0	0	0	**31**
3.2	0	0	0	0	0	0	0	3	**18**	3	3	0	0	0	0	0	0	**27**
3.3	0	0	0	0	0	3	0	1	2	**34**	1	4	0	0	0	1	0	**46**
3.4	0	0	0	0	0	0	0	0	0	2	**26**	2	0	0	1	2	0	**33**
3.5	0	0	0	0	0	0	0	0	0	3	4	**44**	0	0	4	0	2	**57**
4.1	0	0	0	0	0	0	0	0	0	0	0	0	**3**	2	0	0	0	**5**
4.2	0	0	0	0	0	0	0	0	0	2	0	1	1	**10**	0	3	1	**18**
4.3	0	0	0	0	0	0	0	0	0	0	0	6	0	0	**23**	2	5	**36**
4.4	0	0	0	0	0	0	0	0	1	1	2	3	0	1	0	**20**	3	**31**
4.5	0	0	0	0	0	0	0	0	0	6	0	0	0	0	4	3	**26**	**39**
Total	**0**	**0**	**0**	**8**	**20**	**38**	**5**	**30**	**25**	**51**	**36**	**62**	**4**	**13**	**32**	**31**	**37**	**392**

Table 24: Classification accuracy on the basis of field observations

NN	*Class*	Accuracy, %
2.2.	Wet-coastal, with cockle-shell, spots of Saltwort and Sarsazan	87,50
2.3.	Desert crust-puffed and crust soil, without vegetation, spots of bushes (Karabarak, Tamarisk)	70,00
2.4.	Solonchak with blown sand cover, sparse Orach and Selin communities	68,42
2.5.	Shor solonchak of closed sinks, without vegetation, sometimes in Sarsazan setting	80,00
3.1.	Plain (with shell rock), without vegetation or sparse bushes (Saxaul, Tamarisk)	73,33
3.2.	Dune, without vegetation	72,00
3.3.	Pit-and-mount (poor fixed) with sparse wormwood, bush communities and Selin plantings	66,67
3.4.	Hilly, hilly-ridge, without vegetation and poor fixed	72,22
3.5.	Hilly, hilly-ridge, poor-fixed with ephemeral-wormwood-bush communities	70,97
4.1.	Meadow on alluvial plains (reedy, forb-Gramineae) on alluvial-meadow, bog-meadow and meadow-bog soils	75,00
4.2.	Subjected to desertification, hydromorphic Gramineae - halophyte-forb, with bushes	76,92
4.3.	Shrub (halophyte: Tamarisk Karabarak)	71,88
4.4.	Subjected to desertification, shrub	64,52
4.5.	Shrub-Saxaul (desert forest/artificial plantations)	70,27

The class-wise comparison reveals the following classification problems. Wet solonchaks (2.2), including shor solonchaks of closed sinks (2.5) reached the highest accuracy. Class 2.3 was confused with classes 2.2 and 2.5. The reason lies in the discrimination of these classes mainly through the blown sand cover in class 2.3. If this sand cover is only minor, the classes are difficult to distinguish accurately in the satellite image through their spectral properties. The same problem occurred for class 2.4: it was mixed up with classes 2.3, 3.1 and 3.3. Even though all of these classes feature different soil characteristics, they have in common a sparse shrubby vegetation cover. This results in a light vegetation signal in the spectra of these classes, which overlays the soil signal and thereby confuses the classifier. The same explanation is applicable for class 4.4, confused with 4.2, 4.3 and 4.5. and also class 3.5 (mixed with 3.4, 4.3 and 4.5. Another reason for class confusion is that some points of the field surveys were located at the interface of two land cover classes. Contours and boundaries of marsh and wet solonchaks need to be defined more accurately, as well as coast lines and their change under effect of wind speed fluctuations should be determined.

For the solonchak classes 2.3 and 2.4, it is necessary to acquire additional points for the training stage of the classification in order to define their spectral characteristics more precisely, and thereby allow a better discrimination. For class 2.4, a better determination of quantity and composition of the blown sands might increase the classification accuracy. For all sand classes (3.1 - 3.2), a more accurate description of sand texture could more precisely define spectral characteristics and allow a better separation.

These class discrimination problems are typical for arid, sparsely vegetated environments being mapped with multispectral RS data. The image pixels seldomly represent a pure land surface (like soil, sand or vegetation), but rather most of the time show a mixed signal of these features. One workaround for this problem would be a classification scheme with less detailed class descriptions, i.e. in this case a merge of spectrally too similar classes.

Due to the objectives of this study, the detailed classification scheme was indispensable. For the assessment of desertification and erosion risk, the discrimination of the given land cover classes was necessary, but could only be reached by a drop in classification accuracy. Nevertheless, the results are considered as satisfying for the given tasks of this study.

For further research it is advisable to follow a multi-temporal approach, i.e. analyzing images taken in different times of the season. For systematic monitoring purposes, a periodical seasonal satellite acquisition is needed, accompanied by timely field surveys. This approach will correspond to the basic tasks of a satellite monitoring, allow the better identification of class boundaries and give more accurate information on the temporal development of the vegetation cover.

4.3. Ecological hazard assessment on basis of the land cover map

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

The development of the theory of natural-territorial systems is associated with such names as L.S. Berg (1908), V.I. Prokayev (1967), N.A. Solntsev (1981), A.G. Isachenko (1991), F.N. Milkov (1973) and others. The natural-territorial systems are in essence biospheric systems, and they are traditionally studied in the context of physio-geography and biogeography as landscapes. Landscape is a genetically homogeneous natural-territorial system. It is a basic unit of physio-geographic zoning, a genetically indivisible zone with uniform relief, geological structure, climate, general character of surface and groundwater, typical combination of soils, plant and animal communities. We follow the territorial conception of landscape and consider that when the matter concerns nature types (deserts, mountains, etc.), it is necessary to speak about landscape type. Thus, in both territorial and typological terms, landscape is a natural system consisting of different components. One of the major landscape components is vegetation cover.

Landscape is inherently a highly disbalanced dynamic system, for which daily, annual and multi-annual rhythms are characteristic (Perelman 1975). We regard the current transformation of the natural environment in Prearalie on a regional scale as anthropogenic-induced aridization. The particular feature of this process is that man acted as a trigger. The further landscape evolution proceeds under natural laws towards the formation of climax and quasi-climax options. Since the given processes take place under desert zonal conditions, the leading factor of dynamics is moisture reduction, and the landscape evolves towards the forms corresponding to desert systems. This process is referred to as "desertification".

Based on the scale of ecological hazard and agreed class recoding (see chapter 3.2.5), the results of the supervised classification were transformed into a map showing the ecological hazard degree (Fig. 55). Based on this map, an area calculation of each ecological hazard class was done (
Table 25).

Table 25: Area estimation for the ecological hazard classes

Risk class	Area [ha]	Map color
No (practically absent)	858621.4	green
Low risk	311353	yellow
Moderate risk	280842	orange
High risk	785035	red

Fig. 55: Map of erosion risk

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

It is very important to estimate the dynamics of the desertification processes (according to the ecological hazard degree) observed in the territory of the exposed Aral Sea bed. Unfortunately, information material of a similar level of detail of this study is not available for the last years. Therefore, it is attempted to compare the results of the Landsat data processing of 2006 with the following two maps:

- *"South Prearalie Landscape Map", as of 1990 (A. Chernyshev, SANIIRI, digitized by SIC ICWC);*
- *"Map of lithological composition of cover (quaternary) deposits on the dried bed of the Aral Sea" as of 1993-1996 (B. Pinkhasov et al.), provided to us under a contract within the framework of the project*

Since the underlying methodical approaches as well as the purpose of these maps differed significantly, we tried to bring the thematic classes and types of landscapes in natural-territorial systems to a comparable form. The "*South Prearalie Landscape Map*" was generated using field survey results. Unfortunately, the territory of the Akpetki archipelago is not fully covered by this map). The "Map of lithological composition of cover (quaternary) deposits on the dried bed of the Aral Sea" describes the local conditions for 1993-1996 (produced by Institute GIDROINGEO, based on detailed hydro-geological studies of the exposed Aral Sea bed).

Chernyshev's map (Table A2 in the appendix) shows 11 classes with a description of soil, hydro-geological, biological and landscape features. This enabled the establishment of a link to the classes of this study, since all of the indicators of the 1990 map are also available in the detailed table of field survey results for 2005/2006.

This map covers an territory of 823,900 ha, but due to drying-up of the sea extends constantly, doubling up to 1,772,500 ha towards the north. The comparison gave interesting data as shown in Table 26.

Table 26: Change of aggregate indicators by comparing landscape assessments for 1990-2006, thousand ha / %

<table>
<tr><td rowspan="2">Risk degree</td><td colspan="2">Areas by risk degree</td><td colspan="2">Total vegetation covered area</td></tr>
<tr><td>1990</td><td>2006</td><td>1990</td><td>2006</td></tr>
<tr><td>1
(absent)</td><td><u>199.4</u>
24.2%</td><td><u>760.2</u>
42.9%</td><td></td><td></td></tr>
<tr><td>2
(low)</td><td><u>187.5</u>
22.8%</td><td><u>384.0</u>
21.7%</td><td rowspan="2"><u>54.1</u>
6.5%</td><td rowspan="2"><u>512.1</u>
28.9%</td></tr>
<tr><td>3
(moderate)</td><td><u>193.6</u>
23.5%</td><td><u>23.2</u>
1.3%</td></tr>
<tr><td>4
(high)</td><td><u>243.4</u>
29.5%</td><td><u>605.0</u>
34.1%</td><td></td><td></td></tr>
</table>

Thus, the percentages of the risk classes in the study territory have changed significantly. Areas with no ecological hazard increased by 18.7%, caused by a considerable increase in area of the wet coastal solonchaks. These don't represent ecological hazard during the first 3-6 years after exposition by the receding water. Furthermore, the increase of the non-hazardous areas results from the extension of high- projective covered vegetative areas (mainly shrubs, Black Saxaul). The high risk areas have increased by almost 5% due to the expansion of crust-puffed solonchaks. The areas with moderate ecological hazard have considerably decreased by 20% as compared to 1990 which can be explained by natural overgrowing processes observed on the dried seabed. For example, after the construction of a dam on Lake Sudochie, shrub areas within the former Adzhibay bay expanded noticeably. According to the "South Prearalie Landscape Map", as of 1990, the vegetation-covered area in the former Adzhibay bay amounted to 3,700 ha, while in 2006 it reached 29,700 ha, i.e. the overgrown area increased by the factor 8.

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

Even though these estimates give a first impression of the dynamics of the emerging ecosystem, it is necessary to stress that these processes are on-going and that in-depth studies are required in order to validate these estimates.

According to the field observations, overgrowing is particularly enforced near and at the end of artificial plantations, as well as especially on hydromorphic and semi-hydromorphic soils with Saltwort and ephemeral plants (e.g. in Adzhibay bay). This shows impressively the positive effects of the anthropogenic mitigation efforts on the ecologic situation on the dried sea bed.

4.4. Review of the afforestation measures on the southeastern Aral Sea coast

Table 27: Characteristics of the 70 afforestation patches

ID	Area [ha]	Year of planting	Natural shrubs	Shrubs per area [1/ha]	Length planting lines total [m]	Length planting lines successful [m]	Length planting lines unsuccessful [m]	Growth success rate	Mean planting direction [°]
0	175,14	N/A	441	2,52	45042	33644	11399	0,747	75
1	148,4	N/A	327	2,2	75000	36473	38528	0,486	77
2	43,7	N/A	198	4,53	2813	1372	1441	0,488	112
3	104,15	N/A	310	2,98	12305	6928	5377	0,563	112
4	22,73	N/A	0	0	12915	6251	6664	0,484	111
5	166,07	N/A	71	0,43	70387	29057	41330	0,413	115
6	56,03	N/A	18	0,32	44499	19367	25132	0,435	114
7	79,34	N/A	101	1,27	29272	13539	15733	0,463	120
8	40,15	N/A	167	4,16	8491	3425	5067	0,403	110
9	48,4	N/A	16	0,33	40371	16171	24200	0,401	123
10	22,09	N/A	65	2,94	3562	1327	2235	0,372	13
11	58,13	N/A	232	3,99	3406	2023	1383	0,594	117
12	16,38	N/A	2	0,12	10722	5214	5508	0,486	69
13	44,64	N/A	103	2,31	16828	7528	9299	0,447	82
14	72,45	N/A	100	1,38	36858	18319	18539	0,497	84
15	103,89	N/A	375	3,61	41874	21643	20231	0,517	19
16	203,1	N/A	976	4,81	13443	8033	5410	0,598	167
17	72,07	N/A	144	2	40037	17905	22131	0,447	126
18	96,27	N/A	76	0,79	11238	5380	5858	0,479	82
19	120,75	N/A	351	2,91	65220	40875	24344	0,627	48
20	328,71	N/A	635	1,93	78119	41787	36331	0,535	97
21	170,61	N/A	366	2,15	84900	68186	16714	0,803	114
22	71,34	N/A	353	4,95	6023	3785	2238	0,628	96
23	86,08	N/A	421	4,89	21945	10746	11199	0,49	90
24	347,87	N/A	471	1,35	63646	37815	25830	0,594	73
25	194,6	N/A	200	1,03	30491	17651	12840	0,579	97

	Area	Year of planting	Natural shrubs	Shrubs per area	Length planting lines total	Length planting lines successful	Length planting lines unsuccessful	Growth success rate	Mean planting direction
26	282,2	N/A	1118	3,96	29490	19205	10286	0,651	94
27	161,9	N/A	0	0	32836	9069	23768	0,276	70
28	88,89	N/A	0	0	35467	12269	23199	0,346	85
29	219,83	N/A	27	0,12	149155	89924	59231	0,603	84
30	157,98	N/A	0	0	47285	29151	18134	0,616	74
31	103,05	N/A	484	4,7	1606	921	685	0,574	166
32	63,36	N/A	91	1,44	38725	27266	11458	0,704	86
33	47,87	N/A	8	0,17	23492	12953	10539	0,551	20
34	195,95	N/A	322	1,64	60022	33719	26304	0,562	44
35	189,49	N/A	898	4,74	38554	17856	20698	0,463	47
36	130,41	N/A	380	2,91	2802	2187	615	0,781	89
37	203,25	N/A	34	0,17	9221	5928	3293	0,643	98
38	108,95	N/A	2	0,02	5933	3952	1982	0,666	107
39	31,74	N/A	0	0	63	57	7	0,893	105
40	11,83	N/A	38	3,21	3187	880	2307	0,276	12
41	366,28	N/A	N/A	N/A	72522	40307	32215	0,556	129
42	78,72	N/A	N/A	N/A	23777	15214	8563	0,640	70
43	296,91	N/A	N/A	N/A	70832	49324	21508	0,696	153
44	33,01	N/A	N/A	N/A	4370	3330	1040	0,762	121
45	906,79	N/A	N/A	N/A	177791	105260	72531	0,592	107
46	243,48	N/A	N/A	N/A	58193	30341	27852	0,521	98
47	221,38	N/A	N/A	N/A	37422	11555	25867	0,309	87
48	238,32	N/A	N/A	N/A	25495	15279	10216	0,599	103
49	5,90	N/A	N/A	N/A	3177	1804	1373	0,568	101
50	95,52	N/A	N/A	N/A	12683	7118	5564	0,561	94
51	198,96	N/A	N/A	N/A	15278	8654	6624	0,566	105
52	99,42	N/A	N/A	N/A	44351	14223	30128	0,321	97
53	114,49	N/A	N/A	N/A	51272	14291	36980	0,279	119
54	10,87	N/A	N/A	N/A	2554	1810	744	0,709	117
55	33,64	N/A	N/A	N/A	6689	2039	4651	0,305	118
56	92,51	N/A	N/A	N/A	34739	20985	13754	0,604	97
57	18,80	N/A	N/A	N/A	2764	1932	832	0,699	137
58	97,94	2007	N/A	N/A	N/A	N/A	N/A	N/A	N/A
59	94,57	N/A	N/A	N/A	20516	14668	5848	0,715	105
60	37,38	N/A	N/A	N/A	15277	10775	4502	0,705	102
61	26,97	N/A	N/A	N/A	10522	6159	4363	0,585	85
62	182,98	N/A	N/A	N/A	45819	13120	32698	0,286	95
63	108,32	N/A	N/A	N/A	14954	5060	9894	0,338	140
64	309,52	N/A	N/A	N/A	37417	24077	13340	0,643	139
65	19,25	N/A	N/A	N/A	10071	8169	1902	0,811	160
66	276,73	N/A	N/A	N/A	43582	27775	15808	0,637	104
67	16,07	N/A	N/A	N/A	5399	3208	2190	0,594	134
68	48,47	N/A	N/A	N/A	9958	4467	5491	0,449	104
69	25,04	N/A	N/A	N/A	6512	4353	2159	0,668	84
Total	**9188,039597**				**220026**	**121832**	**98195**	**0,549**	

