1. REPUBLIC OF KAZAKHSTAN

1.1. Optimization of the use of water and power resources of the basin Of Syrdarya River under the current conditions - Kazakhstan part, N. Kypshakbayev and A.K. Tasybayev

N. Kypshakbayev , Professor and Director, and
A.K. Tasybayev, Leading Specialist,
Kazakhstan Affiliate of SIC of the International Coordination Water Commission (ICWC)

Introduction

Till 1960, Aral Sea was the fourth biggest lake in the world by its area. The area of the surface was about 66 thous.km^2, and the volume was more than 1000 km^3, while the lake was supplied by natural inflow from two rivers – Amudarya, and Syrdarya (about 60 km^3 per year), by precipitation (5.5-6.5 km^3 per year), and by ground water (about 5-6 km^3 per year). Under these conditions, the level of water in the sea was fluctuating at 50.5-53.0 m, while the volume of evaporation was equal to about 60 km^3 per year.

Before 1960, the intake of water from the basin of Aral Sea did not exceed 63 km^3 per year, what saved the sustainable balance of the sea. However, during the 1950-1955, after the war, the idea of cotton and rice independence of the country began to develop in the Soviet Union. Orientation of the supply of the country with its own cotton and rice began to become truth since 1960-s especially intensively. As a result, the irrigated areas significantly increased, the sowings of cotton in Central Asian republics and in the Northern Kazakhstan, and the areas of rice plantations increased. Kazalynkiy region of Kyzylordinskaya *oblast* became the most northern border of rice allocation in the world. Obviously, cotton and rice sowings in the Soviet Union were first of all allocated in the basins f Amudarya and Syrdarya Rivers. Because of the annual increase in the amount of water first of al for irrigation, as well as for the supply of the population of the region, which increased 2.5 times, the annual amount of water consumption increased up to 95 km^3 per year, and the inflow of water to the sea was decreasing each year, and by 1990 it decreased down to 9 km^3 per year. As a result, an intensive decrease of the level of Aral Sea began by up to 1 m per year. During 1960-1990, the level of Aral Sea decreased by 17 m, down to 36.0 m. Because of that, the surface of the sea decreased by 2 mln.ha, the shore moved by 100 km in some places, and mineralization of water in the sea increased up to 40 g/l. Such degradation lead to almost total stoppage of fishing, and of the fishery industry in the region, as well as shipping in the sea. Large migration of the population occurred from the regions related with this phenomenon (15-20 thous. people during the last 10 years).

Intensive development of irrigation in all parts of the basin of Aral Sea increased the lack of water more and more, what forced the GEK of National Planning of USSR to issue the Decree No.11 dated 05.05.1982, in which they recommended to determine the amount of inflow to Chardara water reservoir not less than 12 km^3 during a middle water level year, and not less than 10 km^3 during a low water level year, corresponding to a 90% supply. However, this decree was fulfilled with difficulties, and not always.

Worrying about the developed threading environmental and biological situation in the region, the leaders of water-use organizations in the Republics of Central Asia and Kazakhstan, at the meeting in Tashkent, on October 10-12, 1991, issued a mutual announcement, in which they recognized the necessity of joining the forces, and of coordination of the activities on the effective resolution of water-use problems in the region under the conditions of increasing environmental tension.

Due to the collision of the USSR in December, 1992, all former Soviet Republics announced their independence, and announced the creation of independent states. In relation to that, resolution of the problems related to Aral Sea became even more difficult, because the single regulation of water resources was terminated, as well as of the created irrigation and power complex of the region.

Under these conditions, on February 18, 1992, at the meeting in Almaty, the leaders of the water-use organizations of the Republics of Kazakhstan, Kyrgyzstan, Turkmenistan, Tadzhikistan, and Uzbekistan signed the Agreement on cooperation in the sphere of joint regulation of the use of water resources of the international sources, in which they created the International Water Coordination Commission (ICWC), its executive and controlling bodies, accepted mutual obligations on the supply of strict fulfillment of the agreed upon order and established rules of the use and protection of water resources. According to Articles 8 and 10 of that Agreement, ICWC and its bodies should annually distribute the limits water intake, strictly fulfill the regime of outflows and the limit of water consumption, carry out sanitary outflows in the river beds of all rivers, and guarantee the determined amount of inflow of water resources to Aral Sea, with the aim of improvement of the environmental conditions, and protection of the necessary quality of water.

On March 26, 1993, in Kyzyl-Orda city, the first Conference of the Heads of the Central Asian countries took place, with the participation of Russian Federation, on the problems of Aral Sea, where they:

- Signed the Agreement on joint activities for solving the problem of Aral Sea and Aral Region, environmental improvement, and support of the social-economic development of Aral Region;
- Created the International Board on the problems of the basin of Aral Sea, determined its members, and the permanent executive committee;
- Created the International Fund for protection of Aral Sea, and approved the Decree on this Fund;
- Elected the President of the International Fund for protection of Aral Sea, and created the board of directors;
- Recognized Aral Sea and Aral Region as an independent water-consumer.

The International Board included the International Water Coordination Commission (ICWC), which was created in February, 1992. Its tasks and functions were approved, and the Commission for social and economic development, and scientific-technical cooperation was created.

During the first 4-5 years (1992-1996), all articles of the Agreement on joint activities for solving the problem of Aral Sea and Aral Region were generally fulfilled by the countries, which signed the Agreement. However, during the last years, some articles of the Agreement and of the decisions of ICWC were breached, especially by the Republics of Kyrgyzstan and

Tadzhikistan, which are located at the springs of the rivers Syrdarya and Amudarya. For example, Kyrgyzstan, where Naryn-Syrdara cascade of HPPs is located, after obtaining its independence, began to use them only for power generation, without paying special attention to the irrigation needs of the countries located down-stream. While this, outflows of water in winter especially damaged the population of South Kazakhstan and Kyzylordynskaya *oblasts* of Kazakhstan, where the demand and the regime of agricultural irrigation were significantly broken, and the amount of inflow to Arnasai increased.

Under these conditions, the countries located in the basins of the rivers Amudarya and Syrdarya, which used the water from these rivers for the needs of their national economy, had to develop national and regional strategies, devoted to protection and improvement of the ecosystem of Aral Sea and Aral Region. These strategies are already developed, but currently are under elaboration.

<u>The regional strategy</u> includes:

- Activities for economic rational use of the irrigation water, based on reconsideration of the structure of sowing areas, the increase in the effectiveness o the existing irrigation systems, etc.;
- Activities for bringing the maximum amount of water to Aral Sea and Aral Region during the years with different levels of water, based on the development of the methods of regulation of water resources, and methods of accelerated flow of water to the sea;
- Activities for improvement of the ecosystem of Aral Region, its flora and fauna, recreation of fishery and shipping in the sea and estuaries of the rivers Amudarya and Syrdarya.

<u>The national water strategy</u> for the protection and improvement of the ecosystem of Aral Sea and Aral Region must be reconsidered and added one more time in each country, located in the basin of Aral Sea, and its strict and complete fulfillment within the established time frame should be the guarantee for the improvement of welfare of the population of the region.

Water and Power Complexes of the Basin of Syrdarya River

Water Resources of the Basin of Syrdarya River

The major flow of the rivers of the basin of Syrdarya River forms in the territory of Kyrgyzstan, partially in the territory of Uzbekistan (about 15%), and Kazakhstan (about 6%).

The length of Syrdarya River within the territory of Kazakhstan is equal to about 1750 km. In that part, the largest tributaries to Syrdarya are the rivers Keles, Arys, Badam, Boraldai, Bugun, as well as small rivers, coming from the south-western hills of Karatau mountain range. In addition to water from Syrdarya, coming through the river bed, water also comes from the territory of Uzbekistan through Dostyk canal for irrigation of the Kazakhstan part of Golodnaya steppe, part of the flow of Chirchik river comes through the system of canals CHAKYR, and the flow of the small rivers is used through the system of canals ARTUR, as well as through other small systems.

Water resources of Kazakhstan part of Syrdarya River are equal to the sum of:

- surface water, equal to the sum of the flow through the river bed of Syrdarya river, and through its tributaries down-stream;
- collected-drainage water (CDW) coming from the irrigated areas; and

- ground water.

Surface Water

The amount of the flow in the alignments of Syrdarya can be characterized by the data from the following hydro-posts: Kokbulak, Shardara, Koktube, and Karateren. Hydro-post Kokbulak is located at the border between Uzbekistan and Kazakhstan, hydro-post Shardara – 1635 km from the estuary, at the tail water of Chardara water reservoir, hydro-post Koktube – 1281 km from the estuary, at the border between South-Kazakhstan and Kyzylordynskaya *oblatsts* (at the place of water intake to Kelintubin main canal), hydro-post Karateren – at the place of direct inflow to Aral Sea, at the estuary of Syrdarya River.

The amount of water resources of Syrdarya River within the territory of Kazakhstan during 1995-1999.

(mln.m^3)

Hydro-posts	Years					
	1995	**1996**	**1997**	**1998**	**1999**	**Average for 1995-1999**
Kokbulak	14600	15925	13970	24440	18314	17450
Shardara	12740	15484	13970	20590	16961	15949
Inflow to Arnasai	3430	820	1200	3050	3130	2326
Koktube	12770	14960	13460	20390	16262	15568
Karateren	4530	4890	3820	7410	6030	5336

As can be seen from the above data, during the last 5 years (1995-1999), the largest amount of the inflow of water to Shardarin water reservoir through Syrdarya River occurred in 1998, while the smaller one occurred in 1997. In 1995, 1998, and 1999, the amount of the forced outflow from Shardarin water reservoir was equal to 3-3.5 km^3, while in 1996 it decreased to 0.8 km^3, that is 3.7-4.3 times (4 times in average). This can be explained, on one hand, by winter outflows from Toktogul water reservoir, and, on the other hand, by high level of water during the given year.

The outflow to the tail water of Chardara water reservoir, in average for 1995-1999, is equal to 15949 mln.m^3 per year. It constitutes 91% of the amount of water coming to the water reservoir. 5336 mln.m^3, or 33.4% of this amount reached Aral Sea. The rest amount was used for ecological objects, and for river bed losses. The ecological objects are represented by lakes, old river beds, *tugai* forests and bushes, pasture lands, water-troughs for cattle, etc..

The largest amount of inflow to Aral Sea from Syrdarya occurred in the high-level year of 1998 (7.4 km^3), and the smallest one occurred in 1997 (3.8 km^3).

Water Supply for Irrigated Lands

The major amount of water consumption is used by irrigation – 88-90% of the whole amount. However, actual supply of water for the irrigated lands was equal to 76.4-86.2% (see table).

Oblasts	Actual supply of water, thous.ha / %			
	1991	**1992**	**1993**	**1994**
South-Kazakhstan	449,8 76	500,3 80	500,3 90	500,3 87
Kyzylordinskaya	286,0 77	292,2 80	285,9 92	285,9 85
TOTAL	785,8 76,4	792,5 80	786,2 80,7	786,2 86,2

Collected-Drainage, and Household Outflows

In general for the basin, the river bed of Syrdarya received the collected-drainage water in the amount of 10.1 km^3 per year in 1987-1997, with the fluctuation from 8.8 to 11.7 km^3, including 1.1-1.6 km^3 per year formed within the boundaries of Kazakhstan.

According to the reported data, annually, 550-910 mln.m^3 of the CDW, which form from the outflow from the irrigated areas of South-Kazakhstan *oblast*, currently get to Syrdarya River. The rest amount goes to the lakes and other relief low lands, located on the left and right shores of the river, in the down-stream.

However, it is necessary to notice, that CDW is the major source of pollution of water environment in the region. Sulfate, chloride, and sodium chlorides, as well as pesticides prevail in CDW.

In 1960, mineralization of the water in Syrdarya River, not only in Bekabad alignment, but even in the down-stream (h/p Kazalynsk) did not exceed 1g/l, while in 1980 this index in Bekabad was equal to 1.38 g/l, and in Kazalynsk it was equal to 1.72 g/l, and in 1985 – 1.4 and 2.26 g/l correspondingly. That is why it is necessary to carry out activities to avoid the increase in the level of mineralization of water, especially CDW, in the territory of all countries of the basin, that is in the whole river bed of Syrdarya.

