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THE ARAL SEA DESICCATION AND POSSIBLE WAYS OF REHABILITATING AND CONSERVING ITS NORTHERN PART

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SUMMARY

The changes in the various components of the water balance of the Aral Sea, since 1960, and the consequent effects on salinity, surface area and water levels, are described. Since 1989 the fall in level has divided the Aral Sea into two parts, a northern Small Aral Sea and a southern Large Sea. The Small Sea receives part of the inflow of the Syrdar'ya and since 1990 its level has risen and its salinity has declined. To prevent the Small Sea overflowing into the south, a dam was constructed. Although this soon failed, the fauna and flora has begun to recover to some extent in the north Aral Sea. The desirability of a scientific and engineering programme to rehabilitate the northern sea is discussed.

KEY WORDS Aral Sea Desiccation Rehabilitation

The Aral Sea first began to dry up more than 30 years ago, in 1961. The main cause has been the abstraction of water for irrigation from the two rivers, the Amudar'ya and the Syrdar'ya, which supply water to this huge inland sea. The Aral Sea is supplied by river flow, rain and underground springs and loses water from evaporation and seepage. Because the sea is located in an arid climate zone, evaporation from the large surface is extremely high. Calculations by Bortnik [1] showed that during the period 1951 to 1960, before the anthropogenic dessication has begun, the annual evaporative loss averaged 66·1 km^3 while 56·0 km^3 of river water and 9·1 km^3 of precipitation reached the Aral Sea each year. Little reliable data is available for the underground component and estimates range from 0·3 km^3 to 3·4 km^3 per year.[2–4] Estimates of annual seepage from the Aral into the shores and bottom are very small and range from 0 to 0·15 km^3.[4–6] During the period from 1951 to 1960 there was an equilibrium between the total gains and the losses. This equilibrium maintained the level of this giant lake up to 1961.

After 1961, as the result of water withdrawal for irrigation, the amount of the water supplied to the Aral Sea began to fall and equilibrium between gain and loss was upset. Figure 1 shows, in terms of equivalent water levels, the main components of the Aral Sea water budget. In the period 1961 to 1970 the annual average river inflow was only 43·3 km^3, and between 1971 and 1980 it fell further to 16·7 km^3. At the beginning of the 1980s the river inflow practically ceased. In the period from 1981 to 1985 the annual average water flow was only 2·0 km^3. In 1982, 1983 and 1985 the

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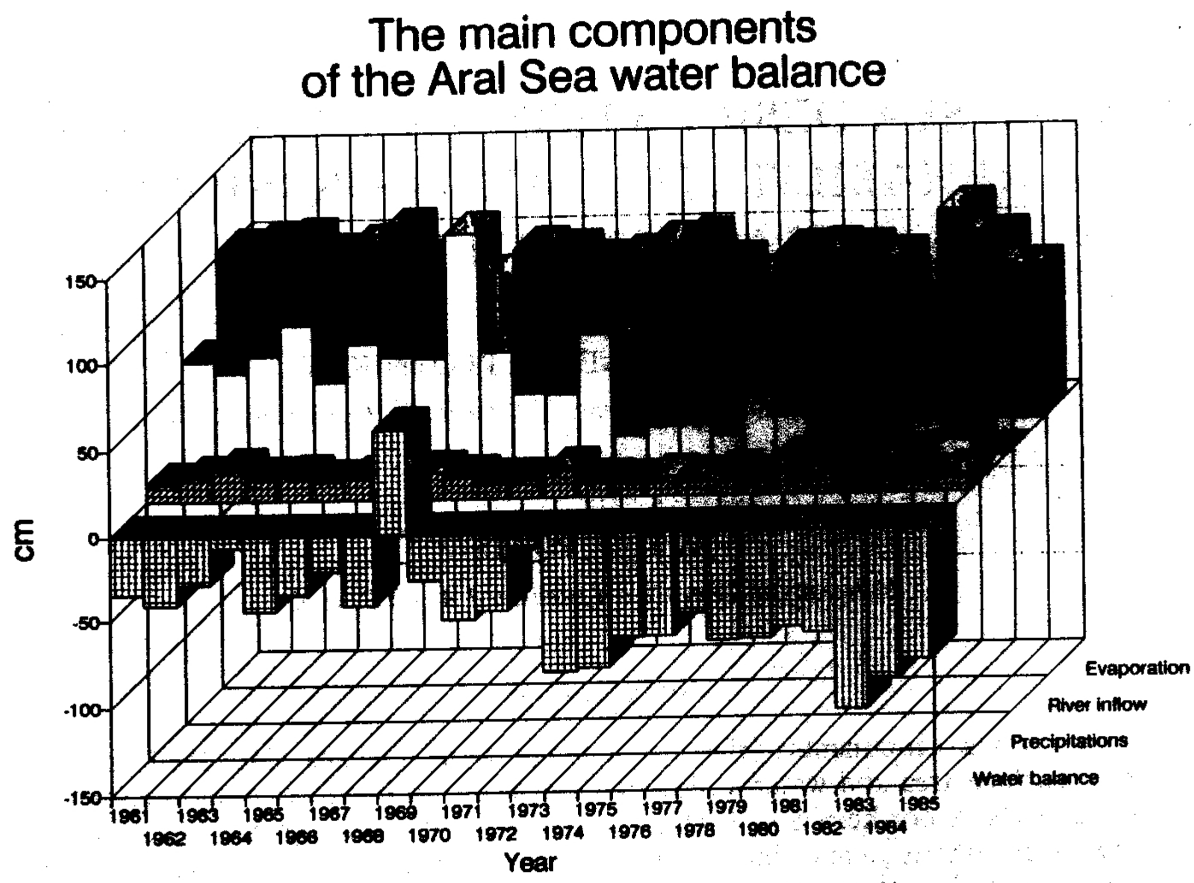