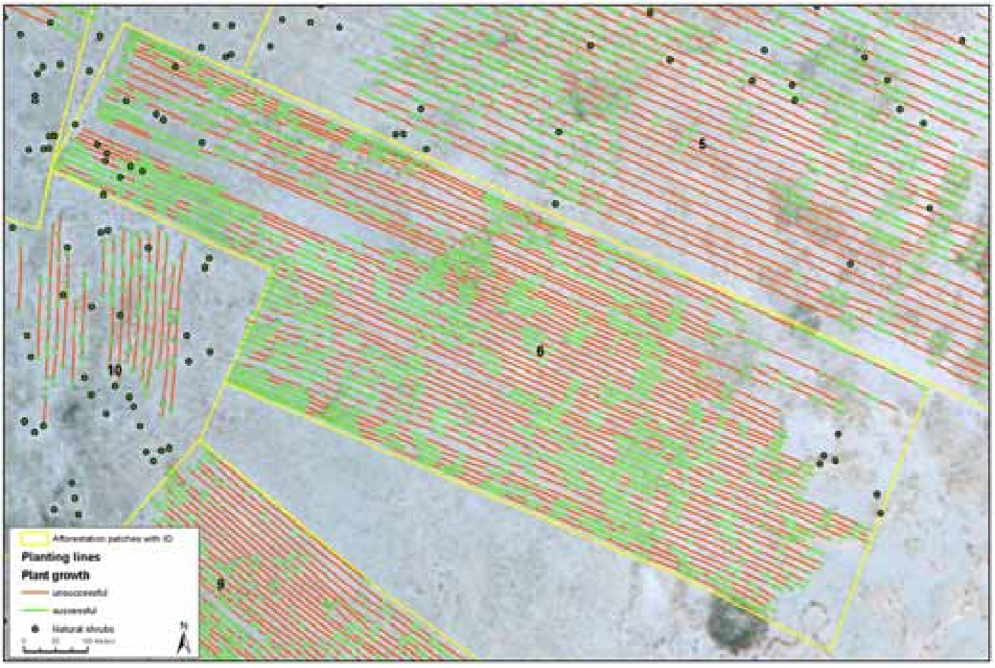


Fig. 56: Afforestation patch with digitized planting lines

Table 27 shows an overview of the artificial afforestations inventorized by high-resolution remote sensing data, as described in chapter 3.3. It is obvious that the success rate has a strong variation, within the afforestation patches (Table 27) as well as among the patches (Fig. 56). The primary explanation for this variation is the intensive heterogeneity in the site conditions (substrate, groundwater). On the other hand it is also dependent on the total length of planting lines identifiable in the satellite images. It has to be considered that only clearly visible line segments were mapped by the interpreter, whereas areas with no identifiable plantings were not considered in the growth success rate. Planting direction of the afforestation patches also shows a high variation among the patches (Fig. 57, Table 27).

The frequency distribution of patch directions indicates that 42 patches are oriented in East (East-Northeast to East-Southeast), 17 in South-East, 7 in North-South and 3 in North-East direction. Considering a prevailing Northern to North-Eastern wind direction estimated for the North of Karakalpakstan (derived from measurements of Muynak and Takhtakupyr meteorological stations during the 2000 dust storm season, as well as long-term and large-scale climatic studies (Wiggs et al., 2003; Kabulow, 1990; Kitoh et al., 1993, cited in Letolle & Mainguet, 1996) , then the 42 patches in East direction (60% of all patches) are designed approximately perpendicular against this dominant wind direction and thereby serve as suitable wind breaks.

The suitability of the orientation of the remaining 40% afforestation patches has not yet been evaluated in detail. Detailed explicit information on the locally occurring wind directions of 2006 shows a rather wide variation of the prevailing erosive winds (speed >6 m/s).

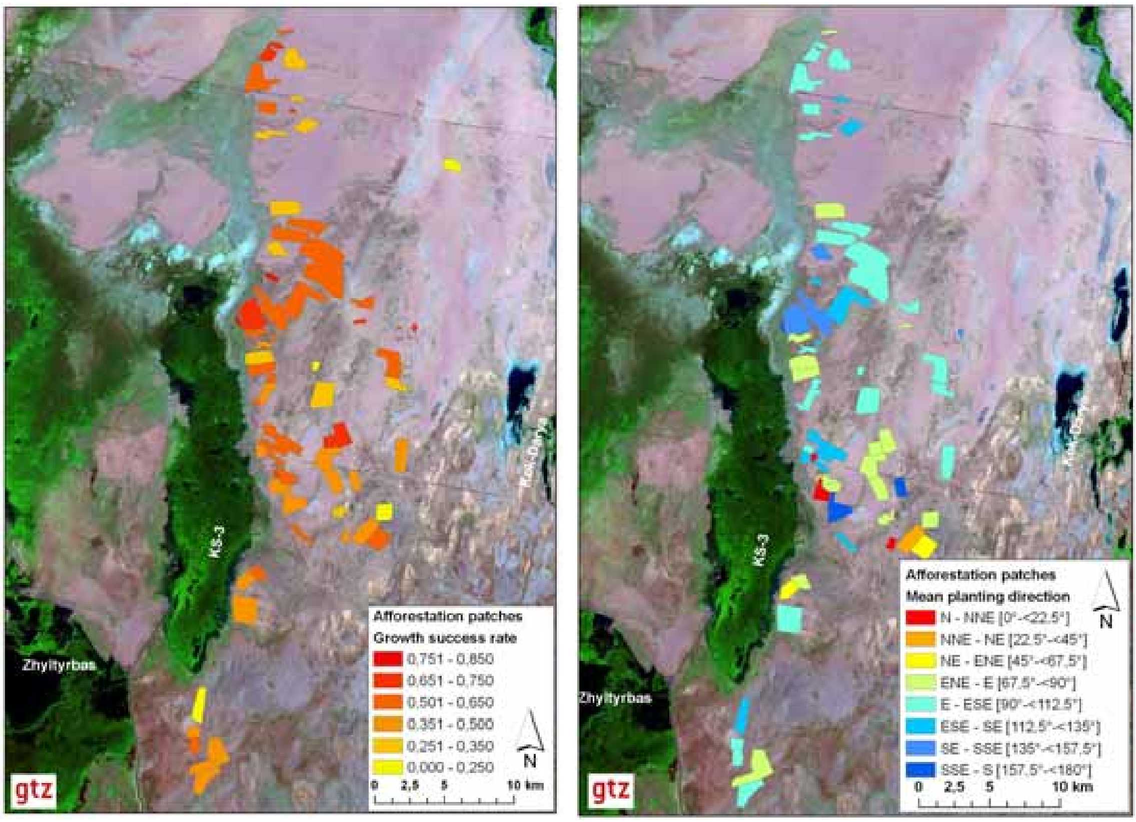


Fig. 57: The afforestation patches, classsified by growth success and planting direction

These distributions can be used to justify variable planting directions, even though a parallel adjustments of the planting lines might induce canalizing effects on the wind. However, detailed assessments on the effect of wind-parallel lines are not available yet and it remains unknown if the possible canalizing overrides the increased surface roughness provided by the afforestations as well as the induced self-overgrowing.

Demarcating the boundaries of the patches for measuring area size is a rather subjective process. It is the decision of the interpreter whether plantations belong to a patch or not. By applying the same criteria on all afforestation patches, the spatial location and extent could be determined reliably and inconsistencies in the data could be minimized.

Information about the age of the plantations could not be extracted from the satellite scenes. Therefore, dendro-chronologic methods could be applied in the field to obtain this information.

5. Discussion

5.1. Soil cover dynamics and their effect on the ecological hazard

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

The on-going desiccation of the Aral Sea leads to changes in the hydro-geological conditions of soil formation, especially within the emerging coastal zone. In the final stages of soil evolution, hydromorphic solonchak-formation processes stop, handing over to the arid-zonal factors that contribute intensively to further transformation of the soil into desert types. Depending on the lithological composition, solonchaks can be de-salinized and thereby be transformed into takyr soils or undergo deflation and be, changed into sands.

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

Fig. 58 shows the main effective forces inducing a change in the soil and landscape and their effect on the landscape classes determined in the previous chapters. Listed in a temporal order, these are: desiccation of the sea, subsequent development of deflation processes, desiccation of lakes and depressions in island and other systems, desertification (or inundation) of the delta, self-overgrowing and man-made plantations in combination with deflation-aeolation processes, deflation processes in affected and poor-overgrown barchans and dunes, and development of self-overgrowing in the area of artificial plantations.

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

If it would be possible to maintain a stable water level in the Sea, or a level periodically fluctuating within 1-1.5 m, as it was in 2003-2005, then the hydromorphic and semi-hydromorphic regime of the zones near the shoreline would keep a stable moistening and a gradual development of Saltwort and sometimes Sarsazan would be possible. While a transformation from one hydromorphic soil class to another one keeps a minimum degree of ecological risk (Fig. 58, transformation from 2.1-2.2 into 2.5), the transformation into automorphic soils immediately put the respective landscapes to next higher risk classes 3 and even 4. Under abrupt drops in the sea level, solonchaks immediately transform into automorphic soil of the respective landscape classes.

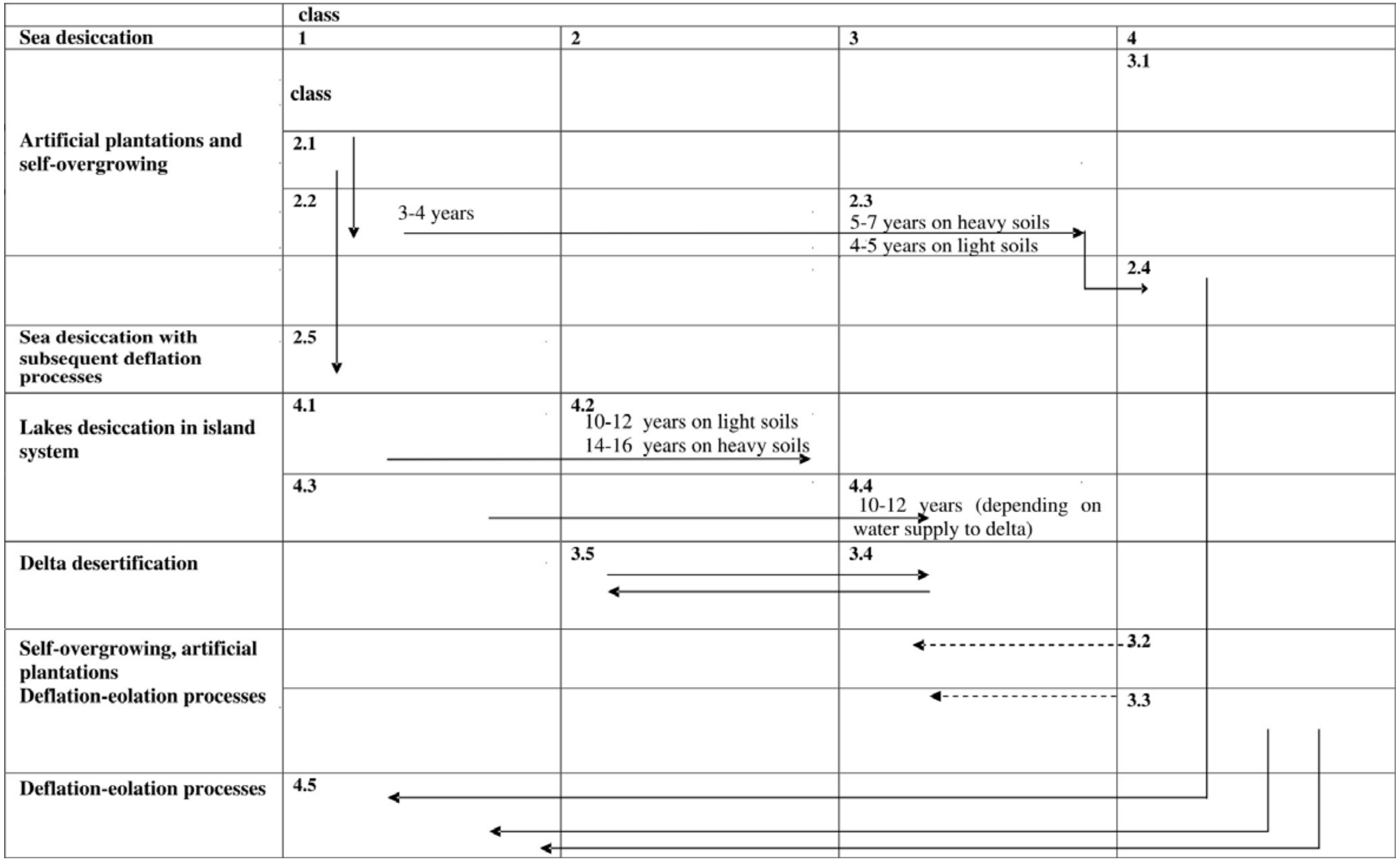


Fig. 58: The desiccating sea surface classes transformation trends
regulated process development ———— possible process development - - - - -

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

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

Automorphic coastal solonchaks are represented by crust, crust-puffed types, becoming takyr-like in some places.

The automorphic solonchak profile is very high overall salinity which peaks in the crust and sub-crust (powdery-puffed solonchak) horizons, which have the maximum salt content (Fig. 59). Their salt content varies from 3-5 to 15-25%. Down the profile, the salt content decreases and changes depending on the texture of the layers. In the lower horizons, the secondary salt maximum is often fixed due to the presence of the highly saline groundwater. The salinity of surface solonchak horizons by anions is sulphate-chloride and chloride-sulphate. Down the profile, the sulphate-chloride type predominates over other salinity types. The figure shows the profiles of soil transforming from hydromorphic to semi-automorphic types, and the process trend. The uniform salt distribution gives place to a salt concentration in the middle part of the profile due to several processes: groundwater level lowering, upper layer desalinization and overlaying by sandy cover.

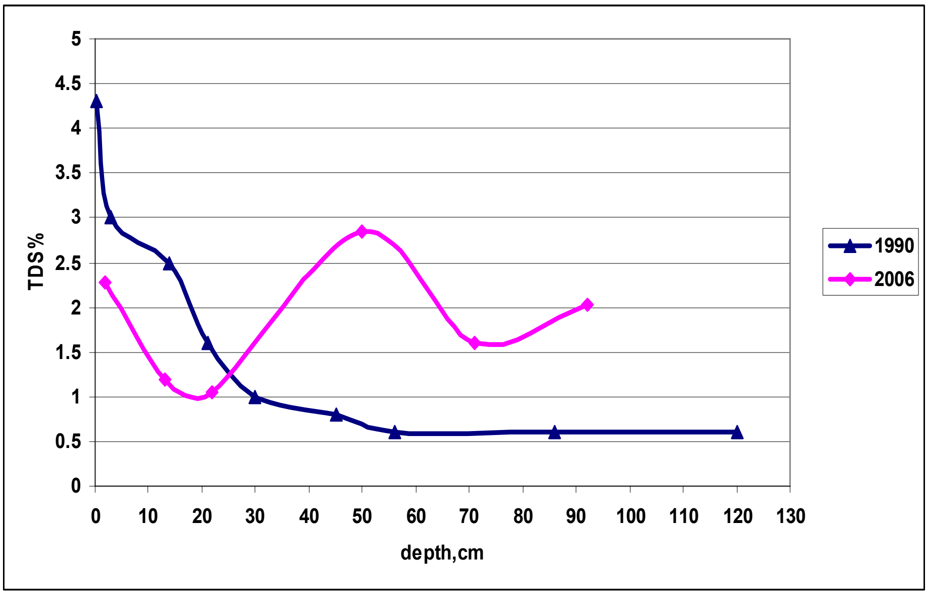


Fig. 59: Salt distribution in hydromorphic soil and in automorphic soil generated from it

The soil drying up is accompanied by deflation processes. Although sandy solonchaks contain less salt than loamy-clayey ones, they become a strong source of salt-dust transport because they are more easily and deeply processed by the wind. Initially, such transformation and erosion processes resulted in aeolian relief formation along the relic seashore. In the course of time, this phenomenon also extended deep into the former sea water area (Fig. 59).

