Saline Lakes Around the World: Unique Systems with Unique Values

NATURAL RESOURCES AND ENVIRONMENTAL ISSUES

VOLUME XV

2009

International Society for Salt Lake Research (ISSLR) 10th International Conference and 2008 FRIENDS of Great Salt Lake Issues Forum

Saline Lakes Around the World: Unique Systems with Unique Values

University of Utah
Salt Lake City, Utah
May 11-16, 2008

Natural Resources and Environmental Issues

Volume XV
2009

This publication was edited by Aharon Oren, David Naftz, Patsy Palacios and Wayne A. Wurtsbaugh and peer-reviewed by a scientific committee composed of experts from the ISSLR and other outside editors.

The Aral Sea: Water Level, Salinity and Long-Term Changes in Biological Communities of an Endangered Ecosystem - Past, Present and Future

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This paper is dedicated to the memory of Prof. William Williams

ABSTRACT

The Aral Sea, which before 1960 was the fourth largest lake in the world, has now split into four separate water bodies. This break-up and desiccation mainly resulted from upstream irrigation withdrawals from the two main influent rivers, the Syr Darya and the Amu Darya. The negative effects on the lake ecosystem due to declining water level and increasing salinity, as well as the profound socioeconomic and human impacts to the riparian populations, have been well documented. This paper focuses on the conservation and rehabilitation efforts for four remaining key water bodies of the Aral Sea: the Northern (Small) Aral and its ecosystem; the Southern (Large) Aral and its ecosystem; the delta and deltaic water bodies of the Syr Darya; and the delta and deltaic water bodies of the Amu Darya. It is encouraging to note the reversal of the degradation in the Northern Aral after the creation of a dike at Berg's Strait in 1992. The dike washed out in 1999 but has been replaced with a new structurally sound dike. The water level in the Northern Aral has increased several meters and salinity is returning to levels that can sustain the pre-1960 ecosystem. However, much less success has been obtained regarding the Southern Aral which continues its retreat and salinization. There have been recent efforts also in the deltas and deltaic regions of the Syr Darya and Amu Darya, the rehabilitation of Sudochie Lake probably being the most famous. These restoration projects are critiqued in this paper and recommendations for future actions are given.

The Aral Sea and its Biodiversity

The Aral Sea was the fourth largest lake in the world by water surface area in 1960 (Figure 1). At that time its area was 6.75×10^4 km^2 (Large Aral 6.14×10^4 km^2, Small Aral 6118 km^2), and the volume was 1089 km^3 (Large Aral 1007 km^3, Small Aral 82 km^3). The Aral Sea was 53.4 m above ocean level with a maximum depth of 69 m. It was a slightly saline lake with an average salinity of about 10 g/l. The Aral Sea was inhabited by about 12 species of fish and about 160 species of free-living invertebrates excluding Protozoa and small-size Metazoa (Atlas of the Aral Sea Invertebrates 1974).