Figure 1. The main components of the Aral Sea water balance 1960–1985

Amudar'ya did not flow into the Aral Sea and only a small part of the flow of the Syrdar'ya reached it.[1] In the second half of the 1980s, when the *perestroyka* began in the U.S.S.R., and national and international public organizations began to express concern about the situation of the Aral Sea, the river flow was reportedly increased to some extent. From 1986 to 1990 the average water flow to the lake was officially 7·0 km^3. After the U.S.S.R. dissolved and the states surrounding the Aral Sea became independent the annual water supply has reportedly increased further and between 1991 and 1993 it exceeded 10 or even 15 km^3,[8] but it should be noted that the data on the river flow in these 3 years is not very reliable. After the U.S.S.R. ceased to exist, the metering stations on the Syrdar'ya and Amudar'ya were closed or reorganized because of financial difficulties. Private statements by the leaders of the public committees for salvation of the Aral Sea in Kazakhstan, Uzbekistan and Karakalpakstan confirm the unreliability of this data. In their opinion between 1991 and 1993 the river flow to the Aral Sea was not increased but remained at the level of 1986 to 1990. This is also the opinion of leaders of these independent organizations expressed in conversations with the UNEP experts in Kazakhstan and Uzbekistan in 1991–1992.[9]

The loss of the equilibrium between evaporation from the Aral Sea surface and the river supply that had existed in the first half of the century caused a rapid fall in water level and increase in salinity. In the period from 1911 to 1960 the water level was stable at +53 m above sea level. Changes in level at this time did not exceed 1 m. For example, the largest deviations in the average value in the Northern Bolshoy Sarychaganak gulf was +40 cm in 1912, 1960 and −45 cm in 1920.[10]

Since 1961 the average level of the Aral Sea has decreased constantly. Figure 2 shows the changes in area and volume of the Aral Sea together with a forecast for year 2001 and for later decades. At the beginning the level fell relatively slowly. Between 1961 and 1974 the level decreased by an average of 27 cm/year but in 1975–1985 the rate of fall had increased to an

