Chapter 15
Efforts to Revive the Aral Sea

Philip Micklin

Abstract The Aral Sea between 1960 and 2012 lost 85 % of its area and 92 % of its volume, while separating into four residual lakes. The Large Aral on the south endured a level drop of 25 m and rise of salinity from 10 g/l to well over 100 g/l. Over this period, the sea suffered immense ecological and economic damage including the destruction of its valuable fishery and degradation of the deltas of its two influent rivers. Nevertheless, in spite of this calamity, and contrary to reports that the sea is a lost cause (popular reports that the sea will "disappear" are simply false), hope has remained that the sea and its deltas could be partially rehabilitated. Various restoration scenarios are discussed. Full revitalization of the sea in the foreseeable future is extremely improbable, but cannot be ruled out for distant times. The project implemented in the first decade of the present century to partially restore the Small (northern) Aral Sea so far has been eminently successful. Partial restoration of the Large (southern) Aral is more problematic as it would be more costly and complicated than the north Aral project. Nevertheless, it is certainly worthy of further investigation. Projects to improve the deltas of the Amu Darya and Syr Darya are also underway. The interested reader should also see Chap. 14 which analyses the potential for biological rehabilitation of the Aral and Chap. 16 focusing on the grandiose Siberian water transfer schemes developed during the Soviet era to radically improve the water balance of the Aral Sea Basin.

Keywords Small Aral • Large Aral • Amu Darya Delta • Syr Darya Delta • Western Basin • Eastern Basin • Siberian diversion • Tshche-bas • Saryshaganak

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Table 15.1 Hydrological and salinity characteristics of the Aral Sea, 1960–2011

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 (Whole)	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 (Whole)	51.1	60,200	89	925	85	15.4	12	120
1976 (Whole)	48.3	55,700	83	763	70	13.7	14	140
1989 (Whole)		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. 2009 (Whole)		8,522	12.6	83	7.7	9.7		
W. Basin Large	26.5	3,702	8	56	5.7	15.1	>100	>1,000
E. Basin Large	26.5	857		0.64		0.7	150–200	1,500–2,000
Tshche-bas Gulf	28	363		0.51		1.4	>100?	>1,000
Small	42	3,600	59	27	33	7.5	10–14	100–140
Sept. 2011 (Whole)		10,317	15.3	84	7.7	8.1		
W. Basin Large	27.8	3,938	10.9	53	5.6	13.5	>100[a]	>1,000
E. Basin Large	27.6	2,268		3.0		1.3	>50?	
Tshche-bas Gulf	28.5	511		0.72		1.4	84[a]	840
Small	42	3,600	59	27	33	7.5	8[a]	0.8

Sources: (1) Data for 1960–2009 with some corrections from Micklin, Philip (2010), "The past, present, and future Aral Sea," *Lakes & Reservoirs: Research and Management*, 15, Table 1, p. 195. (2) Data for 2011 from Report: monitoring of the Amudarya river delta and the exposed bed of the Aral Sea within the framework of the CAWA Project – Dynamics of surface water and groundwater changes in the Amudarya river delta and the exposed bed of the Aral Sea June 2009 – September 2011, Tables 3 and 4 (Available at website Cawaterinfo http://www.cawater-info.net/aral/data/pdf/amudelta_monitoring_sept11_en.pdf)

[a]Salinity measurements taken with a YSI-85 electronic meter and an optical refractometer during an expedition to the Aral Sea from 28 August to 15 September 2011

15.1 Introduction

By September 2011, the Aral Sea had shrunk to a small remnant of what it was in 1960 (Table 15.1 above; Fig. 15.1 below). The lake had separated into four parts: the Small Aral Sea on the north, the Eastern Basin of the Large Aral Sea on the East, the

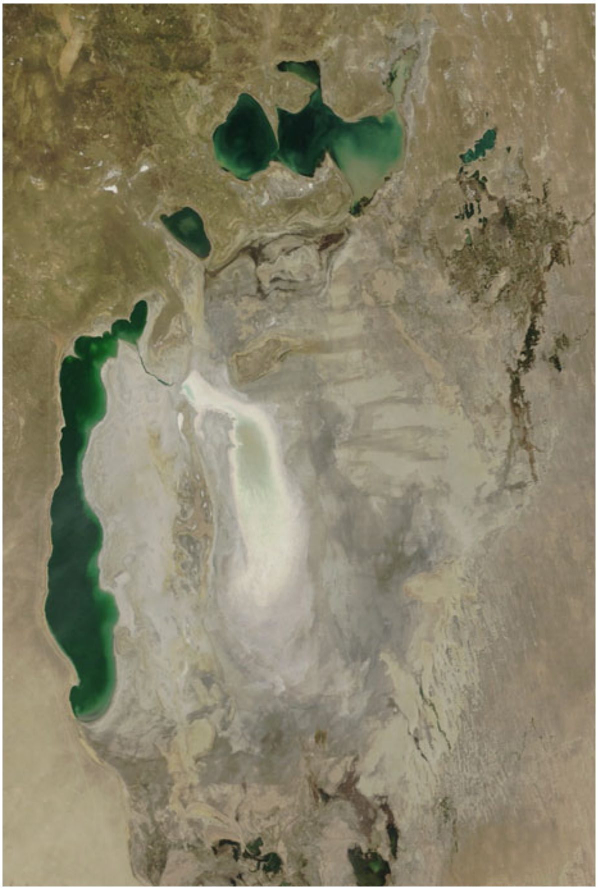

Fig. 15.1 MODIS image of Aral Sea September 22, 2009 (Natural color, 250 m resolution, Terra satellite) (Source: MODIS rapid response (Near real time images) lance.nasa.gov/imagery/rapid-response)

Western Basin of the Large Aral Sea on the west, and Tshche-bas Bay between the Small Aral on the north and the two remnants of the Large Aral on the south. A long, narrow channel, much like a slow moving river, connects the Eastern and Western basins of the Large Aral. Wind direction and speed, the relative levels of the two basins, and salinity-driven water density, determine the direction of flow in the channel: sometimes east to west and other times west to east. The aggregate area and volume of the Aral compared with 1960 had shrunk by 85 % and 92 % respectively.

