Chapter 18
Summary and Conclusions

Philip Micklin

Abstract The first part of this final chapter summarizes the introductory chapter plus the chapters contained in Parts I, II, and III, exclusive of Chap. 18, to remind the reader of the key aspects of each. The second part lays out what in the author's view are the key lessons to be learned from Aral Sea and its modern desiccation. The final part lists and briefly discusses what needs to be done in terms of research and monitoring of the Aral Sea.

Keywords Lessons of the Aral Sea • Research and Monitoring • Remote sensing • MODIS • Landsat

18.1 Summary of Introduction and Part I (Background to the Aral Sea Problem)

The Introduction (Chap. 1) briefly lays out the basic parameters of the modern recession of the Aral Sea that began in 1960 and discusses the complex, severe environmental, economic and human consequences of this catastrophe. This is followed by a review of improvement efforts to alleviate these problems that began during the last years of the Soviet Union. These were carried on by the new Aral Sea Basin states and regional bodies formed by these governments, aided by international donors after the collapse of the Soviet Union in 1991. The last section explains the purpose of the book, its relationship to other recent edited works on the Aral Sea and the organization of the chapters.

Part I is intended to provide background information to better understand the modern (post 1960) desiccation of the Aral Sea (Chaps. 2, 3, and 4). Chapter 2 by

P. Micklin (✉)
Department of Geography, Western Michigan University, 1903 W Michigan Ave., Kalamazoo, MI 49008-5433, USA
e-mail: Micklin@wmich.edu

P. Micklin et al. (eds.), *The Aral Sea*, Springer Earth System Sciences,
DOI 10.1007/978-3-642-02356-9_18,

Micklin provides key information on the Aral Sea and its region. The Aral Sea Basin's geographical setting is discussed, including location, climate, topography, soils, water resources, constituent nations, and basic demographic parameters. Next, the physical characteristics of the Aral Sea (size, depth, hydrochemistry, circulation patterns, temperature characteristics, water balance, etc.) prior to the modern desiccation are summarized. This is followed by analysis of level fluctuations of the Aral and their causes prior to the modern drying.

The author notes that the "Aral Sea is geologically young" with an estimated age around ten millennia, coincident with the Holocene geological epoch. Nevertheless, during this time owing to being a terminal or closed basin lake with inflow but no outflow and situated among the great deserts of Central Asia, the Aral has undergone significant recessions and transgressions as a result of both natural and human influences. The key natural factors have been climate change and the diversion of the Amu Darya westward so that it did not flow into the Aral. The primary human influence was the purposeful diversion of the Amu westward. However, from the mid-seventeenth century until 1960, lake level variations were likely less than 4.5 m. Instrumental observation began in 1911. For the next five decades the sea's water balance was remarkably stable with annual inflow and net evaporation (evaporation from the sea's surface minus precipitation on it) never far apart. The final section is devoted to tracing the most important events in the long history of research and exploration of the Aral up to 1960.

Chapter 2 by Plotnikov, Aladin, Ermakhanov and Zhakova discusses the faunal character of the Aral Sea from 1900 until the 1960s. The authors note that the original fauna of the Aral Sea was characterized by poor species composition. Originally in the Aral Sea there were at least 180 species (without Protozoa) of free-living invertebrates. The fauna had heterogeneous origins. Prior to the modern recession/salinization, species originating from freshwater, brackish-water and saline continental water bodies were dominate. The remaining were representatives of Ponto-Caspian and marine Mediterranean-Atlantic faunas. Parasitic fauna had poor species composition: 201 species were indigenous and 21 were introduced together with fishes. Ichthyofauna consisted of 20 aboriginal and 14 introduced species. The aboriginal fish fauna consisted of species whose reproduction typically occurs in fresh water. There was no fishery on the Aral Sea and local people caught a few fish only from the rivers until in the mid 1870s Russians came here. After construction of a railway in 1905 a commercial fishery developed. Bream, carp and roach provided approximately two-thirds of the commercial catch tonnage. A large number of vertebrate species inhabited the Aral Sea, its shore and islands, the Syr Darya and Amu Darya, and the deltas and lakes of these rivers in their lower reaches. The Aral Sea and its shores provided nesting sites for a large number of various floating and near shore birds. Tugay forests along the banks of the rivers constituted a type of oasis where many animal species lived. By the 1960s flora of the Aral Sea included 24 species of higher plants, 6 species of charophytes and about 40 other species of macroalgae.