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

Fig. 60: Dry channel of the Amudarya river

Under reduced river water inflow into the delta, alluvial deltaic soils degrade, the groundwater level goes down, and salinity increases. The latter process is particularly characteristic for the initial stages of soil desertification. The transformation period of hydromorphic soils into deserted ones is 10-15 years.

The soil cover degradation becomes apparent through a decrease of forage land productivity, loss of organic matters, and reduction of fertility elements. Of course, all of those processes cause severe damage to natural fertility of the soil cover. Moreover, biodiversity declines considerably and the typical deltaic vegetation disappears (Fig. 60, Fig. 61).

Fig. 61: Delta desertification, dried Asiatic poplar trees (Populus pruinosa)

Further we consider the classes from the position of ecological hazard. A brief description of the soil and related landscape classes according in regard to their risk degree is given below.

1. Ecological hazard is practically absent

2.1 Excessively hydromorphic marsh solonchaks, without vegetation or with Saltwort associations
2.2 Hydromorphic wet-coastal solonchaks with shell and rare isolated specimens of Saltwort and Sarsazan
2.5 Hydromorphic and semi-hydromorphic shor solonchaks of closed depressions without vegetation, bordered in some places by Sarsazan
4.1 Meadows of alluvial plains (reed, herbaceous plants, cereals) on alluvial-meadow, bog-meadow and meadow-bog soils
4.3 Shrubs (halophytic vegetation: Tamarisk, Karabarak) on alluvial-meadow soils
4.5 Shrubby-Haloxylon (desert forest/artificial plantations) on desert-sandy soils

2.2 Wet-coastal solonchaks with shell and rare isolated specimens of Saltwort and Sarsazan

Coastal solonchaks are formed on marsh solonchaks in 3-4 years. The groundwater table goes down to 1.5 m. The surface remains wet. Salt accumulation occurs in the upper horizon. While drying, they sometimes look like takyr. This group also includes shor solonchaks in depressions. Saline groundwater at a depth of 1.5-2 m forms moderately hydromorphic solonchaks.

2.5 Shor solonchaks of closed depressions without vegetation, bordered in some places by Sarsazan

In lake depressions of island systems, shor solonchaks are closed and do not represent a danger. Coastal wet solonchaks change into hydromorphic and semi-hydromorphic ones.

4.1 Meadows of alluvial plains, On alluvial-meadow, bog -meadow, meadow-bog sols

This category of land occupies the delta and is regarded as a secure ecological area if it is not in desertification stage. During desertification, this category of land shifts to class 4.2, the transformation period lasts 10-12 years or 20 years at most. Periodical inundations and inflow can stop this transformation process.

4.2 Shrubs

This class is similar to the previous item. It refers to a risk zone during desertification and shifts to class 4.4 during transformation of hydromorphic conditions into automorphic ones.

4.5 Shrubby-Haloxylon (forest, plantations)

Not being a risk zone, the territories require specific measures for restoration and afforestation, depending on their status.

2. Low ecological hazard

1.2. Shallow water areas, with sparse reed
3.5. Fixed hilly, hilly-ridgy sands, with ephemeral-wormwood-shrub communities
4.2. Hydromorphic alluvial-meadow soils subjected to desertification, with cereal-halophytic herb communities and shrubs

3.5 Fixed hilly, hilly-ridgy sands, with ephemeral-wormwood-shrub communities

If this group does not shift to another class, for example, when filled up with unfixed sand, it represents no danger.

4.3 Hydromorphic alluvial-meadow soils subjected to desertification, with cereal-halophytic communities

Desertification processes take place under water shortage; there is a transformation of alluvial-bog soils, drying meadow-bog and alluvial-meadow soils featuring a very high salinity increase. Takyr-like soil, sand and solonchak areas extend. The soil cover degradation becomes apparent in a reduction of forage land productivity. Light soils take 10-12 years for desertification, while heavy soils need 14-16 years.

3. Moderate ecological hazard

2.3 Crust-puffed and crust solonchaks without vegetation, with rare isolated specimens of shrubs (Karabarak, Tamarisk)
3.4 Poorly fixed hilly and hilly-ridgy sands, without vegetation
4.4 Meadow-alluvial soils subjected to desertification, covered with shrub vegetation

2.3 Crust-puffed and crust solonchaks without vegetation, with rare isolated specimens of shrubs

The subtypes of these solonchaks can be semi-hydromorphic, semi-automorphic and automorphic. Semi-hydromorphic solonchaks are formed when the groundwater table is at 2-3 m, and are often of alluvial-marine genesis. Puffed solonchaks with their surface characterized by porous earthy-salt layer, are most prone to wind erosion. These solonchaks are active producers of aeolian salt exported outside the Aral basin. Because the capillary recharge in the soil is weak, the surface dries up and becomes a source of dust and salt. This category becomes more hazardous under transition to automorphic types: when the groundwater table lowers to 3-5 m into semi-automorphic solonchaks and under 5 m into automorphic solonchaks.

Crust-puffed solonchaks formation is characterized by partial salt translocation from the top layer, sometimes forming secondary salt horizon. The process lasts 5-7 years on heavy soils and 4-5 years on light soils. Automorphic coastal solonchaks are widespread in the southern part of the dried seabed, semi-automorphic ones in peripheral parts of the fore-deltas and in the relic coastal zone. Soils are of different texture, of marine and alluvial origin, and are often stratified.

3.4 Poorly fixed hilly and hilly-ridgy sands, without vegetation

This category of land requires additional assessment for a possibility of self-overgrowing or a need for plantation.

4.3 Shrubs subjected to desertification

The transformation of the territory is connected with desertification and change of vegetation.

4. High ecological hazard

2.4. Solonchaks with blown sandy cover and sparse communities of Orach and Selin
3.1. Plain sands (with shell) without vegetation or with sparse shrubs (Saxaul, Tamarisk)
3.2. Dune sands without vegetation

3.3. Pit-and-mount sands (poorly fixed) with sparse communities of wormwood, shrubs and Selin plantings

2.4 Solonchaks with blown sands, automorphic sandy soils

The sand cover on the soil has two different ways of formation, two usually simultaneously occurring processes. Salts and clay-silt particles are deflated by wind erosion, with the sand particles remaining. The drying-up of sandy soils leads to their movement and desalinization. This is why the formed sand cover is usually non-saline and unfixed. The major part of the seabed is occupied with sand or silt-sand deposits containing salts up to 10-20%. The drying-up of the soil causes more intensive aeolian-deflation processes. Fig. 62 shows a summary of landscape and soil classes transformation trends.

In order to identify the general trend of processes, taking into account poor availability of information and lack of systematic observations, we used the results of soil studies conducted by the Soil Institute at the Academy of Sciences of Uzbekistan and the detailed soil map of the dried seabed as of 1990 generated by P.P. Sektimenko (Fig. 62) and compared them with the current status reflected in the soil map for 2005 (Fig. 63).

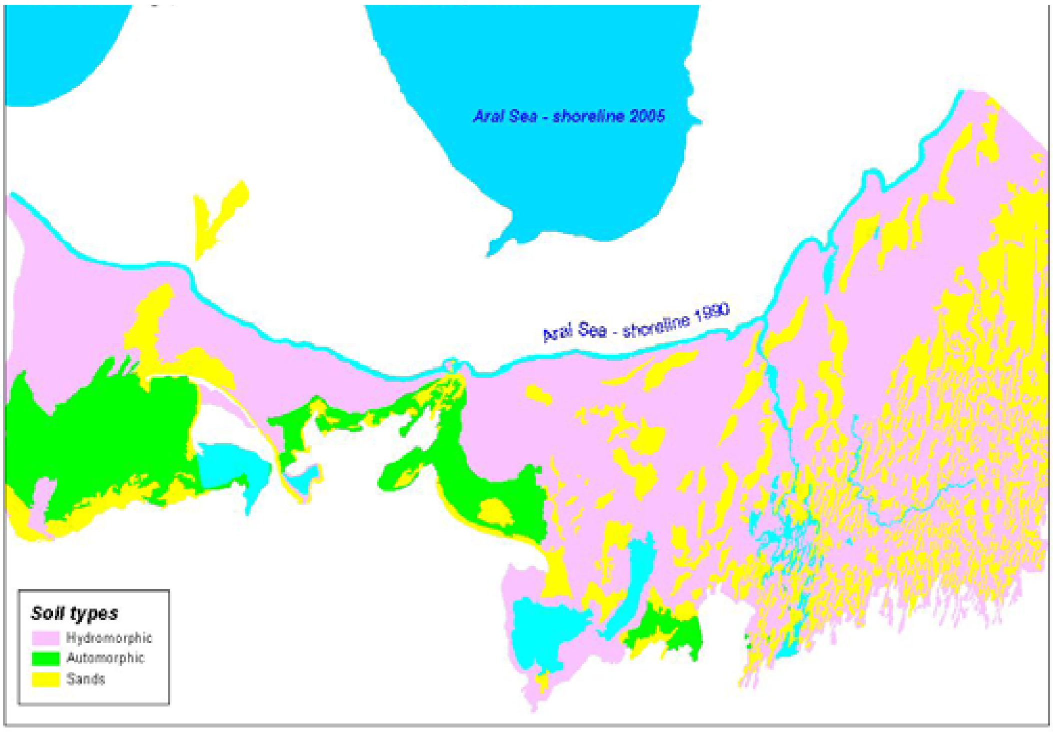


Fig. 62: Soil map as of 1990

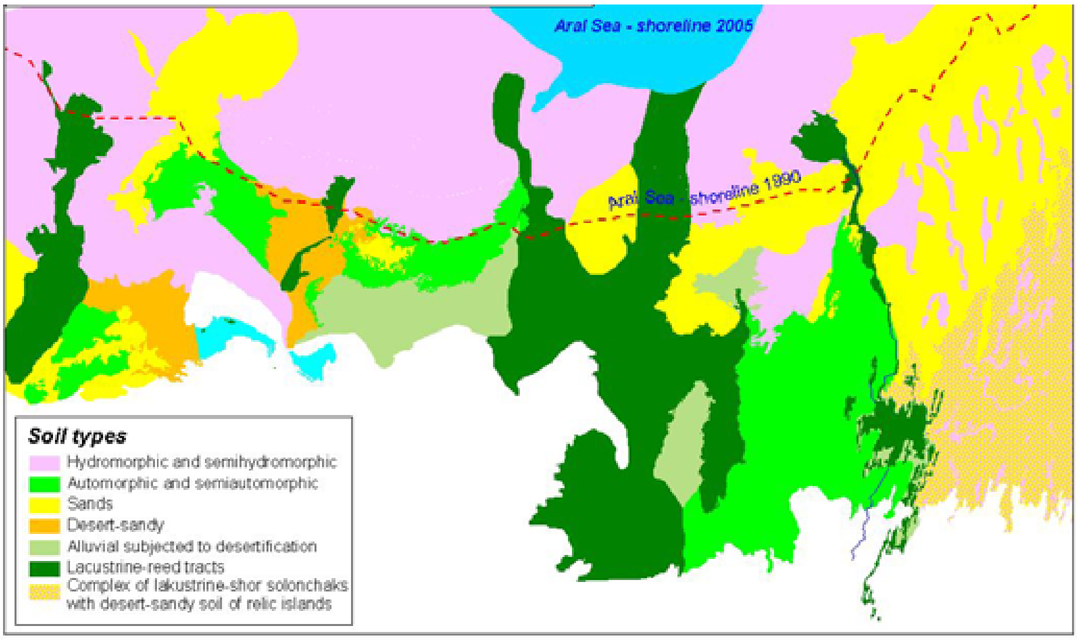


Fig. 63: Soil map as of 2005

The results of the comparison of areas, which were covered by the survey of Sektimenko in 1990 and formed in the drying zone by 2006, are given below (Table 28).

Table 28: Comparative analysis of soil cover change (thousand ha), as compared to 1990

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

The comparison was made overlaying the soil maps. Thus, since 1990, automorphic solonchaks increased by more than 50,000 ha due to groundwater table lowering and transformation of hydromorphic soils into automorphic ones. Moreover, 233,500 ha of desert-sandy soil were formed, which is regarded as a positive sign. However, the sand area considerably increased from 172,000 ha to 322,000 ha which indicates an intensification of erosion processes on the dried seabed.

Similarly, a comparison of the satellite image classification results with data of Pinkhasov (GIDROINGEO) was made (Table A3 in the appendix). The map of GIDROINGEO shows 47 types of natural systems covering an area close to that determined by our expeditions - 1372,000 ha against 1972,500 ha which means that the dried-up area has increased by 600,000 ha.

By comparing exposition rates, we see that from 1990-1996, the increase in area of the dried bed area was about 100,000 ha, while over the last 10 years it the exposition rate was reduced by the factor 1.5 times on average. The explanation for this is the comparably high water availability from 2003 to 2005 when the inflow to the sea was so high that the sea level did not lower.

After integrating the thematic maps into the GIS, the ecological hazard degree for the classes was assessed. The comparison of the "Map of lithological composition of cover (quaternary) deposits on the dried bed of the Aral Sea" with the data from 2006 (Table A3 in the appendix) shows that the total increase in area of the exposed seabed was about 600,000 ha, while the change in ecological hazard degree looks as follows:

- No (practically absent) **- increased by 551,700 ha;**
- Low **- increased by 124,600 ha;**
- Moderate **- increased by 166,800 ha**;
- High **- increased by 340,200 ha**.

Table 29: Assessment of thematic maps for ecological hazard (ha and %)

Ecological hazard degree	Map of landscape in South Prearalie, 1990 *SANIIRI*	Image classification results, according to the map for 1990	Map of natural systems, 1993-1996 *GIDROINGEO*	Image classification results, according to the map for 1993-1996
No (practically absent)	199422.6 24.2	760185.1 42.9	293577.9 21.4	845259.0 42.9
Low	187540.4 22.8	384053.8 21.7	625375.2 45.6	500780.0 25.4
Moderate	193623.5 23.5	23220.05 1.3	191095.8 13.93	24252.0 1.2
High	243354.9 29.5	605007.2 34.1	261952.0 19.0	602200.0 30.5
Total	823944.3	1772466	1372001.8	1972491.0

In other words, from 1990 to 2006 the zones with high and moderate ecological hazard enlarged by more than 500,000 ha, while over ten years from 1996 these zones expanded by about 400,000 ha.

It is characteristic that from 1996-2006, the percentages of the areas with no risk coincided; the areas with high risk increased largely, though in percentage terms they are slightly smaller (by 3.6%) than the same areas under the survey made by Chernyshev. The tendency to overgrowing has remained. The current estimate of the projective vegetation cover is close to the same category under the previous comparisons and amounts to 30.5% in 2006 against 21.6% in 1996. It once again confirms the occurrence of self-overgrowing processes, which evidently have intensified over the last years.

5.2. Measures for the mitigation of the negative consequences of the Aral Sea desiccation

5.2.1. Wetland restoration in southern Prearalie – Case study Sudochie

By 1987, vast areas of the delta and river channels had dried up due to the discontinuation of floods, the lack of permanent moistening, and the lowering of groundwater level from 3 to 5 m (to 8 m in some places). In 2000-2001, the Amu Darya river's runoff was the lowest over the history of hydrological observations. As a result, the water bodies in Prearalie have lost their flowage, which, under high natural evaporation and lack of inflow, has led to a complete shallowing and drying up of most of the water bodies.

A vivid example for the negative effects of low water was the environmental situation in Sudochie wetland - the largest lake system in South Prearalie. Until 2000, the water surface of the wetland had reached 42 thousand ha, while by the end of 2001, it decreased to 6,5 thousand ha. The fish fauna of the lakes was deteriorated: high productive fish species, such as Silver carp, Grass carp, and Sazan were replaced by less productive ones - Crucian carp, roach, and not valuable trash fish. As a result of the shallowing and drying up of the wetland's lakes, all reeds and cattail bushes serving as a source of forage and protection for the musk rat, local and migratory birds found themselves in dry land.