The level of the Small (northern) Aral has been stabilized by a dike and dam finished in August 2005 at 42 m above sea level. (However, one should note that the measurement is made above the gage located at Kronstadt on the Gulf of Finland, which averages about 20 cm higher than ocean level). The Small Aral at 42 m is 11.4 m below its 1960s level. Owing to this project, its salinity decreased substantially reaching an average of about 8 g/l by September 2011, leading to greatly improved ecological conditions and a revitalized fishery (see Chap. 13).

The Large Sea on the south has not been so fortunate. The deeper (average depth 13.5 m) Western Basin at 27.8 m asl had fallen 25.6 m since 1960 and had salinities in excess of 100 g/l, creating conditions where no fishes could survive. The Eastern Basin had nearly dried up by September 2009 with salinities in the shallow pond (average depth 0.7 m) that was left probably exceeding 200 g/l (Fig. 15.1). The author (incorrectly) forecast the basin to completely dry during the summer of 2010 (Micklin 2010).

But 2010 turned out to be the highest flow year on the Amu Darya (measured at the Takhiatash Dam and representing water delivery to the Amu delta and the Aral Sea) since 1998, and the third largest since 1992 ending a 4-year cycle of low flows. Considerable water reached the Eastern Basin from the Amu for the first time since 2006 (Cawaterinfo 2012a, b, c; MODIS 2006–2011). Although providing the primary water supply to the Eastern Basin, this inflow was supplemented by substantial outflow from the Small Aral via the Kok-Aral Dam that creates a series of shallow lakes some of which connect to the Eastern Basin of the Large Aral. The outflow resulted from flow conditions on the Syr Darya in 2010 (fourth largest of the 20 years from 1992 to 2011), which delivered heavier than normal amounts of water to the Small Sea (Cawaterinfo 2012d, e). Between November 2009 and November 2010, the Eastern Basin's area rose from 857 to 5,211 km^2 and its volume from 0.64 to 8.4 km^3 (Cawaterinfo 2012a; Table 3 and 4) (Fig. 15.2). Salinity also dropped dramatically, perhaps, to as low as 20 g/l.

But this major expansion of the Eastern Basin was short-lived as Amu Darya flow decreased dramatically in 2011, the third lowest flow year for the 20-year period 1992–2011. Consequently, the area and volume of the Eastern Basin dropped rapidly reaching, respectively, 2,268 km^2 and 3.0 km^3 by September 2011 (Cawaterinfo 2012a; Table 15.1). Average salinity also rose considerably, certainly taking that parameter back above 50 g/l. By June 2012, the Eastern Basin had almost completely dried and was smaller than in September 2009 (MODIS 2012). Its complete desiccation by late summer seemed inevitable. But in late July Amu water again reached the basin and by mid-August the area of this extremely shallow water body approximated that of the Western Basin. This sequence of near (or complete) drying and then refilling, dependent primarily on inflow from the Amu Darya and secondarily from outflow from the Small Aral, will likely continue for the foreseeable future absent intervention by humans (see below).

By September 2009, Tshche-bas Bay, now cut-off from the Eastern Aral, had fallen 25.4 m from its 1960 level (Table 15.1). Its area had dwindled to 363 km^2, its volume to one-half cubic kilometer, average depth fell to 1.4 m, and salinity rose to probably over 100 g/l. However, in 2010, spring/summer outflow from the Small Aral via the Kok-Aral dam was of such size that a considerable amount of water reached the Bay, for the first time in several years, substantially increasing its area and volume (Cawaterinfo 2012a, Table 3). But as on the Amu, flow of the Syr in 2011 markedly dropped and the bay's area and volume rapidly decreased reaching 511 km^2 and 0.72 km^3 by September 2011.

The key question is what could the future hold for the Aral Sea and its river deltas? Will the Aral completely disappear? Is it possible to return the sea to its

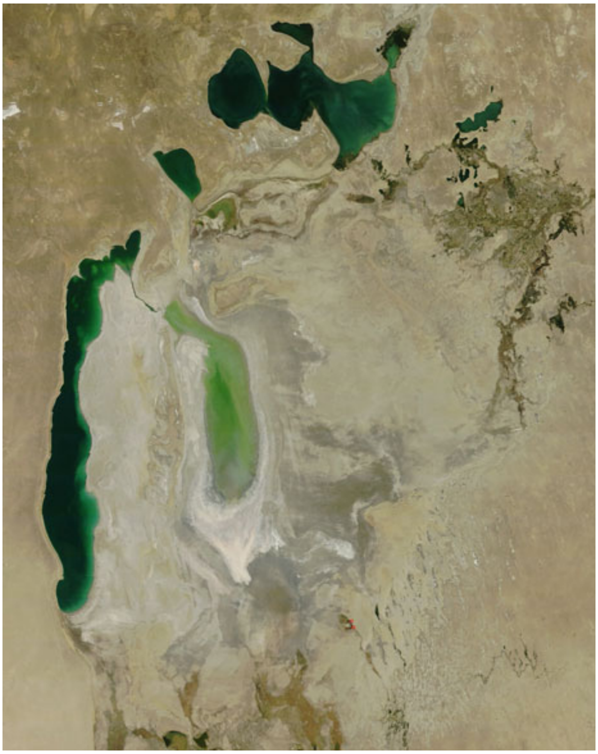

Fig. 15.2 MODIS image of Aral Sea September 16, 2011 (Natural color, 250 m resolution, Terra satellite) (Source: MODIS rapid response (Near real time images) lance.nasa.gov/imagery/rapid-response)

1960 size and ecological condition? What is feasible regarding preservation and restoration of the shrunken and degraded deltas of the Amu Darya and Syr Darya? Below are the author's best estimates of what the future may hold for the Aral and the river deltas.

15.2 Complete Drying Versus Full Restoration

First I must dispose of two diametrically opposite scenarios of the future Aral that are in one case impossible and in the other highly unlikely except, perhaps, in the distant future. The claim sometimes heard, usually in the popular media, that the lake will dry up completely in the twenty-first century is simply wrong and disregards basic physical and hydrologic principles. Even in the highly unlikely event that inflow from the Amu and Syr rivers were reduced to zero, there would still be residual input of irrigation drainage water, groundwater, and snow melt and rain that would probably maintain at least three lakes. Two would be remnants of the Small Aral Sea: Shevchenko Bay at the western end of this water body, which had a maximum depth in 2011 of 16 m and a basin just to the east of it with a maximum depth in 2011 of 18 m (Aral Sea 1981). These would primarily be fed by groundwater draining from surrounding highlands, which create a steep hydraulic gradient as evidenced by numerous artesian wells found around the western part of the Small Aral (Expedition 2005, 2007, 2011).