Chapter 4 by Krivinogov provides a particularly detailed and interesting scientific discussion of the major level changes and evidence for them based on extensive fieldwork. The author reviews the available data on the Aral Sea level changes and presents the current thinking on the sea's recessions and transgressions prior to its modern desiccation. The geomorphologic, sedimentologic, paleoenvironmental, archaeologic and historiographic evidence is reconsidered and combined on the basis of calibrated 14C ages. According to the author, lithology and paleoenvironmental proxies of the sediment cores provide much consolidated information, as they record lake level changes in sediment constitution by deep and shallow water facies and layers of gypsum and mirabilite, which are of special importance for determination of low levels. High levels are recorded in several on-shore outcrops.

The new archaeological data from the now dry bottom of the Aral Sea and its surrounding zone in combination with the historiographic records provide a robust model for level changes during the last two millennia. Discovery of tree stumps in different parts of the bottom indicate low stands of the lake as well. During the last two millennia, there were two deep natural regressions of ca. 2.1–1.3 and 1.1–0.3 ka BP followed by the modern anthropogenic one. The lake level dropped to ca. 29 m asl. Their separating transgressions were up to 52–54 m asl. The middle to early Holocene record of level changes is probably incomplete. Currently the middle Holocene regressions are documented for the periods of ca. 5.5–6.3, 4.5–5.0 and 3.3–4.3 ka BP. The early Holocene history of the Aral shows a long period of a shallow lake.

18.2 Summary of Part II: The Modern Desiccation of the Aral Sea (1960–2012)

Part II presents key information on and critical analysis of the period 1960–2012, which encompasses the modern recession of the Aral Sea. At 67,500 km^2 in 1960, the Aral Sea was the world's fourth largest inland water body in surface area, behind the Caspian Sea in Asia, Lake Superior in North America and Lake Victoria in Africa. As a brackish lake with salinity averaging near 10 g/l, less than a third of the ocean, it was inhabited chiefly by fresh water fish species. 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. They also supported irrigated agriculture, animal husbandry, hunting and trapping, fishing, and harvesting of reeds, which served as fodder for livestock as well as building materials.

Since the 1960s the Aral has undergone tremendous alteration. The level of the southern part of this water body (Large Aral) fell nearly 26 m between 1960 and September 2011 (see Chap. 15, Table 15.1). Its surface area decreased from 67,499 km^2 in 1960 to 10,317 km^2 by September 2011, an 87 % shrinkage. Volume shrank 92 %, from 1089 to 89 km^3, over the same period. Salinity for the southern sea rose from an average annual value of 10 g/l to over 100 g/l, a tenfold increase.

Chapter 5 by Micklin deals with two related water issues: the water resources of the Aral Sea Basin and the Aral Sea's water balance. The Aral Sea's size is dependent on the water resources in its basin and how much these are depleted by human usage. The chief water resources are the main basin rivers Amu Darya and Syr Darya and groundwater. The author discusses the size and character of these and their sufficiency for meeting human demand. Contrary to popular belief, the Aral Sea Basin is reasonably well endowed with water resources. But the high level of consumptive use, overwhelmingly for irrigated agriculture, has resulted in severe water shortage problems. Since the Aral Sea is a terminal (closed basin) lake with no outflow lying amidst deserts, its water balance is basically composed of river inflow on the gain side and evaporation from its surface on the loss side. Precipitation on the sea's surface contributes only about 10 % to the positive side of the balance. Net groundwater input is difficult to determine with any accuracy and likely had minimal influence until recent decades when, owing to major drops in river inflow, its impact on the water balance has grown.

The Aral's water balance was very stable from 1911 until 1960. However, since then it has been consistently negative (losses more than gains) owing to very substantial reductions in river inflow caused by large consumptive losses to irrigation. This was particularly pronounced for the decadal periods 1971–1980 and 1981–1990. More river flow reached the sea over the period 1991–2000, but its water balance remained negative. However, the water balance situation deteriorated during the subsequent decade (2001–2010) owing to recurring droughts. The decidedly negative water balance has led to a rapid and steady shrinkage of the sea.

