# THE DEVASTATION AND PARTIAL REHABILITATION OF THE ARAL SEA: LESSONS FOR LAKE URMIA?

Philip Micklin[1]

The Aral Sea is a terminal, or closed basin (endorheic) Lake, lying amidst the vast deserts of Central Asia (Fig. 1 – Figures and tables follow the text and selected bibliography). Its drainage basin encompasses more than two million km$^2$. As a terminal lake, it has surface inflow but no outflow. Therefore, the balance between inflows from its influent rivers, the Amu and Syr (also known as the Amu Dar'ya and Syr Dar'ya – Dar'ya in the Turkish languages of Central Asia means river) and net evaporation (evaporation from the lake surface minus precipitation on it) fundamentally determine its level.

At 67,500 km$^2$ in 1960, the Aral Sea was the world's fourth largest inland water body in area. The sea supported a major fishery and functioned as a key regional transportation route. The extensive deltas of the Syr and Amu rivers sustained a diversity of flora and fauna as well as irrigated agriculture, animal husbandry, hunting and trapping, fishing, and harvesting of reeds. Since 1960, the Aral has undergone rapid desiccation and salinization, overwhelming the result of unsustainable expansion of irrigation that dried up the two tributary rivers (Table 1).

The last 10 millennia constitute the modern geologic epoch of the Aral Sea. Major regressions of the sea have been, with the exception of the one lasting from the 1600s to the middle of the 20$^{th}$ Century, of much shorter duration than transgressions. Most of these are related to the partial or full diversion of the Amu westward away from the Aral and toward the Caspian Sea owing to natural forces. But ancient civilizations also had an effect on Aral levels. Impacts included sizable irrigation withdrawals and periodic diversions of the Amu Dar'ya westward. Irrigation along the Amu dates to 3000 years B.P. Irrigation during Classical Antiquity (4$^{th}$ Century B.C. to 4$^{th}$ Century A.D.) was extensive with irrigation canals found over 5 to 10 million ha around the Aral. Nevertheless, diversions both accidental and purposeful were by far the most important human influence on levels.

The last major desiccation of the Aral prior to the modern drying, took place from the 13$^{th}$ to 16$^{th}$ centuries when the level may have fallen below 29 meters above sea level (asl) as measured at the Kronstadt gauge on the Gulf of Finland. Historical records as well as archeological sites, preserved tree stumps and relict river channels on the dried bottom of the Aral attest to this event (Figs 2 & 3). The major cause of this recession was the anthropogenic diversion of the Amu westward toward the Caspian Sea initially caused by the Mongol invasion of Central Asia in the 13$^{th}$ Century.

The Amu Dar'ya returned (or was returned) to the Aral and the sea recovered by the mid 1600s. The lake was in a relatively stable generally "high" phase until the modern regression began in the early 1960s. Level fluctuations were no more than 4-4.5 meters and were chiefly related to climatic variation with, perhaps, some effect from expanding irrigation.

Over the past five decades, the sea has steadily shrunk and salinized (Table 1; Figure 4). Expanding irrigation that greatly diminished discharge from the two tributary rivers has been the main cause. As noted above, humans have practiced irrigation in the Aral Sea Basin for at least

[1] Professor of Geography Emeritus, Western Michigan University, Kalamazoo, Michigan 49006 USA

three millennia. But until the 1960s this did not substantially diminish inflow to the sea, owing to substantial return flows from irrigated fields to the Amu and Syr and other compensatory factors such as reduced losses to transpiration and evaporation in the deltas of these rivers. However, growth from around 5 million ha in 1960 to 8.2 million by 2010 pushed irrigation development beyond the point of sustainability leading to a marked reduction of river discharge to the Aral.

The dramatic drop in river inflow for the period after 1960 is shown on Fig. 5 and the sea level decline in Fig. 6. The difference between river inflow and net evaporation increased substantially during the 1960s, 1970s and 1980s accompanied by growing water balance deficits and rapidly dropping levels. More precipitation in the mountains and some reduction in irrigation withdrawals increased river discharge during the 1990s and reduced the water balance deficit, slowing the seas recession. There was a severe drought in 2000-2001 and river inflow only averaged about 2 $km^3$/yr. Higher inflows characterized the period 2002 through 2010 and water balance deficits were significantly lessened.

The Aral separated into two water bodies in 1987 - a “Small” Aral Sea in the north and a “Large” Aral Sea in the south. The Syr flows into the former, and the Amu into the latter. A channel formed connecting the two lakes, allowing water to flow from the former to the latter. Local authorities constructed an earthen dike in 1992 to block outflow in order to raise the level of the Small Sea, lower salinity, and improve ecological and fishery conditions. This makeshift construction breached and was repaired several times. In April 1999 after the level of the Small Aral had risen to over 43 meters, the dike was overtopped, breached and completely destroyed during a wind storm. Subsequently, the World Bank and the Government of Kazakhstan funded construction of an engineeringly sound 13-kilometer earthen dike with a concrete, gated outflow control structure to regulate the flow from the Small to Large seas (Fig. 7). The structure was completed in August 2005 and raised and stabilized the level of the Small Aral at around 42 meters asl.

The desiccation of the Aral Sea has had severe negative impacts. The vibrant commercial fishing industries ended in the early 1980s as the indigenous species that provided the basis for the fishery disappeared from rising salinity. The more salinity tolerant Black Sea flounder (*Platichthys flesus lulscus*) was introduced to the Aral in the 1970s. It flourished in the Small Aral and provided a sizable non-commercial catch, but disappeared from the Large Aral.

The level stabilization project reinvigorated the fishery in the Small Aral by lowering average salinity to near the level of the early 1960s (10 g/l). This has allowed the return and flourishing of commercially valuable indigenous species such as the sudak or pike-perch (*Lucioperca lucioperca)* and sazan (*Cyprinus carpio*), a type of carp as well as several others. Tens-of-thousands were thrown out of work because of the loss of the fishery and associated activities and employment in these occupations today is only a tiny fraction of what it was.