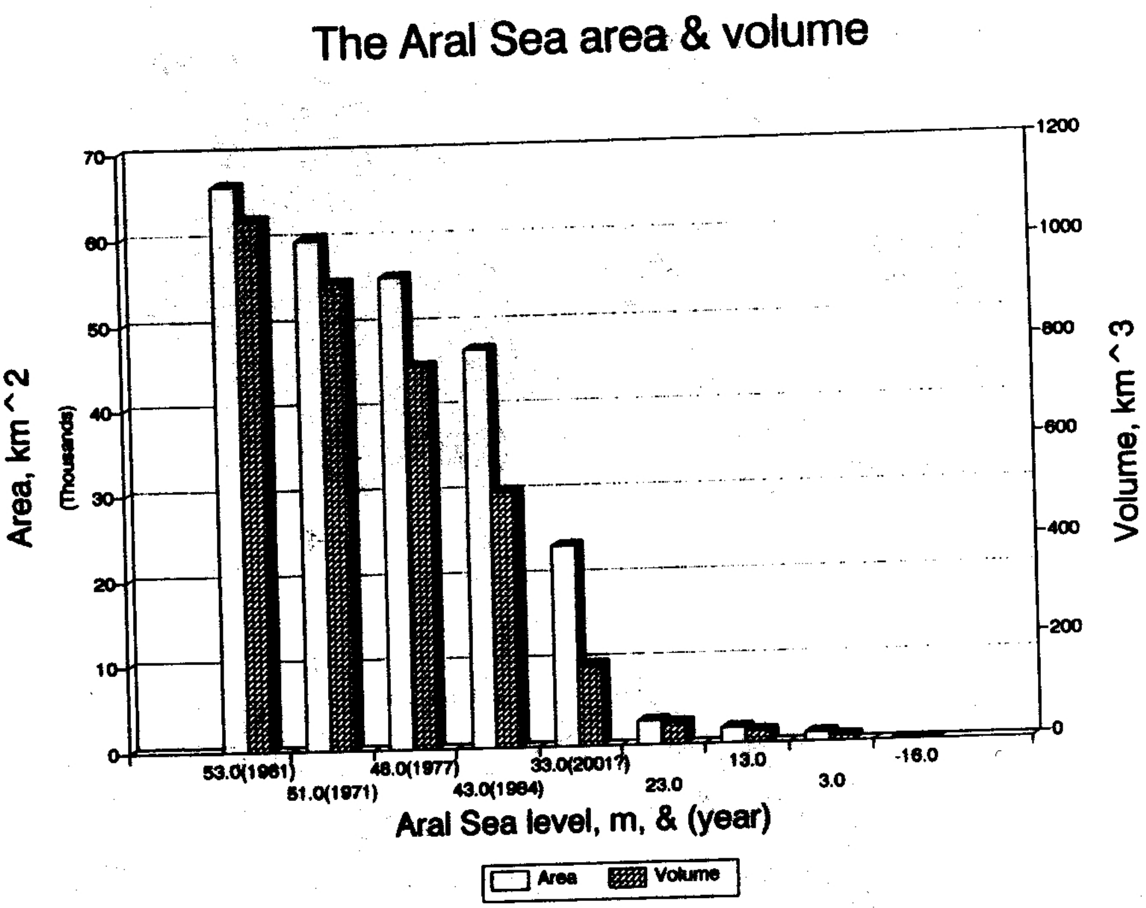

Figure 2. Aral Sea area and volume from 1961. Areas and volume for 2001 and subsequent decades calculated on assumption that present flows are maintained.

average of 71 cm/year.[10] From 1986 to 1990 the Aral Sea level fell even faster, averaging 88 cm/year[11]

In 1989–1990 the fall in level divided the Aral Sea into two parts: a small northern part and a much larger and deeper southern one (Figure 3). It should be noted that due to morphology of the Aral basin there had always been two water areas – the northern Small Aral Sea and the southern Large Aral Sea. Originally the Small Sea was separated from the Large Sea by Kokaral island lying east-west. On the west, between the island and the shore, there was shallow Auzykokaral strait, with a maximal depth of less than 2 m and on the east there was the relatively deep Berg's strait, with a maximal depth of 13 m. The western strait dried out in 1968 but the eastern survived until 1989. Now the Small Aral Sea is completely separated from the Large Aral Sea. However, before July 1992 the Small Sea overflowed on the site of Berg's strait into the Large Sea (Figure 4). The cause of this flow was as follows. In the period from 1961 to 1990 when Berg's strait was open, the fall rate was the same in both the Large and Small Aral seas. However, by far the greater part of the evaporation took place from the much larger southern basin. After 1990 the water level increased in the Small Aral Sea because evaporation from its surface was smaller than the total inflow from the Syrdar'ya river, together with rain and underground inflow. The rising level in the Small Aral caused its water to overflow into the Large Sea. As the southern water continued to dry up, while the northern basin filled, the hydrological gradient of the strait between them began to grow, causing a powerful current to flow from the Small Sea to the Large.

As Figure 4 shows, the contours of the strait between the Small and Large Aral Seas indicate that it is of artificial origin, more like a canal than a natural formation. In the 1980s Berg's strait was deepened by dredging to allow navigation. Later, when Berg's strait had dried up completely,