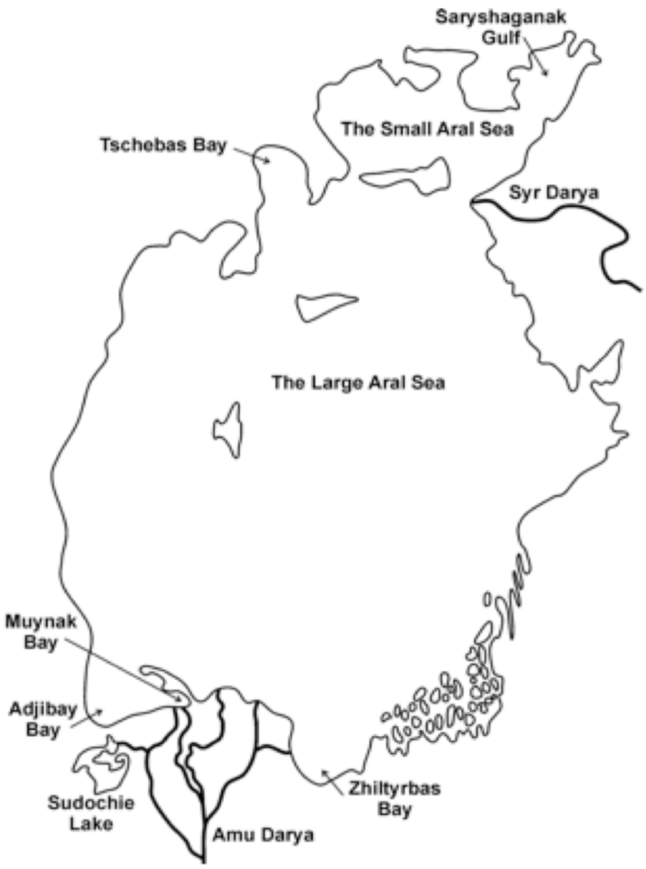

Figure 1–The Aral Sea in 1960.

Since 1960 the Aral Sea has steadily become shallower, mainly as a result of upstream water withdrawals for irrigation. By 2007 the area of the lake was reduced to about 1.4×10^4 km^2 (21% compared to the area in 1960) with a volume of 102 km^3 (9% of 1960). The Large Aral was 1.1×10^4 km^2 (17% of 1960), had a volume of 75 km^3 (8% of 1960) and a salinity that ranged from 100 g/l to well above that figure. The corresponding values for the Small Aral were 3258 km^2 (53% of 1960) and 27 km^3 (33% of 1960), with an average salinity of about 10 g/l (Table 1).

Table 1–Changes in the main hydrological and hydrobiological characteristics of the Aral Sea.

Aral Sea and its constituent parts	Level, meters above sea level	Area (km^2)	Volume (km^3)	Average salinity (‰)	Number of free-living invertebrate species		Number of fish species	
					aboriginal	alien	aboriginal	alien
Aral Sea, 1901	53.60			10	148	-	18	-
Aral Sea, 1961	53.40	66511	1089.0	10	148	5	18	11
Small Aral Sea, 1989	40.60		20.0	30	7*	4*	-	6
Large Aral Sea, 1989	39.07	37410	350.0	30	7*	5*	-	6
Small Aral Sea, 2007	42.00	3487	27.0	11-14	10*	6*	3	7
Tschebas Bay, 2007	30.00	105	0.2	90	8	2	-	-
Eastern Large Aral Sea, 2007	29.50	6117	9.5	120-160	-	1	-	-
Western Large Aral Sea, 2007	29.50		58.0	100	8	2	-	-

* – without Protozoa, small Metazoa and rare species.

Values for the level, area, and volume of the Small Aral for 1989 were derived from the map Dinamika Aralskogo Morya, 1990. Values for 2007 were calculated by interpolation from 1989 map data and data for the area and volume at 43 meters (Bortnik 1990). The area for Tschebas Bay and the eastern and western Large Aral were measured based on the August 11, 2007 MODIS 250 meter natural color image, using a polar planimeter and reference areas derived from pixel counts.

Citizens of Kazakhstan like to call the Small (northern) Aral Sea “Kazaral”, which means “Kazakh Aral”. People in Uzbekistan also sometimes use the name “Uzaral”, meaning “Uzbek Aral”, instead of Large (southern) Aral Sea. We believe that on future maps there will be four main water bodies at the place of the former Aral: Kazaral, Western Uzaral, Eastern Uzaral, and the remnant of Tshebas Bay (Figure 2).