This complex environmental situation was observed throughout the whole Amu Darya delta. Only Muinak and Rybachie bays were preserved, but here also, reeds and cattail bushes found themselves in dry land and nesting places of water fowls were destroyed by jackals and foxes. Additionally, the fish stock of the remaining water bodies suffered from over fishing by local people and numerous fisherman groups. Thus, stable natural landscapes practically disappeared as a result of low water in Prearalie. Unstable, mainly degrading landscapes became prevalent here. In 1999-2000, the main plant associations in the Sudochie wetland were Saltwort, Karabarak and Tamarisks to a lesser degree. Due to intensive grazing, moisture deficit, and locust attacks, reed meadows were suppressed.

The work on water distribution apart of the dried seabed has been taken as a basis for development of an ecologically sustainable profile of Prearalie in its new form. The GEF Agency's Project, Component E "Sudochie Wetland Restoration", which designed and implemented engineering measures for the restoration of the wetland, with regulated water-salt regime, was first-born in this respect. The project's objective was to achieve an environmentally stable situation in the territory of the wetland. Moreover, social and ecological monitoring was undertaken within Sudochie wetland. At present, the project has been completed, and the Sudochie Lake is functioning stably enough to mitigate the negative consequences of the Aral Sea desiccation.

Since August 2000, an intensive watering-up of Sudochie lake system took place. In 2002, the two-year period of low-water gave place to a period of quite high water availability. An inevitable effect of the modification in water regime of wetlands is the change in environmental conditions. Observations in 2002 showed that the water surface of Sudochie system had increased by 40-50%. Thus, under the conditions of a year of high water availability, the set of structures started to operate and the water level and flow distribution regime of Sudochie lake indicated to correspond in the desired way. Another positive effect of the Sudochie wetland restoration is the vegetative overgrowing of the former Adzhibay bay, whereto water is discharged periodically from the Sudochie wetland.

This work initiated SIC ICWC's remote monitoring over water bodies in Prearalie. The results given in Table 30 clearly demonstrate dynamics of the wetland area, depending on low-water (2001) and high-water (2005) periods, when the watered area increased 2.5 times (Fig. 64).

Table 30: Wetland areas in the Amudarya river delta (ha)

No.	Water body	Date				
		April 2000	*June 2001*	*August 2002*	*June 2005*	*August 2006*
1.	Sudochie	41897.73	9570.04	6497.2	62146.73	59302.73
2.	Mejdurechie	10050.42	592.79*	18375.21	19738.06	5633.97
3.	Rybachie	5317.64	2019.68	5513.1	5631.72	6319.38
4.	Muinak	8623.34	1292.23	5163.2	9514.86	16567.9
5.	Dzhiltyrbas	29357.73	5277.33	27620.5	125938.9	80993.93
6.	Former Adjibay Bay	10980.9	656.53	6784.7	39887.68	29676.83
7.	Dumalak	4576.89	927.23	6784.9	19608.71	27119.0
8.	Adzhibay 2 *)	-	-	-	6025.87	4848.33
9.	Makpalkol	-	-	-	4028.73	3590.45
	Total	127639.83	21062.1	79552.71	329285.69	234052.5

**) Adzhibay 2 - Artificial structure located northward of Rybachie and Muinak reservoirs*

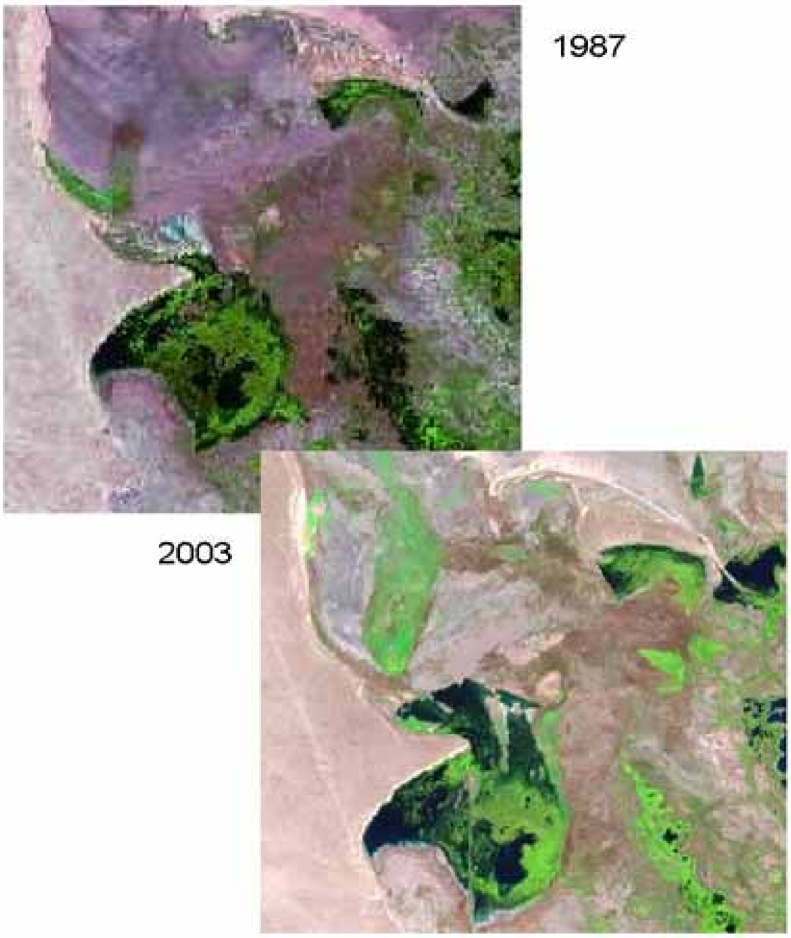


Fig. 64: Sudochie wetland

5.2.2. Suggested strategy and areas for future afforestation measures

As established, the current total area with high risk is 785 thousand ha of the dried seabed within the boundaries of Uzbekistan. According to the forecast in Chapter 5.1, the total area of the dried bed will increase by additional 500 thousand ha (half of the dried area in territory of Uzbekistan) under a pessimistic scenario.

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

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

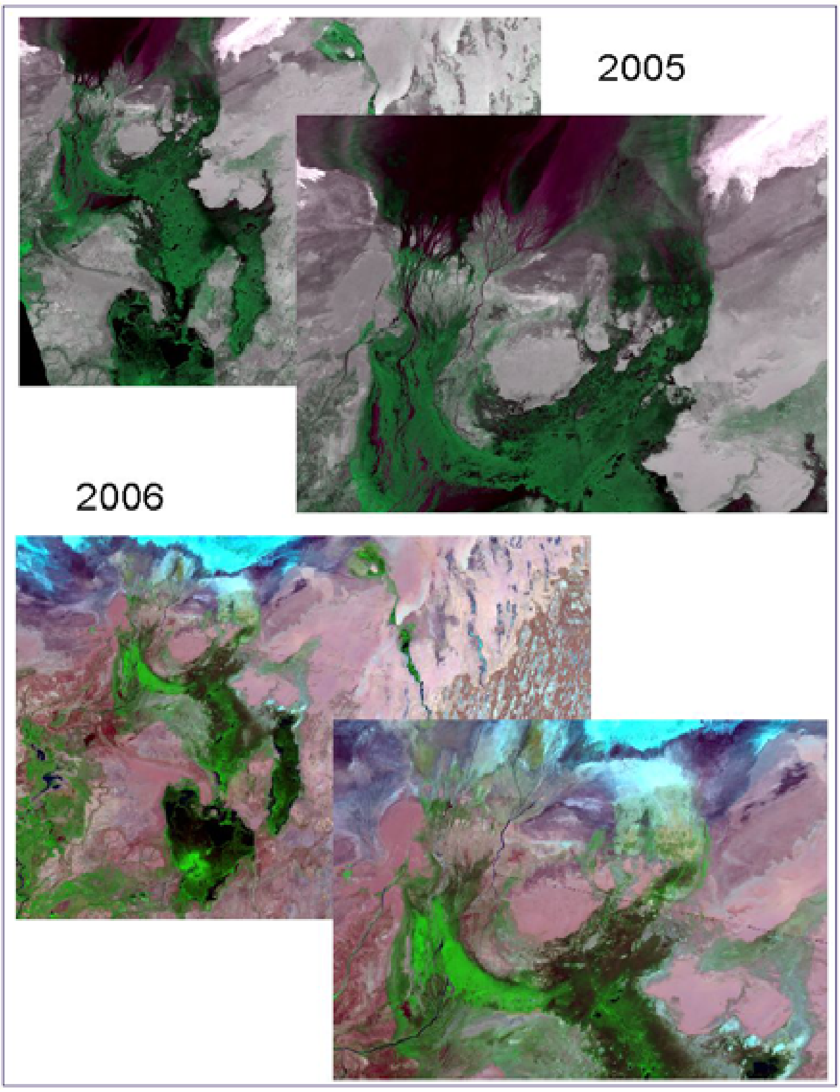


Fig. 65: Change in wet zones within the outlet channel of Dzhiltyrbas

In the humid year 2005, wet zones occurred around outlet channels of Dzhiltyrbas (Fig. 65) and Adzhibay and covered substantial areas on the exposed bed. The total wet area increased by 55 thousand ha, compared to normal (drier) years. Thus, by defining more exactly the areas of landscapes required stabilization and organizing permanent monitoring of these zones, the high risk level zones can be prevented from extending. Not the whole "high risk" zone should be considered as presenting the same degree of hazard to human society. Therefore, within the limits of this zone, territories of intensive development of negative processes should be selected, where sources of stress may arise as a result of aeolian and hydrochemical processes under arid conditions and anthropogenic changes in moisture regime. These sources are represented by:

- barchans and blown sands. The expeditions found a number of such zones(Fig. 67); moreover, the rate of there movement was about 4 km a year (2 km per half year)
- massifs of sandy unfixed landscapes, with light texture, that can be easily transformed into moving barchans
- increased content of readily soluble salts in the soil, thus threatening growth of plants, especially lignose
- development of sites of salt and dust transport, including removal and accumulation of the light fractions of surface deposits (dust and silty sand) and their further transportation
- intermittent or temporal waterways or wells that feed water bodies in desert and serve as a source of life.

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

Present observations at four wind stations located eastward from Dzhiltyrbas indicate the following maximum annual values of salt and dust transfer:

Station № 1 - 1914 kg/ha - in deflation zone;
Station № 2 - 495 kg/ha - on solonchak, near the deflation zone;
Station № 3 - 1200 kg/ha -5-10 km far from the deflation zone;
Station № 4 - 20 kg/ha - on stabilized sands.

Thus, the intensity of salt and dust transfer has decreased as compared to 1980's. As a result, Table 31 and Fig. 66 show the zones to be protected:

Table 31: Areas of potential negative impact and areas to be protected, ha

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

Thus, there are 57,6 thousand ha which should be prioritized for protection out of the total area of more than half a million hectares and 60,0 thousand ha in the dried delta zone. This is an area of distribution between the first-priority afforestation and watering (Fig. 66).

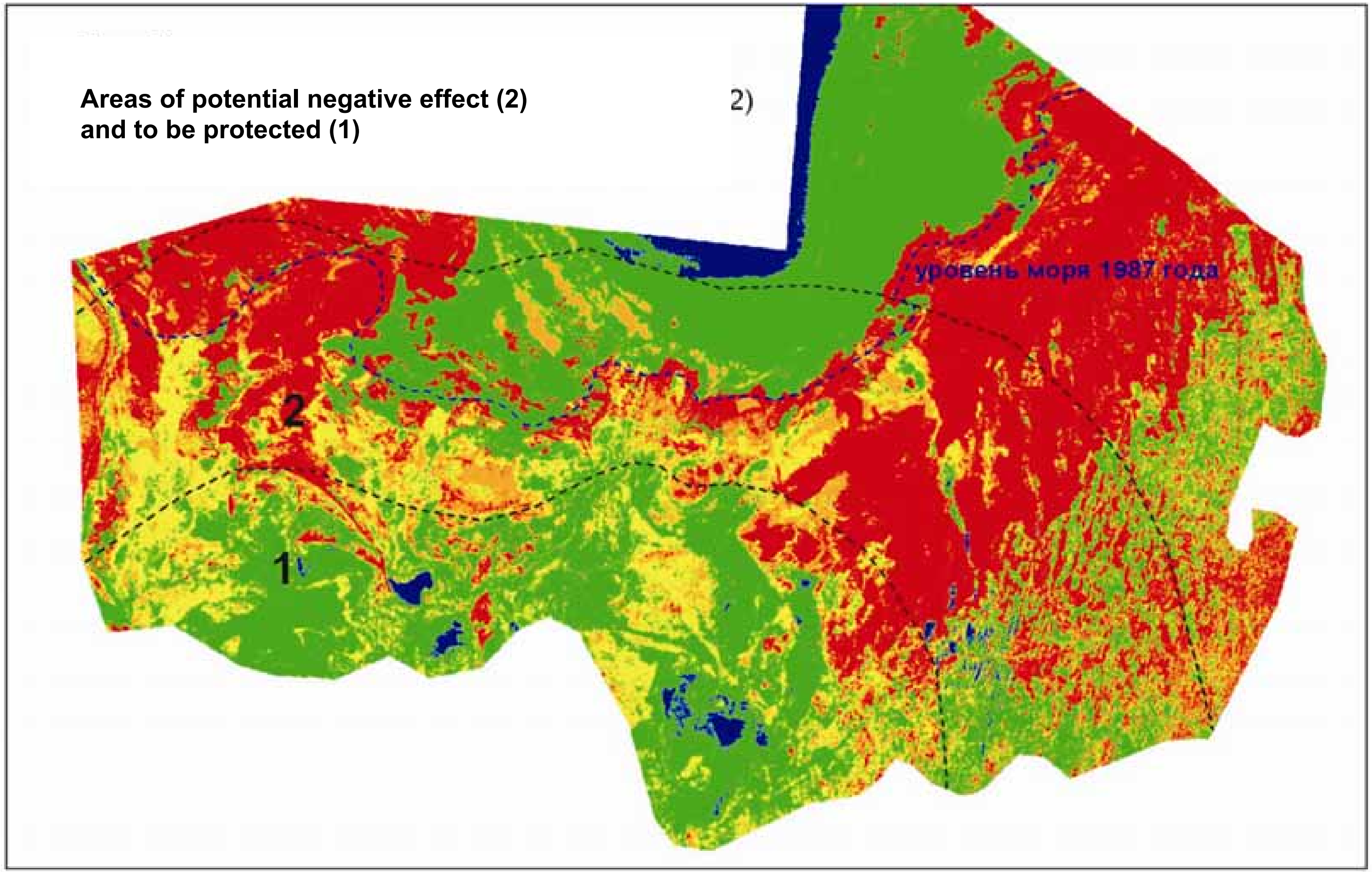


Fig. 66: Zones of potential negative impact and of required protection

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

a) a zone northward of Muinak between the waterway of Rybachie bay and the delta, solonchaks with blown sands and some barchans posing a risk of salt and dust transfer to Muinak;
b) the area between Kokdarya and Dzhiltyrbas, northward of the new GTZ's camp, where barchans advanced to 2 km in the last year, covered the road, and now move toward the new plantings of GTZ (Fig. 67);
c) a zone of poorly fixed sand hills together with sand sinks in the southern exposed bed within Adzhibay bay;
d) a zone in north sand spit (Bakhyt well), where plantings are already underway but their state is ambiguous.

Fig. 67: Sand spreading

In the investigated area, about 30% of the present afforestations show a bad plant establishment. It is recommended to study these areas in detail (soil-hydrogeological and botanical surveys), in order to assess the reasons for the bad establishment and estimate the possibility of self-overgrowing. It is necessary to discuss, as a number of researchers propose (Wucherer, Gintzburger), a possibility of stimulating self-overgrowing though diffusion of Selin seeds (*Aristida karelini*). Besides, a zone located above the elevation of 53 m a.s.l. in the delta part which genetically does not belong to the dried seabed area but where intensive desertification takes place should also be considered for priority protection and needs additional surveys. Here, additional sub-classes need to be included in the remote sensing assessment since the delta is characterized by additional plant associations (Asiatic poplar, riparian woodland) and soil conditions (meadow, meadow-bog, takyrs, and soils subjected to desertification). Those zones may be protected by watering combined with phyto-reclamation.