Ground Water

In South-Kazakhstan and Kyzylordinskaya *oblasts*, 49 deposits of ground water were discovered and approved in GKZ and TKZ.

In Kyzylordinskaya *oblast*, the exploitation reserves are determined for 24 deposits. The largest are Mynbulak , Kyzylkum , Levoberezhnoe, Konedaryn , and Kuandaryn . Total exploitation reserves are equal to 1972.5 thous.m^3/day, 1451.6 thous.m^3/day, or 510.8 mln.m^3/year are approved. The depth of the shafts is equal to 100 to 400-500 m, mineralization of water is equal to 1.5 g/l. Actual water intake from the shafts in 1995 was equal to 71.2 mln.m^3. The amount of water intake from ground water in Kyzylordinskaya *oblast* in 1998 decreased 1.5 times in comparison to 1995.

In South-Kazakhstan *oblast*, the approved reserves in 25 deposits are equal to 2055.5 thous.m^3/day, or 750.2 mlm.m^3/year. The largest are Tassai-Aksu , Badam-Sairam , Mirgalimsai , and Beresek-Kentogan . The depth of the shafts is equal to up to 300-330 m, mineralization of water is equal to up to 1 g/l. Water intake from the shafts in 1995 was equal to 370.1 mln.m^3. The amount of water intake from ground water in South-Kazakhstan *oblast* in 1998 decreased 1.51 times in comparison to 1995.

As mentioned above, during the last 4-5 years (1995-1999) in Kazakhstan, including southern regions, the amount of functioning shafts significantly decreased due to the lack of power, as well as to stoppage of certain industrial enterprises.

Currently, ground water in South-Kazakhstan and Kyzylordinskaya *oblasts* are used for household, agricultural, and industrial water supply. Water intake from ground water for irrigation is carried out only within the boundaries of South-Kazakhstan *oblast*.

Development of Irrigation in Kazakhstan Part of the Basin of Syrdarya River

Development of irrigation is characterized by the following data:

Availability of irrigation areas

(thous.ha)

Regions	**Years**								
	1965	**1966**	**1967**	**1968**	**1990**	**1991**	**1992**	**1993**	**1994**
Kyzylordinskaya *oblast*	105,5	106,9	108,0	108,0	286,0	286,0	292,2	285,9	285,9
South-Kazakhstan *oblast*	233,9	235,4	228,9	228,9	495,8	499,8	500,0	500,3	500,3
Total for the basin	339,4	342,3	336,9	336,9	781,8	781,8	792,2	786,2	786,2

As a result of fulfillment of long-term melioration of lands in the Soviet Union, carried out after the May (1966) Plenum of CC of CPSS, the area of irrigated lands in the basin increased up to 790 thous.ha, or 2.3 times, by 1990, including 2.7 times increase in Kyzylordinskaya *oblast*, and 2.1 times increase in South-Kazakhstan *oblast*.

The changes in the structure of crops in the irrigated areas is characterized by the following data:

The structure of crops in the irrigated areas

Indexes	Kyzylordinskaya *oblast*				South-Kazakhstan *oblast*			
	1967	1968	1993	1994	1967	1968	1993	1994
Irrigated lands used, thous.ha	99,2	106,1	285,9	285,9	211,1	218,3	500,3	500,3
Including grain, thous.ha	54,3	62,0	170,9	160,1	45,4	48,8	143,1	159,6
%	54,7	58,4	59,8	56,7	21,5	22,9	28,6	31,9
Of them, rice, thous.ha	43,4	49,6	79,9	73,1	5,0	5,1	16,3	15,6
%	43,7	46,7	27,9	25,5	2,3	2,3	3,2	3,1
Technical, thous.ha	0,1	0,1	5,1	5,1	77,1	81,4	138,1	129,5
%	-	-	1,8	1,8	36,5	37,3	27,6	25,9
Of them, cotton, thous.ha	-	-	-	-	63,3	65,5	110,5	110,8
%	-	-	-	-	30,0	30,0	22,1	22,1
Feeding, thous.ha	39,0	50,0	106,1	113,8	73,4	77,3	191,1	195,1
%	11,0	12,6	37,1	39,8	20,8	19,5	38,2	39,0
Vegetable-pumpkin, thous.ha	1,8	1,9	2,4	2,2	6,6	6,4	15,5	12,0
%	2,7	2,7	1,0	1,0	3,1	2,9	3,1	2,4

The area of grain crops in Kyzylordinskaya *oblast* in 1967-68 was fluctuating in the range of 54-62 thous.ha, and in 1993-94 it increased up to 160-170 thous.ha, including an increase in the area for rice from 43-49 thous.ha to 73-80 thous.ha, or 1.5-1.8 times.

In South-Kazakhstan *oblast*, the area of grain crops increased from 21.5-22.9 thous.ha in 1967-68 to 28.6-31.9 thous.ha in 1993-94, including an increase in the area for rice from 5.0 to 16.3 thous.ha, or 3.2 times. In 1960-s, 1 ha of rice consumed irrigation standard of about 40 thous.m^3, while in 1990-s it decreased to 30 thous.m^3. Even with such a decrease in the irrigation standard (25%), 2.18 km^3 of water were used for rice production in two *oblasts* in 1967-68, in comparison to 2.88 km^3 in 1993-94, that is even with taking into account the decrease in the irrigation standard (25%), total amount of water used for rice production increased 1.3 times.

In Kyzylordinskaya *oblast*, rice is produced in all regions (excluding Aral Region), while in South-Kazakhstan *oblast* it is produced in Shardara Region.

Technical crops are mainly produced in South-Kazakhstan *oblast*. The area of cotton increased from 63.3-65.5 thous.ha in 1967-68 to 110.5-110.8 thous.ha in 1993-94, that is it increased 1.7 times. Consequently, the amount of water used for cotton production increased 1.5-2 times.

In the irrigated areas of the *oblasts* under consideration, grains are produced (seed, corn, rice), as well as technical crops (cotton, pharmaceutical, sunflower), vegetable-pumpkin crops, potatoes, feeding crops (lucerne, corn, etc.), perennial crops (fruit trees, grapes, etc.), and joint gardens.

The major irrigation areas are the following:

In Kyzylordinskaya *oblast* – Yanykurgano-Chiiliy, Toguskent, Kzylordin, and Kazalin right-shore and left-shore areas.

In South-Kazakhstan *oblast* – part of Golodnaya steppe, Chirchik-Angren-Keles, Kzylkum, and Arys-Turkestan areas.

The Technique and Technology of Irrigation

In South-Kazakhstan *oblast*, in 1980, 371.4 thous.ha were irrigated through furrows, and 40 thous.ha were irrigated by raining machines, that is the share of machinery irrigation was equal to 10.8%. During the following years, the share of machinery irrigation decreased. For example, in 1990, 431.3 thous.ha of 495.8 thous.ha of irrigated areas, or 86.9%, were irrigated through furrows, and 33.2 thous.ha, or 6.7%, were irrigated by raining, while in 1994 these indexes were as the following: 500.3 (100%); 423.4 (84.7%), and 33.2 (6.6%). In addition to that, in 1990-1994, in South-Kazakhstan *oblast*, 14-15 thous.ha of rice plantations were irrigated by flooding of checks.

In Kyzylordinskaya *oblast*, in 1980, 44.8 thous.ha of grains and vegetable-pumpkin crops were irrigated through furrows, and 93.3 thous.ha of rice plantations were irrigated by flooding of checks. In 1990, 90.2 thous.ha (31.5%) of the total irrigated area of 286.0 thous.ha were irrigated through furrows, and 87.0 thous.ha (30.4%) were irrigated by flooding of checks. In 1994, these indexes were as the following: 285.9 (100%); 92.8 (32.4%), and 73.1 (25.5%).

The applied methods of irrigation (1990-1994)

Oblasts	**Years**	**Total, thous.ha**	**Including**		
			Through furrows	**By flooding of checks**	**By raining**
Kzylordinskaya	1990	286,0	90,2	93,3	-
South-Kazakhstan	1990	495,8	431,3	14,0	33,2
Kzylordinskaya	1994	285,9	92,8	73,1	-
South-Kazakhstan	1994	500,3	423,4	15,0	33,2

One of the indexes of effective use of water is the efficiency of the irrigation system, which is currently equal to 0.57-0.58:

Efficiency of the irrigation system

Oblasts	**1995**	**1996**	**1997**	**1998**	**1999**
Kzylordinskaya	0,61	0,60	0,60	0,58	0,58
South-Kazakhstan	0,60	0,60	0,59	0,57	0,57

The total length of irrigation canals in two *oblasts* of Kazakhstan in 1997 was equal to 27.8 thous.km, 73.8% of which have ground bed, and 26.2% of which are reveted canals and pipes.

Dynamics of Water Intake, and of the Use of Water Resources

Water intake is carried out for the following needs:

a) irrigation;
b) household water supply;
c) agricultural water supply;
d) industrial water supply;
e) fishery;
f) water consumption by ecological objects;
g) flooding of hayfields, inflow to Aral Sea, filling in of the delta of the river, etc..

Generalization of the data for 1995-1999 has shown, that, in average, during these 5 years, in Kazakhstan part of the basin of Syrdarya River about 9.05 km^3 of water were annually used, including 8.7 km^3, or 96.2% of the total water intake, from Syrdarya River, and 0.347 km^3, or 3.8% - from ground water. During these years, the average annual amount of water intake for the water-consumers in South-Kazakhstan *oblast* constituted 3.97 km^3, or 43.8%, and for the water-consumers in Kyzylordynskaya *oblast* it constituted 5.09 km^3 (56.2%).

The data on water intake and water consumption during 1995-1999 are presented below:

The amount of water intake (mln.m^3) in 1995-1999 (based on the data of 2-TP)

Oblasts	**Years**	**Total**	**Incl. ground water**
Kyzylordinskaya	1995	4976,5	71,2
	1996	5102,9	61,7
	1997	4840,9	51,6
	1998	5584,8	46,0
	1999	4921,6	
South-Kazakhstan	1995	4438,6	370,1
	1996	4500,9	322,5
	1997	3893,7	279,8
	1998	3686,0	244,2
	1999	3313,8	226,7
TOTAl	1995	9425,1	441,3
	1996	9603,8	384,2
	1997	8734,6	331,4
	1998	9270,8	290,2
	1999	8235,4	

The annual amount of water intake in 1995-1999 decreased in comparison to 1990-1994. In 1990-1994, the annual amount of water intake was equal to 11.5 km^3, while in 1995-1999, it decreased to 9.05 km^3 per year.

a) <u>water consumption for irrigation</u>

In 1990-1994 water consumption for irrigation in Kyzylordinskaya and South-Kazakhstan *oblasts* in total was equal to 9.7-10.6 km^3 per year, while in 1995-1999 it decreased from 8.63 km^3 in 1995 to 6.7 km^3 in 1999.

Water consumption for irrigation in 1995-1999

Years	**Actually irrigated areas (thous.ha)**	**Water intake for irrigation (mln.m^3)**	**Proportional water consumption (m^3/ha)**
1995	696,9	8633,3	12390
1996	636,2	8387,3	13180
1997	574,9	7795,9	13560
1998	521,0	7077,6	13560
1999	533,3	6722,4	12600

As can be seen from the data presented above, the amount of water intake is decreasing year by year: from 10.1-10.6 km^3 in 1990-1992 to 6.7-7.8 km^3 in 1997-1999.

The productivity of the agricultural crops in irrigated areas remains at a relatively low level, and, moreover, year by year it is decreasing due to low level of agriculture, lack of mineral fertilizers, irregular irrigation, lack of production means, etc..