Prior to introduction of fish species and free-living invertebrates to the Aral Sea that started in the 1920s, the following aboriginal organisms were identified: fishes–12, Coelenterata–1, Turbellaria–12, Rotatoria–58, Oligochaeta–10, Cladocera–14, Copepoda–7, Harpacticoida–15, Ostracoda–11, Malacostraca–1, Hydracarina–7, Bivalvia–9, Gastropoda–3; Total–160, not including Protozoa and some other small-size Metazoa (Atlas of the Aral Sea Invertebrates 1974). From the middle of the 19th century until 1961 the shape and salinity of the Aral Sea practically didn’t change. However, due to intentional and accidental introductions that started in the 1920s the number of free-living animals grew substantially. In the Aral Sea appeared: fishes–21, Mysidacea–5, Decapoda–3, Copepoda–3, Polychaeta–1, Bivalvia–4: a total of 37 new species (Aladin et al. 2004). The clam *Abra ovata* and the worm *Nereis diversicolor* introduced by man are of great importance for fish nutrition. *Rhithropanopeus harrisii tridentata* was introduced accidentally, and disturbs the lake sediments.

Originally the Aral Sea contained freshwater, transitional freshwater-brackish water, brackish water and transitional brackish water-marine ecosystems. Brackish water ecosystems occupied the largest area (Figure 3). By the end of the 1980s, due to the increase in salinity, marine ecosystems appeared in the Aral Sea and occupied the largest area instead of the brackish water ecosystems (Figure 4). Presently, all parts of the Large Aral are occupied by hyperhaline ecosystems. In the Small Aral the transitional brackish water-marine ecosystems prevail due to the salinity decrease (Figure 5).

Since 1989, when the level had dropped by about 13 m and reached about +40 m, the Aral Sea has been divided into the Large and Small Aral with a total area of 4.0 x 10^4 km^2 (60% of 1960); volume 333 km^3 (33% from 1960) and an average salinity of 30 g/l (3 times higher than in 1960) (Table 1). After 1989, all discharge of the Syr Darya went to the Small Aral, leading to a decrease in salinity (Aladin et al. 1995).

Following the division of the Aral Sea, its volume decreased from 1000 km^3 to 400 km^3 by 2001 and to 108 km^3 by 2005, with the Large Aral Sea accounting for 85 km^3 and the Small Aral Sea 23 km^3 of the total. Salinity in the Large Aral continued to rise and reached 90 g/l (western part, depth 21 m) and 160 g/l (eastern part, depth 28.3 m) in 2005, while in the Small Aral it decreased and reached 17 g/l in 2005 (Asarin & Bortnik 1987; Bortnik & Chistyaeva 1990; Uzglavgidromet 1994–2003; Water Balance models 1990–2006; Ptichnikov 2000, 2002; Final Report 2004; Expedition 2005, 2007).

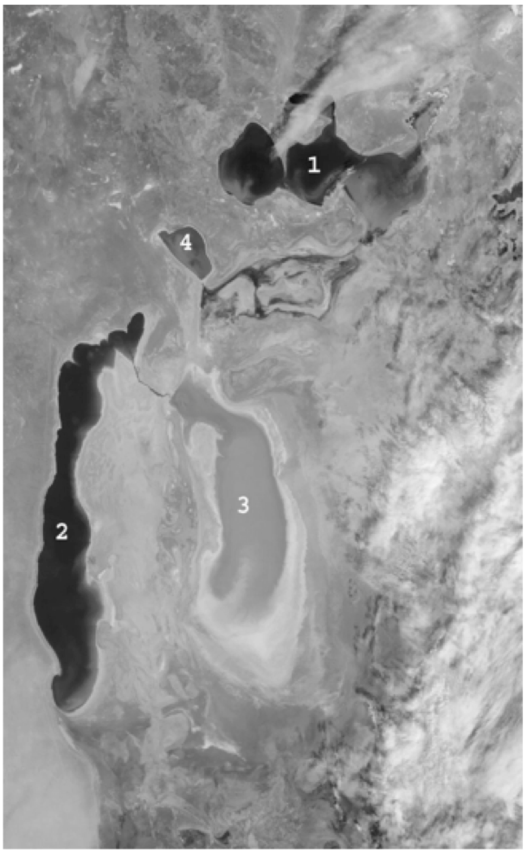

Figure 2–Modern view of the Aral Sea from space. 1–The Small Aral Sea ("Kazaral"); 2–The Western Large Aral Sea (Western "Uzaral"); 3–The Eastern Large Aral Sea (Eastern "Uzaral"); 4–Tschebas Bay.