The rich ecosystems of the Amu Dar’ya and Syr Dar’ya deltas suffered considerable harm from reduced river flows, elimination of spring floods, and declining ground water levels that led to spreading desertification. Salts accumulating on the surface formed pans where practically nothing will grow. Expanses of unique tugay forests along the main and secondary water courses have drastically shrunk. Desiccation of the deltas has significantly diminished the area of lakes, wetlands, and their associated reed communities. These changes caused the number of species of mammals and birds to drop precipitously. Strong winds blow sand, salt and dust from the dried bottom of the Aral Sea onto surrounding lands causing harm to natural vegetation, crops, and wild and domestic animals.

Owing to the sea's shrinkage, climate has changed in a band up to 100 km wide along the former shoreline in Kazakhstan and Uzbekistan. Summers have warmed and winters cooled, spring frosts are later and fall frosts earlier, humidity is lower, and the growing season shorter.

The population living around the sea suffers acute health problems. Some of these are direct consequences of the sea's recession (e.g. respiratory and digestive afflictions, and cancer from inhalation and ingestion of blowing salt and dust and poorer diets from the loss of Aral fish as a major food source). Other serious health problems owe to environmental pollution associated with the heavy use of toxic chemicals in irrigated agriculture mainly during the Soviet era. Nevertheless, the most serious health issues are directly related to 'Third World' medical, health, nutrition, hygienic and water supply conditions.

Perhaps the most ironic and dark consequence of the Aral's modern shrinkage is the story of Vozrozhdeniya (Resurrection) Island. The Soviet military in the early 1950s selected this, at the time, tiny, isolated island in the middle of the Aral Sea, as the primary testing ground for its super-secret biological weapons program. This program stopped with the collapse of the USSR in 1991. As the sea shrank, Vozrozhdeniya grew in size and in 2001 united with the mainland to the south as a peninsula. There was concern that weaponized organisms survived decontamination measures by the departing Russian military and could escape to the mainland via infected rodents or that terrorists might gain access to them. The U.S. government worked with the Government of Uzbekistan to ensure the destruction of any surviving weaponized pathogens.

By September 2009, the Aral had shrunk to a small remnant of its 1960 size and separated into four parts (Table 1). The dike and dam constructed to regulate flow from the Small to Large Aral had raised and stabilized the level of the former leading to greatly improved ecological conditions and a revitalized fishery. The Large Sea on the south was not so fortunate. The deeper Western Basin had fallen 26 meters and had salinities in excess of 100 g/l, creating conditions where no fishes could survive. The Eastern Basin endured a similar level decline and became a shallow pond with salinity likely above 150 g/l. It appeared that it would dry up completely during the summer of 2010. However, a heavy flow year on the Amu in 2010 refilled and revitalized the basin, which since then has shrunk and expanded in a seasonal rhythm combined with interannual cycles of wet and dry years (Figures 4 & 8).

What might the future hold for the Aral Sea and its immediate environs? The claim by some that the lake will dry up completely in the 21st Century is false. Even if river inflow from the Amu and Syr were reduced to zero, a very improbable scenario, there would still be residual input of irrigation drainage water, groundwater, and snow melt and rain that would maintain at least two substantial lakes: the western part of the Small Aral Sea in the north, and the Western Basin of the Large Sea in the south. These lakes would be hypersaline and of little ecological or economic value, except, perhaps for the production of brine shrimp (*Artemia*) eggs.

Return of the sea to its 1960s state is very unlikely in the foreseeable future. It would necessitate restoring average river inflow to 56 $km^3$ and take about 103 years. Restoration would follow a logistics curve: rapid at first as inflow greatly exceeded net evaporation, then slowing and approaching zero as net evaporation grew and approached inflow. However, the sea would reach an area of 60,000 $km^2$ (91% of stability area) in just 43 years.

Average annual inflow to the sea from 2001 through 2010 was only 11 $km^3$ – 20% of what would be needed for realization of this scenario. The only realistic means for substantially increasing inflow to the Aral is reducing the use of water for irrigation. This activity accounts for 92% of aggregate withdrawals. Irrigation efficiency could be substantially improved but at great cost and requiring a long period for implementation. The area irrigated could also be significantly reduced, but would do great economic harm as irrigation plays such an important role in the economies of the new nations of Central Asia.

It is engineeringly feasible to bring water to the Aral Sea from outside Central Asia. The Soviet government developed plans to divert up to 60 $km^3$ from the Siberian rivers Irtysh and Ob' to the region as the panacea for water shortage problems. The initial phase (27 $km^3$) was on the verge of implementation when stopped in 1986 chiefly on the grounds of excessive cost. This grandiose scheme continues to be discussed and promoted in Central Asian water management and governmental circles, but appears to have little chance of implementation in the near to mid-term future. Even if implemented, much less than the 27 $km^3$ diverted, probably less than 15, would reach the Aral owing to substantial evaporation and filtration losses in the transfer system, withdrawals along the route for irrigation and other purposes, and usage in Central Asia for irrigation.

Various partial rehabilitation scenarios for the sea and river deltas hold considerable promise. Around 2.6 $km^3$/yr is all that is required to maintain the current level of the Small Aral (~42 meters asl with an area of ~3200 $km^2$). However, an additional 0.65 km3 is needed to provide sufficient outflow through the Berg Strait Dike to regulate salinity. Thus, the total yearly inflow would need to be maintained at a minimum of 3.25 km3. For 1992 –2011, Syr average annual inflow was near 6 $km^3$ and the minimum yearly flow was 3.23 $km^3$. Since the completion of the dike in 2005, excess water has been released southward creating large, shallow lakes with very high evaporation rates that during some years have reached the Eastern Basin of the Large Aral. A case may be made that these releases could be considerably reduced and used for further raising the level of this water body.