The analysis of soil properties and artificial plantation conditions showed that a good status of plants was observed in those sites, where salt content in 0-10 cm was 1 %. A bad status was observed in places where the salt content was higher than 2 % and the chlorine percentage was 0.3 % and 0.6 %, respectively. Moreover, in the 0-40 cm layer, the salt content is 2.2 % and 1 %, while chlorine percentage is 0.1 % and 0.6 %, respectively. Fig. 68 demonstrates the analysis results. The data collected on permissible salt content fits the respective figures in other literature sources. These results were also considered in the selection of the zones for potential development and afforestation.

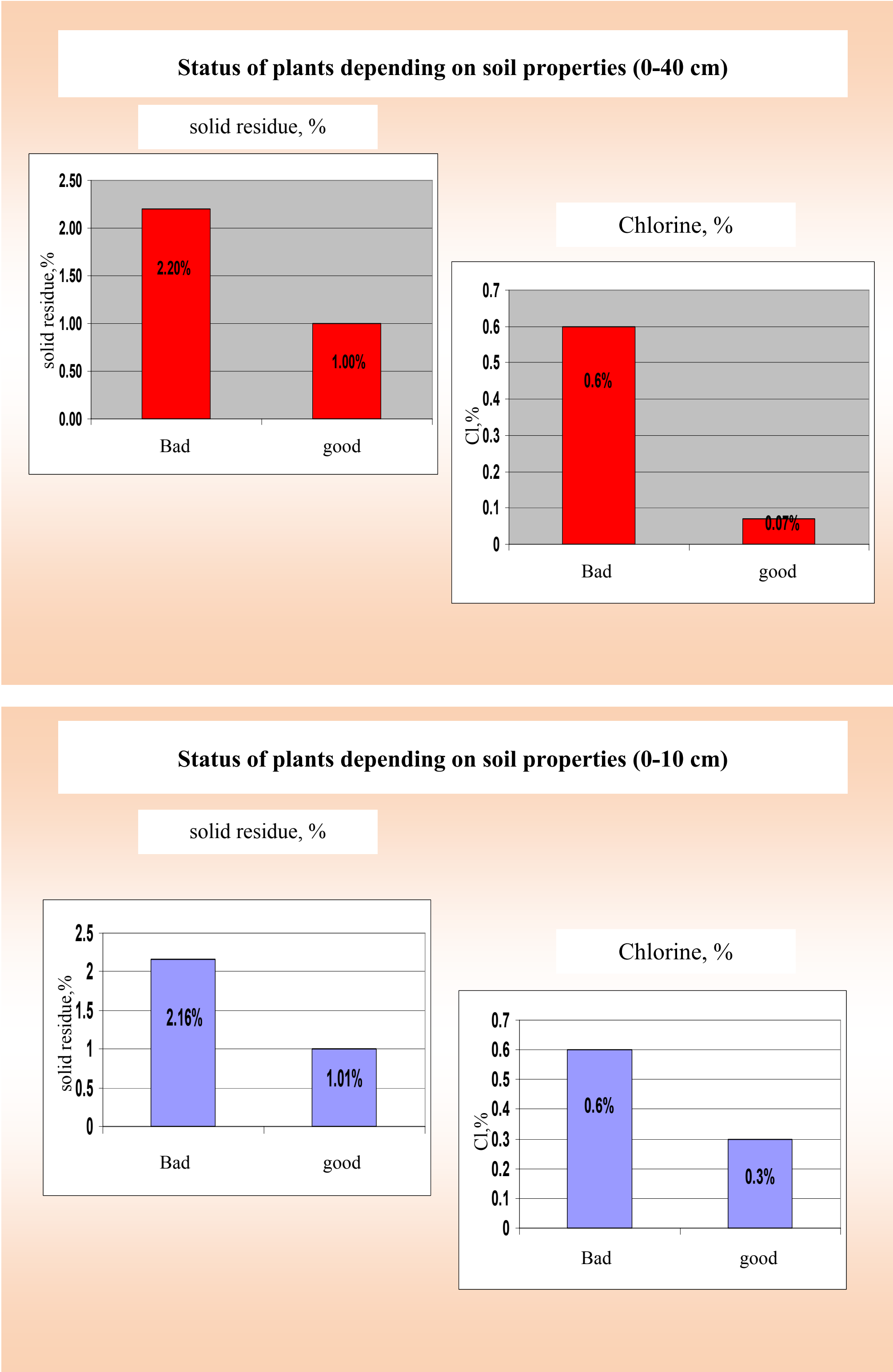


Fig. 68: The status of plants depending on soil properties

One should note that the territories selected for future afforestation are preliminary. For a good plant establishment, a detailed survey of the environmental conditions, including soil cover, is necessary and boundary conditions on groundwater level and salinity should be determined (Fig. 69).

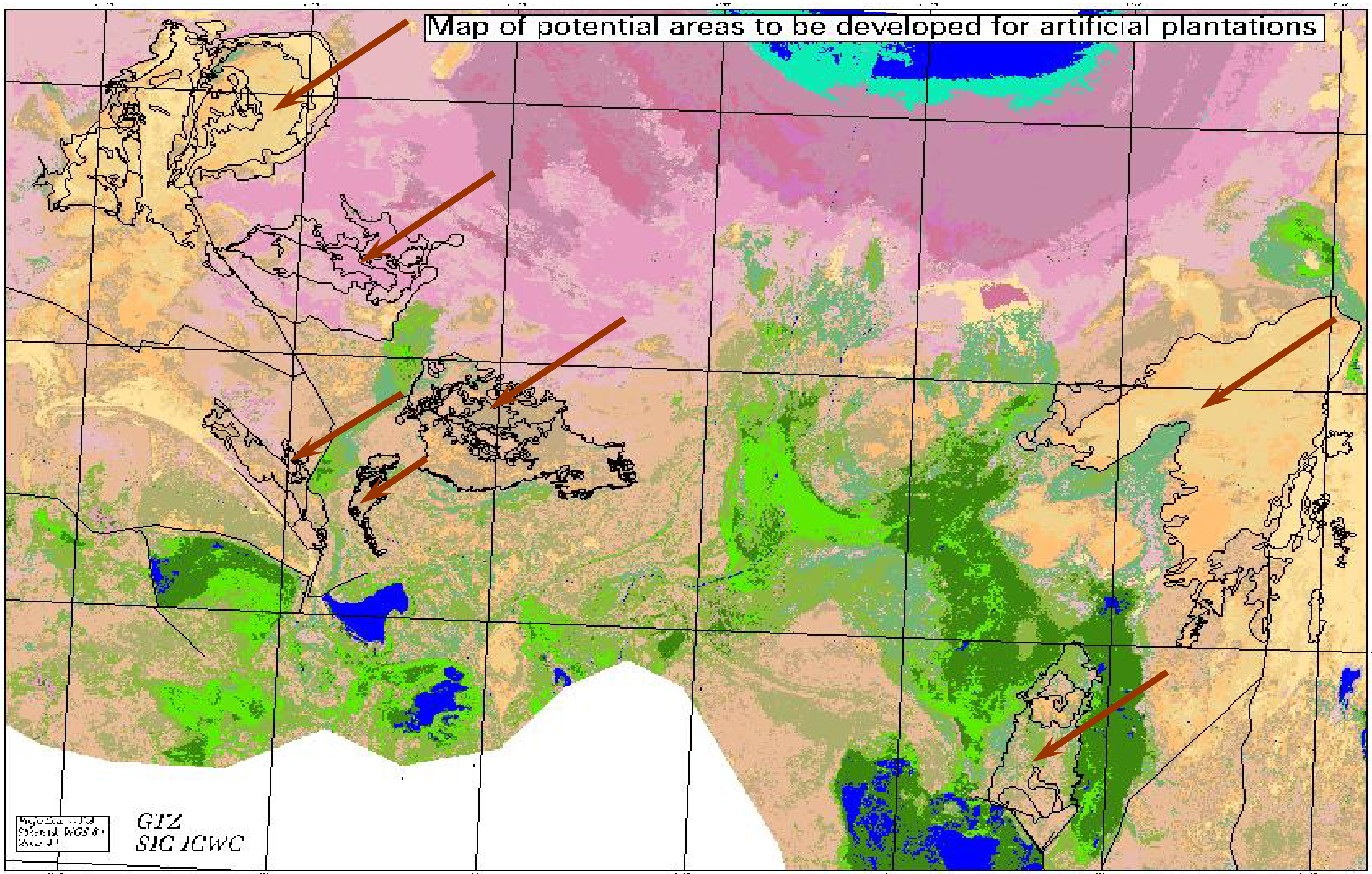


Fig. 69: Zones suggested for development and afforestation

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

1. It is advisable to develop and arrange a procedure for the selection of sites and dates for new afforestations and polish the technique of investigation (soil, hydrogeology, landscape). For the determination of dates and types of planting or seeding, the establishment of 2-3 pilot areas in the risk zones № 3 and 4 is recommended.

2. Based on obtained experimental materials, recommendations should be completed for the development of the exposed bed of the Aral Sea and the desertified delta, including methods of development.

3. Data on greater susceptibility to diseases of drill sowed *Haloxylon aphyllum* are worth to notice. This requires studies of the reasons and the development of recommendations by dendrologists on order of sowing and alternation of strip planting with focal one.

4. Experts developed a range of methods to fix sands and site preparations for phyto-reclamation. It is advisable, perhaps by local specialists, to polish them by organizing, under the leadership of Karakalpakstan's Academy of Science, specific efforts for development of those lands. As a result, recommendations can be prepared for the development of future territories of the stabilized seabed. The recommendations can differ depending on the conditions of given sites selected for afforestation.

5. The historic development of the territory should be analyzed in order to identify the causes of poor establishment: type of planting, sowing, quality of seeds, etc.; simultaneously, landscape dynamics must be considered. For this, special research and comparison of sowing dates with initial hydro-geological and soil conditions is necessary. Information on these conditions' dynamics during growth are also needed.

6. For an efficient development, the project documentation should be drawn up. It will include the results of detailed surveys in the selected area, a plan of measures and their justification and the procedure of development. It is proposed to create a group on the basis of GTZ for the elaboration of the proposed site development projects, with involvement of professionals from the Ministry of Agriculture and Water Resources, experts of SIC ICWC, forest reclamation scientists (Novitsky Z.B., Ametov M.) and SANIIRI's laboratory.

7. For an efficient implementation of site development recommendations, a monitoring procedure should be elaborated. Regular monitoring should be undertaken for all the associated parameters, including dates, method, seeds, seedlings, their quality, soils, salinity, groundwater level, etc.

8. In order to improve the accuracy of the remote sensing based monitoring, it is necessary to refine the classification procedure proceeding from sand features,

surface irregularity and other land covers. The reflective properties of arid landscapes largely depend on the structure of vegetation cover and texture of soil surface. The reflectance of vegetation in arid zones is varying constantly according to seasonal and weather conditions. The degree of sand fixation depends on both quantity of bushes growing during long period of time in a year and density of grass fixing the sands. Grass on sands develops in spring; during this period of time fixed sands are covered by highly dense bush and grass. Thus, it is highly recommended to advance the use of RS data towards a multitemporal analysis, with multiple image acquisitions covering various times of the season.

5.3. The future of the Aral Sea

This chapter presents the results of the project REBASOWS "The Rehabilitation of the Ecosystem and Bioproductivity of the Aral Sea under Conditions of Water Scarcity" (Vienna-Tashkent, May 2006). The project objectives were to make a forecast of salt and water balances for the Aral Sea under various variants of available inflows.

As initial data for the assessment of the future for the Aral Sea, we used satellite-based observations for 2006. According to those observations, the water surface areas are as follows in the table below. (Table 32)

Table 32: Water surface areas of the Aral Sea, 2006

No.	Aral Sea	m^2	ha
1	Western bowl	4962799000	496279,9
2	Eastern bowl	9244248000	924424,8
3	Bays of Eastern bowl	1509301000	150930,1
4	Isthmus	55425610	5542,561
	Large sea	15771773610	1577177,361
5	Small sea	2864854000	286485,4

Water surface areas of the Aral Sea

The future of the Aral Sea is quite clearly defined for the waters of the Northern Sea, namely the level of the latter should be maintained at the elevation of 42 m, thus, keeping its volume at 27.0 km^3 and the water surface area at 290 km^2. The water volume of the Northern Sea's "appendix", former Sary-chaganak bay, will be increased through additional 120 km^2 and 0,5 km^3 of water.

The possibility of achieving a stable sea level and maintaining an adequate salt regime in the water bodies of the larger sea will depend on three types of scenarios:

- scenarios for the Aral Sea basin development as concerns salty or non-salty elements of water changes, water conservation, water infrastructure development;
- scenarios for the maintenance of the sea's water bodies;
- scenarios for the improvement of the Amu Darya river delta and respective withdrawals for its maintenance.

Out of numerous water development scenarios, the project analyzed the following three ones: "business as usual", "optimistic scenario" and "national vision". Each of those scenarios was considered for two 20-year periods in terms of water availability: dry period (1972-1991); and, humid period (1952-1971).

The analysis made for 20-year periods from the natural water series since 1914 to 2001 (Fig. 70, Fig. 71) indicates a great variability of water availability both of the Amu Darya and the Syr Darya basins as a whole and of the rivers themselves in the given periods. The total water availability of 20-year periods varies from 87.2 km^3/year (the mean for 1972-1991) to 96.1 km^3/year (the mean for 1952-1971) in the river basins as a whole. This corresponds to a 94% probability of dry period and a 3% probability of humid period. The river flow variability for the 20-year periods is shown in Table 33.

Table 33: River flow volume per 20-year period (sampling from series 1914-2001)

River	Years	Probability, %	Mean flow for the period, km^3/yr
Amu Darya	1970-1989	99	63.56
	1951-1970	2	69.53
Syr Darya	1925-1944	99	22.09
	1952-1971	2	26.78

The periods 1972-1991 (dry) and 1952-1971 (humid) were selected as basic series and were transferred to the future (2006-2025).

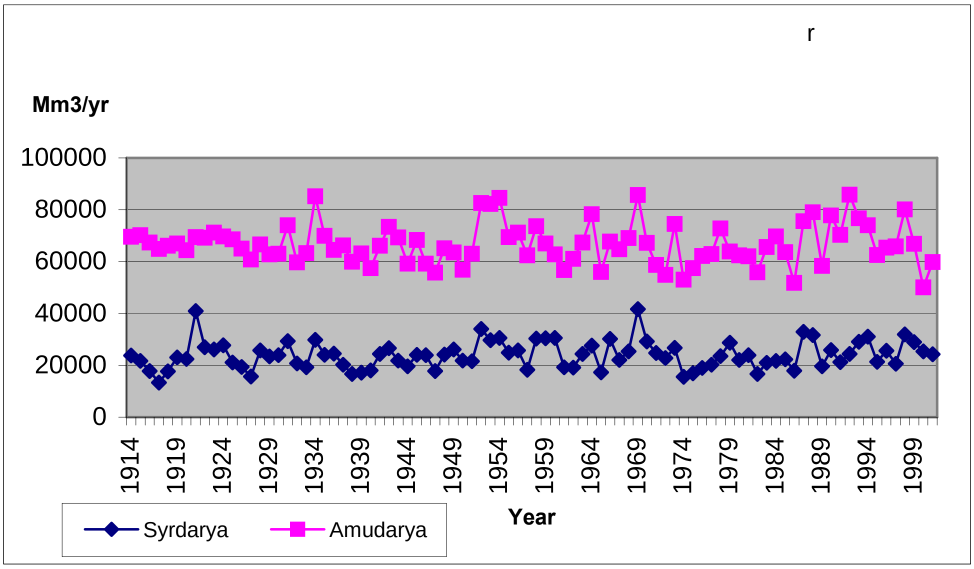


Fig. 70: Natural resources of the Amu Darya river and Syr Darya river (sample 1914-2001)

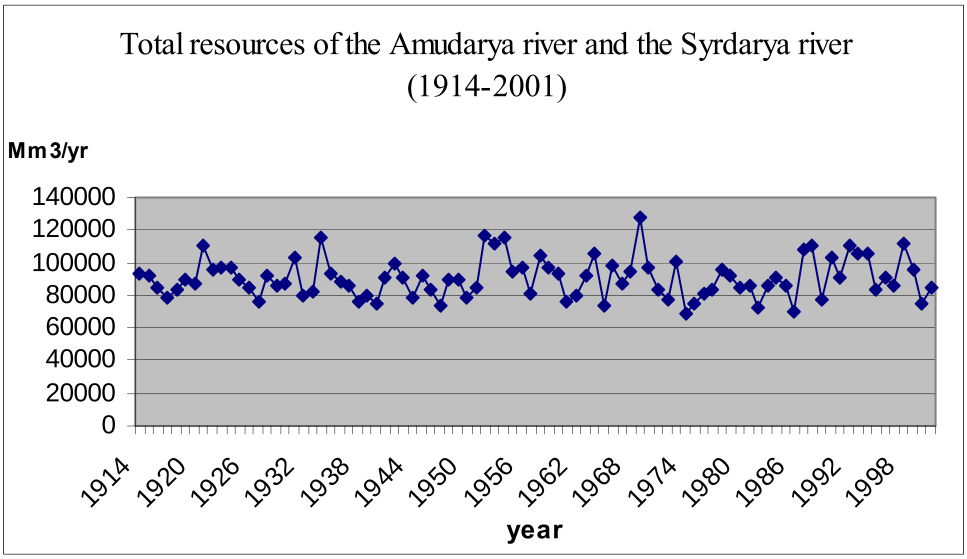


Fig. 71: Total resources of the Amu Darya river and Syr Darya river (1914-2001)

Table 34 shows the natural flows of the Amu Darya and the Syr Darya, i.e. mean flows for the dry period of 1972-1991 (MIN) and the humid period of 1952-1971(MAX) that are considered as hydrological series of extreme water availability for future scenarios (dry and humid 20-year periods).