After the separation of the Aral Sea in 1989, when the average salinity was about 30 g/l, the following free-living animals survived: fishes–10; Rotatoria–3; Cladocera–2; Copepoda–2; Ostracoda–1; Decapoda–2; Bivalvia–2; Gastropoda–> 2; Polychaeta–1; a total of > 25. The zooplankton community was composed of the following invertebrates: Rotatoria–*Synchaeta vorax*, *S. cecilia*, *S. gyrina*; Cladocera–*Podonevadne camptonyx*, *Evadne anonyx*; Copepoda–*Calanipeda aquaedulcis*, *Halicyclops rotundipes aralensis*; larvae of Bivalvia. The zoobenthos community included Bivalvia–*Abra ovata*, *Cerastoderma isthmicum*; Gastropoda–*Caspiohydrobia* spp.; Polychaeta–*Nereis diversicolor*; Ostracoda–*Cyprideis torosa*; Decapoda–*Palaemon elegans*, *Rhithropanopeus harrisii tridentata*. Fishes were represented by *Pungitius platygaster*, *Clupea harengus membras*, *Platichthys flesus*, *Atherina boyeri caspia*, *Knipowitschia caucasicus*, *Neogobius fluviatilis*, *N. melanostomus*, *N. syrman*, *N. kessleri*, and *Proterorchinus marmoratus*.

Conservation and Rehabilitation of the Aral Sea and its Ecosystems

The desiccation and salinization of the Aral Sea had serious negative impact not only on aquatic ecosystems but also on the environment of surrounding areas and the life of local people. To improve this situation, there are four main ways to conserve and rehabilitate the Aral Sea and its ecosystems, as first discussed at the United Nations Environment Programme (UNEP) meeting held in September 1992 in Geneva:

1. Conservation and rehabilitation of the Small Aral;
2. Conservation and rehabilitation of the Large Aral;
3. Conservation and rehabilitation of the delta and deltaic water bodies of Syr Darya;
4. Conservation and rehabilitation of the delta and deltaic water bodies of Amu Darya.

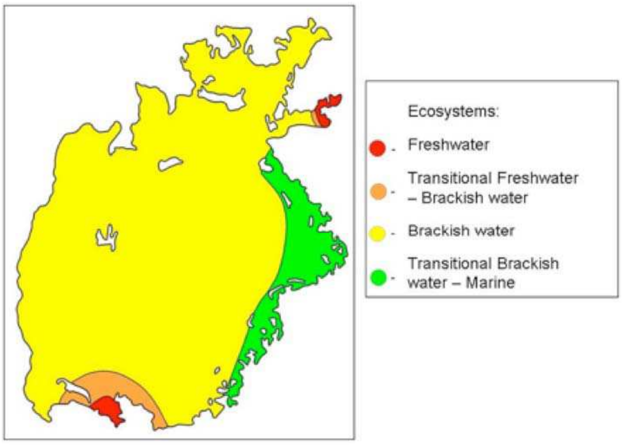

Figure 3–Ecosystems in the Aral Sea as a function of salinity before the onset of salinization.

Conservation and Rehabilitation of the Small Aral and its Ecosystems

Discharge of water from the Small Aral occurs primarily in spring-early summer which is the peak period of water flow for the Syr Darya. Since August 2005 outflow is controlled by a discharge structure (gates) in the dike. The dike in Berg strait is preserving the Small (northern) Aral, contributing to the rehabilitation of its biodiversity. The old dike (Figure 6) was built according to our proposal in August 1992 (Aladin et al. 1995). It existed, with periodic partial breaches, until April 1999, when after the water level rose to +43.5 m a catastrophic breach occurred that destroyed the dike. While the dike existed, the number of organisms increased, showing that even such a short period allowed partial rehabilitation of the biodiversity in the Small Aral.