Average productivity of the major agricultural crops (quintal/ha)

Years	**South-Kazakhstan *oblast***					**Kyzylordinskaya *oblast***			
	Cotton	**Rice**	**Winter wheat**	**Corn for grain**	**Lucenre**	**Rice**	**Winter wheat**	**Corn for grain**	**Lucerne**
1990	27,1	56,7	43,6	34,6	70,3	52,3	29,4	17,7	41,4
1991	24,9	55,0	26,1	31,9	63,8	49,0	20,0	14,5	49,4
1992	22,6	49,1	25,7	35,4	62,8	44,9	22,5	14,0	49,6
1993	18,3	35,1	21,4	30,5	52,3	36,4	10,5	9,7	44,7
1994	18,8	29,1	10,4	22,9	42,7	27,3	7,4	7,5	27,2
1995	21,6	15,2	9,2	17,6	31,0	25,8	8,3	13,0	28,3
1996	17,8	16,3	14,0	14,0	25,0	36,7	3,0	9,3	27,7
1997	19,2	15,1	14,0	16,9	20,1	40,4	13,3	24,2	29,3
1998	14,1	19,7	11,8	25,0	19,4	40,3	10,8	19,9	28,1
1999	17,7	26,7	14,4	27,1	N/a	39,6	N/a	N/a	N/a

Currently, the average yield of cotton in South-Kazakhstan *oblast* is equal to 15-20 quintal/ha, rice – 15-25 quintal/ha, winter wheat – 10-14 quintal/ha, corn for grain – 20-24 quintal/ha, and lucerne – 28-30 quintal/ha; while in Kyzylordinskaya *oblast*: rice – 35-40 quintal/ha, winter wheat – 10-11 quintal/ha, corn for grain – 20-24 quintal/ha, and lucerne – 28-30 quintal/ha.

b) <u>water consumption for industrial and household water supply</u>

is carried out in small amounts in the cities and regional centers, located at the shores of Syrdarya River. Even less amounts of water are consumed by households because of low quality of water from the river.

Household and industrial water consumption in 1995-1999

Oblasts	**Water consumers**	**Consumption, mln.m^3/year**				
		1995	**1996**	**1997**	**1998**	**1999**
Kyzylordinskaya	Household, total	23,09	21,8	32,18	38,3	22,55
	Including ground water	8,92	6,76	6,50	5,50	10,76
	Industrial, total	84,37	51,8	38,77	36,50	35,48
	Including ground water	37,10	28,99	21,14	13,35	12,50
South-Kazakhstan	Household, total	100,70	106,20	81,40	59,40	65,00
	Including ground water	99,91	104,06	79,15	56,40	49,30
	Industrial, total	102,98	74,00	88,13	40,60	78,68
	Including ground water	86,58	62,32	41,20	35,00	31,10
Total	Household, total	123,79	128,00	113,58	97,70	87,55
	Including ground water	108,83	110,82	85,65	61,90	60,06
	Industrial, total	187,35	125,90	126,90	77,10	114,16
	Including ground water	123,68	91,31	62,34	48,35	43,60

During the period since 1995 till 1999, the amount of household water supply in Kyzylordinskaya and South-Kazakhstan *oblasts* in total decreased from 123.79 to 87.55 mln.m^3, or 1.3 times, while the amount of industrial water supply decreased from 187.35 to 114.16 mln.m^3, that is 1.6 times. The total amount of household and industrial water consumption in 1999 was equal to 201.7 mln.m^3 (while in 1990 it was equal to 311.14 mln.m^3).

c) <u>water consumption for fishery needs</u>

At the current level, the water from the river bed of Syrdarya is used for filling in of the artificial ponds and fisheries, and separate fishery lakes.

The amount of non-returnable water consumption for fishery in average for 1990-1994 was equal to 138.66 mln.m^3. However, it has a tendency for decrease. In 1995 water consumption for fishery needs was equal to 157.89 mln.m^3, while by 1999 it decreased to 60.75 mln.m^3.

(mln.m^3)

Years	**1995**	**1996**	**1997**	**1998**	**1999**
Water consumption	157,89	94,40	102,53	69,78	60,75

In average, the annual amount of water consumption for fishery needs can be estimated as 90-100 mln.m^3.

d) <u>water consumption for ecological objects</u>

The ecological objects are located in the water-meadows of Syrdarya River in the part from the border of South-Kazakhstan *oblast*, and are represented by flooded old river beds, low-lands, lakes, valleys, which are the place of growing of grass, reed, bushes, *tugai* forests, the place of location of animals, birds, the place of watering of cattle, pastures, and oasis for the population.

Flooding of these objects depends on the level of water in Syrdarya River. That is why water supply for these goals significantly fluctuate year by year, and transportation of water to these objects is related with significant losses due to long length of the canals.

In general, the guarantee of water supply for the mentioned above ecological objects does not exceed 50%, and the effectiveness of water use here is not high, and depends on the level of water during the given year.

Along with the spring high water and winter outflow from Chardara water reservoir, the collected-drainage water (CDW) play their role in water supply of ecological objects, which are coming from irrigated areas located on the left and right shores of Syrdarya River. On the right shore, CDW coming from Arys-Turkestan area, Bugun water reservoir, and the spring flow from small rivers of south-western slopes of Karatau mountain range come to Shoshkakol lake and flooded hayfields, and CDW from Yanykurgano-Chiiliy irrigated area comes to Telekol flood-lands and Khankozha lake, while CDW from the right-shore Kyzylordin irrigated area comes to Karauzek flood-lands. CDW from the left-shore Kyzylordin irrigated area come to the water-meadows of dry low-lands of Zhanadarya and Kuandarya, and CDW from the left-shore Kazalyn irrigated area come to Bozkol lakes. Water consumption by ecological systems in average for the last 25 years is the following:

Water consumption by ecological systems
(in average for the last 25 years, mln.m^3)

<table>
<tr><th rowspan="4">Total</th><th colspan="6">Including</th></tr>
<tr><th rowspan="3">South-Kazakhstan oblast – Shoshkakolskaya lakes system</th><th colspan="5">Kyzylordinskaya oblast</th></tr>
<tr><th rowspan="2">Total</th><th colspan="3">Including</th></tr>
<tr><th>Telekolskaya</th><th>Zhanadarynskaya</th><th>Karaozek</th></tr>
<tr><td>1591,7</td><td>383,5</td><td>1208,2</td><td>118,5</td><td>418,0</td><td>671,8</td></tr>
</table>

e) <u>flooded hayfields</u>

Hayfields are the basis for feeding production in the regions located far from Syrdarya River, in terms of the availability of winter reserves of food for cattle.

The area of hayfields (thous.ha)

Oblasts	**Total**	**Water-meadows**	**Delta**	**Ecological systems**
Kyzylordinskaya	103,7	29,6	19,7	54,4
South-Kazakhstan	31,3	-	-	31,3
Total	135,0	29,6	19,7	85,7

The actually flooded areas of water-meadow hayfields during the last years were equal to 26.0 thous.ha, and their water consumption was equal to 138.10 mln.m^3.

f) <u>Delta of Syrdaya River</u>

Before the beginning of intensive development of irrigation (early 1960-s), the delta of Syrdaya River was receiving up to 4-5 km^3 of water per year. The environmental-economic complex consisting of small lakes, hayfields, *tugai* forests, water-marsh lands was normally developing, and served as the source for flora and fauna. After that, inflow to the delta significantly decreased, what became the major cause for the degradation of the delta and its drying.

Dring 1976-1990, the average inflow of water to the delta decreased down to 850 mln.m^3, while during separate years the delta was receiving not more than 500 mln.m^3.

During 1990-1994, the amount of inflow of water to the delta of Syrdarya River increased due to high water level in the sources, changes in the structure of crops (a decrease in the share of cotton and rice), as well as an increase in the outflow from Toktogul water reservoir for the purpose of increase in power generation during the winter period.

The actual amount of inflow of water to the delta (h/p Kazalynsk)

(mln.m^3)

Years	1991	1992	1993	1994	1995	1996	1997	1998	1999
Inflow, mln.m^3	3,69	4,54	9,1	10,06	5,5	6,72	5,68	9,23	7,94

During 1991-1999, the average annual water consumption by the delta was equal to 1-2 km^3 per year, what significantly increased the level of water. In future, in case of fulfillment of the established amount of hydro-technical activities for the increase of the capacity of the river in the part from Shardara to Kazalynsk, and exclusion of useless outflow of water to Arnasai lakes, the level of water in the delta of Syrdarya River will significantly increase.

g) <u>Aral Sea</u>

The Agreement of the International Board of Central-Asian countries on the problems of the basin of Aral Sea recognized Aral Sea and the delta of Amudarya and Syrdarya rivers as a separate water consumer. In Kazakhstan part of the Aral Sea, currently, the main task is to save the Northern part of the sea, which is called Northern Aral Sea. The required water consumption of the Northern Aral Sea consists of the amount equal to evaporation and filtration, as well as cleaning with the aim of decrease and remaining of mineralization at the level of not more than 16-17 g/l. The major part of inflow to the Northern Aral Sea takes place in winter, because in summer irrigation consumes the major part of the water outflowing from Chardara water reservoir, while in spring and in autumn hayfields are flooded, or lakes are filled in. That is why the fulfillment of the agreed upon regime of the cascade of water reservoirs, carrying out of activities for widening the river bed of Syrdarya River down-stream from Shardara, and exclusion of the outflow of water to Arnasai lake are the necessary conditions for saving of and further increase in the amount of water in Northern Aral Sea. Construction of Kokaralskaya dam will allow to stabilize the necessary level, and will cover with water a significant part of the dry bottom of the sea, will decrease the amount of salt and dust pollution of the atmosphere.

In terms of the additional water resources of the neighboring countries in the basin of Syrdarya River, it is planned to provide inflow of water to the Northern Aral Sea in the amount of not less than 5-7 km^3 per year. Actual inflow of water directly to Aral Sea through Syrdarya River was equal to:

1995 – 4.53 km^3,
1996 – 4.89 km^3,
1997 – 3.82 km^3,
1998 – 7.41 km^3,
1999 – 6.03 km^3.

h) <u>Losses of the flow in Syrdarya River</u>

Losses of the flow in Syrdarya River include:

- losses from Chardara water reservoir;
- losses from the river.

Losses from Chardara water reservoir consist of natural losses for filtration in the river bed and reservoir, plus evaporation from the surface of the water reservoir, as well as the forced losses related with the outflow of water to Arnasai low land.

The natural losses from the water reservoir are determined during the long period of exploitation, and are equal to 500-750 mln.m^3 per year, depending on the climate and level conditions.

Since the moment of putting of Chardara water reservoir into exploitation, the water intake for irrigation significantly increased in Kyrgyzstan, Uzbekistan, as well as in South-Kazakhstan *oblast*, as a result of what the amount of flow in the river bed of Syrdarya became smaller and smaller, and the areas of water-meadow and above-water-meadow floods were decreasing each year. In addition to that, during the last 5 years, the regime of exploitation of Toktogul water reservoir also changed from irrigation to power. Winter inflow to Chardara water reservoir significantly increased. During certain years, as early as by the middle of December the water reservoir was filled in at the level of the standard horizon, and outflow began. Because the amount of outflow exceeded the capacity of the river bed of Syrdarya in the down-stream region, in order, on the one hand, to avoid destruction of hydro-technical water-flow constructions on the river, and, on the other hand, to avoid flooding of populated areas, under the conditions of icy river bed and water-meadow, the surplus amounts had to be directed to Arnasai lakes as early as in December.

During 1993-1999, Arnasai low-land received total of 23.2 km^3 of water, including:

1993 – 2.40 km^3,
1994 – 9.20 km^3,
1995 – 3.43 km^3,
1996 – 0.82 km^3,
1997 – 1.20 km^3,
1998 – 3.05 km^3,
1999 – 3.13 km^3.

Water losses consist of river bed losses (filtration, and evaporation from the surface of water), ecological (in case of coming of water to the water-meadow, and from the water-meadow in case of high water), and flooding of hayfields and pastures. According to the data provided by GGI, the Ministry of Water Resources of Kazakhstan, the Institute of "Sredazgiprovodkhlopok", etc., the total losses are significantly fluctuating, and, depending on the level of water during the given year, are equal to 1.4-6.3 km^3 per year. Actual river bed losses, according to the data provided by Aral-Syrdaryn BWU of Kazakhstan, are equal to:

1996 – 2.21 km^3,
1997 – 2.59 km^3,
1998 – 3.79 km^3,
1999 – 4.03 km^3.