Chapter 6 by Plotnikov, Aladin, Ermakhanov and Zhakova discusses the changes in the biology of the Aral as a result of the modern desiccation. Regression of the Aral Sea began in 1961. At first, changes in the fauna were primarily the result of fish and invertebrate introductions. In the 1970s regression accelerated. The main factor influencing fauna has been increasing water salinity. In the 1970s and 1980s invertebrate fauna went through two crises. First, freshwater species and brackish water species of freshwater origin became extinct. Then Ponto-Caspian species disappeared. Marine species and euryhaline species of marine origin survived, as well as faunal species of inland saline waters.

By the end of the 1990s the Large Aral became a complex of hyperhaline lakes. Its fauna was passing through the third crisis period. Incapable of active osmoregulation, hydrobionts of marine origin, and the majority of osmoregulators disappeared. A number of species of hyperhaline fauna were naturally introduced into the Large Aral. Salinization of the Aral Sea has resulted in depletion of parasitic fauna. All freshwater and brackish-water ectoparasites and a significant part of helminthes began to disappear. Together with the disappearance of hosts, the parasites associated with them in their life cycle also disappeared.

Regulation of the Syr Darya and Amu Darya and decreasing of their flow altered living conditions of the Aral Sea fishes, especially their reproduction. In 1971 there were the first signs of negative effects of salinity on adult fishes. By the middle of the 1970s natural reproduction of fishes was completely destroyed. Commercial fish catches decreased. By 1981 the fishery was lost. In 1979–1987 flounder-gloss was introduced and in 1991–2000 it was the only commercial fish. After the construction of the Berg Strait dike was completed in 2005 and the level of the Small Aral rose resulting in decreased salinity, aboriginal fishes began migrating back to the sea from lacustrine systems and the river. This allowed the achievement of commercial numbers of food fishes. Since the end of the 1990s, the Large Aral Sea is a lake without fishes. Regression and salinization of the Aral Sea caused destruction and disappearance of the majority of vegetational biocenoses.

Chapter 7 by Reimov and Fayzieva describes and analyzes the ecological and human situation in the South Aral Sea area (mainly the Republic of Karakalpakstan in Uzbekistan). They point out that the Aral Sea was once the world's fourth largest inland body of water in terms of surface area. Fed by two rivers, the Amu Darya and the Syr Darya, it supported a diverse ecosystem and an economically valuable fishery. Intensive agricultural activity related to cotton production with high water demands during the Soviet era caused excessive water diversion for irrigation purposes from the rivers. As a result, since the early 1970s the shores of the sea have been steadily receding. The disappearance of the Aral Sea has caused several severe environmental and economic impacts. The fishery is no longer viable. The seabed became exposed leading to the airborne dispersal of salts and pesticide residues. The river delta flora and fauna have deteriorated such that fewer species exist. The decreasing level of the Aral Sea was accompanied by a rise of salinity, which resulted in the degradation of the ecosystems in the Aral Sea area as well as those of the fertile delta lands. The exposed seabed has turned into a desert, which at the present time is a source of tons of salty dust, blown away by the wind and carried for thousands of kilometers. The quality of river water and other sources for drinking water have deteriorated. Environmental degradation in the Aral Sea area, especially in the south part in Karakalpakstan has resulted in significant worsening of the socio-economic and public health situation.

Chapter 8 by Micklin traces the history and development of irrigation in the Aral Sea Basin. In 2010, irrigation networks covered 8.1 million ha here and accounted for 84 % of all water withdrawals. Irrigation as a highly consumptive user of water is the primary cause of the desiccation of the Aral Sea as it has severely diminished the inflow to the Aral from the Amu Darya and Syr Darya. Irrigation has a long history in the Aral Sea Basin dating back at least 3,000 years. During the Soviet era, irrigation was greatly expanded and water withdrawals for it increased considerably, primarily to grow more cotton. In the post-Soviet period (after 1990), the area irrigated grew slowly while water withdrawals for it declined somewhat. The latter has been primarily due to shrinkage of the area planted to high water use crops such as rice and cotton and not to the introduction of more efficient irrigation techniques on a substantial scale. Irrigation systems in the Aral Sea Basin since collapse of the USSR have badly deteriorated owing to lack of proper maintenance of them and insufficient investment in them. And the problems of soil salinization and water logging continue to worsen. There is certainly much that could be done to improve irrigation and use less water for it. This in turn could allow much more water to be supplied to the Aral Sea. But significant improvement of irrigation will require much greater effort and investment along with institutional reforms.