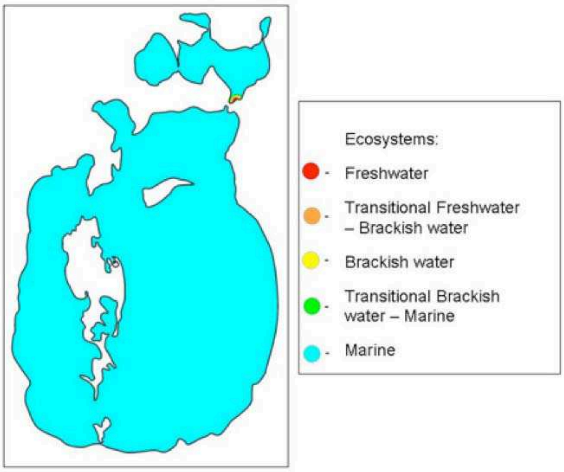

Figure 4–Ecosystems in relation to salinity at the division of the Aral Sea.

Since the separation of the Small Aral Sea from the Large Aral in 1989, the number of organisms in the lake increased as the salinity decreased to about half the earlier value, reaching about 17 g/l in 2005. At that time, the Small Aral's area was 2804 km^2 (47% from 1960), volume 23 km^3 (28% from 1960), and level +40.4 m a.s.l. Our survey in September 2007 showed the following number of species: fishes–12; Rotatoria–3; Cladocera–2; Copepoda–2; Ostracoda–2; Decapoda–2; Bivalvia–2; Gastropoda– > 1; Polychaeta–1; total: > 27. The zoobenthos of the Small Aral Sea today consists of the following: Bivalvia–*Abra ovata*, *Cerastoderma isthmicum*; Gastropoda–*Caspiohydrobia* spp.; Polychaeta–*Nereis diversicolor*; Ostracoda–*Cyprideis torosa*, *Eucypris inflata*; Decapoda–*Palaemon elegans*; Insecta: Chironomidae larvae. Fishes of the Small Aral are: *Clupea harengus membras*, *Platichthys flesus*, *Atherina boyeri caspia*, *Knipowitschia caucasicus*, *Neogobius fluviatilis*, *N. melanostomus*, *N. syrman*, *N. kessleri*, *Pungitius platygaster*, *Proterorchinus marmoratus*, *Ctenopharyngodon idella*, and *Sander lucioperca*. After construction of the first dike in Berg Strait in 1992, fishing on the Small Aral resumed. According to reports of fishermen in 2004, silver carp (*Ctenopharyngodon idella*) reappeared in the Small Aral.

The Russian company "Zarubezhvodstroy" built the most recent dike in Berg strait. It was completed in autumn 2005. In the spring of 2006 the level of the Small Aral had reached the designated mark of 42 m, well ahead of schedule. The Small Aral area in 2007 was about 3258 km^2, with a volume of 27 km^3. The dike in Berg strait improved the brackish water environment of the Small Aral (Figure 7).

Conservation and Rehabilitation of the Large Aral and its Ecosystems

Since the Aral Sea divided into two lakes in the late 1980s, the level of the Large Aral Sea has constantly been declining. Since the beginning of 2003, when the level in the Large Aral Sea had dropped by 23 m and reached an elevation of about +30 m, the Large Aral Sea has practically been divided into the eastern Large Aral, the western Large Aral, and Tschebas Bay. The salinity in the western part in September 2007 was 100 g/l. It is considerably higher in the eastern Large Aral, where it may reach 150-160 g/l. In both the eastern and western Large Aral, salinity has increased so much that most species that previously inhabited the lake have disappeared. At the end of the 20th century, the brine shrimp *Artemia salina* (*A. parthenogenetica*) appeared in the Large Aral Sea. Industrial harvesting by the international company INVE Aquaculture was being considered, but in 2005 the company postponed activities until salinity would increase to levels more favorable for brine shrimp.