Regulation of the Flow of Syrdarya River in the Down-Stream Region

Within the territory of Kazakhstan, Shardara, Kzylordin, and Kazalyn hydro-junctions are located at Syrdarya River, as well as water intakes to the main canals Togusken, Kelintubin, Novochiliy, Novosolotubin, and hydro-posts Koktube, Tomenaryk, Kergelmes, Tasbuget, Dzhusaly, etc..

Out of the hydro-junctions mentioned above, only Chardara has the purpose of accumulation of the flow in the water reservoir, while the rest hydro-posts are distributing the flow of the river to irrigation areas.

Chardara hydro-power complex has the following major purposes:

- Accumulation of the autumn-winter flow of Syrdarya River for the further outflow to irrigation areas of Kyzylordinskaya *oblast*, that is regulation of the flow with the aim to increase water supply for the irrigated areas, and to support ecological objects in the down-stream region of the river.
- Power generation for the needs of power-consumers in Southern Kazakhstan. The average annual power generation is equal to 377 mln.kWh, while the estimated capacity is equal to 100 MW.
- The volume of the water reservoir at the level of NPG of 252 m is equal to 5.2 km^3. The maximum capacity to the tail water is equal to 1800 m^3/s, while the maximum outflow to Arnasai low land is equal to 2160 m^3/s. In case of an increase in the level of water above NGG of 252 m, outflow of surplus water to Arnasai lake is carried out. The amount of outflow depends on the level of water during the given year, as well as on the fulfillment of

the generally accepted regime of Toktogul , Andizhan , and Kairakkum water reservoirs, located within the territory of Kyrgyzstan and Tadzhikistan, as well as of Chavak water reservoir in Uzbekistan.

The Central Asian countries are facing the task of avoiding idle outflows to Arnasai lakes. For this purpose, first of all (and mainly), it is necessary to develop together with Kyrgyzstan, Uzbekistan, and Tadzhikistan the optimum regime of operation of the cascade of water reservoirs on the rivers of Naryn, Shyrshyk, Karadarya, and Syrdarya, and to provide its fulfillment in any year. In addition to that, in the down-stream of Syrdarya River (down-stream from Chardara water reservoir), it is necessary to carry out a complex of projecting-examination and repairment-construction activities in order to increase the capacity of the river bed, which require significant investments.

The Influence of Water Intake Over the Condition of Aral Sea and Natural Complexes of the Basin

It is known in terms of general evaluation, that, as a result of water intake from Amudarya and Syrdarya Rivers without taking into account the water demand of Aral Sea, the condition of the Sea and Aral Region was significantly damaged: the amount of water in the sea, as mentioned above, decreased more than 2 times, the shore moved in some places by up to 100 km, half of the sea bottom uncovered and became the source of salt and dust pollution, the deltas of the rivers began to dry up, *tugai* and reed forests dried up, flora and fauna decreased, mineralization of sea water increased up to 40 g/l.

In the down-stream of Syrdarya River unfavorable conditions developed in terms of the quality of the surface flow due to coming of a significant amount of highly mineralized water to the river bed, which is enriched with chlorides, pesticides, and totally not cleaned or not sufficiently cleaned household and industrial waste water.

The total amount of inflow of highly mineralized water to the river bed of Syrdarya in the basin is equal to:

1993 – 11.70 km^3,
1994 – 11.15 km^3,
1995 – 7.83 km^3,
1996 – 8.19 km^3,
1997 – 8.87 km^3.

In the basin of Syrdarya River, the natural surface water resources are almost fully consumed, and the coefficient of their use is close to 1.5.

Mineralization of water in the upstream region of Syrdarya River does not exceed 0.3-0.5 g/l, while at the border of Ferganskaya valley it is equal to 1.2-1.4 g/l, in the alignment of Shardara – 1.4-1.6 g/l, in Kyzylorda city – 1.6-2.0 g/l, and in the alignment of Kazalynsk – 1.7-2.3 g/l.

Mineralization of water in the alignments of Syrdarya River (g/l)

Years	Bekabad	Shardara	Kzylorda	Kazalynsk
1960	0,64	0,68	0,70	0,95
1970	0,97	0,94	0,98	1,01
1980	1,38	1,55	1,74	1,72
1985	1,40	N/a	1,58	2,26
1990	1,48	1,46	1,69	1,87
1995	1,20	1,47	1,37	1,50
1998	1,28	1,48	1,33	1,59
1999	1,35	1,24	1,33	1,57

It can be clearly seen from the table, that in all alignments mineralization of the water in comparison to 1960-70-s increased due to the increase in irrigated areas, and, consequently, with the increase in the inflow of collected-drainage water to the river bed of Syrdarya, with the use of chemical fertilizers and pesticides on cotton and rice plantations. Along with mineralization of river water, the marginal concentrations of sulfates, chlorides, magnesium, copper, iron, faeces, etc. also increase.

The increase in mineralization of water also significantly affected the increase of salting of irrigated areas, and, as a consequence, the decrease in productivity of agricultural crops, as well as the environment.

Surface water not only in the down-stream region, but also in the middle-stream region of Syrdarya, are not suitable for drinking.

Ground water in these regions (middle-stream and down-stream) is hydraulically connected with surface water, and, consequently, are also not suitable for these purposes. Significant pollution of water in Syrdarya River, and lack of drinking water lead to increase in illnesses among local population. The illnesses distributed through drinking water, such as hepatitis, tiff, and stomach illnesses are widely developing.

Current Condition of Water and Power Complexes of the Basin, and their Relationships

Water Complex

Only one water reservoir is located in Kazakhstan part of Syrdarya River – Chardara , while Kzylodrin (Tasbuget) and Kazalyn water distribution hydro-junctions are functioning on the river bed, as well as water intake constructions to Kzylkum , Togusken , Novochiliy , and Novosolotubin main canals, the system of canals CHAKYR, ARTUR, Bugun and other small water reservoirs, and a dozen of pumping stations, which carry out direct water intake to the inter-farm canals.

The total length of the inter-farm network by 01.01.1995 was equal to 4535 km (including 2206 in South-Kazakhstan *oblast*), only 570 km of which were covered by concrete, all in South-Kazakhstan *oblast*. The actual effectiveness of the main and inter-farm canals is equal to 0.83.

The total length of main and inter-farm collectors by 01.01.1995 was equal to 2008.9 km, 1079.5 km of which are located in Souh-Kazakhstan *oblast*. All of them have ground river bed.

The total length of the internal irrigation network in South-Kazakhstan *oblast* by 01.01.1995 was equal to 13892 km, 10650 km of which have ground river bed. These indexes for Kyzylordinskaya *oblast* are the following: 13896, and 13893 km correspondingly.

The length of the collection-drainage network (CDN) in two *oblasts* is equal to 14659.3 km, 10987.6 km of which are located in Kyzylordinskaya *oblast*. The internal CDN is represented by horizontal and vertical drainages. The vertical drainage (149.1 thous.ha) is carried out by 2112 shafts equipped with internal pumps. However, only 1370 of them were operating in 1994.

By 01.01.1995, the balance cost of the major production funds of the water complex (Melioration fund) in South-Kazakhstan and Kzylordinskaya *oblasts* was equal to 2375.2 mln.Tenge, including:

- Main and inter-farm irrigation canals	1059.3 mln.Tenge
- Inter-farm collectors	187.7 mln.Tenge
- Water reservoirs and torrent reservoirs (20 items)	221.6 mln.Tenge
- Pumping stations at inter-farm irrigation canals (11 items)	11.0 mln.Tenge
- Hydro-constructions at main and inter-farm canals, including at the places of water distribution to farms (2498 items)	501.2 mln.Tenge
- Hydro-constructions at inter-farm collector system (2 items)	1.2 mln.Tenge
- Pumping stations at collection-drainage network (8 items)	9.2 mln.Tenge
- Shafts for irrigation (62 items)	20.1 mln.Tenge
- Automobile roads (1479 km)	113.6 mln.Tenge

In addition to melioration funds, the water-using organizations' balances of the two *oblasts* of Kazakhstan also include industrial and household constructions, communication and transportation facilities, the cost of which by 01.01.1994 was equal to 2827.3 mln.Tenge.

National and Regional Bodies for Regulation of Water Resources

The water-using organizations: Aral-Syrdarya basin water union (BWU), South-Kazakhstan and Kzylordin *oblast* republican national enterprises, separate departments for the regulation of water reservoirs, hydro-junctions, and other structures are included in the Committee of water resources of the Republic of Kazakhstan. Since 1998, the Committee of water resources is included in the Ministry of Nature Use and Environment Protection of the Republic of Kazakhstan.

The regional regulation bodies are the basin unions "Syrdarya" and "Amudarya", SICs which operate under direct control of the International Water Coordination Commission (ICWC).

National and Regional Interests of the Countries in Terms of the Use of Water and Power Resources of the Basin

The main directions of the water strategy of the Republic of Kazakhstan in the basin of Aral Sea are the following:

- A social task, which includes supply of the population with high-quality drinking water, and improvement of the quality of water resources;
- An ecological-technical task, which includes carrying out of activities in order to stop drying up of Aral Sea, for recreation and protection of the Small (Northern) Sea, flooding of natural complexes in the delta and down-stream region of Syrdarya River (lakes, old river beds, natural hayfields and pastures, etc.).

In terms of these purposes, Kazakhstan faces the task of reaching additional inflow of water to Aral Sea through Syrdarya River in the amount of 6-7 km^3 by 2010.

The complex of the activities being designed by the Republic of Kazakhstan includes the following:

- complete stoppage of outflows to Arnasai lakes; establishment of the optimal regime of operation of Naryn-Syrdaryn cascade of water reservoirs, increase in the capacity of the river bed of Syrdarya by means of reconstruction of the river bed hydro-constructions, and construction of dams in certain places, in order to increase the inflow of water to the delta of the river and to Aral Sea;
- carrying out activities for the economic and rational use of water resources, first of all at irrigated areas;
- improvement of the regulation of water-using complexes in the basin of Syrdarya River;
- regional interests of the countries include softening of the affects of the developed environmental conditions over all nations, located in the basin of Aral Sea. The developed complex of technical, organizational, and investment-economic activities provides water supply to the sea in the amount of 30-35 km^3 per year, together with the needs of the delta.

Major Problems in the Relationships Between the Countries of the Basin in the Sphere of Joint Use of Water and Power Resources of Syrdarya River

- To develop and strictly fulfill the agreed upon regime of water flow through Syrdarya River, and to provide the consumers with water in the necessary amount and quality in a timely manner;
- To achieve annual improvements in the quality of the water in Syrdarya River by means of reduction of the inflow of collected-drainage water, as well as industrial and household waste water;
- To improve the structure of crops, to increase the effectiveness of irrigation systems, and to implement progressive technologies of irrigation of agricultural crops;
- To provide inflow of the agreed upon amount of water to Aral Sea and Aral Region;
- To develop together an agreed upon option of the model of optimization of the use of water resources of the basin of the river, which should provide water equally (rationally) to all water-consumers of the region, including the down-stream areas, and Aral Sea, and should

guarantee within the boundaries of the countries not only the quantity, but also the quality of water with mineralization of not more than 1 g/l;

- To improve the activities of the regional bodies of ICWC in the sphere of regulation of water resources of Syrdarya River;
- To complete and put into operation legal and normative documents for the control of the use and protection of water resources, in order to regulate water relationships between the Central Asian countries;
- The Agreement "On the Organizational Structure of Joint Regulation, Protection, and Development of the Over-Border Water Resources in the Basin of Aral Sea";
- The Agreement "On Exchange of Information and Creation of the National, Basin, and Regional Databases for Complex Use and Protection of the Over-Border Water Resources in the Basin of Aral Sea";
- The Agreement "On the Use, Development, and Protection of Water Resources in the Basin of Aral Sea";
- Basing on the interests of the Central Asian countries, the members of coordination group should agree upon the final version of the optimal regime of operation of Naryn-Syrdaryn cascade of water reservoirs, and present it for approval to the Governments of Kazakhstan, Kyrgyzstan, Tadzhikistan, and Uzbekistan;
- The major tasks of the water-users of the region are providing economic and effective use of water by means of carrying out annual works in order to increase and improve the technical level of water-using systems and constructions.