Table 34: Flows of the Amu Darya and the Syr Darya (km^3/year) averaged for a period of 20 years, corresponding to water availability scenarios (MAX, MIN)

River basin	MAX	MIN	Difference
Amu Darya	69.30	64.68	4.62
Syr Darya	26.80	22.52	4.28
Total	96.10	87.20	8.90

The inflow to Prearalie from the Amu Darya river as computed by ASBMM for two water availability scenarios – dry (MIN) and humid (MAX) – for 20-year period and the three national development scenarios ("national vision", "business as usual", "optimistic") is shown in Table 35. It was assumed that dry and humid 20-year periods (Table 35, item A) would occur in the future (over the period 2005/2006 – 2025). The computation was corrected based on inflow for 2005/2006 (Table 35, item B) for all scenarios. To this end, actual flow data for October 2005 – May 2006 and flow forecast for June-September 2006 (derived from expected trend) were used.

Table 35: Design flow of the Amu Darya (Samanbai gauging station) mean for 2005/2006-2025 (km^3/year)

Development scenarios	MAX	MIN	Difference
A. Computation by series	1952-1971	1972-1991	
1. National vision	7.51	6.04	1.47

Development scenarios	MAX	MIN	Difference
2. Business as usual	8.24	6.96	1.28
3. Optimistic	11.47	9.08	2.39
B. Adjustment to 2005/2006			
1. National vision	7.04	5.5	1.54
2. Business as usual	7.77	6.48	1.29
3. Optimistic	11.16	8.9	2.26

Table 34 and Table 35 show that the difference (4.6 km^3/year) in the mean natural flow volumes for dry (MIN) and humid (MAX) 20-year periods at the border of Prearalie (Samanbai gauging station) decreases to 1.3…2.3 km3/year, depending on the basin development scenario.

Thus, the natural river flow variability is “smoothed” down the stream through withdrawal fluctuations and flow losses that are higher in humid periods than in dry ones.

Fig. 72 shows the flow hydrographs of the river in Samanbai gauging station for various scenarios of water availability and basin development and the integral curves (summing up flow amounts progressively in time) that indicate the water availability range, within which an expected hydrograph of inflow to Prearalie varies. The annex of the report shows a graph comparing all options of the Amu Darya river flow in Samanbai gauging station.

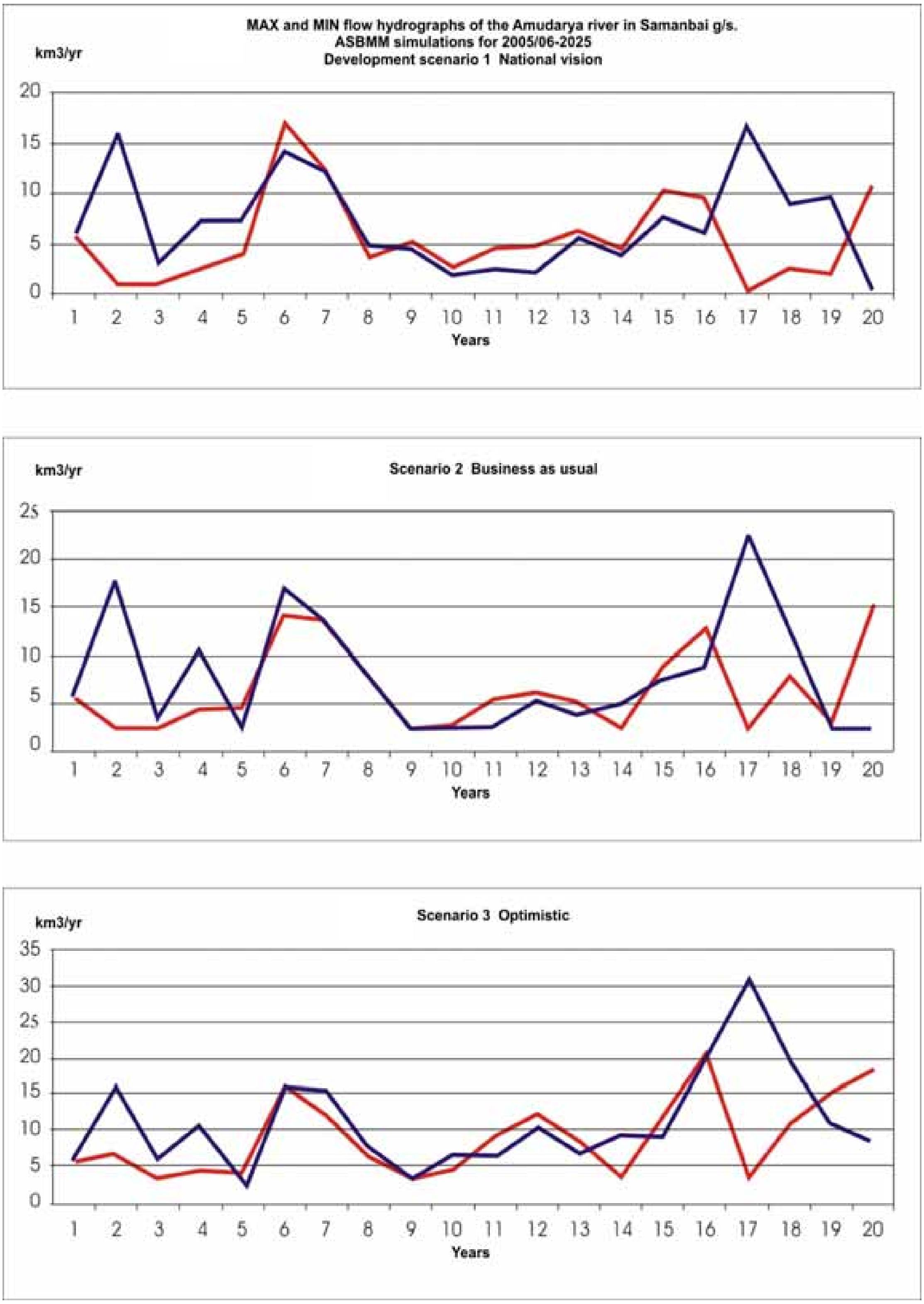


Fig. 72: Hydrographs of the river in Samanbai gauging station

The inflow to Prearalie from the Syr Darya as computed by ASBMM for two water availability scenarios – dry (MIN) and humid (MAX) – for 20-year period and the three national development scenarios ("national vision", "business as usual", "optimistic") is shown in Table 37. It was assumed that the dry and humid 20-year periods would occur in the future (over the period 2005/2006 – 2025) (Table 36, item A). The computation was corrected based on the inflow for 2005/2006 (Table 36, item B) for all scenarios. To this end, actual flow data for October 2005 – May 2006 and flow forecast for June-September 2006 were used.

Table 36: Flow of the Syr Darya (Kazalinsk gauging station) mean for 2005/2006-2025 (km^3/year)

Development scenarios	MAX	MIN	Difference
A. Computation by series	1952-1971	1972-1991	
1. National vision	3.98	2.91	1.07
2. Business as usual	5.27	4.02	1.25
3. Optimistic	7.22	4.96	2.26
B. Adjustment to 2005/2006			
1. National vision	3.95	3.04	0.91
2. Business as usual	5.22	4.12	1.10
3. Optimistic	7.27	5.03	2.24

The comparison of Table 36 and **Table 37** shows the same behavior in the Syr Darya basin as in the Amu Darya basin: the natural flow variability is “smoothed” down the stream through withdrawal fluctuations and flow losses.

Fig. 73 shows the flow hydrographs of the Syr Darya in Kazalinsk gauging station for the various scenarios of water availability and basin development and the integral curves, and **Table 37** shows the inflow distribution among the seasons and salinity.

Table 37: Flow (km^3/season) / salinity (g/l) of the Syr Darya river mean for 2005/2006-2025, growing (April-September) and non-growing (October-March) seasons

Development scenario	Season	MAX	MIN
National vision	non-growing	3.46 / 1.47	2.61 / 1.61
	growing	0.49 / 1.35	0.43 / 1.51
Business as usual	non-growing	4.43 / 1.36	3.50 / 1.50
	growing	0.79 / 1.30	0.62 / 1.46
Optimistic	non-growing	4.76 / 1.05	3.17 / 1.12
	growing	2.51 / 1.00	1.86 / 1.10

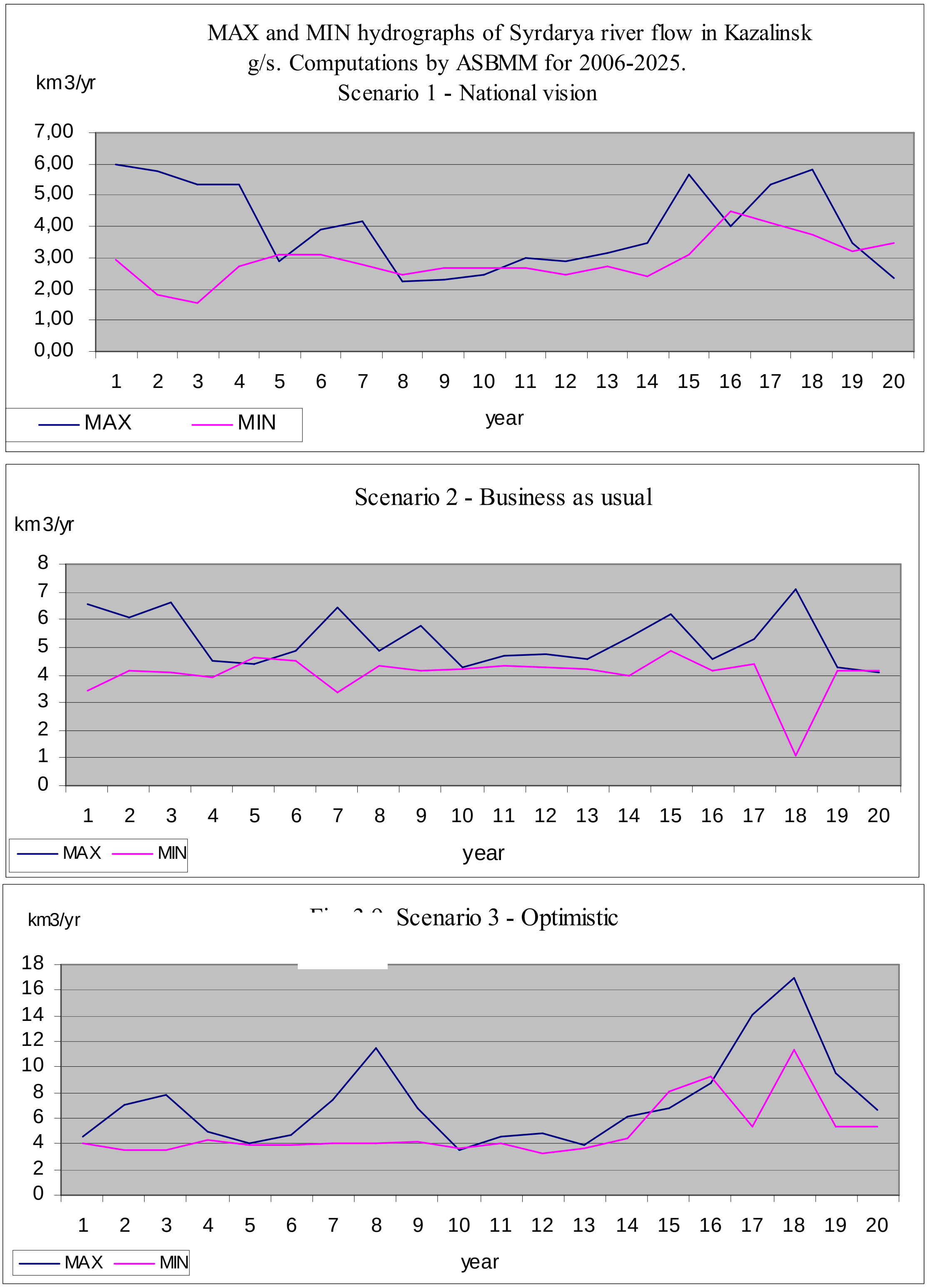


Fig. 73: Hydrographs of the Syr Darya in Kazalinsk gauging station

Those scenarios are overlaid with three options for the maintenance of water bodies:

- The Western Sea exists, the Eastern Sea dries up since a dam blocks the northern flow path.
- The Eastern Sea exists, no flow to Western Sea.
- Both seas exist.

Moreover, three additional options are possible for the inflow to Amu Darya delta

- Existing inflow within "status quo" in delta.
- Inflow to the Eastern Sea according to the scheme suggested by NATO Project SFP 974357.
- Inflow through the delta to the Western Sea according to the scheme suggested by NATO Project SFP 974357 (hypothetical option).

All probable combinations of inflow options is shown in Table 38.

Table 38: Matrix of probable combinations of options for sea's water bodies and options for inflow to the sea

	I	II	III
1		X	X
2		X	X
3	X		X

Besides, 6 forecast options for water level and salinity in the Northern sea were computed (Table 39). These computations show that the level of 42m a.s.l. is guaranteed in all development options for the Syr Darya river, though salinity is favorable for fish spawning only in options 3 and 4.

Table 39: Dynamics of water level (m) and salinity (g/l) in Northern sea(by the beginning of year) per option

Year	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
2010	42 / 16,2	43,32 / 14,3	42 / 15,8	43,75 / 13,7	41,60 / 16,7	42,47 / 15,7
2015	42 / 15,8	44,65 / 13,0	42 / 14,7	46,69 / 10,9	40,61 / 18,5	41,66 / 17,5
2020	42 / 15,7	45,63 / 12,4	42 / 14,1	47 / 10,8	42 / 17,2	42,49 / 16,7
2025	42 / 15,4	46,55 / 11,9	42 / 11,4	47 / 9,8	42 / 17,2	43,35 / 15,6
2030	42 / 15,6	46,29 / 12,6	42 / 11,4	46,84 / 10,2	42 / 17,7	43,43 / 16,1
2035	42 / 15,9	46,34 / 13,0	42 / 10,6	47 / 9,9	42 / 18,1	43,63 / 16,3
2040	42 / 16,0	46,61 / 13,2	42 / 9,6	47 / 9,6	42 / 18,2	44,27 / 15,8
2045	42 / 15,9	4,97 / 13,2	42 / 8,4	47 / 9,1	42 / 17,8	45,50 / 14,6
2050	42 / 15,6	46,68 / 13,5	42 / 7,2	47 / 8,4	42 / 17,5	46,44 / 13,9
2055	42 / 15,2	47 / 13,5	42 / 6,3	47 / 7,8	42 / 17,6	46,41 / 14,3

For the Large sea, the situation is quite uncertain.