The Kazakhstan Government is planning a second phase to the Small Aral restoration project. One alternative is to raise the level of water only in the Gulf of Sary Shaganak, which extends northeast off the eastern part of the Small Sea, to 50 meters. For this a new dike and dam would be placed at the Gulf's mouth and part of the flow of the Syr Darya diverted northward via a canal into Sary Shaganak to maintain its level. The gulf would be brought back to the town of Aralsk the former main port at the northern end of the Aral Sea. This would allow fishing vessels direct access to the newly rebuilt fish processing plant in Aralsk. Cost of this project is estimated at 200 million USD. The other alternative would rebuild the dike and dam separating the Small Aral from the Large Aral, raising the level of the entire lake to 48 meters above sea level (Figure 9). This alternative would likely provide more economic and ecological benefits than the Saryshaganak Reservoir plan but would also require more inflow from the Syr Dar'ya. An estimate of the amount inflow to maintain the 48 meter level and regulate salinity by releases through the dike is 4.9 $km^3$/yr but could be lowered to 4.6 $km^3$ if the discharge point were moved to the western end of the Small Aral (see Fig. 9).

The future for the Large (southern) Sea is more problematic. The Eastern Basin has become a very shallow seasonal waterbody with high salinity and little value. The Western Basin depends largely on net groundwater inflow, direct runoff from rain and snowmelt, and some input from the overflow from the Small Aral. If present trends continue, the level and area of the Western Basin will decrease considerably from recent figures, perhaps stabilizing around 21 meters asl by 2100 $km^2$. It would continue on the path of hypersalinization, steadily moving toward conditions characteristic of the Great Salt Lake in the United States, the Dead Sea in the Middle East, and Lake Urmia in Iran (200-300 g/l). Only brine shrimp *(Artemia)* and some bacteria could survive such harsh conditions.

But there are more optimistic scenarios for the Western Basin of the Large Aral. Figure 9 shows a concept developed by the author based on earlier work by two Soviet experts. It would require an average annual inflow in the lowest reaches of the Amu Darya of around 12.5 $km^3$. Flow here for 1990 through 2011 was around 5.4 $km^3$/yr so it would require a bit more than doubling this, which could be accomplished via feasible improvements in irrigation efficiency in the Amu River Basin. This alternative would cost considerably more than the 85 million USD expended on the first stage of the Small Aral restoration. The greatest obstacle to implementation is that the plan would complicate exploration for and exploitation of oil and gas deposits from parts of the now dried bottom of the Aral Sea.

Rehabilitation and preservation of the lower Amu Dar'ya delta has been a priority since the late 1980s. This is being done through creation of artificial ponds and wetlands and rehabilitation of former lakes and wetlands in the delta and on the dry bed of the Aral Sea. Benefits of are enhanced biodiversity, improved fisheries, greater forage production, treatment of wastewater by aquatic vegetation, and some reduction in salt and dust transfer from the dried sea bottom. A companion measure is the revegetation of parts of the dried bottom with salt tolerant shrubs, grasses, and trees to stabilize them and lower their deflation potential. Less ambitious efforts are also underway to improve wetlands and lakes in the lower Syr Dar'ya Delta.

Are their lessons, particularly for Lake Urmia, that we can learn from the Aral and its modern desiccation? Below is an attempt to explicate what this writer views as the most important of these.

1. The modern desiccation of the Aral Sea illustrates once again that the natural environment can easily and quickly be wrecked but that repairing it, if possible, is a long and arduous process. Hence, humankind needs to be very cautious about large-scale interference in complex natural systems. And it is essential to carefully evaluate the potential consequences of such proposed actions before hand rather than, as so long has been the case, recklessly plunging ahead, hoping for the best as the Soviet Union did with the Aral Sea.
2. Even though a particular human activity has not resulted in serious problems in the past is no guarantee that it will not cause problems in the future. Wide-spread irrigation in the Aral Sea Basin did not seriously impact the sea prior to the 1960s because large water withdrawals were off set by compensatory factors such as significant irrigation return flows to the Syr and Amu rivers, reduced downstream flooding and associated losses to evaporation and transpiration by phreatophytes growing along the rivers and in the floodplain. However, these compensating factors were exhausted or overwhelmed as irrigation expanded from the deltaic zones into the surrounding deserts, increasing losses to exfiltration from lengthy, often unlined canals, and reducing return flows to the rivers as drainage water accumulated in lakes and evaporated or went to fill pore spaces in dry desert soils. The associated construction of extensive, shallow reservoirs in the desert and semi-desert plains also contributed to large water losses to the rivers owing to increased evaporation. Thus irrigation that had been practiced for thousands of years in this region without placing major stresses on the natural environment passed a tipping point in the early 1960s beyond which the expansion of this activity could not be supported by the hydrologic and related natural systems without incurring significant damage to them.
3. Beware of appealing but facile solutions for complex environmental and human problems. The Aral situation has been unfolding for 50 years and will not be resolved

over night. "Quick fixes" that have been proposed such as major cuts in cotton growing to save water and help the sea may well cause problems worse than they attempt to solve. Cotton growing is a key economic activity and source of employment in the Aral Sea Basin. Major cuts in it, if implemented hurriedly and carelessly, would not only cause damage to national economies, but also substantially raise unemployment and contribute to social unrest. Long term, sustainable solutions require not only major investments and technical innovations to improve irrigation water use efficiency, but also fundamental political, social and economic change that take time.