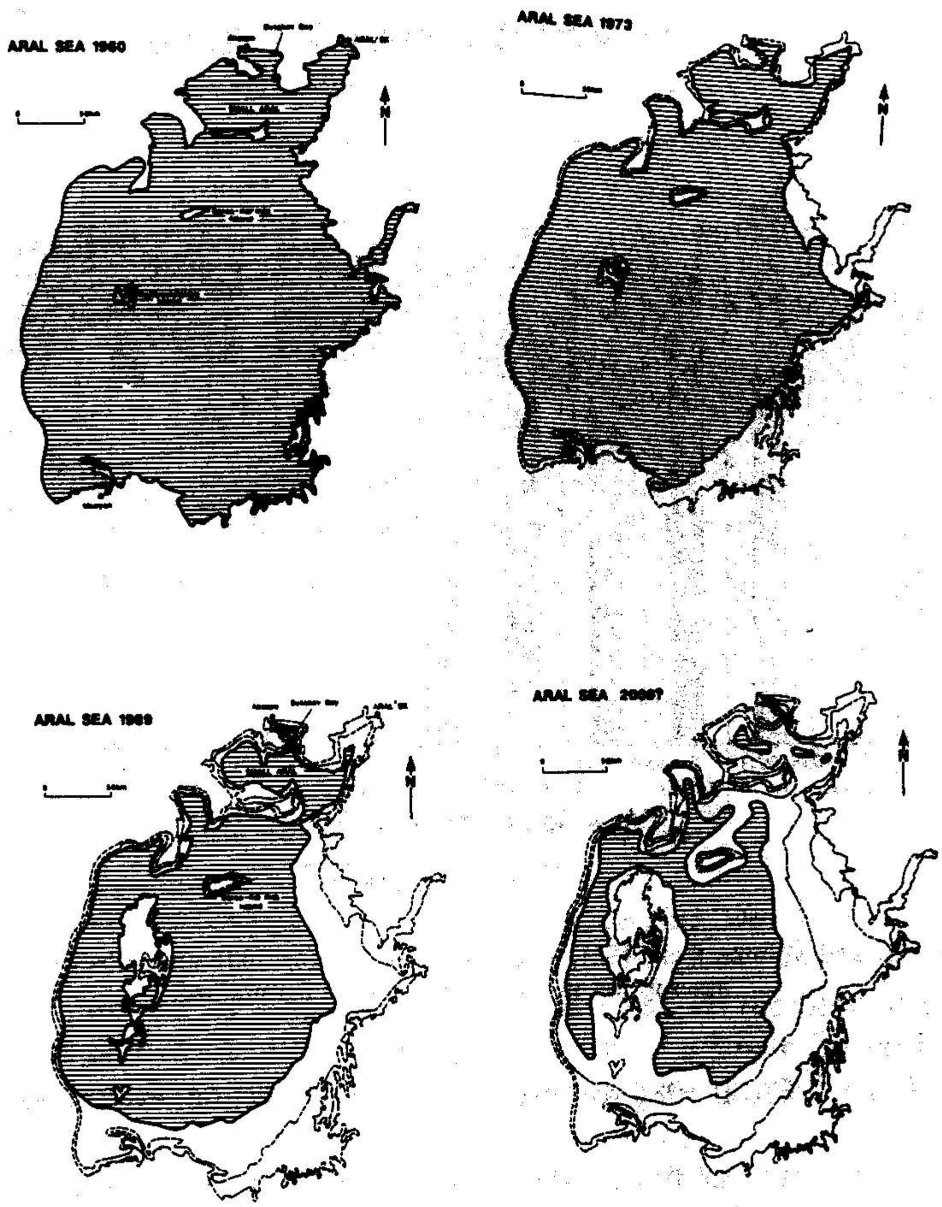

Figure 3. Changes of surface of Aral Sea from 1960

the former artificial recess on the bottom appeared on the surface as a channel. Investigations of the channel in the autumn of 1989 showed that it was completely filled with silt and on its surface there was a chain of residual water bodies and lakes, not connected one with another. At this time there was flow from north to south. The length of the dry channel was nearly 4 km. Later, when the level of the Small Aral Sea began to rise in the spring 1990, a stream started to flow along the channel, slowly at first but increasing in volume. At the beginning the overflow channel was wide and shallow but after a while the water cut down through the accumulated sediments and the stream now flows between the artificial banks. As the gradient between the Small and Large Aral Seas gradually increased, the channel has increased in depth and length. In the spring of 1992 the depth reached nearly 2 m, the length about 5 km, and the width nearly 100 m. Where the channel reaches the Large Sea a distinct delta was formed with three branches. In the spring of 1992 the flow from the north to the south became considerable. Our measurements showed that in May 1992 the flow exceeded 100 cumecs. Because the bottom ground in the former Berg's strait is loose sediment there is danger that the channel will deepen and as a result the level of the Small Aral Sea begin to fall again. Eventually the channel could cut back to the mouth of the Syrdar'ya and divert most or all of its flow into the southern basin. In this case there is a danger that the Small Sea might completely disappear in a few years.