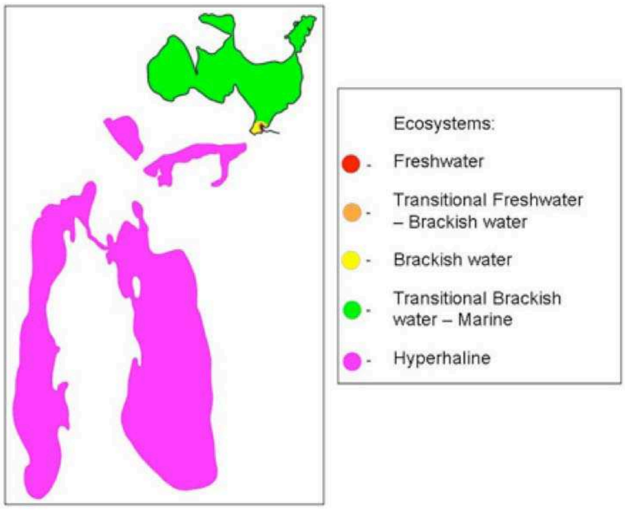

Figure 5–Ecosystems in relation to the present-day salinity.

In 2007 the zooplankton of the western Large Aral Sea consisted of: Infusoria–*Fabraea salina*; Rotatoria–*Brachionus plicatilis*, *Hexarthra fennica*; Branchiopoda–*Artemia salina* (*A. parthenogenetica*). In addition it is possible to find Cladocera–*Moina mongolica* and Copepoda–*Halicyclops rotundipes aralensis*. The zoobenthos consists of: Infusoria–*Frontonia* sp.; Turbellaria–*Mecynostomum agile*; Polychaeta–*Nereis diversicolor*; Ostracoda–*Cyprideis torosa*, *Eucypris inflata*; also it is possible that Gastropoda–*Caspiohydrobia* spp. and Bivalvia–*Abra ovata* still survive. In Tschebas Bay zooplankton and zoobenthos resemble those of the western

Large Aral Sea. During this time the high salinity in the Eastern Aral Sea (150-160 g/l) restricted the zooplankton community to *Artemia salina.* No living macro- and meso-Metazoa were found in the zoobenthos of the eastern Aral Sea.

By 2005 all fishes of the Large Aral Sea had disappeared. Nevertheless, there is a chance that in places in the western Large Aral, where salinity is lower due to inflow of underground waters, some highly salinity-tolerant fish species could still survive: *Pungitius platygaster*, *Platichthys flesus*, *Atherina boyeri caspia*, and *Neogobius melanostomus*. There is unconfirmed oral information that flounder (*Platichthys flesus*) has been observed in Tschebas Bay in water with a salinity of 80-90 g/l. Also there is unofficial information that in the remnants of the strait between the western Large Aral and the eastern Large Aral, *Atherina boyeri caspia* was found in water with 60-80 g/l salinity. Only a few free-living invertebrates could survive such high salinity conditions: Infusoria–2; Rotatoria–3; Cladocera–2; Copepoda–2; Ostracoda–2; Branchiopoda–1; Decapoda–2; Bivalvia–2; Gastropoda - > 2; Polychaeta–1 for a total of > 18.

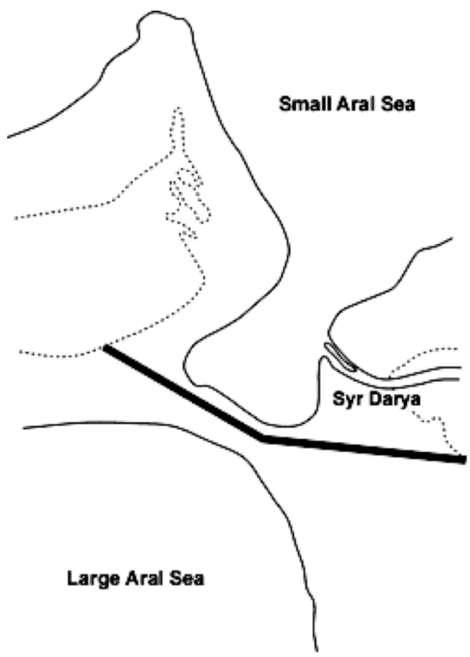

Figure 6–The dike in the Berg Strait (Aladin et al. 1995).