**4.** But all is not gloom by any measure. The natural environment is amazingly resilient. Hence, don't abandon hope and efforts to save it, even when the task seems overwhelming. Many wrote off the Aral Sea earlier as a lost cause, but it now has been unequivocally demonstrated that significant parts of it can be preserved and ecologically restored. Furthermore, even though not realistic in the foreseeable future, over the long-term, it may even be possible to reduce the use of water sufficiently to provide adequate discharge to bring the sea back to what it was a half-century earlier. As the archeological and sedimentological record proves, the Aral has suffered desiccations as great as the present one and recovered.

**5.** Preservation of biological refugia is key for saving endemic species. Even though a species may disappear from one habitat owing to changing environmental conditions that drive it to extinction, it may be preserved in another nearby location. If the alternative site is preserved, than if and when habitat conditions in the original site become favorable, endemic species are able to return on their own or can be reintroduced by humans. This is exactly what happened in the Small Aral Sea. A number of endemic species (fishes and invertebrates) could not withstand the dramatic increase in salinity. But these species were preserved in the Syr Darya and in that rivers' deltaic lakes. When the Small Sea separated from the Large in the late 1980s and the first earthen dike was constructed in 1992, salinity began to drop and some of these species began to return. After the engineeringly sound Berg Strait (Kok-Aral) dike was completed in August 2005, the level was raised and stabilized and salinity dropped to near the levels characteristic of pre-desiccation conditions, many other endemic species repopulated the sea.

**6.** Large-scale environmental restoration projects such as the Small Aral Sea project require careful monitoring and follow-up. This is necessary not only to make sure they are working as expected and to provide management feedback, but to learn new lessons that may improve the success of similar actions elsewhere.

Selected Bibliography

Krivinogov, Sergey (2014). "Changes of the Aral Sea level," pp. 77-111 in Philip Micklin, Nikolay Aladin and Igor Plotnikov (eds.), *The Aral Sea: The Devastation and Partial Rehabilitation of a Great lake* (Heidelberg, Springer), 454 pp +x.

Micklin, Philip (2014a) (Chief Editor), Nikolay Aladin (Associate Editor), and Igor Plotnikov (Associate Editor). *The Aral Sea: The Devastation and Partial Rehabilitation of a Great lake* (Heidelberg, Springer), 454 pp +x.

Micklin, Philip (2014b). "Aral Sea Basin Water Resources and the Changing Aral Water Balance," pp. 111-137 in Philip Micklin, Nikolay Aladin and Igor Plotnikov (eds.), *The Aral Sea: The Devastation and Partial Rehabilitation of a Great lake* (Heidelberg, Springer), 454 pp +x.

Micklin, Philip (2014c). "Irrigation in the Aral Sea Basin, pp. 207-233 in Philip Micklin, Nikolay Aladin and Igor Plotnikov (eds.), *The Aral Sea: The Devastation and Partial Rehabilitation of a Great lake* (Heidelberg, Springer), 454 pp +x.

Micklin, Philip (2014d). "Efforts to Revive the Aral Sea," pp. 361-405 in Philip Micklin, Nikolay Aladin and Igor Plotnikov (eds.), *The Aral Sea: The Devastation and Partial Rehabilitation of a Great lake* (Heidelberg, Springer), 454 pp +x.

Micklin, Philip (2010). "The past, present, and future Aral Sea." *Lakes & Reservoirs: Research and Management*, 15, pp. 193-213.

Micklin, Philip and Nikolay V. Aladin (2008). "Reclaiming the Aral Sea," *Scientific American*, April pp. 64-71.

Micklin, Philip ( 2007). "Destruction of the Aral Sea," pp. 320-326 in Claire L. Parkinson et al. (eds.), *Our Changing Planet: the View from Space* (New York: Cambridge University Press).

Micklin, Philip (2007). "The Aral Sea Disaster," Raymond Jeanloz et al. (eds.), *Annual Review of Earth and Planetary Sciences*, Vol. 35, 2007, pp. 47-72, Palo Alto, California (doi: 10.1146/annurev.earth.35.031306.140120). Available on line at http://arjournals.annualreviews.org/doi/pdf/10.1146/annurev.earth.35.031306.140120.

Plotnikov, Igor S., Nikolay V. Aladin, Zaualkhan K. Ermakhanov, and Lyubov V. Zhakova (2014a). Biological Dynamics of the Aral Sea Before Its Modern Decline (1900–1960), pp. 41-47 in Philip Micklin, Nikolay Aladin and Igor Plotnikov (eds.), The Aral Sea: The Devastation and Partial Rehabilitation of a Great lake (Heidelberg, Springer), 454 pp +x.

Plotnikov, Igor S., Nikolay V. Aladin, Zaualkhan K. Ermakhanov, and Lyubov V. Zhakova (2014a). The New Aquatic Biology of the Aral Sea , pp. 137-171 in Philip Micklin, Nikolay Aladin and Igor Plotnikov (eds.), The Aral Sea: The Devastation and Partial Rehabilitation of a Great lake (Heidelberg, Springer), 454 pp +x.

Zavialov P (2010). Physical oceanography of the large Aral Sea, pp. 123-147. In: Kostianoy AG, Kosarev AN (eds) The Aral sea environment, vol 7, The handbook of environmental chemistry. Springer, Berlin/Heidelberg.

**Figure 1. Location of Aral Sea Basin in Central Asia**


Source: Modified from Micklin, Philip and Nikolay V. Aladin,., "Reclaiming the Aral Sea," *Scientific American*, Vol. 298, No. 4 (April 2008), p. 66.