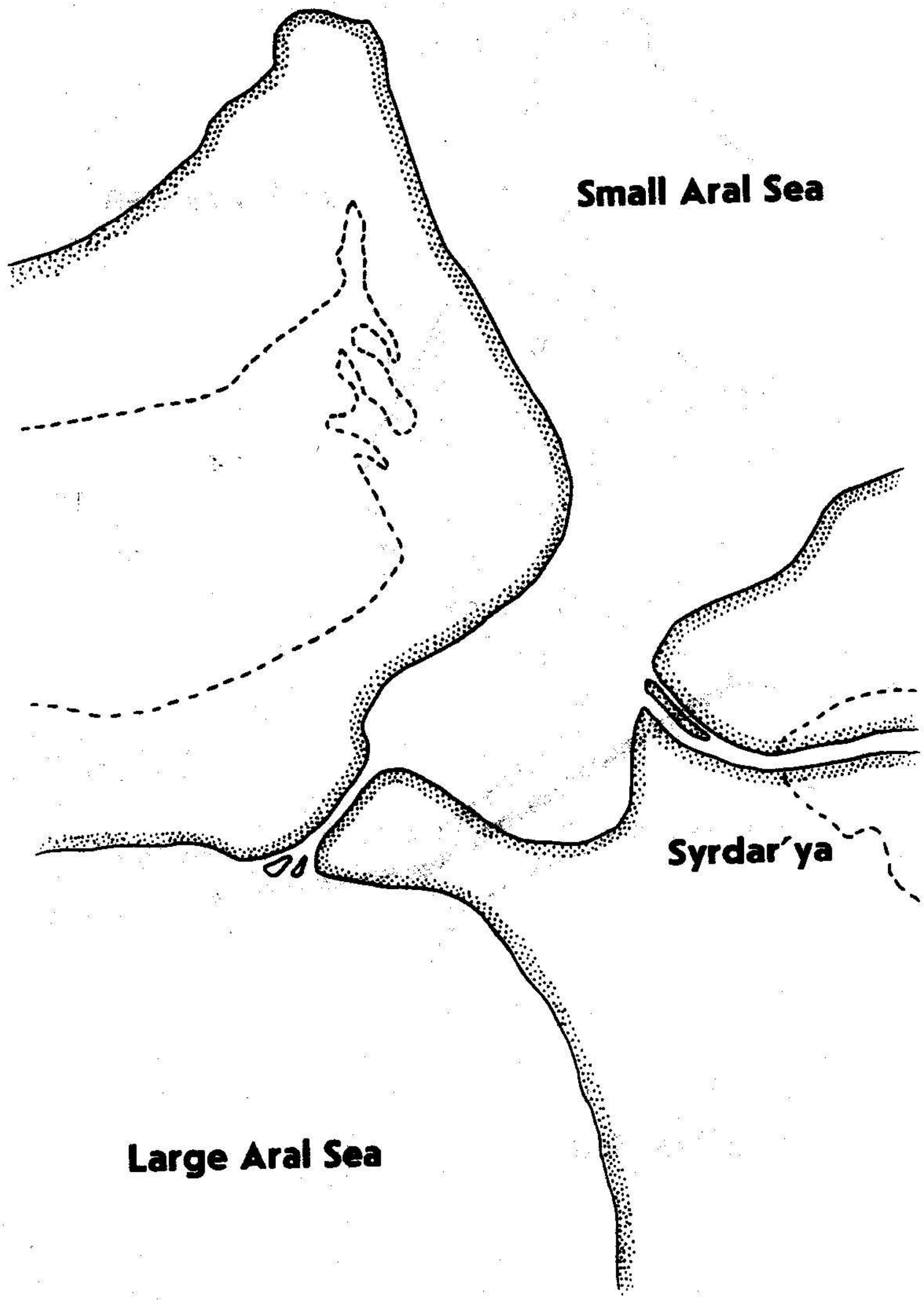

Figure 4. Map of channel between Large and Small Aral Sea before July 1992

These dangers were reported to the head of Aral district administration B. Kayupov, who in turn reported them to the administration of the Kzyl-Orda region. After discussions, the government of Kazakhstan decided to fill up the artificial channel and construct a dam in Berg's strait. At the beginning of July 1992 the channel was filled and a dam constructed, but after a few days the dam broke under the pressure of water. Only on the second attempt, at the end of July and the beginning of August, was a dam built capable of withstanding the pressure of the water. Eventually a small dam 1 m high was constructed across the whole width of Berg's strait (Figure 5). In the region of the channel it was constructed on top of the earlier dam in the channel itself.

The desiccation of the Aral Sea has caused not only the level to fall but has also increased salinity of the water. At first the salinity increased relative slowly because the evaporation only