The Purpose and the General Requirements for the Model

The hydro-chemical regime of Syrdarya River is formed mainly under the influence of economic activities of people, as well as under significant influence of regulation of the flow, water intake for irrigation and industrial-household water supply, inflow to the river of returning water polluted by fertilizers and chemical substances, inflow of non-cleaned industrial and household waste water to the river.

Along with mineralization of the river water, the process of increase in marginal concentrations of sulfates, chlorides, magnesium, copper, iron, phenols, lead, etc.. During 1990-s, the concentration of nitrate nitrogen and DDT geksochlorine in the river significantly increased. The increase in mineralization of river water also significantly affected the increase in salting of irrigation areas, and, as a consequence, on the decrease in the productivity of agricultural crops, such as cotton and rice.

Due to lack of water in Syrdarya River, its delta suffered first of all. Here, during the whole year, difficult situation is developing in terms of supply of high-quality drinking water to the population. This negatively affects the level of life of the population located in the region.

That is why taking into account the qualitative characteristics of water when calculating the optimal regimes of water distribution becomes vital task, especially for the Republic of Kazakhstan. The Member of the Coordination Group representing the Republic of Kazakhstan – N.K.Kypshakbayev – mentioned this many times.

Unfortunately, we cannot take into account all characteristics of the quality of water (toxicants, phenols, metals, etc.), because such substances take part in chemical and chemical-physical reactions between each other, and the rules of these reactions are not examined enough.

In addition to this, pollution of water with these components is not significant in comparison to the total mineralization of water.

Due to this, (according to the order of N.K.Kypshakbayev) we designed a mathematical model, in which the salting factor participates in optimization equally with water factor.

Initial Data

For the informational support of the problem, with the help of EPIC program, materials were collected about mineralization of water in Syrdayra River. The data were taken from hydro-chemical bulletins, and from the observation data in South-Kazakhstan and Kyzylordinskaya *oblasts*. The data were processed by statistical methods in order to determine the relationships between the water level in the river, and mineralization. The data from 10 observation posts were collected for the period of about 20 years (1980-1999).

Analysis of the data on hydro-chemical regime of Syrdarya River for a period of many years shows, that mineralization of water in the river increases when moving down-stream.

Analysis of the quality of water in Syrdarya River shows, that it does not correspond to the standards for water resources with fishery and household drinking purposes.

Analysis of the causes of degradation and pollution of river water shows, that mainly the actual remaining flow, formed by collected-drainage and waste water, was coming to Kazakhstan from the upstream neighboring countries during low water level years.

During the last years (1991-1999), a relative decrease in the level of mineralization can be seen, due to large amounts of flow (high water level years), and a decrease in actually irrigated areas, caused by the economic crisis of agriculture.

Formulation of the Mathematical Model

Dr.MacKeiny's approach was adjusted for the Central Asian conditions by the BWU "Syrdarya". However, taking into account of the salting factor in the basi model of BWU "Syrdarya" was not considered.

On the basis of the model of irrigation-river system of BWU "Syrdarya" (water factor), the block of quality of the water was added as an additional group of equations and limits. While this, the Criterion function is not changed.

Equations of the mathematical model of the optimal regime of regulation of water resources with the account for their quality are the following:

Simple junctions, hydro-posts junctions, distribution hydro-junctions, controls.

Water

$$\underline{\Sigma} Wout,j,t = \Sigma Win,j,$$

Salt

$$Sout,j,t = \frac{(\Sigma Sin,j,t / \Sigma Win,j,t)*(Wout,j,t)}{\underline{\Sigma} Wout,j,t}$$

for each junction of the given type **j,** and for each moment of time **t**, where:

Wout,j,t - outflow of water from the junction (mln.m^3)
Win,j,t - inflow of water to the junction (mln.m^3)
Sout,j,t - outflow of salt from the junction (thous.t)
Sin,j,t - inflow of salt to the junction (thous.t)

<u>For the consumers of the flow</u>

$$Sout,j = Wout,j*Ms,j$$

<u>Determined sources of water resources</u>

$$Sout,j,t = Ms,j,t * Ws,j,t + \Sigma Wout,j,t * Mu,j,t$$

where:

Ws,j,t - set hydrograph of the inflow of water to the soucre **j**, (mln.m^3),
Ms,j,t - mineralization of water in the given source **j** (g/l).
Wout,j,t - inflow of returning water
Mu,j,t - mineralization of returning water from the consumer **U** (g/l).

<u>Water reservoirs</u>

$$Sv,j,t - Sv,j,t-1 = \Sigma Sin,j,t - \Sigma Sout,j,t$$

$$Sout,j,t = \frac{Sv,j,t * Wout,j,t}{Vj,t * \Sigma Wout,j,t}$$

$$Sv,t = Ms,j,o * \mathbf{Vj,o} \qquad \text{at the beginning of the calculation}$$

$$\mathbf{V}j,t = \mathbf{Vj,o} \qquad \text{at the beginning of the calculation}$$

where:

Vj,t - amount of water in the water reservoir at the moment of time t, (mln.m^3),
Vj,t-1 - amount of water in the water reservoir at the moment of time t-1 (mln.m^3),
Sv,t - concentration of salt in the water reservoir at the moment of time t, (thous.t),
Sv,t-1 - concentration of salt in the water reservoir at the moment of time t-1 (thous.t),
Ms,j,o - weighted average mineralization at the initial moment of time in the water reservoir j

Limits

This model allows to calculate the following variables:

Wout,j,t - outflow of water from a given object at the river in any direction;
Win,j,t - inflow of water to a given object at the river from any direction;
Sin,j,t - outflow of salt from a given object at the river in any direction;
Sout,j,t - inflow of salt to a given object at the river from any direction;
Vj,t - amount of water in a given water reservoir;
SV,j,t - amount of salt in a given water reservoir.

All these variables are determined for each calculation period of time. For each of the variables, for each separate junction of the river system, and for each period of time three types of limits can be set:

1) lower limit;
2) upper limit;
3) fixed amount.

In case of setting of one of the three types of limits for any of the variables at any period of time, a solution will be found, in which this condition will be strictly fulfilled. Currently, the ecological factor is taken into account by means of setting sanitary outflows at the separate parts of the river network through lower limit for transit consumption of water.

The issue of including of the qualitative characteristics of the water into the criterion function requires detailed examination in terms of the construction of the component in the criterion function. Currently, regulation of the quality of water is achieved through setting limits in the model for the amount of salt in the water in a given alignment.

Examples of the Calculations, and Grounds for the Exactness of the Results

The average monthly mineralization of water in the river is usually determined through statistical relationships. The examples of the obtained relationships are presented in the attachment (graphs 1-5).

The graphs are informative enough, and their description would take a lot of space and time. The group of graphs on the post Kal' is the most interesting.

It is a chronological set of water levels and mineralization of water. It can be seen, that the maximum water level between 6^{th} and 8^{th} months does not correspond to the degree of decrease in mineralization during this period of time. It is clear, that this is provided by the inflow of returning mineralized water to the main river bed of Syrdarya.

After determination of the relationships for the existing alignments between mineralization of water and water level in the river, a new calculation scheme was designed.

The basis of this scheme is the scheme designed by the specialists of BWU "Syrdarya" presented in figure 1. The curves were added, through which it was possible to calculate the movement of returning water back to the river (figure 2).

The returning water is calculated through the following linear statistical relationship:

$$Q_{return} = a * Q_{intake} + в$$

Mineralization at the alignments of the river is known, while mineralization of returning water, due to lack of data (mineralization of returning water should be determined in the zone of formation of returning water, that is in the planning zone), is assumed as constantly equal to 3 g/l for the test calculations. In future, this index can be determined more exactly on the basis of the data provided by the model of the planning zone.

An important difference between our task, and the task of BWU "Syrdarya", in terms of the water factor, is that we calculate returning water but do not set constant amounts.

Water distribution along the water intakes is calculated in the model of irrigation-river system of BWU "Syrdarya", and mineralization of the water is calculated at the same time. Notice, that almost new enlarged model of regulation of water-salt factor is created here, which is saved in a separate file. However, both models, while not having limits for mineralization, provide identical results.

The limits for mineralization can be set at the alignments of the river, or in parts of the river, or at the borders between countries, or for the inflow of water to Aral Sea, and a given month, especially during vegetation period. As a result of adding of the quality of water, the calculation becomes much longer.

Test calculations.

1st test calculation. Without taking mineralization into account. (the model of irrigation-river system of the BWU "Syrdarya").

5 water reservoirs with the initial amounts of water.

Consumers with certain demands for water. Satisfaction of the consumers has a high priority.

Results of the calculations:

- Consumers receive water according to the set demand in full amount.

2nd test calculation. No limit of mineralization.

5 water reservoirs with the initial amounts of water with mineralization of 0.5 g/l in the upstream water reservoirs, and mineralization of 1 g/l in the downstream water reservoirs. Consumers with certain demands for water. Returning water from the consumers are calculated through a linear statistical relationship. Mineralization of returning water is assumed constantly equal to 3 g/l. Satisfaction of the consumers has a high priority.

Results of the calculations:

- The time of calculation increased, because mineralization is consequently calculated.
- Consumers receive water according to the set demand in full amount.
- All outcoming data on water correspond to the 1st test calculation.
- Mineralization of water downstream from Chardaryn water reservoir during the second month of calculation achieved 1.6 g/l (Table 1).

3rd test calculation. Mineralization is limited by 1.5 g/l downstream from Chardaryn water reservoir.

Results of the calulations:

- Consumers receive water according to the set demand in full amount.
- The limit of mineralization of the flow of 1.5 g/l is fulfilled mainly by means of regulation in the water reservoirs. However, mineralization slightly increased during the third month of calculation.
- The outcoming data do not correspond to the 2nd test calculation, except for the consumers (Table 2).

4th test calculation. Mineralization is limited by 1.2 g/l downstream from Chardaryn water reservoir.

Results of the calulations:

- Not all consumers received water according to the set demand in full amount; out of 5 consumers which have returning water 2-3 consumers are not satisfied by 2-10%, the rest consumers received water according to the set demand in full amount.
- The limit of mineralization of the flow of 1.2 g/l downstream from Chardarynkoe water reservoir is fulfilled mainly by means of regulation in the water reservoirs, and reducing of water intakes, and, consequently, returning water (Table 3).

5th test calculation. Mineralization is limited by 1.0 g/l downstream from Chardaryn water reservoir.

Results of the calulations:

- Not all consumers received water according to the set demand in full amount; out of 5 consumers which have returning water 4-5 consumers are not satisfied by 8-30%, the rest consumers received water according to the set demand in full amount.
- The limit of mineralization of the flow of 1.0 g/l is fulfilled by means of regulation in the water reservoirs, and reducing of water intakes, and, consequently, returning water (Table 4).

The initial text of our model is created automatically through the menu designed by the specialists of BWU “Syrdarya”.

The carried out test calculations indicate a direct relationship between highly-mineralized returning water consisting of collected-drainage water, and the qualitative characteristics of the river.

The sanitary-epidemiological condition of the region mainly depend on the quality of water in the river basin, so it is necessary to achieve decrease in the inflow of returning water to the water objects.