Table 1. Hydrological and Salinity Characteristics of the Aral Sea, 1960–2013

| **Year and portion of sea** | **Level (meters asl)** | **Area ($km^2$)** | **% 1960 area** | **Volume ($km^3$)** | **% 1960 volume** | **Average depth (meters)** | **Avg. salinity (g/l)** | **% 1960 salinity** |
|---|---|---|---|---|---|---|---|---|
| 1960 (all) | 53.4 | 67,499 | 100 | 1,089 | 100 | 16.1 | 10 | 100 |
| Large | 53.4 | 61,381 | 100 | 1,007 | 100 | 16.4 | 10 | 100 |
| Small | 53.4 | 6,118 | 100 | 82 | 100 | 13.4 | 10 | 100 |
| 1971 (all) | 51.1 | 60,200 | 89 | 925 | 85 | 15.4 | 12 | 120 |
| 1976 (all) | 48.3 | 55,700 | 83 | 763 | 70 | 13.7 | 14 | 140 |
| 1989 (all) | | 39,734 | 59 | 364 | 33 | 9.2 | | |
| Large | 39.1 | 36,930 | 60 | 341 | 34 | 9.2 | 30 | 300 |
| Small | 40.2 | 2,804 | 46 | 23 | 28 | 8.2 | 30 | 300 |
| Sept 22, 2009 (all) | | 7,146 | 10.6 | 83 | 7.7 | 10.8 | | |
| W. Basin Large | 27 | 3588 | | 56 | | 15.1 | >100 | >1000 |
| E. Basin Large | 27 | 516 | | 0.64 | 5.7 | 0.7 | >150? | >1500 |
| Tshche-bas Gulf | 28 | 292 | | 0.51 | | 1.4 | ~85 | 850 |
| Small | 41.5 | 2750 | 45 | 27 | 33 | 9.8 | 10-13 | 100-130 |
| Oct 19, 2013 (all) | | 7,648 | 11.3 | 83 | 7.7 | 8.1 | | |
| W. Basin Large | 26.5 | 3,279 | | 54 | | 13.5 | >100 | >1000 |
| E. Basin Large | 26.2 | 770 | | 3.0 | 5.6 | 1.3 | >150? | >1500 |
| Tshche-bas Gulf | 28.5 | 372 | | 0.72 | | 1.4 | 84 | 840 |
| Small | 42 | 3227 | 52.7 | 27.5 | 33.5 | 8.5 | 8-10 | 0.8-1 |

Sources. (1) Data for 1960-1989 from Micklin, Philip (2010),“The past, present, and future Aral Sea,” *Lakes & Reservoirs: Research and Management*, 15, Table 1, p. 195. (2) Data for 2009 and 2013: areas calculated from MODIS 250 meter resolution natural color images for these dates using ImageJ software; volume data author estimates; salinity data for 2009 author estimates based on measurements taken with a YSI-85 electronic meter during an expedition to the Aral Sea in September 2007 and data provided by Dr. N. Aladin of the Zoological Institute, Russian Academy of Sciences, St. Petersburg, Russia, on salinity measurements taken in 2008; salinity data for 2013 based on measurements taken with the YSI-85 meter and an optical refractometer during an expedition to the Aral Sea in August and September 2011.

**Figure 2 Kerdery 1 Masoleum with relict channel leading off former bed of Syr Darya in the background (Dr. Aladin is sitting by ceramic artifacts; photo by P. Micklin)**

**Figure 3. Landsat band 5 Image of 9-11-07 showing former channel of Syr Dar’ya on dried bottom of Eastern Basin of Large Aral with sub-channels leading off to the northwest**