In total, 18 combinations of different alternatives were considered and grouped into 3 inflow infrastructure options.

Maintaining the current infrastructure in the Amu Darya delta without radical reconstruction

According to this option – the least capital intensive, the Eastern sea level will keep lowering to a maximum of 28m a.s.l. in "national" water use scenario under low water availability. In case of the "optimistic" scenario and a maximum water availability, the minimum water level in large sea will lower maximally to 29,5m a.s.l., but in all options the sea level stabilizes between 29m and 31m. Moreover, water salinity will increase to 150 g/l in all the options by 2008, and then the trend line will depend on the water use scenarios and water availability – in the worst case, the salinity jumps to 300 g/l and further stabilizes around 200 g/l. In the "optimistic" scenario, the salinity will stabilize around 100 g/l by 2010 and then will decrease to 25 g/l in the last five-year period 2020 - 2025. This is solely related to huge releases from Northern Sea (on average 7.3km^3/yr, with maximum 12.8 km^3/yr in the five-year period 2021-2025). In the scenarios of “national vision” and "business as usual", the salinity will vary from 100 to 250 g/l under low water availability options.

In the Western bowl, by 2020, water level will drop at different rates – to 17.5 - 18.9m a.s.l. during low water availability years under “national” and “business as usual” scenarios. In the “optimistic” scenario, the level will raise to 31-34m a.s.l. during last five years under high water availability and to 27m under low water availability (unlikely).

The salinity increases in all the options – to 102 g/l in the best case and to 190 g/l in the worst case.

Further, two options that start to work since 2006 are considered. Certainly, none of these options can be implemented in one year; therefore, the achieved results should be considered as probable Aral Sea development alternative.

NATO SFP 974357 Project’s infrastructure in Amudarya delta

A construction of infrastructure measures under this project will improve the delta productivity and reduce socio-economic and environmental damage but will aggravate state of affairs in Large Sea: The Eastern sea level lowers to 27,5m a.s.l., the Western sea level to 27,6 m a.s.l. in the worst cases, while the salinity reaches 370 g/l in the Eastern sea, though it decreases to 90-106 g/l in “optimistic” scenarios. A better situation will be observed in the Western bowl, where the water salinity averages at 65-75 g/l, and decreases to 53 g/l in the optimistic scenario by 2025.

Hypothetical option

Water is supplied to the Western bowl through a newly constructed system of waterways from Amu Darya to Sudochie and Adzhibay bay. This system is completely focused on the deeper reservoir. The Eastern bowl is fed only through overflows from the Western sea to the Eastern sea, plus releases from the Northern sea. In all options, the water horizon in the Western bowl is set within 29-31m a.s.l., with a short-term minimum of 28m and a maximum of 32,3m. The Eastern bowl is also stabilized at 26-27m. A rise to 30m in the optimistic option should be considered as impossible. Such inflow will allow achieving a stable trend towards salinity decrease in the Western sea to 45 g/l ±16 by 2025.

However, the salinity in the Eastern bowl increases to 380 g/l, though under such high salinity, the assumptions made in the model will become invalid and require a more detailed hydro-chemical modeling for highly-saturated solutions.

While considering the report of the CR-4 group on bioproductivity, it seems to be rather doubtful or impossible to implement the “hypothetical option” of water supply from the Amu Darya to the Western sea on such a scale maintaining a cost-effectiveness of the Western sea preservation under environmentally active parameters – when salinity goes to less than 20 g/l. This would require the following:

- adoption of the optimistic scenario of water use in the basin;
- good natural water availability of hydrological series;
- rapid (5 – 6 years) implementation of the water supply to the Western sea;
- additional supply of collector-drainage water from Ozerny collector, with water pumping to GLK system and further to Sudochie;
- capital investments in an amount of 1,500 – 1,800 million USD.

Undoubtedly, there is one possibility to find such investments – attract funds of gas and oil companies that develop Prearalie, taking into account their interests in exploiting gas and oil reserves located under the Eastern Aral Sea.

Under the present conditions, the main attention should be paid to the establishment of a sustainable bioproductivity in Amu Darya and Syr Darya deltas according to the earlier developed NATO Project.

In the Eastern sea, the future level will vary depending on inflow and water availability, from 20,2m under the "National vision" to 32,7m under the "optimistic" option.

Moreover, in 20 years, the water level in the both water bodies will be stabilized, with some fluctuation within 1,5-2 m as subjected to inflow. This will lead to a drying-up and flooding of the coastal strip within 4000 km^2 maximally.

For some options (National vision) this will imply a reduction (increase) of area of residual water bodies at a level of 60% of medium-stabilized bodies at the end of given period (Table 40).

Table 40: Preservation of the Aral Sea waters in different options by 2025

Options		Western Sea		Eastern Sea		Total surface area
		level	water surface area	level	water surface area	
Current delta infrastructure						
National vision	2021	21,6	2439	31,0	10365	12804
	2025	20,2	2245	29,6	6177,2	8422
Business as Usual	2021	23,8	2865	31,3	11166,2	14031
	2025	23,4	2732,5	30,3	7975,0	10707
Optimistic	2021	31,5	5987,5	32,0	13267,8	20254
	2025	32,0	6405,4	32,2	13621,8	20026
NATO infrastructure						
National vision	2021	26,0	3374,9	30,2	7866	11240
	2025	24,0	2911,1	28,8	4940,1	7851
Business as Usual	2021	27,3	3770,8	31,0	10419,1	14189
	2025	25,9	3348,6	29,7	6818,4	10167
Optimistic	2021	31,6	6156,6	31,8	12823,4	18980
	2025	31,3	5844,3	31,4	11189,2	17033
Hypothetical option						
National vision	2021	31,6	6119,8	29,5	6934	13054
	2025	29,6	4721	28,3	3797	8518
BAU	2021	21,7	6218,6	30,8	9872,7	16091
	2025	30,5	5255,5	29,6	6257,4	11513
Optimistic	2021	32,7	6979	32,5	14333,0	21312
	2025	32,1	6484	32,0	13336,9	19813

Thus, taking into account that present water surface area is 20 thousand square kilometers (2006), the exposed area is expected to increase by 10 thousand square kilometers on average or additional one million hectares. Half of this area will be subjected to continuous rise or lowering of the sea level. As to the "optimistic" option, it is possible that the flooded area extends slightly as compared to the present level; however, the probability of this is very low. Hence, the exposed seabed will be the subject of concern in the future as well, and a need for a constant monitoring will prevail.

6. CONCLUSIONS

1. The comprehensive two-year expedition studies (soil, hydro-geological, biological, and environmental) on the dried seabed in combination with remote sensing techniques allowed us to monitor the newly emerged landscapes exposed to rapid changes.

2. Proceeding from the research tasks, a characterization of landscape was proposed by classes aggregated into four groups of environmental stability, with multiple characteristics.

3. The remote sensing approach allowed the identification of 11 out of 17 classes with high accuracy. For more accurate identification of the other 6 classes, additional comprehensive reference ground surveys and analysis of multitemporal images, particularly in spring, are needed.

4. The studies showed that the change processes on the desiccated sea bed were bilateral: degradation of landscapes and increase of their environmental instability, on one hand; and, stabilization of earlier disturbed and deflated surfaces, on the other hand.

5. The developed techniques enable a permanent monitoring over the dried seabed and coastal zones and also an assessment of the establishment of plantations and development of self-overgrowing. This allows planning first-priority measures for preventing an adverse effect of the risk zone on socially-important objects. Detail studies of the scale of stabilization and particularly self-overgrowing, will help to control those processes.

6. The research needs to be continued in the line of a permanent monitoring, the application of traditional methods and the search of new ways to fix the ground surface and mitigate the environmental hazards of the dried seabed.

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Appendix

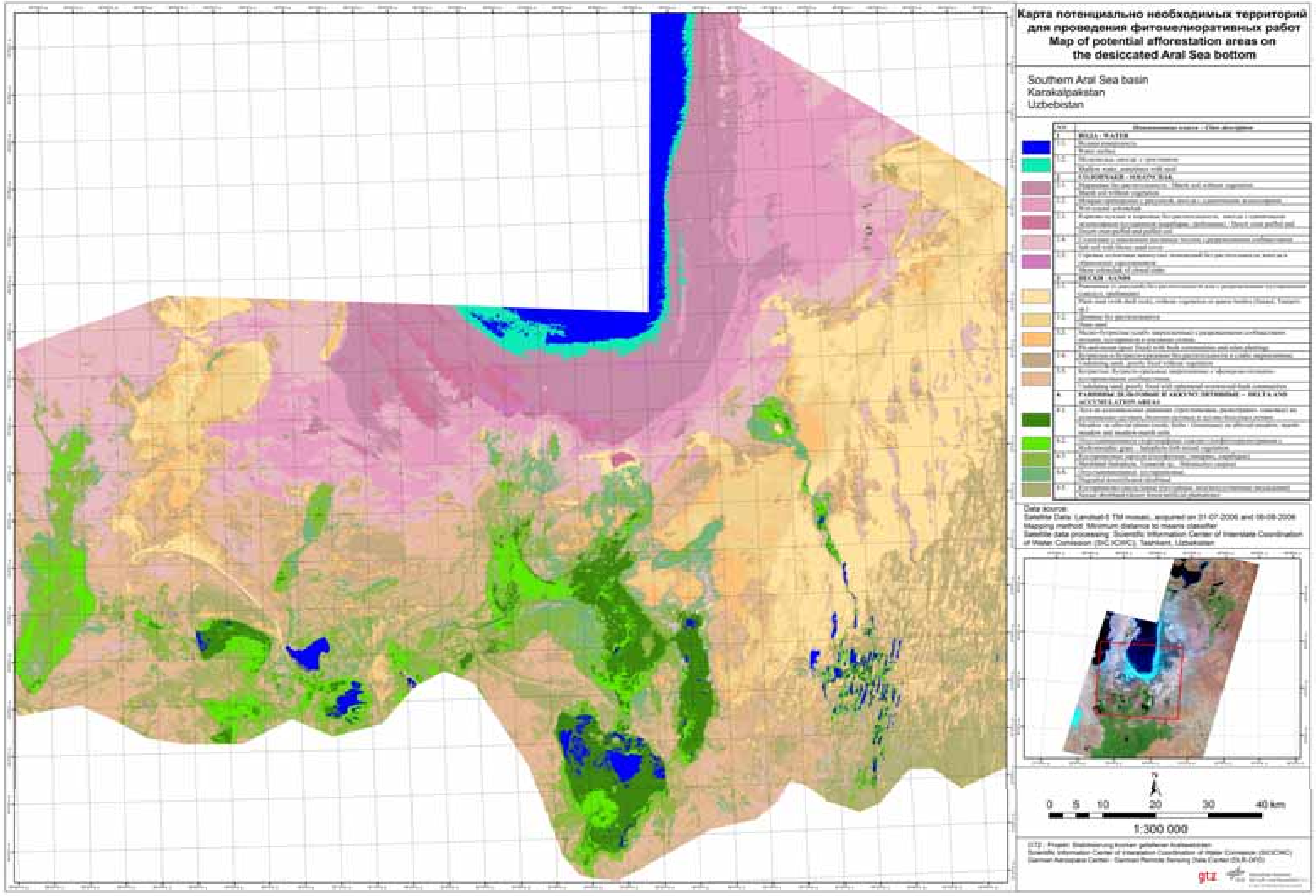

Fig. A1: Land cover map of the desiccated Aral Sea bed

Table A1: Table of distribution of field survey's points among thematic classes

NN	*Class*	Number of expedition				
		1	*2*	3	4	5
1	**WATER**					
1.1.	Water surface	-	-	-		
1.2.	Shallow water, sometimes with reed	-	-	-		
2	**SOLONCHAK**					
2.1.	Marsh soil, without vegetation or with Saltwort community	-	-	-		
2.2.	Wet-coastal, with cockle-shell, spots of Saltwort and Sarsazan	-	101,105,106,108	-		124,125,126, 128
2.3.	Desert crust-puffed and crust soil, without vegetation, spots of bushes (Karabarak, Tamarisk)	4,35	7,18,32,34,100, 102,107	-	150	37,39,40,41,42,4 3,44,59,127, 152
2.4.	Solonchak with blown sand cover, sparse Orach and Selin communities	2,19,31	3,24,26,28,29, 30,31,37,63, 103,109,135	59,63,71	37,57,111,114, 122,123,124,125	51,52,53,65,66,6 9,70,71,77,82,11 9,131,147
2.5.	Shor solonchak of closed sinks, without vegetation, sometimes in Sarsazan setting	13,16,37	142,143	-		
3	**SANDS**			-		
3.1.	Plain (with shell rock), without vegetation or sparse bushes (Saxaul, Tamarisk)	8,25,34,39,46	17,60,61,141,	-	15,17,18,46,47, 50,51,103,104, 107,109	24,32,33,45,46 133,157,160, 161,162
3.2.	Dune, without vegetation	40,41	40,43,58	41,42	7,9,10,12,14,40 49,81,79,12,128,13 2,135,137	132,141,144, 145,158
3.3.	Pit-and-mount (poor fixed) with sparse wormwood, bush communities and Selin plantings	14,26,28,43,45 47	9,42,62,136	50,53,67,76, 78	4,5,6,8,16,23, 24,25,28,30,31,415 4,58,61,63,66,6770 ,77,78,106,	104,117,130, 135,138,139, 140,146,148, 150,155

NN	*Class*	Number of expedition				
		1	**2**	**3**	**4**	**5**
					110,140,141	
3.4.	Hilly, hilly-ridge, without vegetation and poor fixed	10,24	36,39,57,77, 79,86,87	9,32,44,62,65, 66,72,74	1,3,64,71,73,76, 138,139	34,35,76,102, 103,121,122, 137,142,149, 154
3.5.	Hilly, hilly-ridge, poor-fixed with ephemeral-wormwood-bush communities	15,21,36	35,83,84,85,89, 99,110,115,116, 121,130,132	5,21,33,36,40, 43,48,49,51, 54,56	2,20,22,26,29,32, 34,39,55,90,91, 92,93,99 100,101,145,147,1 48,151,154	5,7,8,73,74,75, 89,96,100,101, 105,112,116, 123,143
4.	**PLAIN DELAIC AND OF DEPOSITION**					
4.1.	Meadow on alluvial plains (reeds, forbs-Gramineae) on alluvial-meadow, bog-meadow and meadow-bog soils	-	72,125	45,20		
4.2.	Subjected to desertification, hydromorphic Gramineae -halophyte-forb, with bushes	27,30	14,22,124, 149	3,7,13	38,48	6,62
4.3.	Shrub (halophyte: Tamarisk Karabarak)	1,9,18,29	19,21,128, 131	2,6,8,12,18,19 22,29,34,39	84,95,102	3,36,47,60,61, 63,64,80,91, 108,109
4.4.	Subjected to desertification, shrub	3,7,23,32	94,95,97	4,10,11,15,16 30,31,60,73	36,42,43,44,53, 116,117,149,155	56,72,107,113, 114,115
4.5.	Shrub-Saxaul (desert forest/artificial plantations)	5,6,11	4,5,6,122,133, 138	14,17,24, 26,27,37,38, 69,70,75	59,69,74,75,82,838 6,94,96,97,98, 142,146	2,4,88,90,111

Table A2: Assessment of change in the territory of South Prearalie from 1990 to 2005, based on the South Prearalie Landscape Map and satellite image processing results