Chapter 9 by Mukhammadiev deals with the challenges of transboundary water resources management in Central Asia, with a focus on the Aral Sea Basin. The major river basins of Central Asia link the countries of Afghanistan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. Water management in Central Asia continues to be the most important transboundary environmental issue and the biggest problem remains how to allocate water for upstream hydropower production and downstream irrigation. Disagreements between the upstream and downstream states have increased regional tensions and slowed development plans. National responses to existing cooperative opportunities are essentially driven by a policy of national self-sufficiency in energy and water.

While it is reasonable to be concerned about water and/or energy security, it is also critical to understand that a policy of self-sufficiency incurs substantial costs for all. As long as self-sufficiency dominates the policy agenda, the benefits of cooperation will not materialize. International water law could provide a rational avenue toward achieving international consensus on both use and allocation of water resources in the basin, with international legal agreements to reinforce the consensus. Incentives to cooperate through the application of the benefit-sharing concept as a development model in the basin would include decreased costs and increased gains in many dimensions of regional cooperation, including the benefits that stem from better agricultural practices and its competitiveness, joint developing of the region's energy resources, and better management of regional environmental risks.

Chapter 10 is the first of two chapters that focus on the use of remote sensing to study the Aral Sea and its regions. These techniques are essential to the timely, cost effective and comprehensive monitoring of such a large region and will become even more so in the future.

In Chap. 9 Ressl and Colditz use time series analysis of remote sensing data to study and monitor vegetation and landscape dynamics of the dried sea bottom adjacent to the lower Amu Darya Delta. The Aral Sea region is a rapidly transforming landscape due to the continuous desiccation process. This study describes the vegetation and landscape dynamics in the lower Amu-Darya delta and adjacent parts of the dried sea bottom using MODIS surface reflectance data and EVI time series for the years 2001–2011. The potential of MODIS time series for monitoring landscape and vegetation dynamics of the dried sea bottom adjacent to the lower Amu-Darya Delta was evaluated concerning data availability and spatial and temporal resolution. Two time series with different quality considerations were generated to subsequently characterize the yearly changes in the dried part of the sea bed, a simple layer stack (LS) of observations and quality-filtered and smoothed time series using a double logistic function (DL). The EVI values show a small dynamic inter- and intra-annual range. The majority of the EVI values fluctuate between −0.2 and +0.1, which indicates generally low vegetation dynamics in the desiccated areas.

Looking at the inter-annual behavior of the LS/DL time series plots, the noise of the data and data fluctuations seem to become less for areas which have been dry for a longer period. A regional differentiation of the landscape dynamics between the Eastern and the Western basin of the southern Aral Sea could be observed. The observation points for the Western basin show a more stable behavior of the EVI values in comparison to the samples on the Eastern basin as seasonal or inter-annual flooding is less frequent. A typical pattern as a result of clear vegetation dynamics could not be observed in the EVI LS and DL time series plots.

In Chap. 11 Cretaux and Berge-Nguyen employ remote sensing to analyze Aral Sea hydrology. According to them, space technologies have been widely used over the last 10 years for water surface monitoring worldwide and have shown their capability to monitor components of the water cycle and water balance at regional scales and on time scales ranging from months to decades. For their study they use data acquired from radar altimetry and satellite imagery (Terra/MODIS) over the Aral Sea Basin (ASB). Radar altimetry, which has been designed to study the ocean, has opened a new era in monitoring lakes, rivers and reservoirs. The recent missions of satellite altimetry (Topex-Poseidon, Jason-1/2, Envisat, ERS-1 and ERS-2) have made it possible to measure with great precision inland sea level variations that can be used to determine water mass balances. Radar altimetry, coupled with complementary in situ data, has allowed quantifying precisely the water balance of the Aral Sea since 1992 as well as balances for large reservoir systems along the Syr Darya, in particular Chardarya, Toktogul and Aydarkul. This approach has also made it possible to ascertain the water balances of lakes and wetlands in the deltas of the Syr Darya and Amu Darya.