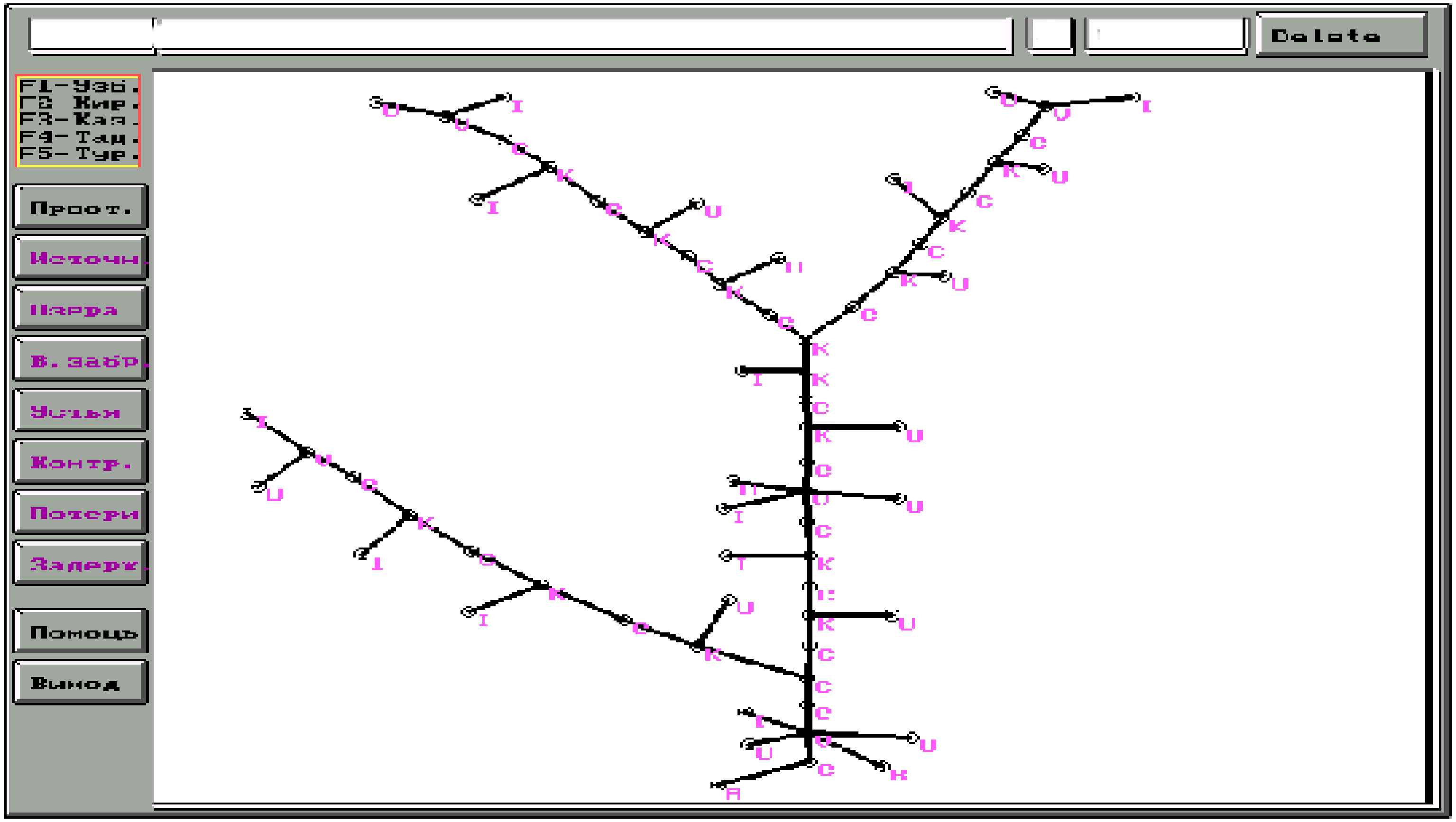

Figure 1. Syrdarya River network without return flow arcs.

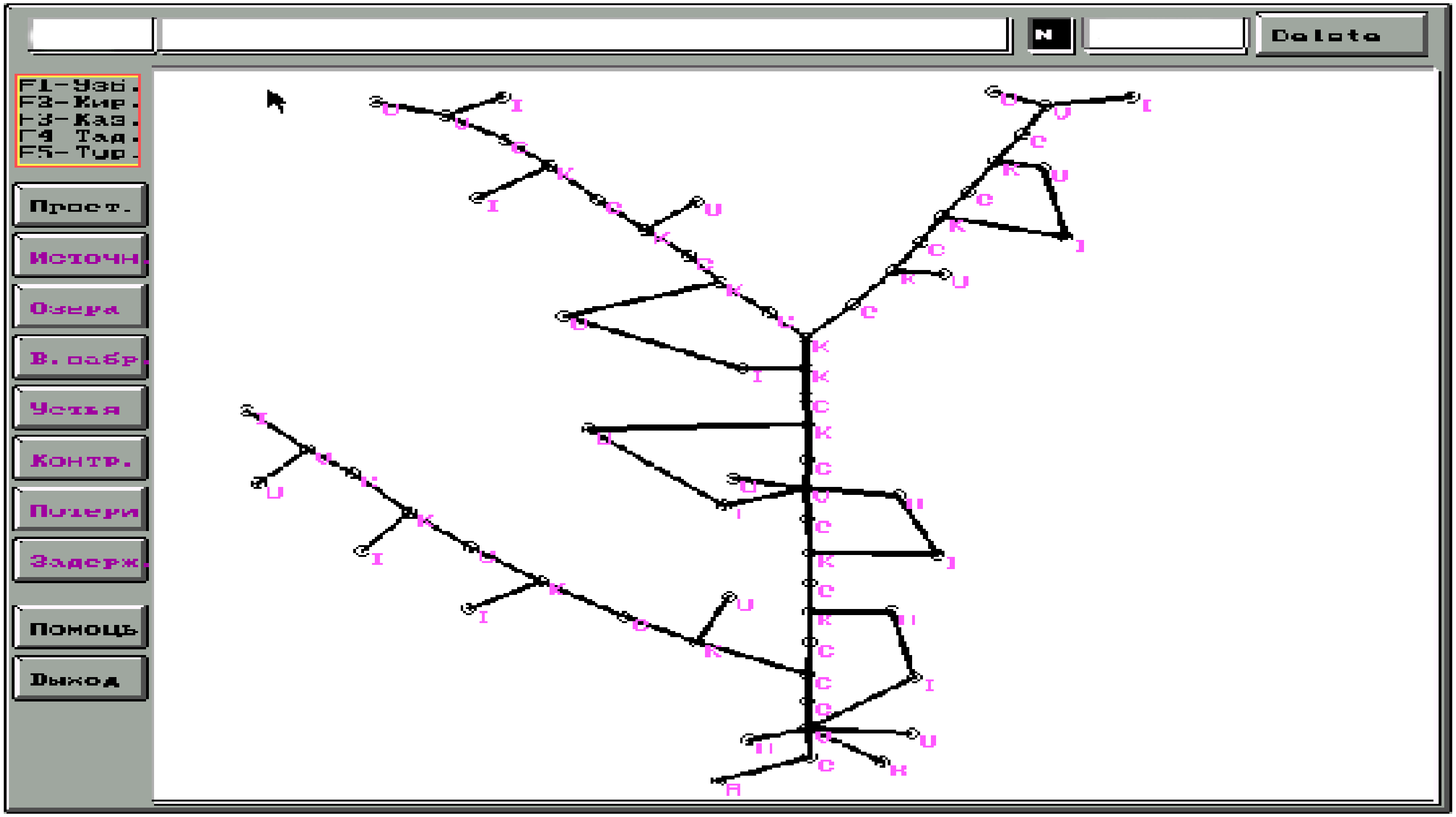

Figure 2. Syrdarya River network with return flow arcs.

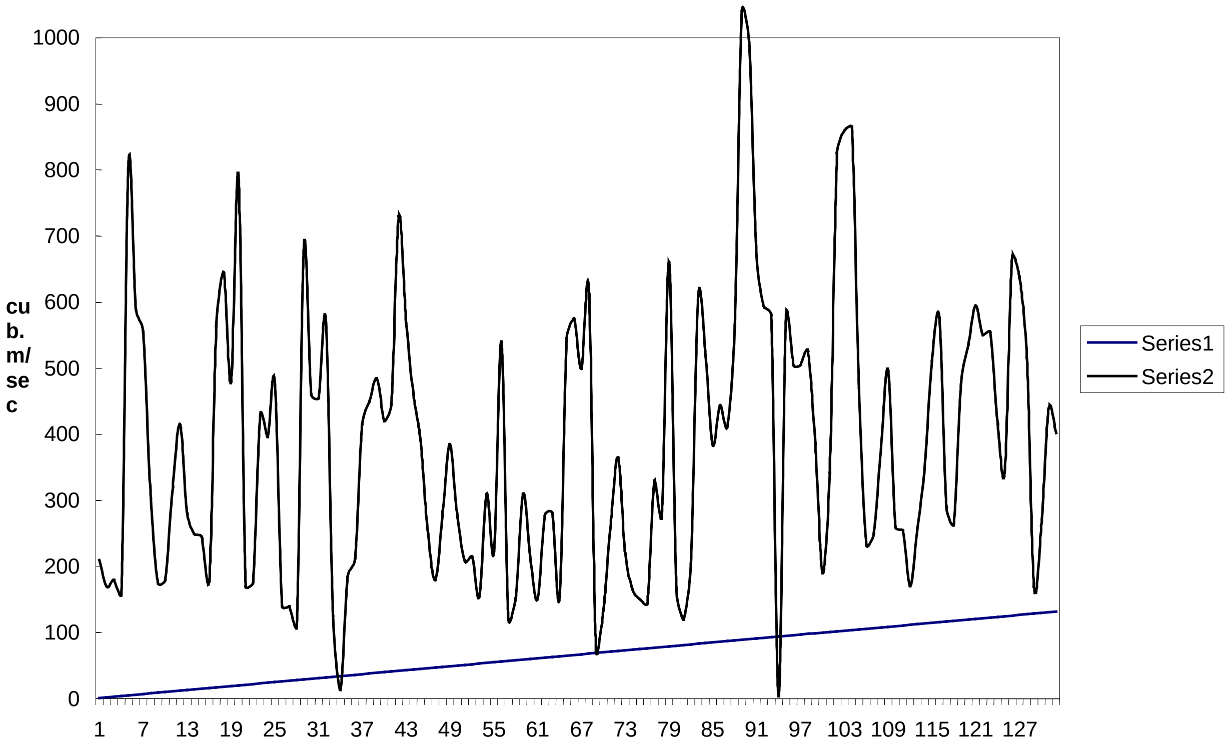

Figure 3a. Hydrograph of flow at the post Kal during 11 years.

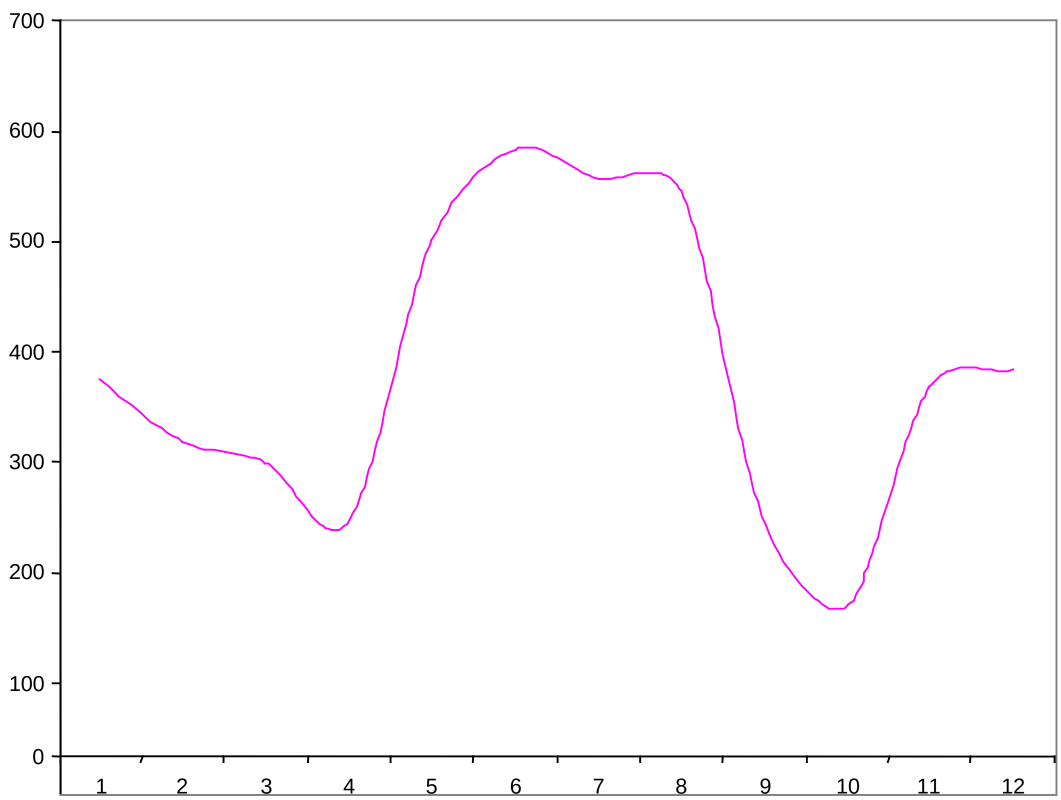

Figure 3b. Average hydrograph of flow at the post Kal during 11 years.