However, the largest remnant lake would be located in the Western Basin of the Large Sea in the south. In spite of the huge decline in level since 1960 (Table 15.1), the maximum depth here in 2011 was still 44 m and sizable parts of the basin had depths in excess of 15 m (Aral Sea 1981). As with the remnant lakes of the Small Sea, the lake (or lakes) here would mainly be fed by ground water emanating from the Ust-Urt Plateau rising to heights of slightly more than 200 hundred meters immediately to the west of the basin. On the other hand, the Eastern Basin of the Aral would completely disappear, as nearly happened in 2009. It is possible a small residual lake would be preserved in Tshche-bas Bay (2011 max depth of 4.5 m) owing to drainage from surrounding highlands (again evidenced by the presence of artesian wells). All the remnant lakes of the Aral Sea would be hypersaline and of little ecological or economic value, except, perhaps for the production of brine shrimp (Artemia) eggs.

What about bringing the Aral Sea back to its pre-desiccation conditions, characteristic of the first 60 years of the twentieth century with a level near 53 m, area of the water surface about 66,100 km^2, volume around 1,064 km^3 and average salinity from 9.3 to 10.3 g/l (Bortnik and Chistyaevaya 1990, p. 7)? This would be ideal, but is it realistic? Such rejuvenation would require average annual aggregate inflow from the Amu + Syr rivers of 56 km^3, assuming surface net evaporation of 869 mm (evaporation of 993 mm minus precipitation of 124 mm derived from data published in Bortnik and Chistyayeva 1990, p. 39, Table 4.2) and estimated net groundwater inflow of 2.5 km^3. According to an Excel based annually iterated fill model devised by the author that assumes a trapezoidal cross section for the portion of the sea to be restored, refilling would require about 103 years given its area and volume in September 2011 (Table 15.1) (Micklin 2012a). The 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 total inflow from the rivers Amu Darya and Syr Darya plus net groundwater influx. However, the sea would reach 50 m (94 % of stability level) and have an area of 60,000 km^2 (91 % of stability area) and volume over 800 km^3 (75 % of stability volume) in just 43 years.

Complicating the situation, however, is the likely increase of surface evaporation from the Aral caused by global warming induced rising temperatures in its basin (Cretaux et al. 2009). Thus, it might take substantially more than an average inflow of 56 km^3 to raise and stabilize the sea near 53 m. For example, if surface evaporation for a future Aral rose to 1,100 mm/year or by 11 %, likely a conservative assumption, with other water balance parameters remaining the same, it would take 63 km^3/year and 97 years to refill the sea its pre-1960s conditions. The level of 50 m, area of 60,000 km^2 and volume of 800 km^3 would be reached in 40 years. But the recent flows to the Aral have been far below 56 km^3, let alone 62–63 km^3. The author estimates the average annual inflow to the sea from 2000 through 2011 at 8.8 km^3 (6.6 km^3 from the Syr and 2.2 km^3 from the Amu, including direct irrigation drainage channel inflow to the sea from the latter). This is only 16 % of what would be needed to refill the sea under the first scenario above.

The only realistic approach to substantially increasing inflow to the Aral is reducing the consumptive use of water (that portion of withdrawals not directly returned to river flow) for irrigation in the sea's drainage basin, by far the main contributor to decreased inflow. The irrigated area in the Aral Sea Basin by 2010 had reached 8.2 million ha for which 92 km^3 were withdrawn, accounting for 84 % of all water withdrawals in the basin during that year. (See Chap. 8 for a detailed discussion and analysis of irrigation in the Aral Sea Basin.)

Without question irrigation in the Aral Sea Basin is highly inefficient. Substantial improvements to it, technical, economic, and institutional, could save considerable water. Attempts are underway to implement improvement measures, but the comprehensive program needed would be extremely costly. According to estimates by water management experts in 1996, complete renovation of antiquated irrigation and drainage systems on 5.4 million ha could cost 16–22 billion USD (see Chap. 8). Certainly the cost today would be substantially more. The resulting net water savings based on 1995 withdrawals of 12,594 m^3/ha are estimated at 9.2 km^3/year. To reach substantially larger savings, let us say 20 km^3, which would require economically and institutionally reforming irrigation and implementing an array of modern technical improvements on the entire irrigated area to lower average withdrawals for irrigation from an estimated 11,258 m^3/ha in 2010 to 8,000 m^3/ha, would cost far more. It is likely today's cost to realize water savings of 9.2 km^3 and certainly 20 km^3 is beyond the willingness, and perhaps ability, of the basin states to pay, even with major aid from international donors. Indeed, the technical condition of irrigation systems in the basin, far from improving, is steadily deteriorating owing to inadequate funding for, and lack of management responsibility over, operation and maintenance activities.

Converting more of the irrigated area to less water intensive crops (e.g., substituting grains, soybeans, fruits, and vegetables for cotton and rice) and reduction of the irrigated area are other means of significantly reducing water usage in irrigation (see Chap. 8) The two largest cotton-growing nations in the Aral Sea Basin (Uzbekistan and Turkmenistan) have reduced their cotton hectarage. Between 1990 and 2011 the former decreased the planted area by 27 % and the latter by 8 % (see Chap. 8). However, further reductions in the area devoted to cotton in the two countries are unlikely as both are intent on keeping cotton as a major crop since it is the key foreign currency earner. The irrigated area in the Aral Sea Basin has remained essentially the same since 1995, increasing from 8.07 to 8.20 million ha. Future reductions are considered unlikely as all of the former Soviet Republics, except Kazakhstan, consider it necessary to raise more irrigated food crops to meet the needs of a growing population.