Satellite imagery, from low to high resolution (1 km to a few meters) offers a useful tool to monitor surface water area for lakes and floodplains. MODIS data provide every 8 days the surface water area from 2000 to 2012, with a spatial resolution of 500 m. It has been used to create a spatial time series for the Aral Sea and the lakes and wetlands in the deltas of Amu Darya and Syr Darya where the water area has been precisely measured. Along with in situ observations and hydrological modeling, space observations have the potential to improve significantly our understanding of hydrological processes at work in large river basins, (including lakes, reservoirs and floodplains) and their influence on climate variability and socio-economic life.

Unprecedented information can be expected coupling models and surface observations with data from space, which offer global geographical coverage, good spatial-temporal sampling, continuous monitoring over time, and the capability of measuring water mass change occurring at or below the surface. Based on these different techniques the authors determined the surface area of water features within the Aral Sea Basin, as well as volume variations, which are the key parameter to the understanding of hydrological regimes in ungauged basins. A focus on the Aral Sea and the water bodies in the deltas of the Syr Darya and the Amu Darya rivers over the last 20 years from satellite data is presented in this chapter, with some implications for the water balance. The specific behavior of the

Western and Eastern basins of the Large (South) Aral Sea over the last 5–6 years is also described.

White in Chap. 12 discusses the complicated interrelationships between Nature and Society in the Aral Sea Basin. He notes that the desiccation of the Aral Sea since 1960 has been a notorious and well-documented example of anthropogenic ecological devastation. Equally ominous has been the devastating impact on the livelihoods and health conditions of the human populations inhabiting the Aral Sea region. As a socio-ecological crisis, the Aral Sea's recession has demonstrated interrelationships between humans and the biophysical environment. An important societal dimension through which to access these relationships is the Aral basin's regional economy.

The Aral crisis itself has largely been a result of the large-scale Soviet-era water diversion projects whose impetus was primarily the production and export of cotton. The Aral Sea Basin today remains a globally important cotton production and export region. The most important economic activities devastated by the crisis have been fishing and fish processing. Once defunct enterprises, these activities have only recently been revived with the recent rehabilitation of the northern Aral Sea in Kazakhstan. This chapter examines the post-1960 developments of the cotton sector within the Aral basin and the fishing sector in the Aral Sea itself. Nature-economy linkages inherent in these sectors inform broader generalizations regarding human-environment interrelationships in the Aral Sea Basin today.

Chapter 13 by Micklin, Aladin and Plotnikov describes an international scientific expedition to the northern part of the Aral Sea conducted from August 29 to September 16, 2011. The expedition was organized by the Zoological Institute of the Russian Academy of Sciences in St. Petersburg Russia and received logistical support from the Barsakelmes Nature Preserve (Zapovednik) headquartered in the Kazakhstan City of Aralsk and the Aralsk Branch of the Kazakhstan Fisheries Institute. The major focus of the expedition was to investigate the biological and hydrological improvements to the Small Aral Sea that had occurred as a result of raising its level by 2 m in 2005–2006 as well as what might be done to further improve the ecology and economic value of this water body in the future. The expedition also visited the channel that connects the Western and Eastern basins of the Large Aral Sea as well as the former Barsakelmes Island, now a desolate plateau on the dried bottom of the Aral Sea.

18.3 Summary of Part III: The Future of the Aral Sea

Part III discusses the future of the Aral Sea, or to speak more accurately, the possible futures of this Lake and its surrounding region. Chapter 14 by Plotnikov and Aladin discusses the biological future of the Aral Sea. The Aral Sea in 2012 consisted of four residual water bodies with different hydrological regimes. The Kok-Aral dam raised and stabilized the level of the Small Aral Sea. Growth of salinity here has stopped and a process of gradual salinity reduction is in progress.

By the autumn 2011 water salinity in the open part of the Small Sea dropped to 8 g/l. The future of its biota depends on future salinity. If the current regime will remain, then the decrease in salinity will continue and the Small Aral will turn from a brackish to a nearly freshwater body. This freshening will cause substantial changes in the fauna as a result of the disappearance of marine and brackish species and reintroduction of freshwater forms. Currently two variants of further rehabilitation of the Small Aral are under consideration. The first one involves an additional dam at the entrance to Saryshaganak Gulf to create a reservoir out of it and the filling of this water body via a canal from the Syr Darya. The Small Sea under this plan would then have both freshwater and brackish water parts. The second variant is to increase the level and area of the Small Aral Sea by raising the height of the Kok-Aral dam. In this case, all the Small Sea remains brackish except the existing freshened zone in front of the Syr Darya Delta. Both these variants would avoid further strong freshening of the Small Aral Sea and associated with this adverse changes in the fauna.