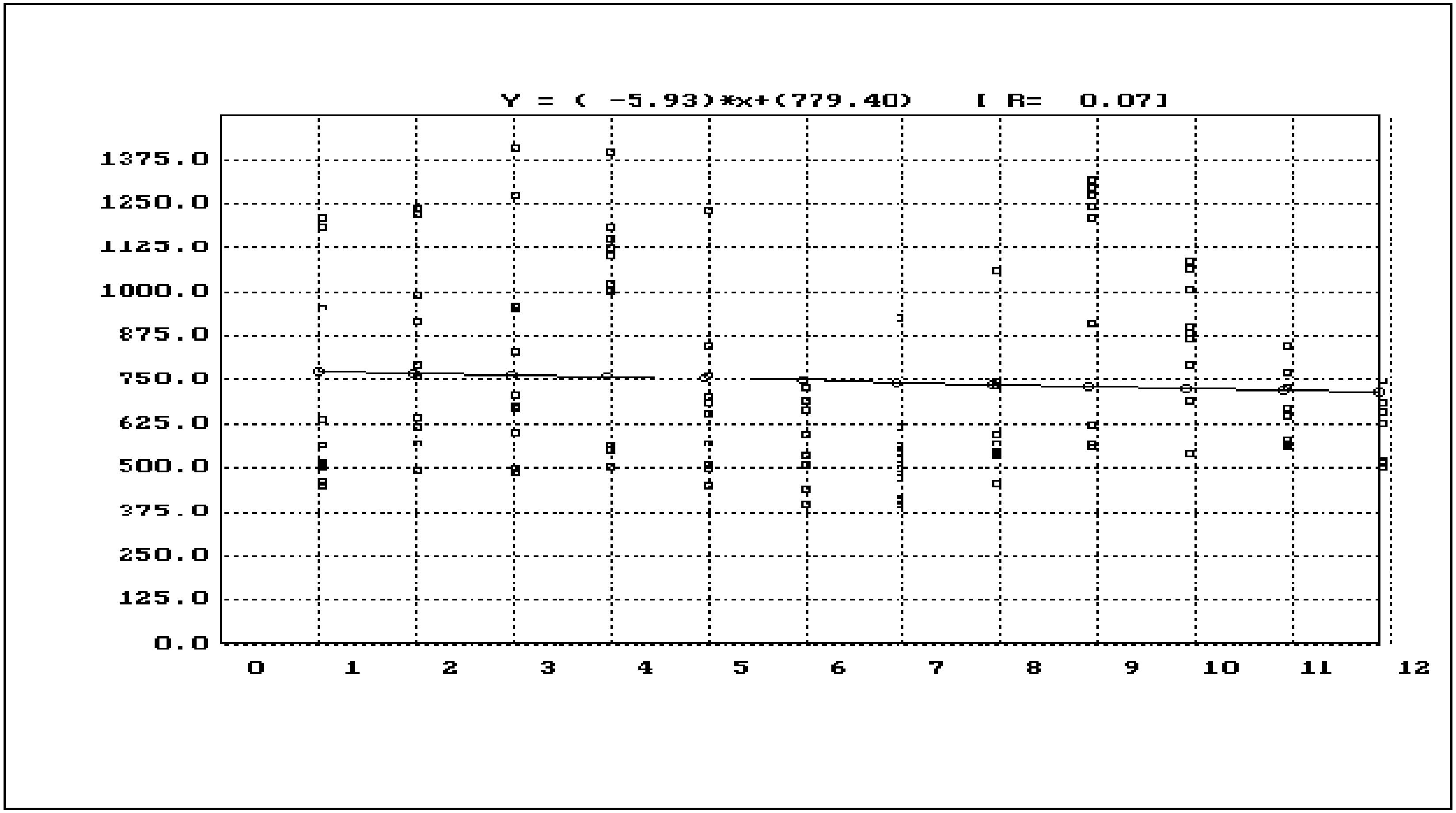

Figure 4. Average annual chronology of the process of mineralization of water at the post Kal

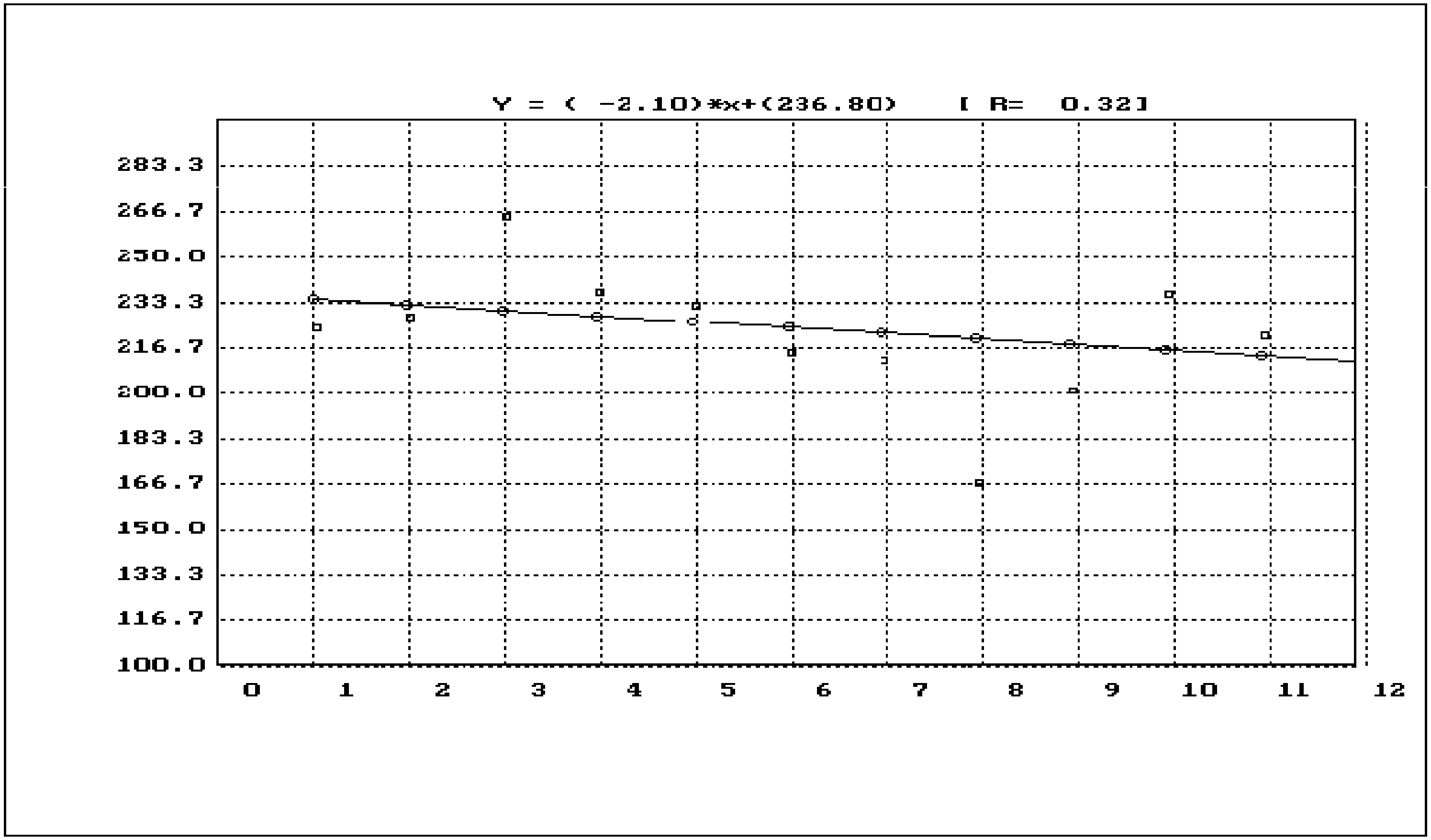

Figure 5. Average annual chronology of the process of mineralization of water at the post Karabagshi

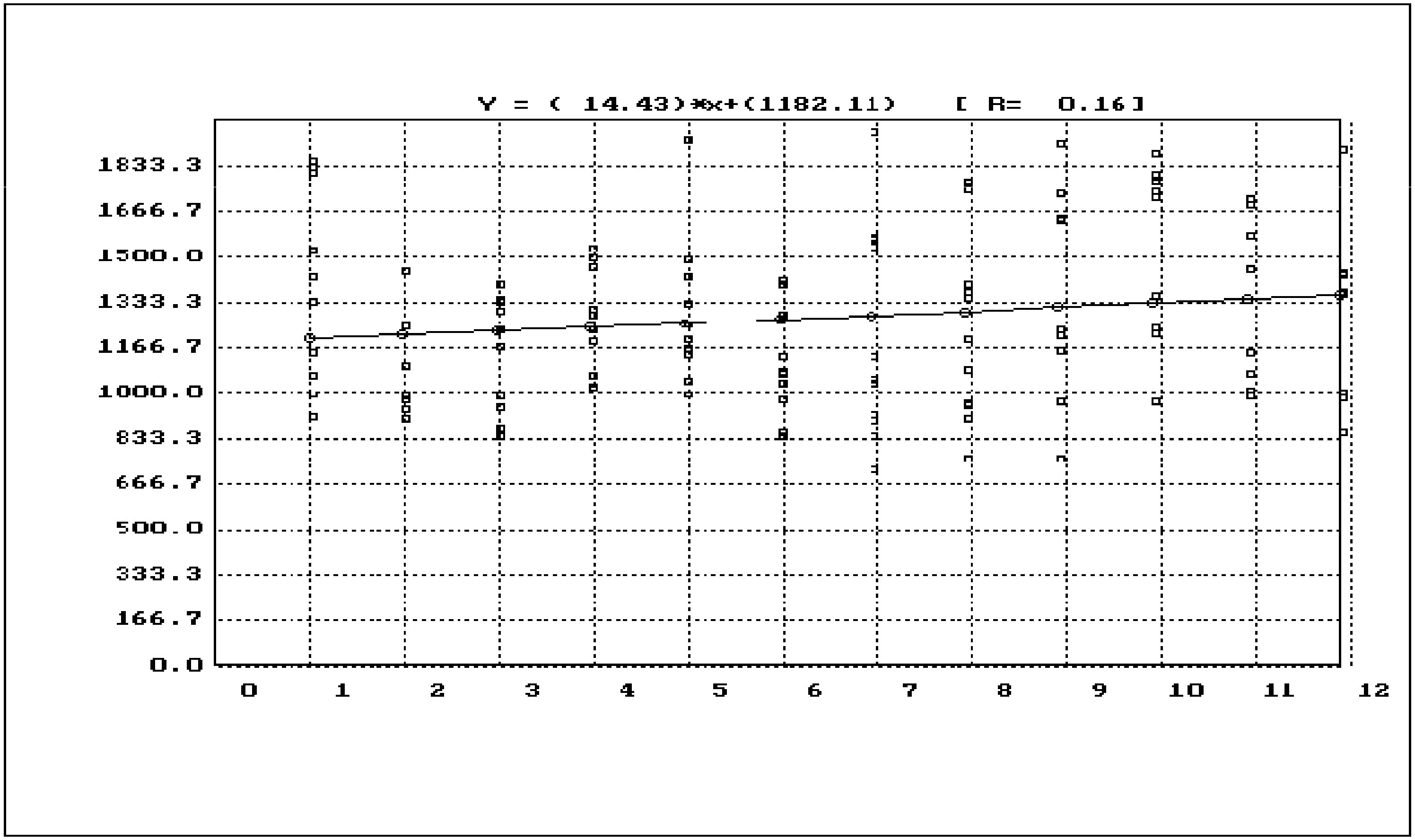

Figure 6. Average annual chronology of the process of mineralization of water at the post Nadezhdinskliy