It is doubtful the Aral could be restored to its former grandeur in the foreseeable future. The amount of water that would need to be saved is far above even the most optimistic and costly scenario of water use efficiency improvements. For example, assuming net water savings in irrigation of 20 km^3/year could be reached, there still would be a deficit of 27 km^3, assuming average future inflow of 8.8 km^3 that was experienced from 2000 through 2011. Taking the 8,000 m^3/ha withdrawal estimate and reducing it by return flows to rivers that would be lost by taking land out of irrigation (estimated at 1,280 m^3/ha) gives net savings of 6,270 m^3/ha. Thus, to cover the deficit, would require reducing the 2010 irrigated area of 8.2 million ha by about 3.42 million ha or 42 %. Such a reduction would wreak economic and social havoc on the countries of the basin. It is more likely much larger reductions would be needed because it is doubtful the major irrigating nations of the basin could in the near or even medium term future meet the 8,000 m^3/ha efficiency goal.

Nevertheless, we should not give up hope for a completely restored Aral. As discussed in Chaps. 2 and 4, the Aral in the past has several times come back from very severe desiccations. Perhaps in the more distant future, when the economy of the Aral Sea Basin countries has become far less dependent on irrigated agriculture and great improvements have been made in irrigation efficiency, this could again happen.

15.3 The Siberian Water Transfer Project

Of course it is engineeringly feasible to bring water to the Aral Sea from outside Central Asia. Proposals for large-scale water transfers from Siberian rivers date to late nineteenth century Tsarist times. But serious interest in such projects only began during the Soviet period in the late 1940s after World War II. (See Chap. 16 for a detailed treatment of the Siberian river diversion question.) Beginning in the late 1960s, detailed plans started to be developed by the water management hierarchy in Moscow and in Central Asia to send massive quantities of water, up to 60 km^3, from the Siberian rivers Irtysh and Ob to the Aral Sea Basin as a panacea for perceived water shortage problems. The initial stage of this project would have taken 27 km^3 from the Irtysh-Ob river confluence on the Western Siberian Plain of Russia. It was on the verge of implementation when stopped by the Gorbachev regime in 1986. Although real and serious potential ecological threats (of regional, not global magnitude as claimed by some opponents) were cited as the chief reason for canceling the project, its enormous cost appears to have been the primary motivation behind this decision.

This grandiose scheme continues to be discussed and promoted in Central Asian water management and governmental circles and in the new millennium has, again, found a sympathetic ear among some water management professionals and bureaucrats in Russia. However, implementation of this project in any but the far term, if ever, seems a pipe dream. Costs today would likely run 50–60 billion USD, and even if Russia were willing to help finance the project, it is doubtful sufficient funds could be accumulated for construction from other sources. International donors, such as the World Bank, given their newfound sensitivity to environmental concerns, have stated opposition to such a project. Finally, there is tremendous opposition among Russians to sending water from their precious Siberian rivers to Central Asia where, in their view, it would be wasted. 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. Thus, while it could certainly help significantly improve the Aral's water balance, it alone would not provide sufficient water to bring the sea back to its 1960 level. Even along with the 20 km^3 that might be saved by complete renovation of irrigation facilities in the Aral Sea Basin, the total, a maximum of 35 km^3 would still be 21 km^3 short of the amount of water needed to bring the Aral back to its 1960 level. Certainly, it would be more rational to spend precious capital and effort on improving regional water management rather than importing water from Siberia.

Recently, two "megaengineeering" proponents have proposed a variant of the Siberian project, which would take water only from Lake Zaysan in Kazakhstan, which is the source of the Irtysh, and deliver it into the Syr Darya from where it would flow into the Small Aral Sea (Badescu and Schuiling 2009; also see Chap. 16 of this book). This would make the political negotiations for implementing the project much simpler as it would be implemented in only one country. The authors also see a much lower cost for this project as the route would be considerably shorter and water would flow gravitationally to the Syr River rather than requiring huge electrical inputs for pumping over the low topographic divide (127 m) between Western Siberia and the Aral Sea Basin. But it would require drilling a 100 km tunnel through a mountain range for which the costs are speculative.

Although an interesting concept, it has serious deficiencies beyond the tunnel issue. The most serious problem is that the idea of taking water from Lake Zaysan to refill the Aral just won't work. Even if you were to take the entire available outflow from the Lake, which is controlled by a dam, it would amount to no more than 18 km^3/year on an average annual basis. There would also be inevitable losses along the canal part of the route and in the new Syr Darya Delta to evaporation, filtration and transpiration from hydrophytes. Farmers along the route would also surely take some of the additional water for irrigation. Hence, it is questionable that more than 12 or 13 km^3 would reach the Small Aral, not the 30–40 km^3 claimed by project proponents.

Furthermore, taking the entire water balance surplus of the Lake would mean no outflow and hydropower from the Bukhtarma Dam, which is a major power producer. Also, the bed of the Irtysh would be dry for many kilometers downstream, which would be very ecologically harmful and cause water supply problems for people, industry and agriculture along the river as well as losses of power production at other dams farther down that river. Realistically, it is doubtful the Kazakhstan government would ever allow diverting more than about 1/2 of the surplus, which would be 9 km^3. If this were all that could be sent toward the Aral, the project would just not be worth the cost.

15.4 Other Improvement Scenarios for the Aral Sea and Its Deltas

Although restoration of the Aral to, or even near, its 1960 level is not realistic in the foreseeable future, partial rehabilitation of parts of the sea and its river deltas hold considerable promise and are discussed below.

15.4.1 Partial Restoration of the Small (Northern) Aral Sea

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 Darya flows into the former, and the Amu Darya into the latter. After separation, a channel formed connecting the two lakes, with flow from the higher level Small Sea to the lower level Large Sea. This flow was primarily during the spring/early summer period when discharge from the Syr Darya to the Small Aral was greatest. 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 (Aladin et al. 2008). This makeshift construction had only crude means (a culvert) to release water southward toward the Large Aral. The dike breached and was repaired several times in the 1990s, but did considerably lower salinity and improve biodiversity and the fishery (primarily of the introduced kambala or Black Sea flounder). On April 20, 1999, the dike suffered a catastrophic failure after the lake level rose to 43.5 m ASL and overtopped the structure during a windstorm that drove water against the dike. It was completely destroyed with the loss of the lives of two workers who were attempting emergency repairs (Micklin 2010).