The expected future of the biota of the residual hyperhaline water bodies of the Large Aral is quite different. In this case, there is no possibility of reducing their salinity leading to a recovery of fauna represented by marine and widely euryhaline species. On the contrary, even stronger salinization is likely. The East Large Aral Sea could dry out completely, and the West Big Aral could turn into a lifeless water body akin to the Dead Sea.

Chapter 15 by Micklin describes and analyzes prospects for the recovery of the Aral Sea. He notes that this water body 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. The author discusses various restoration scenarios. Full restoration of the sea in the foreseeable future is extremely improbable, but cannot be ruled out for distant times. Micklin devotes considerable attention to the project implemented in the first decade of the present century to partially restore the Small (northern) Aral Sea, an efforts that so far has been eminently successful. Partial restoration of the Large (southern) Aral is also discussed. This effort would be more costly and complicated than the north Aral project, but is certainly worthy of further investigation. Projects to improve the deltas of the Amu Darya and Syr Darya are also underway.

Chapter 16 by Micklin discusses the famous (or infamous depending on your point of view) plans to transfer water from Siberian rivers flowing to the Arctic to Central Asia. The author notes that the twentieth century was the era of mega-engineering thinking. This was a worldwide phenomenon, but perhaps had its clearest expression in the Soviet Union, a nation with a well-developed ideology promoting man subduing nature for purported human betterment. Soviet plans to transfer huge amounts of water long distances from Siberian rivers to Central Asia were initially conceived, during the Stalinist era, as a way to fundamentally transform the physical environment of this region. During the period 1960 to the mid 1980s, much scaled down, but still unprecedentedly huge versions of these projects were primarily seen as the best means to provide more water for irrigation expansion and, secondarily, as way to provide more water to the Aral Sea. After several decades of intense scientific study and engineering development, a final design for Siberian water transfers was on the verge of implementation when an abrupt change of national policy in 1985–1986 put it in on hold for the foreseeable future. The plan foundered owing to Russian nationalist opposition, enormous costs, a changing political environment, and the threat of significant environmental damage. The collapse of the USSR has probably doomed the project although it continues to be promoted by Central Asian governments and even some prominent Russians as a means to bring back the Aral Sea.

Chapter 17 by Lioubimtseva concerns the question of the impact of climate change on the Aral Sea and its basin. Climate change and its consequences is certainly one of the most crucial issues of our time. Climatic and environmental changes in the Aral Sea Basin represent a complex combination of global, regional, and local processes of variable spatial and temporal scales. They are driven by multiple interconnected factors, such as changes in atmospheric circulation associated with global warming, regional hydrological changes caused by mountain-glacial melting, massive land-use changes associated with irrigation, as well as hydrological, biogeochemical, and meso- and microclimatic changes in the Aral Sea and its quickly expanding exposed dry bottom. Human vulnerability to climate change involves many dimensions, such as exposure, sensitivity, and adaptive capacity and affects various aspects of human-environmental interactions, such as water availability and stress, agricultural productivity and food security, water resources, human health and well-being and many others at various spatial and temporal scales.

18.4 Lessons of the Aral Sea: Myths and Realities

Are their lessons 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 offset by compensatory factors such as significant irrigation return flows to the Syr and Amu rivers and 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 with out 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, but also fundamental political, social and economic changes 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 indigenous 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, then if and when habitat conditions in the original site become favorable, indigenous 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 indigenous species (fishes and invertebrates) could not withstand the dramatic increase in salinity. But these species were preserved in the Syr Darya and in that river's 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 indigenous 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.

18.5 Research and Monitoring Needs

Research on and monitoring of the Aral Sea and its surrounding region is absolutely essential to understanding the key natural and human processes that are occurring and designing rational strategies and plans and programs to improve the situation. Below are listed recommendations for these research and monitoring activities. This list is updated and revised from "Recommendations for Further Scientific Research" developed at the NATO Advanced Research Workshop, "Critical Scientific Issues of the Aral Sea Basin: State of knowledge and Future Research Needs," Tashkent, Uzbekistan, May 2–5, 1994 (Micklin and Williams 1996, pp. ix–x). Certainly research efforts have been devoted to a number of these issues since the mid-1990s, but much critical work remains to be done.