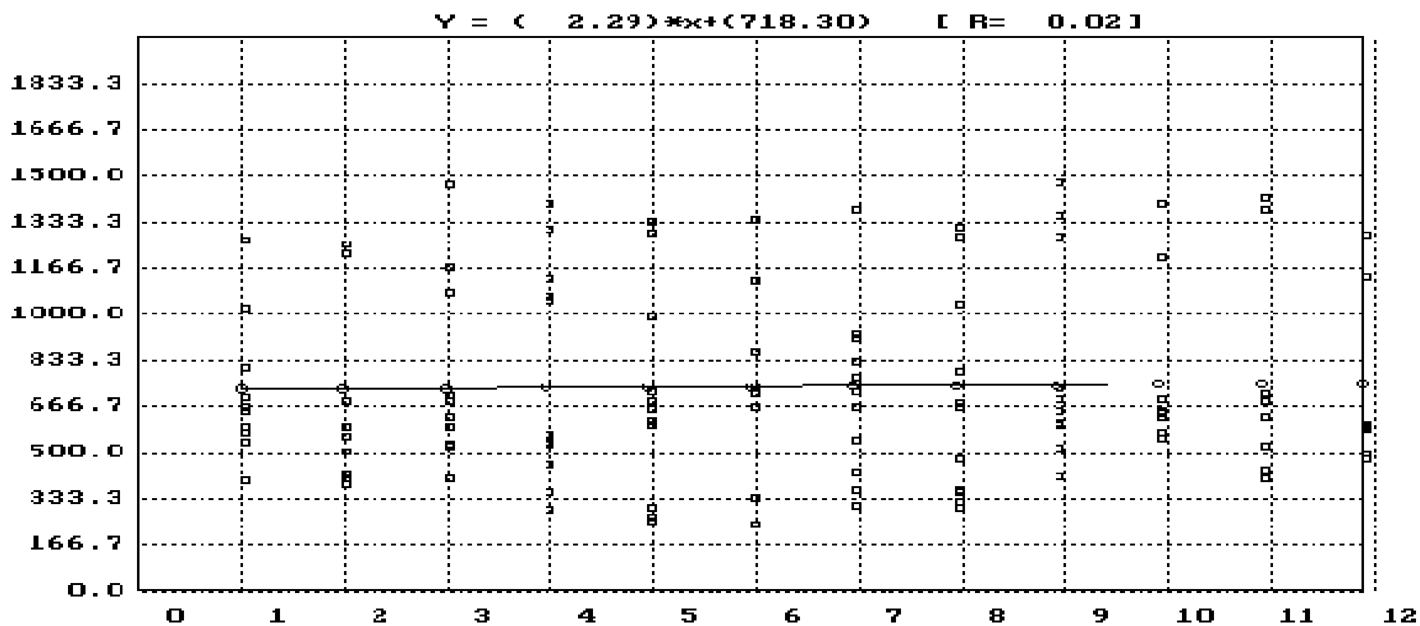

Figure 7. Average annual chronology of the process of mineralization of water at the post Kchinaz-Syrdarya

Table 1. No Limit on Salinity.

Toktogul reservoir

month	inflow	amount	outflow	salinity
1	589.6	16038	321.61	0.4963
2	505.05	16286.6	256.42	0.4897
3	436.84	14559.4	2164.1	0.4843
4	369.84	12629.2	2300	0.4793
5	329.12	10862.8	2095.51	0.4744
6	385.92	9900	1348.76	0.4687

Andijan reservoir

month	inflow	amount	outflow	salinity
1	125.96	532.4	172.64	0.4799
2	134.68	550.1	118.04	0.44
3	107.2	579.3	79.07	0.4112
4	91.12	543	129.52	0.3926
5	91.96	517.9	119.12	0.3768
6	123.28	500	143.2	0.3613

Charvak reservoir

month	inflow	amount	outflow	salinity
1	257.28	1235.7	269.59	0.4809
2	212.38	1107.4	342.56	0.4486
3	182.24	1068.9	222.69	0.4234
4	160.8	1044.4	189.02	0.404
5	142.78	1015.8	175.14	0.3885
6	168.84	1000	188.3	0.3747

Kairakkum reservoir

month	inflow	amount	outflow	salinity
1	341.25	500	515.89	1.3694
2	321.68	553.9	282.33	2.0522
3	2254.21	936.9	1890.05	1.2764
4	2314.83	681.5	2610.28	0.8318
5	2137.35	500	2350.59	0.9466
6	1435.36	500	1463.36	0.9998

Chardara reservoir

month	inflow	amount	outflow	salinity
1	783.6	722.1	773.36	1.2877
2	506.31	500	744.44	1.5919
3	2238.94	1383	1378.07	1.4571
4	2843.67	1569.3	2719.51	1.2053
5	2760.02	500	3876.79	1.0985
6	1980.13	500	2007.65	1.2537

Table 2. Limit of Salinity of 1.5 g/l.

Toktogul reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	589,6	0,3	16038	0,4963	321,61	0,4963
2	505,05	0,3	16286,6	0,4897	256,42	0,4897
3	436,84	0,3	14757,2	0,4843	1966,32	0,4843
4	369,84	0,3	12827	0,4793	2300	0,4793
5	329,12	0,3	10856,1	0,4745	2300	0,4745
6	385,92	0,3	9900	0,4689	1342,05	0,4689

Andijan reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	125,96	0,3	531,5	0,48	173,56	0,4799
2	134,68	0,3	546,2	0,44	120,96	0,44
3	107,2	0,3	575,2	0,411	79,29	0,411
4	91,12	0,3	540,3	0,3923	128,1	0,3923
5	91,96	0,3	516,9	0,3765	117,39	0,3765
6	123,28	0,3	500	0,361	142,21	0,361

Charvak reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	257,28	0,3	1125,5	0,4809	379,72	0,4809
2	212,38	0,3	970	0,4457	369,79	0,4457
3	182,24	0,3	967,4	0,4179	186,68	0,4179
4	160,8	0,3	990,2	0,3975	141,61	0,3975
5	142,78	0,3	1001,7	0,3822	134,99	0,3822
6	168,84	0,3	1000	0,3692	174,2	0,3692

Kairakkum reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	342,4	5,823	611,9	1,3686	406,18	1,3685
2	324,83	5,6714	500	1,9503	451,92	1,9501
3	2059,03	3,7651	813,2	1,2721	1762,97	1,2721
4	2313,55	3,8441	500	0,8419	2661,01	0,8419
5	2340,09	3,7902	500	0,9303	2368,09	0,9302
6	1428,07	3,941	500	0,9739	1456,08	0,9738

Chardara reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	790,01	4,2415	930,1	1,2221	573,7	1,222
2	735,21	4,2986	500	1,5001	1183,31	1,5
3	2076,54	4,326	972	1,5001	1622,97	1,5
4	2847	3,9313	1230,2	1,1847	2638,59	1,1847
5	2737,44	4,0958	500	1,0971	3509,12	1,0971
6	1959,21	4,219	500	1,2465	1986,7	1,2464

Table 3. Limit of Salinity of 1.2 g/l

Toktogul reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	589,6	0,3	14332,2	0,4963	2027,36	0,4963
2	505,05	0,3	12537,3	0,489	2300	0,489
3	436,84	0,3	11092,4	0,482	1881,71	0,482
4	369,84	0,3	10173,8	0,4755	1288,48	0,4755
5	329,12	0,3	9795,5	0,4695	707,44	0,4695
6	385,92	0,3	9900	0,4635	281,41	0,4635

Andizhan reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	125,96	0,3	574,4	0,4799	130,6	0,4799
2	134,68	0,3	641,1	0,4426	69,1	0,4426
3	107,2	0,3	675,8	0,4171	73,71	0,4171
4	91,12	0,3	661,5	0,4	107,75	0,4
5	91,96	0,3	584,9	0,3858	170,81	0,3858
6	123,28	0,3	500	0,3703	210,26	0,3702

Charvak reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	257,28	0,3	1267,5	0,4809	237,74	0,4809
2	212,38	0,3	1365,4	0,4493	116,55	0,4493
3	182,24	0,3	1366,1	0,4285	183,51	0,4285
4	160,8	0,3	1261,1	0,4124	269,88	0,4124
5	142,78	0,3	1082,8	0,3984	324,95	0,3984
6	168,84	0,3	1000	0,384	255,35	0,384

Kairakkum reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	2017,39	3,7931	500	0,9106	2192,01	0,9105
2	2326,68	3,7116	1044,2	0,7759	1801,8	0,7759
3	1977,06	3,7504	1781,9	0,7935	1269,62	0,7934
4	1286,75	4,0949	1885,1	0,9122	1256,87	0,9121
5	812,27	4,3687	1544,4	1,0954	1222,72	1,0953
6	429,95	5,4054	500	1,3477	1521,95	1,3476

Chardara reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	2439,75	4,1029	2769,2	1,1418	399,58	1,1418
2	1812,08	4,075	4179,1	1,2	461,17	1,2
3	1587,94	3,9975	5227,6	1,1921	613,65	1,192
4	1580,3	3,9838	6000	1,1617	977,3	1,1617
5	1788,12	4,2021	6000	1,1587	1966,24	1,1587
6	2108,32	4,4368	500	1,2	7720,65	1,2

Table 4. Limit on Salinity of 1 g/l.

Toktogul water reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	589,6	0,3	14059,6	0,4963	2300	0,4963
2	505,05	0,3	12264,6	0,4888	2300	0,4888
3	436,84	0,3	10401,5	0,4817	2300	0,4817
4	369,84	0,3	9658,8	0,4748	1112,57	0,4748
5	329,12	0,3	9745,2	0,4686	242,64	0,4686
6	385,92	0,3	9900	0,4625	231,17	0,4625

Andizhan water reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	125,96	0,3	572,4	0,48	132,65	0,4799
2	134,68	0,3	635,9	0,4425	72,29	0,4425
3	107,2	0,3	680,1	0,4168	64,18	0,4168
4	91,12	0,3	637,7	0,3999	135,82	0,3998
5	91,96	0,3	500	0,3852	231,8	0,3852
6	123,28	0,3	500	0,3675	125,26	0,3675

Charvak reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	257,28	0,3	885,2	0,481	619,97	0,4809
2	212,38	0,3	1036,3	0,4372	63,04	0,4372
3	182,24	0,3	1190,5	0,4125	30	0,4125
4	160,8	0,3	1322,6	0,3964	32	0,3964
5	142,78	0,3	976	0,3848	493,21	0,3848
6	168,84	0,3	1000	0,371	148,51	0,371

Kairakkum reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	2314,75	3,7073	2918,9	0,8423	90,84	0,8423
2	2350,72	3,663	500	0,7803	4804,45	0,7802
3	2408,01	3,6491	2848,6	0,6844	93,7	0,6844
4	1182,56	3,9657	4000	0,7592	147,66	0,7591
5	431,45	5,0311	500	0,8714	4016,8	0,8713
6	307,96	5,9513	749	1,7272	91,39	1,727

Chardara reservoir

Month	Inflow	Salinity	Amount	Salinity	Outflow	Salinity
1	752,21	3,448	1285,8	1,0001	183,41	1
2	4857,11	3,9007	6000	0,9772	204,09	0,9772
3	262,55	4,0717	6000	0,9843	351,6	0,9843
4	265,11	3,3168	6000	1	443,22	1
5	4780,92	3,9381	6000	0,9864	4959,03	0,9864
6	580,32	4,7734	500	1	6192,65	1