The World Bank and the Government of Kazakhstan had been considering funding construction of a more engineeringly sound facility as part of the Phase 1 Aral Sea Basin Program (ASBP) since the program inception in 1993 (Aral Sea Program 1994). Detailed Design of the project was completed by the early years of the new century (Expedition 2005). The main element of the project would be a 13-km low dike (named Kok-Aral for the former Island/peninsula on its western side) across the former Berg Strait that formerly connected the Small Aral to the Large Aral. The dike would have a concrete regulating dam with 9 gates to control outflow from the Small Aral. A new dam was also to be built at Ak-Lak on the lower Syr to regulate flow and allow the diversion of some water eastward to supplement the water balance of deltaic lakes. The dam was to be equipped with a fish ladder to allow access of migratory fish to the Syr Darya upstream of the dam. Improvements were also to be made to the bed of the Syr Darya down stream of the Chardarya Dam to enhance water flow to the sea. Cost of the entire project was set at 86 million USD with the World Bank providing 65 million and the Kazakhstan government 21 million.

Construction work began in 2003 and the dike and dam were completed by August 2005 (Expedition 2005). Because of heavier than expected winter inflow to the Small Aral, the level rose much more rapidly than expected and reached the design mark of 42 m above the Kronstadt sea level gauge on the Baltic Sea by March 2006, allowing renewed outflow to the Large Aral. For a number of reasons, the Ak-Lak facility was not completed and put into operation until 2011 (Expedition 2011).

The Small Aral at 42 m asl has an area around 3,600 km^2, volume of 27 km^3 and average salinity (as measured in early September 2011) at 8–9 g/l (Expedition 2011). Assuming net evaporation from the water body of 840 mm/year (evaporation of 960 mm and precipitation of 120 mm taken from Shivareva et al. 1998) and net average annual groundwater inflow estimated by the author at no less than 0.1 km^3, 2.3 km^3 is all that is required to maintain stability at the 42 m level.

The author estimates that for the period 1992–2011 Syr inflow was near 6 km^3 (based on adjustments for flow losses downstream of the lowest gauging station of Ak-Lak), well above what is needed to maintain the 42-m level. Since the completion of the Kok-Aral dike in 2005, excess water has been released southward creating large, shallow lakes with very high evaporation losses but that during some years have reached the Eastern Basin of the Large Aral and Tshche-bas Bay, supplementing their water balances and even creating flow through the connecting channel into the Western 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 the Small Aral. The key reason for this belief is that they serve no beneficial purposes to the south of the dam as it is doubtful that the outflow from the Small Aral is sufficient to contribute in any meaningful way to restoration to an ecologically productive state of the Eastern Basin and Tshche-bas Gulf in the foreseeable future. However, at times some releases may be necessary to adjust salinity in the Small Aral.

The Kazakhstan Government is planning a second phase to the Small Aral restoration project. Two alternatives have been under consideration. One is to raise the level of water only in the Gulf of Saryshaganak, which extends northeast off the eastern part of the Small Sea, to 50 m from its current level of 42 m. This would be accomplished by placing a new dike and dam at the Gulf's mouth where it is connected to the main part of the Small Sea and diverting part of the flow of the Syr Darya northward via a canal into Saryshaganak to maintain its level. The project would bring the gulf back to the town of Aralsk the former main port and transshipment point at the northern end of the Aral Sea, but the canal dug earlier to connect the port to the receding sea would need to be restored to maintain adequate depths for vessels to reach Aralsk.

The reservoir created would have near fresh water salinities of 2–3 g/l. Locks would be installed at the dam allowing passage of fishing and cargo boats from the main part of the Small Aral to the gulf and vice versa. This would allow fishing vessels direct access to unload their catch at the newly rebuilt and quite modern fish processing plant in Aralsk. Currently fish are hauled some distance to the plant via refrigerated truck (Expedition 2011). Cost of this project is estimated at 200 million USD. In September 2011, the word was that President Nazerbayev of Kazakhstan had selected the Saryshaganak variant (Expedition 2011). The World Bank is supportive of the project and the Kazakhstan Government has requested a loan to cover part of the cost from that organization.

The other project would rebuild the Kok-Aral dike and dam, raising the level of the entire lake to 48 m and increasing its area and volume to 4,830 km^2 and 53.5 km^3 respectively. The second project would likely provide more economic and ecological benefits than the Saryshaganak Reservoir plan, including more improvements to the fishery, better sea-borne transport prospects, and more ecologically suitable salinity conditions that are closer to what prevailed prior to the modern desiccation. The main objection to this plan is concern over insufficient water available from the Syr Darya on an annual average basis to maintain this level. However, calculations by the author suggest there may be sufficient inflow from the Syr Darya.

The estimated average annual inflow to the Small Aral from the Syr Darya for 1992 through 2011 is 5.98 km^3. Assuming the same average annual water balance parameters as used earlier for the Small Aral ($E = 960$ mm, $P = 120$ mm and net groundwater inflow = 0.1 km^3), the 48-m level could be maintained with an average annual discharge from the Syr of 4.55 km^3. But you would also need an outflow from the sea sufficient to maintain a reasonably stable salinity, which means in the simplest terms removing with the outflow the amount of salt brought in by the river (the salt contribution of net groundwater inflow is excluded from the calculation as groundwater is likely so small compared to river input).

Using values measured during our groups September 2011 expedition (Expedition 2011; see also Chap. 13) of salinity (1 g/l) for inflow from the Syr Darya and outflow salinity of 6 g/l at the Kok-Aral Dam, this could be realized with a discharge of 1.14 km^3 on an average annual basis (calculated using an iterative approximation process that takes account of the additional salt added by the increased inflow). Therefore, the average minimum annual inflow would need to be 5.69 km^3, which based on estimated inflows for the period 1992–2011 is obtainable. Average annual outflow from the Kok-Aral Dam would be 1.43 km^3 ($5.98 - 5.69 + 1.14$) based on the estimated Syr Darya flows to the Small Aral from 1992 through 2011.

If the outflow point were shifted to the very western end of the Small Aral where the salinity is higher, the salinity balance could be maintained with less discharge. For example using the same salinity of 1 g/l for Syr Darya inflow and what the author measured at several points around the western end of the water body (8 g/l), only 0.76 km^3 would be required, lowering the necessary inflow from the Syr Darya to 5.31 km^3. Moving the outflow location would also improve the water circulation in the Small Sea. Obviously, average annual outflow from the discharge works at the western end of the Small Aral would be the same as for the other variant 1.43 km^3 ($5.98 - 5.31 + 0.76$) based on the Syr Darya flows to the Small Aral from 1992 through 2011, but this variant is better adapted to lower inflow conditions.