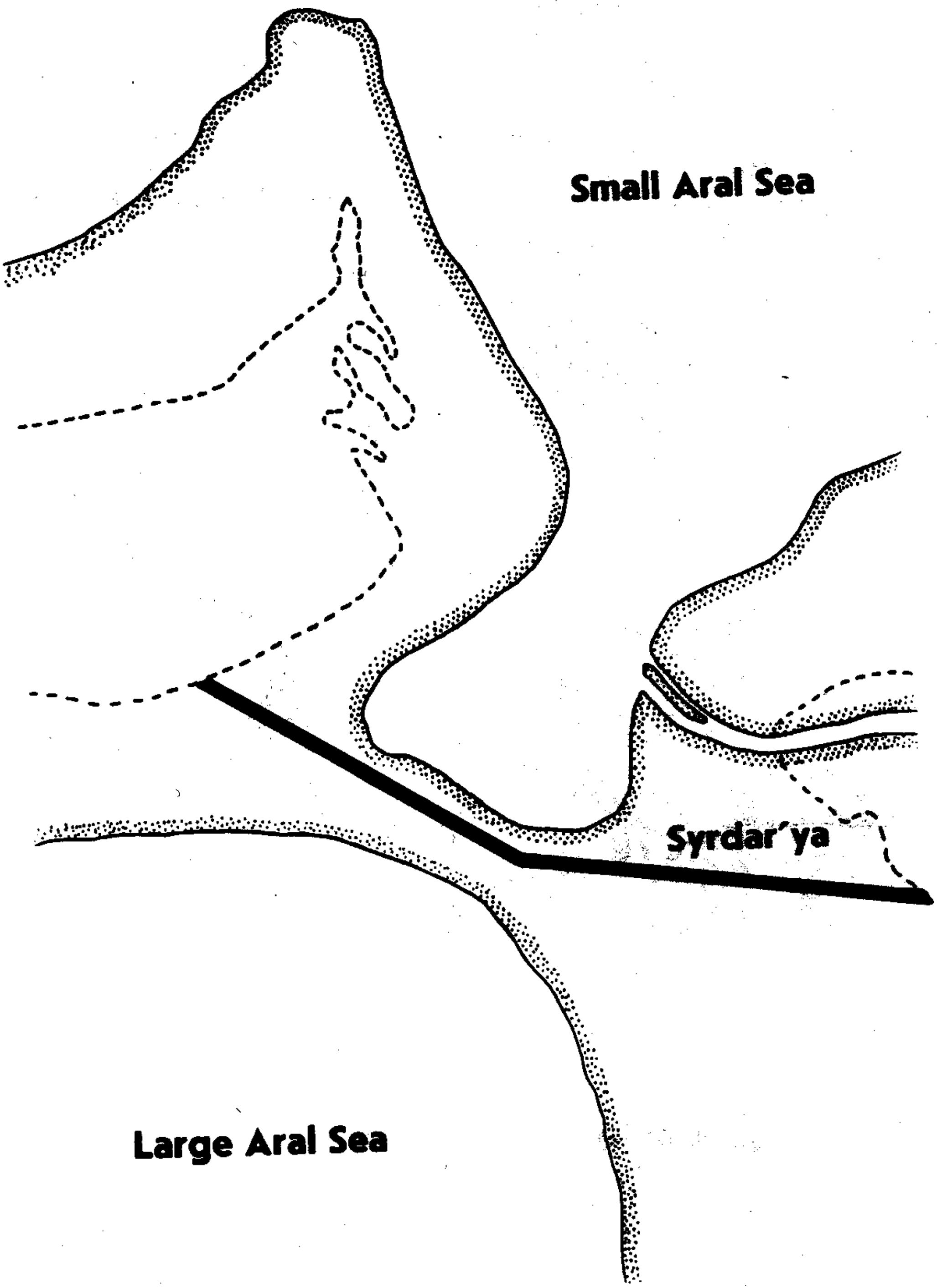

Figure 5. Map of dam between Large and Small Aral Sea before April 1993

slightly exceeded the total inflow of river water, underground water and rain into the Aral Sea. During the first half of the 20th century the average salinity was about 10·2–10·3‰.[12,13] However, it began to increase steadily after 1961. As the Aral Sea dried up its surface area diminished but the rate of river flow always decreased faster than the rate the evaporation decreased. Figure 6 shows the relationship between the level and the salinity in the Aral Sea for the period from 1961 to 1990. From 1961 to 1970 the salinity increased by 1·6–1·8‰ and reached an average annual value 11·50‰.[1] During this time the river flow decreased from 56·0 km^3/year to 43·3 km^3/year and amount of precipitation also fell from 9·1 km^3/year to 8·0 km^3/year. Nevertheless, the losses by evaporation in this period only fell insignificantly, from 66·1 km^3/year to 65·4 km^3/year, because the decrease in surface area was also very small, from 66,100 km^2 to 59,600 km^2.[1]