It may be desirable to provide more water to the eastern Large Aral from the Small Aral via the Berg Strait dike and water discharge from the Mezhdurechensky reservoir on Amu Darya via the Ak Darya river bed. The western Large Aral Sea could, perhaps, maintain its level using groundwater flow from the Amu Darya delta and the Ustjurt plateau. Realization of this project will help protect biodiversity of salt tolerant hydrobionts.

In 2005 a special water discharge facility (dike, water way and water discharge gates) was constructed to supply the Eastern depression of Large Aral with Amu Darya water from the Mezhdurechensky reservoir via the Ak Darya river bed. Unfortunately the completed spillway and water gates were destroyed by water in the autumn of 2005. Now this complex is under restoration.

Conservation and Rehabilitation of the Delta and Deltaic Water Bodies of the Syr Darya

After the construction of the first dike in Berg Strait in the summer of 1992 additional rehabilitation projects were initiated. The Syr Darya delta shifted slightly northwards and a number of freshwater reservoirs were built. Along the lower Syr Darya near the Small Aral several freshwater lakes have been rehabilitated: Tuschibas, Kamyslybas, Zhalanashkol, Karasholan, and others. These small projects allow restoring freshwater fisheries, hunting, and trapping. Fish farms were also renewed and more young fish are released into the local water bodies. Fish farms are also planned to reintroduce sturgeon into the Small Aral.

Conservation and Rehabilitation of the Delta and Deltaic Water Bodies of the Amu Darya

The Uzbekistan branch of the International Fund for Saving the Aral Sea (IFAS) in cooperation with other national institutions prepared a plan for rehabilitation of the Amu Darya delta. In the lower reaches of the Amu Darya several freshwater and brackish water reservoirs and lakes were established. One of the most successful projects is Sudochie Lake. Sudochie Lake is now completely filled and is contributing some water to the western Large Aral Sea via underground flow. Reeds, aquatic birds and hydrobionts have almost recovered in Sudochie Lake. Other former Aral Sea bays have or could be rehabilitated, including Sarbas, Muynak, Adjibay and Zhiltyrbas. Fisheries and hunting activities have been resumed in the rehabilitated areas.