What this design for the second phase of the Small Aral restoration project would look like is shown on Fig. 15.3. The cost of facilities to raise the level of the entire Small Aral from 42 to 48 m is unknown. It would require a much more massive Kok-Aral dike and completely replacing the concrete regulating dam. If the discharge point were moved to the western end of the sea, only a higher dike

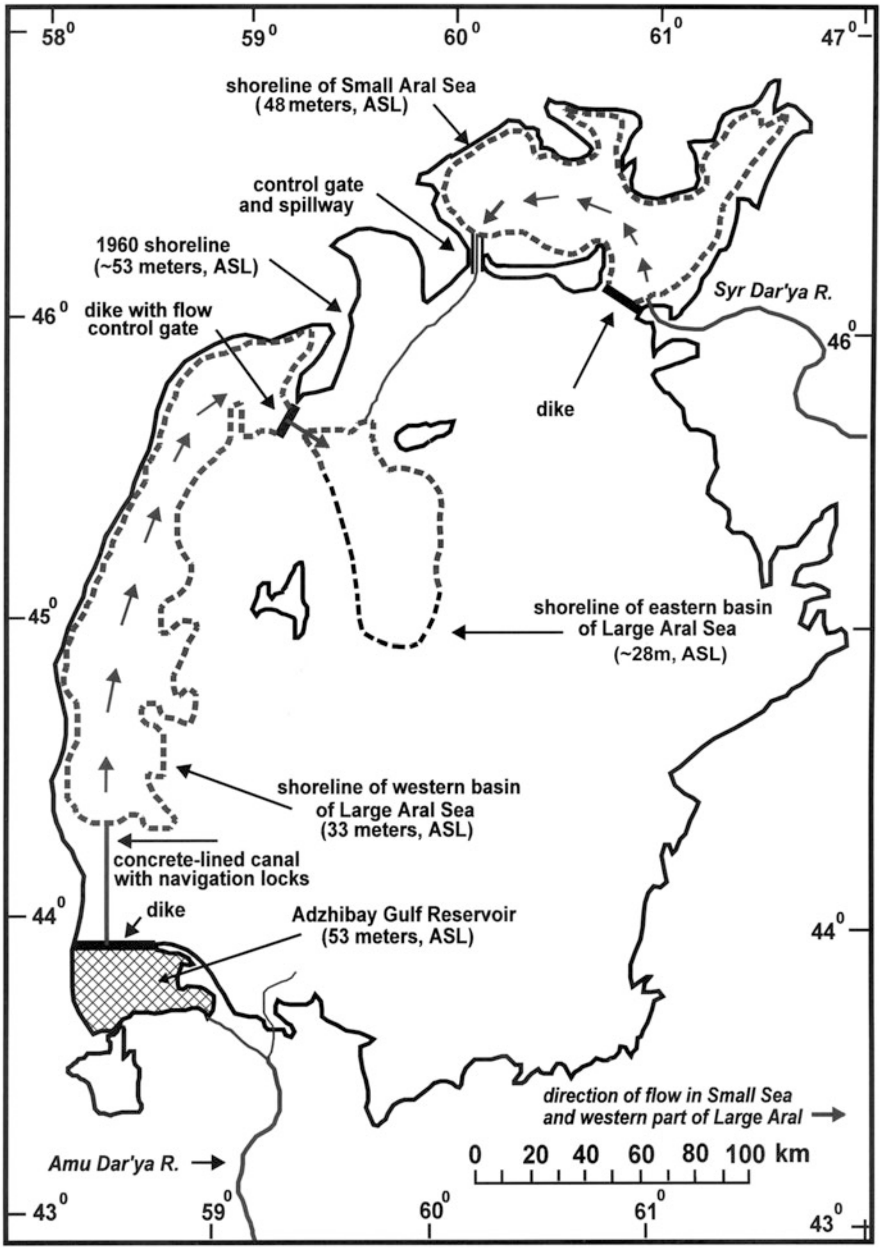

Fig. 15.3 Optimistic scenario of the future Aral Sea (after 2030) (Legend. *Small Aral Sea*: level = 48 m, surface area = 4,830 km^2, volume 53.5 km^3, avg. annual river inflow = 5.31 km^3, avg. annual outflow = 1.43 km^3, avg. annual salinity = 8 g/l. *Western Basin of Large Aral sea*: level = 33 m, surface area = 6,200 km^2, volume = 85 km^3, average annual river inflow = 6.6 km^3, avg. annual outflow to Eastern Basin = 2.09 km3. Salinity steadily decreasing reaching 42 g/l by 2055 and 15 g/l by 2110. *Eastern Basin of Large Aral Sea*: level ~ 28 m, surface area ~ 2,378 km^2, volume ~ 3.0 km^3, avg. annual salinity > 200 g/l. *Adzhibay Gulf Reservoir*: level = 53 m, surface area = 1,147 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 = 2 g/l)

would be necessary to replace the present Kok-Aral facility. But a second dike and flow regulating structure would need to be built at the new discharge point. Also a ship access canal would be needed to the former port of Aralsk.

15.4.2 Restoration Prospects for the Large (Southern) Aral Sea

The future for the Large (southern) Sea is more uncertain. The Eastern Basin nearly disappeared in 2009. Owing to a heavy flow year in 2010, substantial flow reached it from the Amu Darya (and lesser amounts via outflow from the Small Aral Sea) and it was rejuvenated as a large, but very shallow lake (Table 15.1). Owing to another low flow year on the Amu in 2011, little or no water reached the Eastern Basin and it shrank rapidly. Assuming no human intervention, this pattern of shrinking (and perhaps even disappearing) during low flow cycles on the Amu Darya alternating with partial refilling during higher flow years will likely go on for the foreseeable future.

The Western Basin's fate in the absence of human intervention depends largely on net groundwater inflow, as it does not receive any direct flow from the Amu Darya. This input is not known with any degree of accuracy, but may be substantial owing to the hydraulic gradient from the Ust-Urt plateau, which it abuts on the west (Micklin and Aladin 2008; Expedition 2011). Nevertheless, if present trends continue, the level and area of the Western Basin will decrease considerably from the 2011 figures (Table 15.1), perhaps stabilizing around 21 m above the Kronstadt gauge at 2,100 km^2. It would continue on the path of hypersalinization, steadily moving toward conditions characteristic of the Great Salt Lake in the United States and the Dead Sea in the Middle East (200–300 g/l). Only brine shrimp *(Artemia)* and some bacteria could survive such harsh conditions.