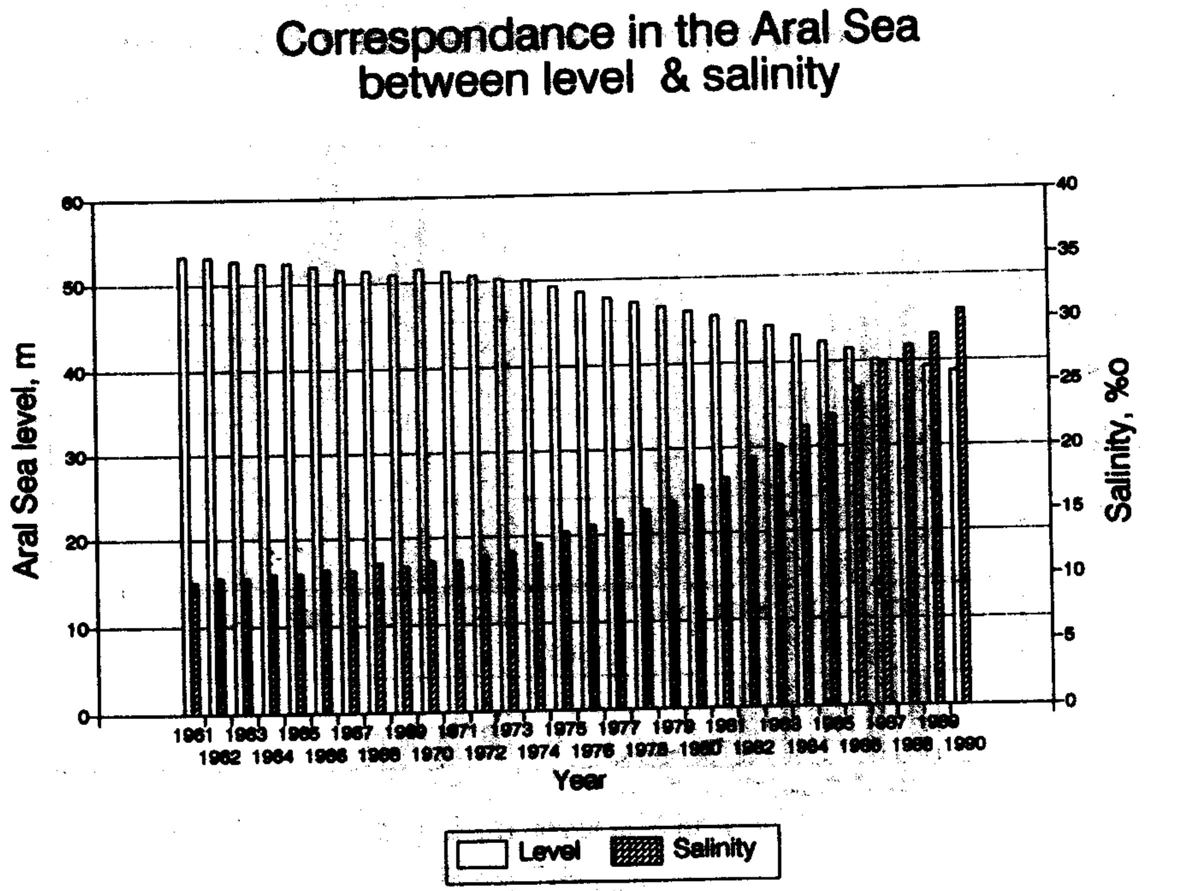

Figure 6. Correlation between level and salinity in Aral Sea 1961–1990

During the period from 1971 to 1980 the salinity rose by 6‰ and reached an average annual value 17·01‰.[1] During these years the inflow dropped to 17·7 km^3/year, the amount of precipitation also fell to 6·3 km^3/year, partly due to the declining surface area. Meanwhile the evaporative losses remained high but declined slightly to 55·2 km^3/year, as the Aral Sea surface shrank to 51,000 km^2.[1] In the period from 1981 to 1990 the salinity increased much more rapidly and reached an average annual value of 30·0‰.[7] When in 1989–1990 the water body split into the Small and Large Seas, the total Aral Sea volume was 370 km^3 and its surface area was 40,400 km^2. The volume of the Small Aral Sea was less 30 km^3 and its surface area was only 3500 km^2. Figure 7 shows the dynamics of the Large and Small Aral Sea areas and volumes separately. A forecast for year 2001 and even for later times is included, assuming that the inflow remains low. At the time when the two independent water bodies separated, the volume of the Large Sea exceeded that of the Small Sea by more than 11 times and the area was more than 10 times greater. It is noteworthy that in 1960, before dessication began, the volume of the southern basin exceeded that of the northern basin by more than 12 times and surface area was more than 10 times larger. It should be emphasized that the average salinity of the Large and Small Seas always differed to some extent but these differences were insignificant in the period from 1961 to 1970 because of water exchange between the northern and southern parts through the Auzykokaral strait on the west and Berg's strait on the east. In 1971–1985, after the western strait had disappeared and the eastern one had become shallower, the water exchange declined and the average salinity in the Small Sea became 1·5–3·0‰ higher than in the Large Sea. However, in 1986 the difference in average salinity of the north and south decreased again because the maximal depth of Berg's strait had become less than 2 m and the main flow through the Syrdar'ya's river delta had been displaced to the north, following the decline in river flow. Before this time, the river flowed into the sea strictly in the middle of the western coast of Berg's strait and its waters were distributed more or less evenly between the Large and Small Seas. Now