No. on map	*Landscape type* *Source: "Map of landscapes in South Prearalie", as of 1990* *SANIIRI*	*Area (ha)* *Ecological hazard degree*	*No. of class on image*	*Landscape type* *Source: Map "Erosion hazard area on the dried bed of the Aral Sea", as of 2006*	*Area (ha)* *Ecological hazard degree*
1	Coastal marine plain. Groundwater discharge area with hydromorphic regime of coastal "marsh" solonchaks formation. Accumulative sandy and silt-loamy marine deposits of stratified structure. Prevailing sandy loams in the delta area. High groundwater salinity - 25-50 g/l. Seepweed-Saltwort vegetation on spots. Characterized by water erosion. In terms of time, it is a beginning of polygonal soil structures formation.	146952.91 *No*	2.1.	Marsh solonchaks without vegetation or with Saltwort communities. Seepweed-Saltwort vegetation on spots.	168708.88 *No*
2	Seaside plain with micro-relief and formed coastal hydromorphic crust and unstable crust solonchaks, puffed in places. Groundwater salinity is 25-5 g/l. Soils: stratified complexes, mainly sandy-clayey, with layers of sandy loam of different fractions. Richter Saltwort, Tamarisk and other plant associations root in some places, besides seepweed-saltwort vegetation. Total projective cover is 0.1%. In terms of time, it is termination of polygonal surface structures formation.	30183.95 *No*	2.2.	Wet-coastal solonchaks with shell, with rare isolated specimens of Saltwort and Sarsazan. Richter Saltwort, tamarisk and other plant associations root in some places, besides seepweed-Saltwort vegetation. Total projective cover is up to 5%.	125357 *No*
3	Plain formed of accumulative mixed stratified alluvial-deltaic and marine sandy-loamy and silty fractions. Represented by coastal residual hydromorphic and southward semi-hydromorphic crust, crust-puffed solonchaks, puffed in places and slightly covered with sand and sandy loam. Widespread seepweed on solonchaks and sands. As soil salinity decreases, perennial hydrophytic and mesophytic plants take roots. Polygonal structures contribute to soil drying, exposed to precipitation and wind effect, filled up with	92549.88 *Moderate*	2.3.	Crust-puffed and crust solonchaks without vegetation, with rare isolated specimens of shrubs (Karabarak, Tamarisk). Total projective cover is 5 to 7%.	23220 *Moderate*

No. on map	*Landscape type Source: "Map of landscapes in South Prearalie", as of 1990 SANIIRI*	*Area (ha) Ecological hazard degree*	*No. of class on image*	*Landscape type Source: Map "Erosion hazard area on the dried bed of the Aral Sea", as of 2006*	*Area (ha) Ecological hazard degree*
	sand, thus causing salt movement in micro-depressions. Polygonal elements contribute to germination of ephemer and perennial plants. Depending on contour location, texture can considerably vary from heavy to light fractions.				
4	Differs from the 3rd item in texture and lighter fractions in surface layer, by increased capacity for salt migration. Prevailing hydromorphic and semi-hydromorphic groundwater regime. Groundwater salinity is about 40 g/l in the central part, over 50 g/l in the western part. Vegetation cover represented by sparse seepweed groups, and Orach and seepweed-orach groups when joining to sandy loam soils (in the west and south of the contour). Characterized by water and wind erosion.	53024.75 *High*	2.4.	Solonchaks with blown sandy cover and sparse communities of orach and silen. Total projective cover is up to 10%.	226477.69 *High*
5	Vast marine plain composed of clays, heavy and medium loams with layers of sandy loam and sand; the surface overlain by layer of loams sandy loam and sand at initial stage of wind transformation. Represented by coastal residual automorphic, rare semi-automorphic and crust solonchaks in micro-depressions. They form during intensive evaporation of moisture accumulated on the surface through precipitation. Salt, sand and sandy loam easily washed off by precipitation into cracks of polygonal structures. The territory is subjected to potential desalinization and takyr-formation. Hydrophytic and mesophytic vegetation develops in places of moisture accumulation. Of perennial plants, the territory is covered with tamarisk. Total overgrowing coefficient from 0 to 1%. Intensive coverage with perennial plants up to 5% is observed in centers, and more dense colonies in seashore recession ridges. Groundwater salinity varies from 25 to 50 mg/l.	18919.68 *Low*	2.5. 3.4. 3.5.	Landscape type prevailing in the territory of Akpetki archipelago. Composed of new-Aral deposits. Low-high barchan sands. Oval hollows composed of salt-bearing black silt, loam and fine sand; overlain by thenardite puffed solonchak, bedded deposits of mirabilite-halite and brine. Partially fixed with vegetation. Total projective cover is 40 to 50%.	326578.73 *Low*
6	Marine plain, the relief formed under the influence of: sea currents;		4.3.	Relict seashore landscapes with	

No. on map	*Landscape type Source: "Map of landscapes in South Prearalie", as of 1990 SANIIRI*	*Area (ha) Ecological hazard degree*	*No. of class on image*	*Landscape type Source: Map "Erosion hazard area on the dried bed of the Aral Sea", as of 2006*	*Area (ha) Ecological hazard degree*
8	surface water; wind effect. Accumulated fractions are represented by sandy and sandy-loam layers underlain by loam and clay; as a whole, flat and pit-and-mount, semi-fixed sands combined with raw desert-sandy soils. The major part is characterized by meso-relief. Orach-seepweed groups and tamarisk develop on soils; area coverage varies from 0.5 to 10%. Regime is automorphic. Characterized by water and wind erosion.	101073.59 *Moderate*	4.4. 4.5.	fragments of sandy shore bank. Shrubs (halophytic vegetation: tamarisk, Karabarak) - natural overgrowing and Shrubby-Haloxylon - artificial plantations. Total projective cover is 50 to 60%.	389823.15 *No*
7	Marine plain located in the center of the former Dzhiltyrbas bay, differs from the former Adzhibay bay by higher coverage with annual and perennial plants. Semi-automorphic groundwater recharge regime. Groundwater salinity varies from 30 to 60 g/l.	22285.77 *No*	4.1.	Meadows on alluvial plains (reed, herbs, cereals) on alluvial-meadow, bog-meadow and meadow-bog soils. Total projective cover is 45 to 50%.	76295.98 *No*
9 10	Marine plain on accumulative marine sandy-loamy and sandy-silty-loamy deposits. Such territorial formations represent inclusions in form of micro-depressions that conduces to secondary salinization and solonchak formation due to surface salt distribution. Prevailing semi-automorphic and automorphic solonchaks. Hydrophytic combined with mesophytic vegetation develops in highly moistened places (the coefficient of overgrowing in saline areas is no more than 1-2%). Owing to partial surface desalinization, there are favorable conditions for intensive establishment and development of ephemeral and perennial vegetation. Vegetation cover coefficient is 15% in these areas, up to 25-30% on highly overgrown areas. Characterized by water and wind erosion. Groundwater salinity varies from 30 to 50 g/l.	168623.67 *Low*	4.2.	Hydromorphic soils subjected to desertification, with cereal-halophytic herb communities and shrubs. Total projective cover varies from 10% in saline areas to 70% in highly overgrown areas (partially artificial plantations).	57475.04 *Low*
11	Sands in drying-up zone represent sufficiently vast territories		3.1.	Unfixed sands at different stages	

No. on map	Landscape type Source: “Map of landscapes in South Prearalie”, as of 1990 SANIIRI	Area (ha) Ecological hazard degree	No. of class on image	Landscape type Source: Map “Erosion hazard area on the dried bed of the Aral Sea”, as of 2006	Area (ha) Ecological hazard degree
	differing in sediments origin only. Most of sand area is not fixed and movable. The fixing process is slow and associated with formation of hillocks, barchans and ridges. Sand mobility conduces to exportation of muddy particles and salts. More intensive sand fixing is observed in the Amudarya river delta. Best germination and development of 5 plants is in the places of a combination of thin sand layer (from 10 to 50 cm) covering sandy-loam and clayey platforms. Such combination keeps soil moisture well.	190330.13 *High*	3.2. 3.3.	of wind transformation: plain sands (with shell) without vegetation or with sparse shrubs; dune sands without vegetation; pit-and-mount sands (poorly fixed) with sparse communities of wormwood, shrubs and Selin plantings. Total projective cover varies from 20% to 30% (partially artificial plantations).	378529,54 *High*
	TOTAL AREA	***823944.33***		***TOTAL AREA***	***1772466.01***

Table A3: Assessment of change in the territory of South Prearalie, based on the Map of lithological composition of cover (quaternary) deposits on the dried bed of the Aral Sea and satellite image processing results

No. on map	*Landscape type* *Source: "Map of lithological composition of cover (quaternary) deposits on the dried bed of the Aral Sea", as of 1993-1996 GIDROINGEO*	*Area (ha) Ecological hazard degree*	*No. of class on image*	*Landscape type* *Source: Map "Erosion hazard area on the dried bed of the Aral Sea", as of 2006*	*Area (ha) Ecological hazard degree*
1, 2, 25, 26	Littoral plain and marsh zone composed of wet fine- and medium-grained, underwater-beach sands and wet silty clay covered with salty crust. No vegetation.	52978.56 *No*	2.1.	Marsh solonchaks without vegetation or with Saltwort communities. Seepweed-saltwort vegetation on spots.	176185 *No*
3, 27	Littoral plain composed of wet fine-grained sands and loams - wet and drying. Covered with salt-gypsum crust (0.5-2 cm), with numerous small heaving hillocks and banks and cracks on loamy deposits. Loams are subjected to active physical-chemical weathering, during 5-6 years, without shrub vegetation.	159904.31 *No*	2.2.	Wet-coastal solonchaks with shell, with rare isolated specimens of Saltwort and Sarsazan. Richter Saltwort, tamarisk and other plant associations rooting in some places, in addition to seepweed-saltwort vegetation. Total projective cover is up to 5%.	163604 *No*
43, 44	Plains in combination with solonchak depressions on sands. Plains are composed of flat fine-grained sands, dusty sandy loam and loams covered with thin dry salty crust. Solonchak depressions are crust and crust-puffed. 20-30% of the territory is affected by aeolation processes. Flat sands alternate with sands in initial stage of wind transformation represented by deflated and accumulative forms of relief. Projective cover of the territory varied from 1 to 5%.	191096.7 *Moderate*	2.3.	Crust-puffed and crust solonchaks without vegetation, with rare isolated specimens of shrubs (Karabarak, tamarisk). Total projective cover is 5 to 7%.	24252 *Moderate*

No. on map	*Landscape type* *Source: "Map of lithological composition of cover (quaternary) deposits on the dried bed of the Aral Sea", as of 1993-1996 GIDROINGEO*	*Area (ha) Ecological hazard degree*	*No. of class on image*	*Landscape type* *Source: Map "Erosion hazard area on the dried bed of the Aral Sea", as of 2006*	*Area (ha) Ecological hazard degree*
7, 11, 28, 34-36	Plains composed of sands and loams, covered with thin salty crust or puffed crust, in initial stage of wind transformation. A part of the territory is represented by sands blown onto wet solonchaks. Loams are divided into large polygons, separated by desiccation cracks; physio-chemical weathering process is completed. Active deflation, wind accumulation. Isolated tamarisk, Kandym.	115006.2 *High*	2.4.	Solonchaks with blown sandy cover and sparse communities of Orach and Selin. Total projective cover is up to 10%.	198573 *High*
4, 40-42, 47	Holocene old-Aral and new-Aral marine deposits on Akpetki archipelago. Islands of Akpetki archipelago are composed of sand and aleurite-clay materials. Old-Aral sands are flat and low hilly, deepened by deflation in some places. Dense small (1.5 - 2 m) Saxaul bushes (60-80%). Saxaul depressed and semi-dried. The dried bed of bays and straits of the archipelago is composed of new-Aral deposits. Sands are well-overgrown with high tamarisk and Saxaul. Projective cover varies from 20 to 40%. The bed of numerous oval hollows (1-2m) of the Togyzarkan channel and flow path is composed of salt-bearing black silt, loams and fine sands overlain by puffed solonchak tenardite, bedded deposits of mirabilite-halite. Total projective cover is 40 to 50%.	384926.1 *Low*	2.5. 3.4. 3.5.	Landscape type prevailing in the territory of Akpetki archipelago. Composed of new-Aral and old-Aral (island part) deposits. Low-high barchan sands. Oval hollows composed of salt-bearing black silt, loams and fine sands; overlain by puffed solonchak ternadite, bedded deposits of mirabilite-halite and brine. Partially fixed with vegetation. Total projective cover is 40 to 50%.	401027 *Low*
12, 19-24, 31-33, 45, 46	Coastal islands and sandy beaches created by wave-cut activity, and bank slope joined with them. Sands are highly over-blown. The hilly and porous relief of islands, overgrown with Calligonum, Kandym and strong bushes of tamarisk. Trees and herbs grow as well. Beach sands are partially fixed with Saxaul,	167286.2 *Low*	4.3. 4.4. 4.5.	Relict seashore landscapes with fragments of sandy shore bank. Shrubs (halophytic vegetation: tamarisk, Karabarak) - natural overgrowing and	397549 *No*

No. on map	*Landscape type* *Source: "Map of lithological composition of cover (quaternary) deposits on the dried bed of the Aral Sea",* *as of 1993-1996* *GIDROINGEO*	*Area (ha)* *Ecological hazard degree*	*No. of class on image*	*Landscape type* *Source: Map "Erosion hazard area on the dried bed of the Aral Sea", as of 2006*	*Area (ha)* *Ecological hazard degree*
	Kandym, tamarisk, Calligonum (10-30%). Prevailing deflation salt transport to lower areas on the adjacent dried seabed. Channel banks and depressions separating them are composed of sands and aleurites responding to the final cycle of the Amudarya accumulation. The plain was formed in the 1960-1980s during the extension of the estuarine channels following the receding sea. The hilly sands are partially fixed with shrubs (10-30%).			Shrubby-Haloxylon - artificial plantations. Total projective cover is 50 to 60%.	
30, 38, 39	Plain of the former coastal-marine reed-covered shallow water area. Sandy plains composed of sandy loams, with small lakes and puddles periodically emerging during water releases from reservoirs. Sandy plains are complicated by low shore banks (0.5-1.5m) and solonchak depressions. Aeolation processes are slow. Non-saline territories are well-overgrown with tamarisk, Karabarak and reed. Projective cover is 30 to 60%.	80695.06 *No*	4.1.	Meadows on alluvial plains (reed, herbs, cereals) on alluvial-meadow, bog-meadow and meadow-bog soils. Total projective cover is 45 to 50%.	107921 *No*
14, 37	Flat and low-hilly sands in combination with solonchaks (numerous hollows of the former lakes). Composed of puffed solonchak sandy loams, loams and sands. Stand in different stages of wind transformation: from areal deflation fields to formed barchans. Active deflation and wind accumulation. Mosaic overgrowing, from isolated tamarisk to areas covered with dense reed, in periodically flooded territories. Projective cover is 10 to 40%.	73162.86 *Low*	4.2.	Hydromorphic soils subjected to desertification, with cereal-halophytic herb communities and shrubs. Total projective cover varies from 10% in saline areas to 70% in highly overgrown areas (partially artificial plantations).	99753 *Low*
5, 6, 8-10, 13, 15-18,	Low- and high-barchan and phyto-hilly sands. Expanding thin covers of flat and low-hilly sands, with gravel in some places, overgrown with tamarisk, Kandym and Selin (projective cover from 10 to 30%). Fine and medium, unfixed, low- and high-	146945.8 *High*	3.1. 3.2. 3.3.	Unfixed sands in different stage of wind transformation: plain sands (with shell) without vegetation or with sparse shrubs;	403627 *High*

No. on map	*Landscape type Source: "Map of lithological composition of cover (quaternary) deposits on the dried bed of the Aral Sea", as of 1993-1996 GIDROINGEO*	*Area (ha) Ecological hazard degree*	*No. of class on image*	*Landscape type Source: Map "Erosion hazard area on the dried bed of the Aral Sea", as of 2006*	*Area (ha) Ecological hazard degree*
29	barchan sands, practically without vegetation. Inter-ridge depressions are covered (enriched) with cardium shell "deposited" from sand blown by wind. Active wind accumulation. Fine-grained high-barchan sands, without vegetation, being in stage of active dynamic development. Partially fixed with Saxaul, Kandym and tamarisk (Projective cover from 5 to 30%). In the territories with fine-grained high-barchan sands, aeolation processes are slow.			dune sands without vegetation; pit-and-mount sands (poorly fixed) with sparse communities of wormwood, shrubs and Selin plantings. Total projective cover varies from 20% to 30% (partially artificial plantations).	
	TOTAL AREA	***1372001.79***		***TOTAL AREA***	***1972491***

Printed in SIC ICWC

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