On the other hand, there are more optimistic scenarios for the Western Basin of the Large Aral. Figure 15.3 shows a concept developed by the author (Micklin 2010). It is adapted and updated to take account of current conditions from designs first put forward in 1978 by two Soviet water management experts (Lvovich and Tsigelnaya 1978). It would require an average annual inflow in the lowest reaches of the Amu Darya of around 8 km^3. However, adding this to the water needed to support deltaic lakes (4.35 km^3) the total inflow needed would be near 12.5 km^3. The author estimates average annual flow here for 1990–2011 at about 5.4 km^3, so it would require more than doubling this. Although substantial this could be accomplished with reasonably obtainable improvements in irrigation efficiency in the basin of the Amu River where withdrawals in 2010 were 58.6 km^3 (Cawaterinfo 2012f). So for example, assuming present overall irrigation system efficiency at 65 % (ratio of water withdrawn to that used productively), raising it to 75 % (a 20 % improvement) would reduce withdrawals by 7.8 km^3.

All of the residual flow of the Amu (after meeting needs of deltaic lakes and wetlands, described below) would need to be directed northwestward into the former Adzhibay Gulf refilling it to 53 m with an area of 1,147 km^2, volume of 6.43 km^3 average depth of 5.6 m, and salinity around 2 g/l. This would mean no water would be allowed to flow to the Eastern Basin, except possibly in very heavy flow years on the Amu Darya. The existing channel (Glavnoye myaso) that currently takes a portion of river water to maintain a wetland/lake (Muynak Bay) on part of the dried gulf could probably be deepened and widened to accomplish this. A restored Adzhibay Gulf would improve the local climate, be of great ecological value to migratory and non migratory birds and aquatic mammals, and could become a major fishery.

Adzhibay Gulf reservoir, on average, is estimated to have evaporation of 1,400 mm/year, precipitation on its surface of 105 mm/year and groundwater inflow of 0.1 km^3/year (evaporation data from Gorelkin and Nikitin 1985, Fig. 8, p. 22; precipitation data from Bortnik and Chistyaeva 1990, Fig. 2.2, p. 20, and groundwater estimate by Micklin). Thus to maintain it would require 1.4 km^3 of water. The remainder, averaging 6.6 km^3/year, would be released via control gates to a channel connected to the Western Basin of the Large Aral Sea. The channel would need to be lined with concrete or clay to reduce filtration losses. Assuming water balance parameters for the Western Basin of E = 1,000 mm, P (on the sea surface) = 111 mm (E and P values taken from Bortnik and Chistyaeva 1990, Fig. 2.5, p. 20 Table 4.1, p. 36) and using an estimated net groundwater inflow of 1 km^3 (which may be on the low side), a level of 33 m, area of 6,200 km^2, and volume of 85 km^3 could be maintained with an average annual inflow of 4.51 km^3.

The excess inflow (2.09 km^3) would be discharged to the Eastern Basin via a regulating structure (dike and dam) at the northern end of the Western Basin where the connecting channel now joins the East and West basins of the Large Aral. The Western Basin would freshen as more salt is carried out than is brought in. At first this process would go rapidly with inflowing river water at 2 g/l and groundwater (also assumed at 2 g/l) while outflow would be at more than 100 g/l, but slow as the average salinity of the Western Basin decreased. Assuming project construction starting in early 2015 and finishing in early 2018, when filling would commence, the design level of 33 m, based on the spreadsheet fill model mentioned earlier, would require another 10 years and be completed by early 2028, when water releases to the Eastern Aral would begin (Micklin 2012a). At this time owing to the inflow of lower salinity (2 g/l) water from the Adzhibay Reservoir and groundwater, average salinity would be around 79 g/l compared to 110 g/l before filling started.

Employing an Excel based salt balance model indicates that by 2058, the average salinity would drop to less than 42 g/l allowing the introduction of kambala (Black Sea flounder) and possibly other salt tolerant fishes (Micklin 2012b). When salinities fell below 15 g/l, stocking with indigenous Aral Sea species such as sazan (a type of carp) and sudak (pike-perch) would be possible. However, this could take until 2119. But it is possible that density stratification would create a layer of saline water on the bottom and less saline on top that would accelerate the freshening process (Kostianov et al. 2004). Of course if inflow from Adzhibay Gulf could be increased the process could go more rapidly. For example, if this were 10 instead of

6.6 km^3, increasing outflow to 5.49 km^3, less than 42 g/l would be reached by 2039 and salinity would fall below 15 g/l by 2057. This would require raising the average annual delivery of water to the lower Amu Darya Delta to 15.9 km^3, about three times what the average was for 1990–2011.

The saline lake formed on the former Eastern Aral Basin would have a level near 28 m, surface area of 2,378 km^2, assuming precipitation on its surface of 111 mm/year, evaporation from the surface of 1,200 mm/year (evaporation would be higher than from the Western Basin owing to higher water temperatures in this very shallow water body) and estimated net groundwater inflow of 0.5 km^3. Its volume would be about 3 km^3. It would be beneficial in its own right by reducing the area of barren, salt-covered desert that contributes so heavily to dust/salt storms. Also, it might be used for harvesting of brine shrimp eggs, as with salinities over 200 g/l the water body would provide ideal habitat for brine shrimp.

This concept has so far been little studied as to its engineering feasibility, ecological consequences, and economic benefits and costs. Without doubt it would require more funding than the 85 million USD spent to implement the first stage restoration project for the Small Aral. This project would also eliminate the possibility of commercially harvesting brine shrimp eggs in the Western Basin, as salinity would be far too low for this species' survival. Implementation would require agreement, funding and cooperation from both Kazakhstan and Uzbekistan, as about 30 % of the Western Basin is within the former country and the remaining 70 % in the latter. Kazakhstan where the outflow structure would be build might not have that much interest in the project as restoration of the Small Sea is far more important to that nation's government. Even more critical, the expanding search for gas and oil being pursued by a consortium of Chinese, Uzbekistan, Russian, Malaysian, and Korean companies and extraction of these fossil fuel resources on the bottom of the former Adzhibay Gulf and southern Aral Sea would be made considerably more difficult (CNPC 2012). If major deposits are found, as is expected, this in itself may doom the restoration plan to never going beyond the drawing board, as Uzbekistan would have little interest in it (CNPC 2012).