18.5.1 Hydrologic and Meteorological/Climatic Processes and Phenomena

1. Studies of hydrologic changes in the basin of the Aral Sea since the 1960s and forecasts of future conditions (e.g. glacier and snowfield melt and runoff, river flow, groundwater resources and their potential sustainable use).
2. Assessment of micro, meso, and macro scale climatic change owing to desiccation of the Aral Sea. Micro and meso scale changes in a zone around the sea are clearly apparent and demonstrated. But macro level changes over the Aral Sea Basin are not at all clear and the subject of considerable argument.
3. Studies of the impact of human influenced Climate Change (Global Warming) on the Aral Sea and its basin. This is certainly one of the most important

phenomena impacting both the natural and human environment here and needs much more detailed research.

4. Evaluation of the character, intensity, range, and impacts of salt/dust transfer from the dried -bottom of the Aral Sea.
5. Modeling of key hydrodynamic processes occurring in the residual lakes constituting the modern and future Aral Sea. An international team led by Oceanographer Peter Zavialov of the Shirshov Institute in Moscow has carried out important research on changes in the northern part of the Large Aral since 2002 (Zavialov 2010). This work needs to be continued and expanded to the entire Large Aral as well as the Small Aral Sea.
6. More intense investigation and modeling of groundwater's role in the water balance of the desiccated Aral Sea. As river flow has diminished and ground water flow increased, this water balance parameter has become, and will become ever more, important.
7. Study of the water balances and hydrology of the Western and Eastern Basins of the Large Aral Sea, the Small Aral Sea, and Tshche-bas Gulf as separate water-bodies with their own unique conditions.
8. Determination of the minimum amount of surface and groundwater that needs to be reserved (from consumptive and polluting uses) for ecological sustainability in the Aral Sea Basin.

18.5.2 Ecosystems and Their Changes

1. Continued investigation of biotic (floral and faunal) changes in the Aral Sea, and deltas of the Amu and Syr Darya brought about by drying of the Aral Sea with better integration of research on different aspects of the region's ecology and stress on the employment of contemporary methods of understanding ecosystem dynamics in a holistic framework. Development of computer models of ecosystem changes as a means of integrating and understanding the dynamics of very complicated systems.
2. The team led by N. Aladin and his colleague, I. Plotnikov (associate editors of this book) from the Zoological Institute in St. Petersburg in collaboration with Western scientists and research groups in Kazakhstan and Uzbekistan has done and continues to do exceptionally valuable work on the aquatic biology of the Aral Sea (see Chaps. 3, 6, and 14). This work needs to be better financed and continued.
3. N. Novikova of the Institute of Water Problems in Moscow, collaborating with researchers from the Institute of Geography in Moscow such as A. Ptichnikov and counterpart organizations in Karakalpakstan conducted high quality work on landscape and botanical dynamics in the lower reaches of the Amu Darya based on extensive field surveys (Novikova 1997; Ptichnikov 2002). These efforts have greatly diminished in recent years but need to be reinvigorated.

4. Attention to issues of biodiversity and endangered species loss, particularly in the deltas of the Amu and Syr Darya.
5. Investigation of how best to use the potential natural resources of the residual Aral seas as they are presently constituted and will be in coming years. Of particular interest in this connection is the possibility of using these water bodies for aquacultural purposes (e.g., the heavily salinized Large Aral for production of brine shrimp eggs), either in an extensive or intensive form.

18.5.3 Agricultural Production and Management

1. Studies of land tenure and use in the Aral Sea Basin and how these relate to water use and ecological degradation here.
2. Investigation of the extent and nature of agricultural water use in the Aral Sea Basin and of means effectively to implement water-saving technologies in irrigated agriculture. Evaluation of presently non-utilized and under-utilized sources of water (e.g., groundwater and ephemeral desert lakes) to augment currently fully or over-utilized sources.