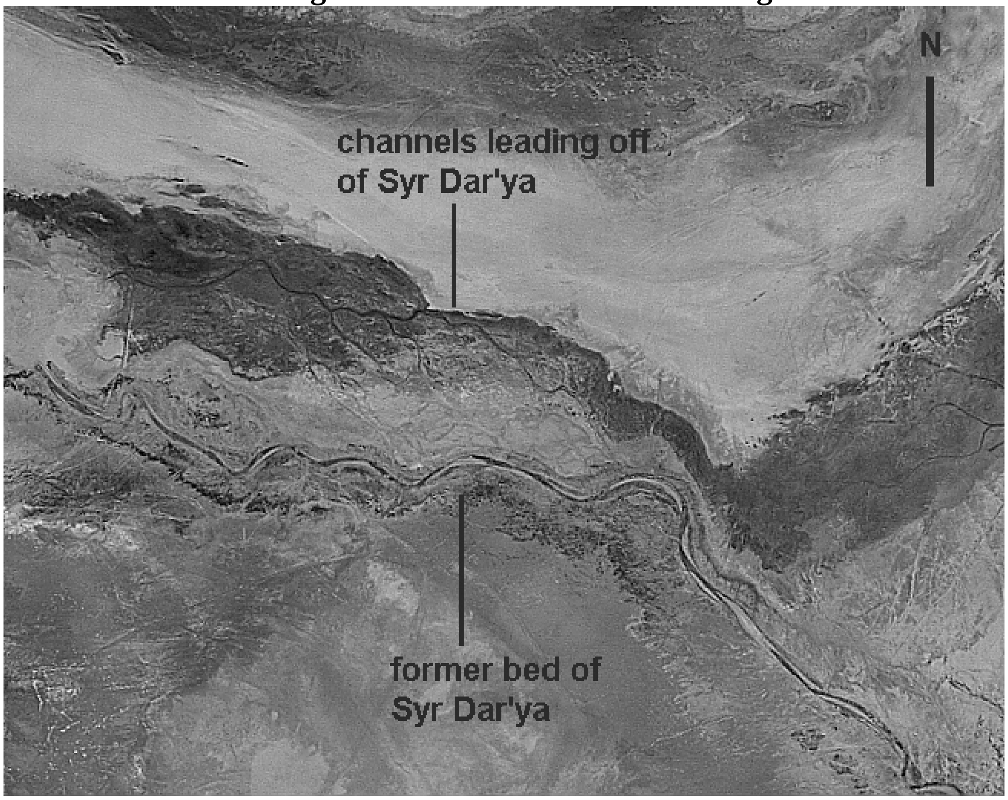


**Figure 4. The Changing Profile of the Aral Sea: 1960-2025**

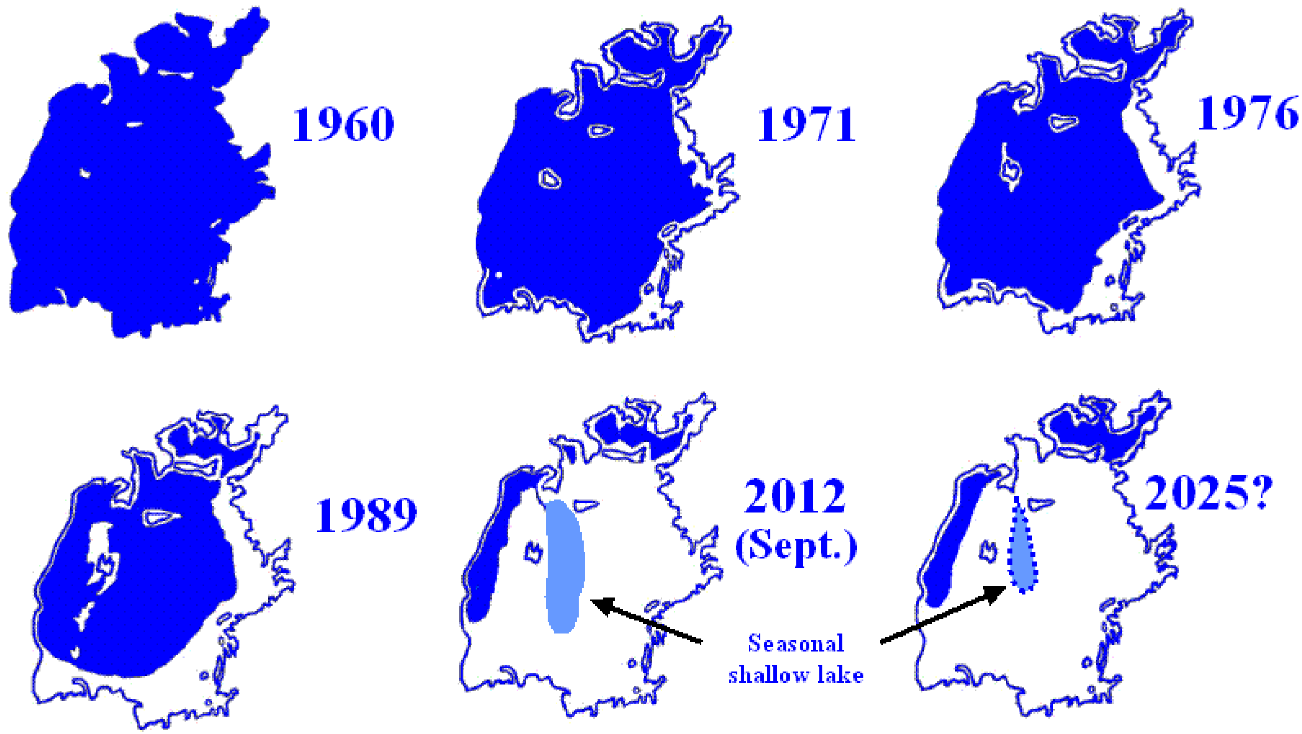



**Figure 5. Inflow to the Aral Sea 1910-2010 (in km$^3$)**

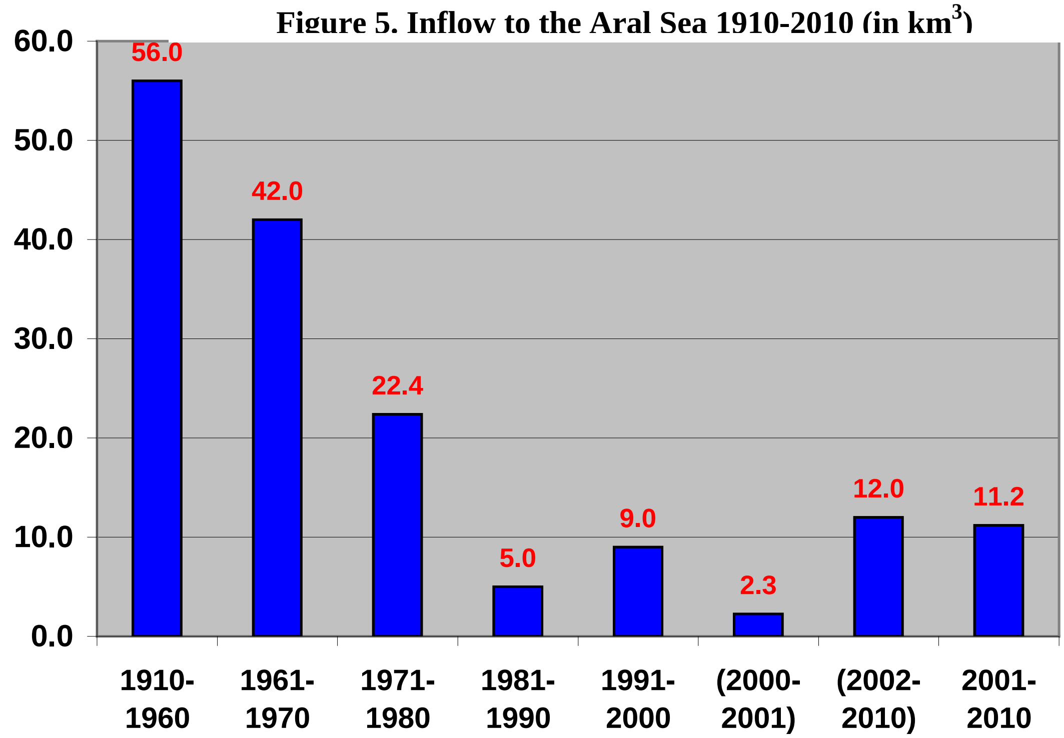


**Figure 6. Changing Level of the Aral Sea: 1950-2010**
(Measured in reference to the Baltic Sea level gage at Kronstadt Russia on the Gulf of Finland, which is approximately 20 cm above sea level.)