15.4.3 Restoration of the Lakes and Wetlands of the Deltas of the Amu Darya and Syr Darya

The Soviet government initiated rehabilitation of the lakes and wetlands of the lower Amu Darya Delta in the late 1980s. After independence at the end of 1991, the new states of Central Asia in collaboration with international donors continued this work. The prime objective of the largest effort (the Aral Sea Wetland Restoration Project or ASWRP), which was implemented by the International Fund for the Aral Sea (IFAS) and funded by the Global Environmental Facility (GEF), has been rehabilitation of former lakes and wetlands (of greatest importance Sudochye) and the creation of several artificial lakes and wetlands in the lower delta (Mezhdurechensk and

Dumalak) and on the dry bed of the Aral Sea (Muynak, Rybachye, Dzhiltyrbas) (Micklin 2007; Scheme 2002; GTZ and ICWC 2007, pp. 136–137). The objective was to restore the biological diversity and productivity of these water bodies that have not only great ecological importance (for migratory birds, fishes, and aquatic mammals) but considerable economic value as well as sources of edible fish, for trapping fur bearing mammals, and as places where reeds can be harvested for domestic animal feed and for construction purposes.

The rehabilitation plan cost six million USD. Experts have estimated that 4.35 km^3 of water (3.1 of relatively clean river flow supplemented by 1.25 of irrigation drainage) are needed to support minimally acceptable "hydro-ecological conditions" in the lower delta of the Amu Darya, including 1,800 km^2 of natural and artificially created lakes and wetlands there (MKVK 2002, p. 39, 2010, p. 75). Water requirements would specifically depend on the flow year on the Amu: 8 km^3 in a high flow year, 4.6 in an average flow year, and a minimum of 3.1 in a low flow year. As mentioned earlier, remaining flow could be used to support the rehabilitation project for the Large Aral Sea described above. For the plan to work successfully salinity of the river flow needs to be maintained between 0.8 and 1.2 g/l and even in low-flow years, priority water bodies must receive adequate inflow.

A problem for the restoration program has been that in low flow cycles on the Amu Darya, the lakes and wetlands dry and shrink with severe adverse effects on the habitat for migratory birds and on fisheries (Micklin 2010, pp. 74–78). For example in the 2000-mid 2002 drought and low-flow period, the lake/wetland area suffered a severe decline, with the aggregate area falling from 1,276 in April 2000 to 796 km^2 by August 2002 (GTZ and ICWC 2007, pp. 136–137). The area of Lake Sudochye, the largest and most important water body, shrank from 419 to only 65 km^2. Normal and above normal flows returned in ensuing years, and by June 2005, the aggregate area had grown to 3,293 km^2 and the area of Lake Sudochye to 621 km^2.

Drought and low-flow conditions recurred in the 2007–2009 period with the aggregate area falling from 2,674 in the former year to 1,049 km^2 by November of the latter (Cawaterinfo 2012a, Table 5, 5a). Figures for Lake Sudochye for the same time period were 534 and 314 km^2. As noted earlier, 2010 was a heavy flow year and much water reached the lakes and wetlands of the lower Amu Delta with the aggregate area growing to 3,561 and Sudochye to 597 km^2.by October. Dry conditions returned in 2011 and very little water reached the lower delta. As a result, aggregate area shrank to 2,928 and Lake Sudochye to 389 km^2 by September 2011. Complaints have been made that even in average flow years, deliveries of water to the lower delta are only half of what they should be (MKVK 2010, pp. 74–78). In early 2011, 21 new gages were installed at key locations in the lower delta to provide more accurate measurements of water levels and discharges in canals, collector drains, and lakes in the Amu Darya Delta (Cawaterinfo 2012f).

V. Dukhovnyy head of the Scientific Information Center (SIC) of the Interstate Coordinating Water Management Commission (ICWC) has promoted a more ambitious version of the restoration plan for the Amu Darya Delta. In addition to the lakes and wetlands of the delta, it would create so-called large, shallow "anti-polder" reservoirs on the dried bottom of the southern Aral Sea to stop sand dune encroachment on the delta and reduce the wind transport of sand and dust here. These have been controversial for a number of reasons, including fears of excessive evaporation from them and insufficient water availability to sustain them. So far none have been constructed.

A related effort has been the development of a technology and its implementation for afforestation of parts of the dried bottom of the southern portion of the Aral Sea. Known as "Stabilization of the desiccated Aral Sea bottom in Central Asia," this program has been funded and conducted by the German government foreign aid agency GTZ in cooperation with the Forestry Research Institute of Uzbekistan (GTZ and ICWC 2007, pp. 10, 123–127). Its purpose is to plant drought resistant trees and shrubs (mainly saksaul- *Haloxylon aphyllum*) on the dry bottom to help stabilize the soils and lower their deflation potential. Reportedly by 2010 this program had led to self-sustaining forests growing on 2,000 km^2 of the dried bottom (MKVK 2010, pp. 74–78)

Less ambitious, but still significant' efforts are underway to improve wetlands and lakes (mainly Kamyshlybas, Karashalan, and Tushchibas) in the lower Syr Darya Delta by providing them with more water from the Syr (as noted earlier this is one of the purposes of the Ak-Lak hydrocomplex) and undertaking other measures to enhance their ecological condition and improve their fishery potential (Expedition 2011; MKVK 2010, pp. 74–78). For the Syr Darya Delta preservation of the lakes and wetlands of six lake systems encompassing an area of 1,520 km^2 requires an ensured water delivery of 1.78 km^3, including 0.133 km^3 of collector-drainage water. After reconstruction of the lake systems, this could be reduced to 1.4 km^3. In recent years a fish hatchery and nursery has been built on the shore of Kamyshlybas, the largest of the lakes, which has by far the most important fishery (Expedition 2011; also see Chap. 13. The fish as they grow larger are progressively raised in a series of ponds and then released into the lake fishery. The hatchery is jointly funded by Israel and the United States.

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