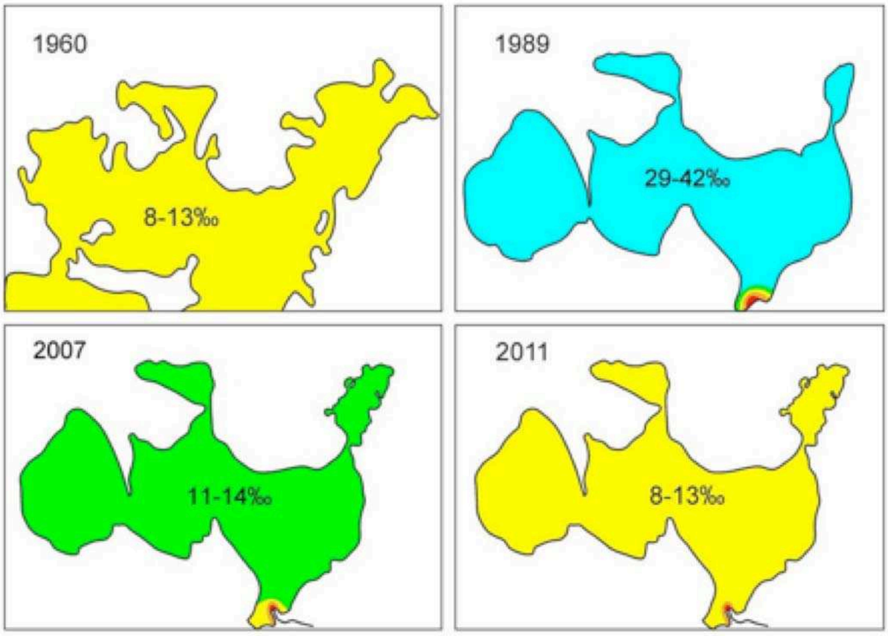

Figure 7–Decrease of salinity of the brackish water in the Small (Northern) Aral Sea as a result of the building of the dike in the Berg Strait funded by Global Environment Facility (GEF) and the Kazakhstan government.

Evidence of Desiccation of the Aral Sea in the Middle Ages

As the Aral dried, remnants of saxauls plants (*Haloxylon aphyllum*) were found on its former bottom. Some stumps were also found underwater close to the modern shoreline (Aladin & Plotnikov 1995). Radiocarbon analysis dated these to medieval times. For more paleoenvironmental reconstruction of medieval desiccation, special corings in the Aral Sea were made under the CLIMAN project (INTAS). At the end of the 20th century, Kazakh hunters found ruins of a medieval mausoleum (Kerdery) on the dried bottom. In 1960, the area was under about 20 m of water. Bones of *Homo sapiens* and domestic animals, millstones, elements of ceramics, and other artifacts were found near the mausoleum. All these findings were studied by an international team of archeologists, also under the CLIMAN project (Boroffka et al. 2005). Recently remnants of medieval river beds on the former Aral Sea bottom were also detected on satellite images. Preliminary investigations on this matter were made by D. Piriulin (personal communication).

An Alternative Second Phase of the Small Aral Rehabilitation Project

In our opinion, the future of the Aral Sea is connected with oil and gas extraction. Oil and gas drilling rigs are now widespread on the former Aral Sea bottom. A gas condensate plant was built not far from Muynak. Local decision makers even permanently closed the channel that formally fed water into the Muynak reservoir. The gate has been closed in order to lower the groundwater level in the area. A high water table level promotes softening of the ground, endangering drill towers so that they could fall over or start to lean.

The dike in Berg's Strait has caused an increase in the level of the Small (northern) Aral Sea to +42 m a.s.l. Presently the average salinity in the Small (northern) Aral Sea is about 10 g/l. For further amelioration of the situation, irrigation efficiency has to be increased to improve the water balance. It is possible to increase the height of the present dike somewhat and raise the level up to +45 m a.s.l. This will allow an enlargement of the volume and area of the Small (northern) Aral Sea.

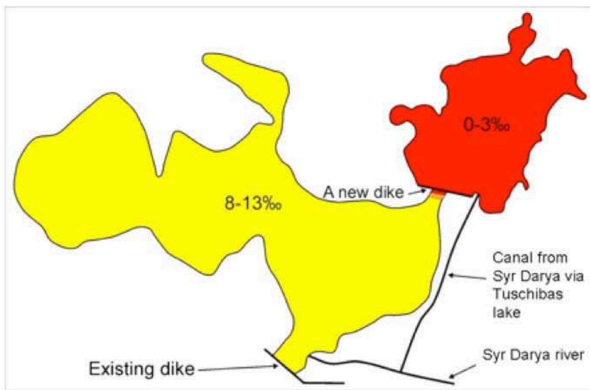

Figure 8–A variant of the second phase of the Small Aral Sea rehabilitation project.

Another possible variant of the second phase of the “Kazaral” rehabilitation project is shown in Figure 8. It would involve construction of a new dike at the mouth of the Saryshaganak Gulf to raise its level to near its 1960s mark of +53 m. Part of the flow of the Syr Darya would be diverted northward to fill the reservoir.

The second phase of the project will allow further improvement of the health of the local people, a decrease in unemployment and an increase of living standards as well as income to the local families. The local economy also will be improved (fishery, shipping, etc.). Finally, the local microclimate around the Small (northern) Aral Sea will become much more agreeable.

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