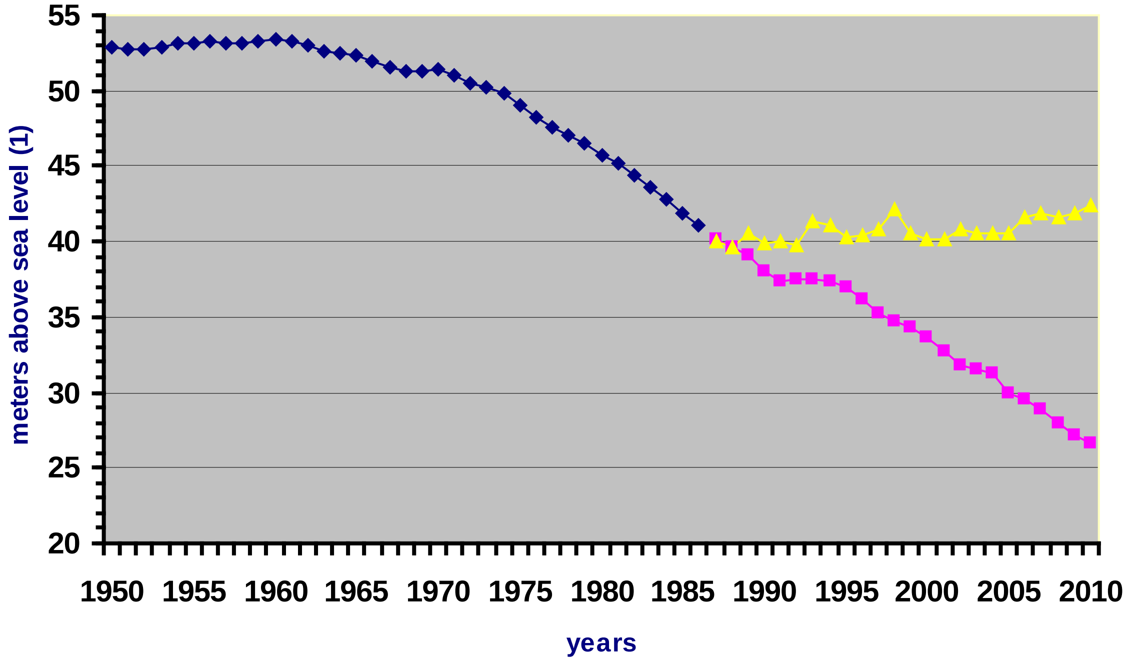
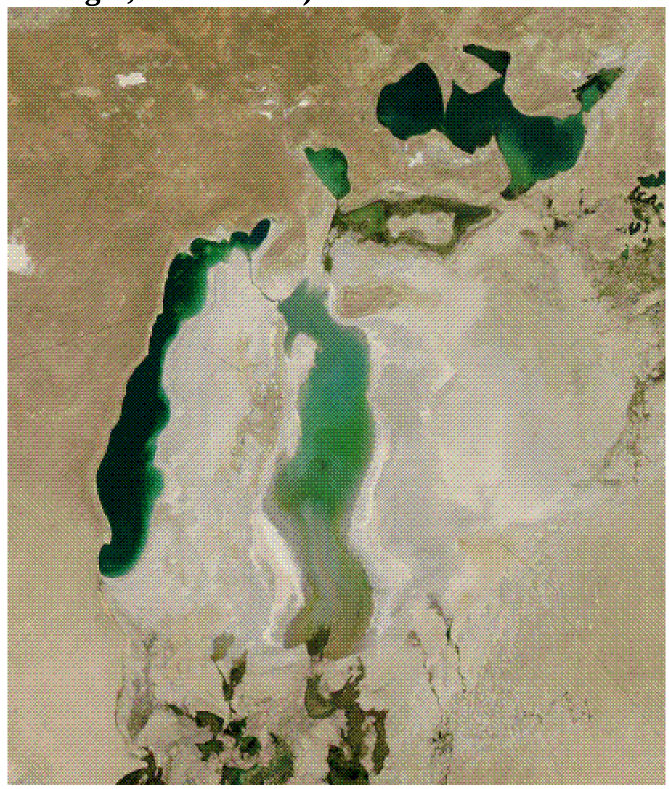



**Figure 7. Kok-Aral Dam and Dike from Lower Side (Sept. 2007)**
**(photo by P. Micklin)**

**Figure 8. Aral Sea on September 6, 2009 (left), September 7, 2010 (right) and October 19, 2013 (below)**
**(MODIS 250 meter, true color images, bands 1-4-3)**