18.5.4 Medical, Health, Social, Economic, Cultural, and Demographic Issues

1. Studies of demographic dynamics in the Aral Sea Basin, of how these exacerbate environmental and other regional problems, and of means of alleviation.
2. Investigations of the economic structure of the Aral Sea region and of means for its improvement.
3. Studies of the medical and health situation in the Aral Sea region of "Ecological Calamity" and of means for its improvement, including developing effective means to monitor the health of human populations in the Aral Sea region.
4. Investigation of the inter-nation and intra-nation legal structures in the Aral Sea Basin and their relationship to ameliorating the most serious environmental problems.

18.5.5 Toxic Contaminants (Biocides, Metals, Other Organic and Inorganic Compounds)

1. More intensive study and monitoring of toxic contaminants, including their sources, amounts, environmental pathways, persistence and biological effects and sinks in the Aral Sea region.

2. Development of less harmful substitutes for toxic contaminants and alternative means of controlling pest species of plants and animals (e.g., integrated pest control primarily dependent on natural biological approaches with the limited use of chemicals).

18.5.6 Application of Satellite Remote Sensing and GIS Research and Monitoring Technologies

1. Research on and monitoring of hydrologic processes, landscape and ecosystem dynamics, irrigation characteristics and other appropriate subjects in the Aral Sea Basin employing contemporary satellite-based remote sensing technologies is of vital importance. This field has seen enormous advancements in the last two decades and today (and even more so in the future) can be the basis of near real-time monitoring of critical natural and human systems in the Aral Sea Basin.
2. The MODIS (Moderate Resolution Imaging Spectroradiometer) sensor on the U.S. Earth Observation System satellites (Terra and Aqua) has become particularly important since that programs launch in 2001 (modis.gsfc.nasa.gov/). With a maximum pixel resolution of 250 m and viewing the entire Earth's surface every 1–2 days while acquiring data in 36 spectral bands, is the best existing tool for closely following medium to large-scale environmental changes in the Aral Sea Basin (see Chaps. 10 and 11). Furthermore, this imagery can be downloaded in viewable and also processable format via the Internet by anyone with a broadband connection at no cost.
3. This imagery is complemented by higher resolution products with less frequent coverage from the French Spot satellite and others, including the U.S. Landsat series, which provides downloadable viewable and processable imagery also at no cost (glovis.usgs.gov/).
4. Satellite images in processable format can be combined with other data via GIS (Geographic Information System) software to create sophisticated, computer-based models for analysis, monitoring, and decision support systems for the Aral Sea and Aral Sea Basin. Efforts along these lines are already underway.
5. Radar altimetry, used over the past decade and a half, to accurately determine the levels of the ocean and lakes (see Chap. 11) may in the near future be employed to much more accurately estimate river flows. Work is underway to perfect this application of radar altimetry (Michailovsky et al. 2011). This would be of great use in determining the inflows to the Aral Sea from the Amu and Syr rivers and more reliably determine the water balances for the Aral Sea (to be more precise, for the separated water bodies that now constitute the modern Aral Sea).
6. Research is needed to determine the optimal means for introducing the above described technologies on a broad scale into the Aral Sea Basin research, monitoring and management effort and for training local scientists and technicians in their use. Efforts have been are being made to promote this, but more needs to be done (http://www.cawater-info.net/index_e.htm; Ptichnikov 2002).

References

Michailovsky CI, Berry PA, Smith RG, Bauer-Gottwein P (2011) Radar altimetry for hydrological modeling and monitoring in the Zambezi River Basin. A paper presented at the fall 2011 meeting of the American Geophysical Union. Abstract available at http://adsabs.harvard.edu/abs/2011AGUFM.H11K..08M

Micklin PP, Williams WD (eds) (1996) The Aral Sea Basin (Proceedings of an advanced research workshop, May 2–5, 1994, Tashkent, Uzbekistan), vol 12, NATO ASI series. Springer, Berlin

Novikova N (1997) Principles of preserving the botanical diversity of the deltaic plains of the Turan. Scientific report for the doctoral degree in geography. Institute of Water Problems, Moscow (in Russian)

Ptichnikov A (ed) (2002) Bulletin. 3 NATO Science for peace project 974101. Sustainable Development of Ecology, Land and Water Use through Implementation of a GIS and Remote Sensing Centre in Karakalpakstan, Uzbekistan (in Russian and English)

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