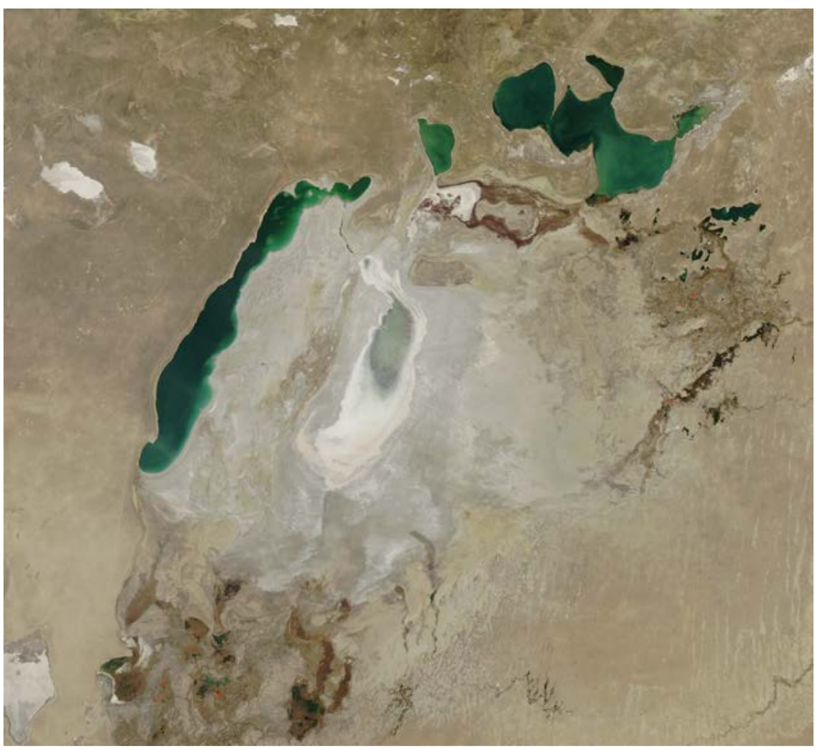
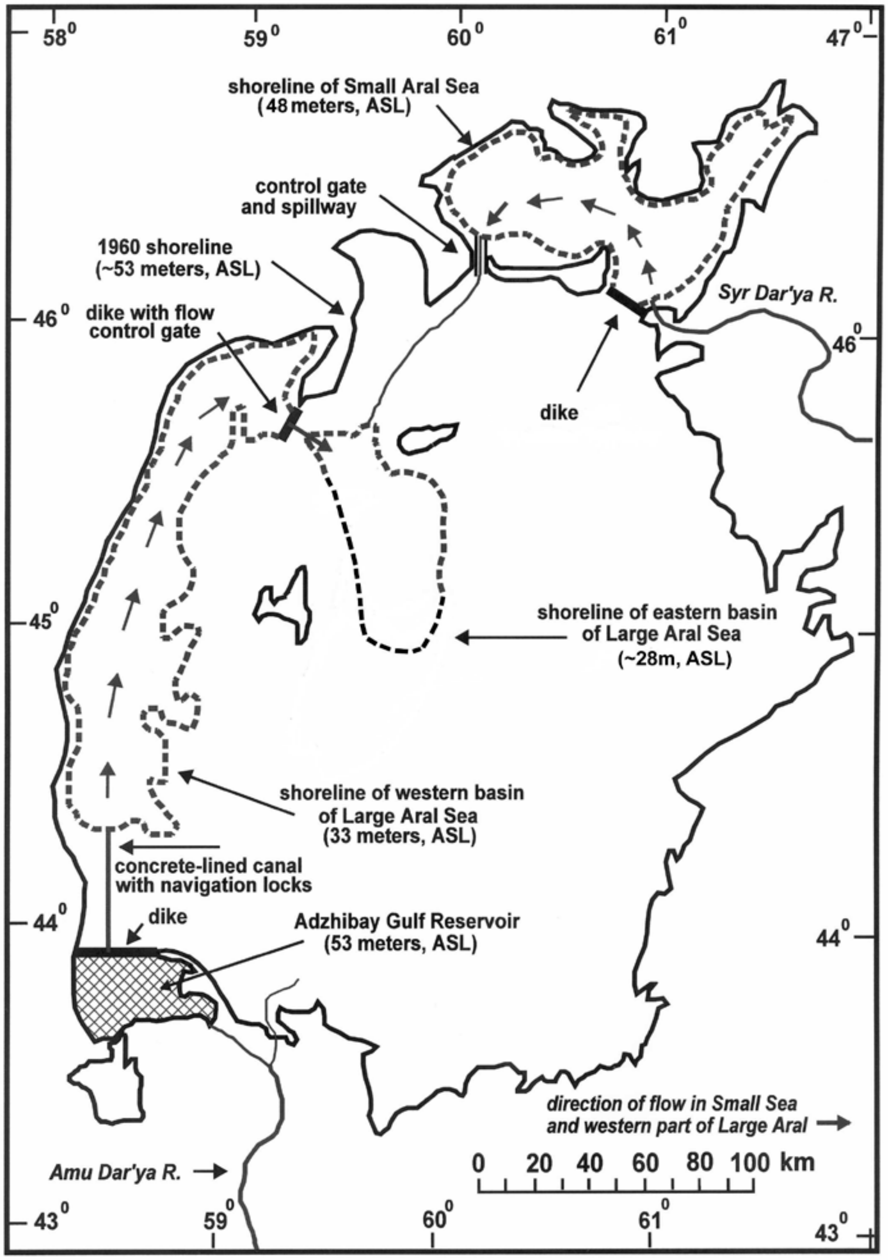


**Figure 9. Optimistic Scenario of the Future Aral Sea (after 2030).**




**Legend. <u>Small Aral Sea</u>: level = 48 m, surface area = 4830 km$^2$, volume 53.5 km$^3$, avg. annual river inflow = 5.31 km$^3$, avg. annual outflow = 1.43 km$^3$, avg. annual salinity = 8 g/l. <u>Western Basin of Large Aral sea</u>: level = 33 m, surface area = 6200 km$^2$, volume = 85 km$^3$, average annual river inflow = 6.6 km$^3$, avg. annual outflow to Eastern Basin = 2.09 km$^3$. Salinity steadily decreasing reaching 42 g/l by 2055 and 15 g/l by 2110. <u>Eastern Basin of Large Aral Sea</u>: level ~ 28 m, surface area ~2378 km$^2$, volume ~ 3.0 km$^3$, avg. annual salinity > 200 g/l. <u>Adzhibay Gulf Reservoir</u>: level = 53 m, surface area = 1147 km$^2$, volume = 6.43 km$^3$, inflow = 8 km$^3$, outflow to Western Basin of Aral Sea =6.6 km$^3$, avg. annual salinity = 2g/l.**