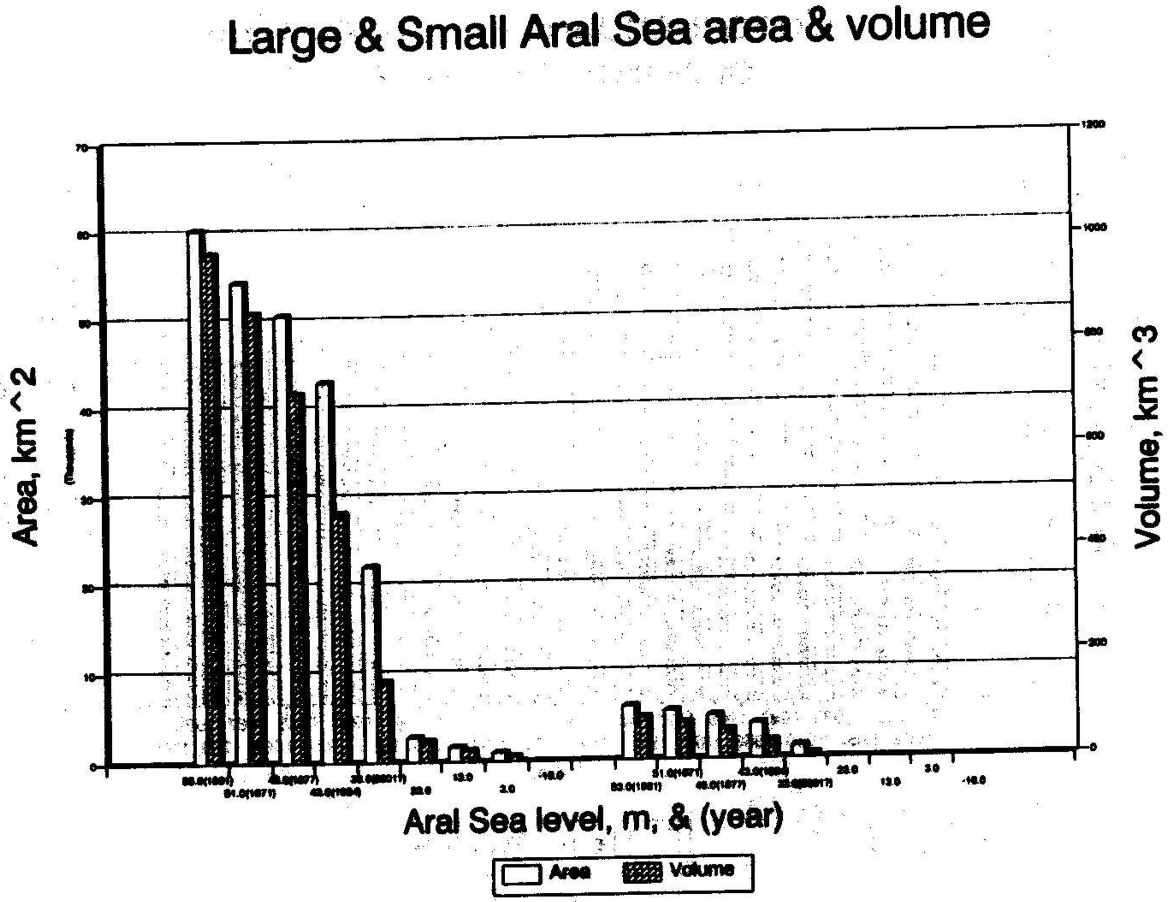

Figure 7. Areas and volumes of the Large and Small Aral Seas from 1961. Data for 2001 and following decades calculated on assumption that present flows are maintained

practically all the flow of the Syrdar'ya goes into the Small Sea. Since 1988 the average salinity in the Small Sea has fallen 1·5–2·0‰ lower than that of the Large Sea. Following the drying of Berg's strait in the spring of 1990, more marked differences have appeared in the salinity regimes of these water bodies. Before July 1992, when water outflow from the Small Aral Sea was blocked, the average salinity in the north was gradually falling while increasing in the south. Recent measurements of the salinity, by the autumn expedition of 1992, have shown that salinity of the Large Sea, at the southern side of the dam in Berg's strait, ranged from 24·2‰ to 30·0‰, while the salinity of the Small Sea, on the northern side of the dam, was only 16·2‰ to 18·3‰. It should be noted that the salinities of both the Small Sea and the Large Sea are significantly lower than those reported by Bortnik for these two water bodies. According to his measurements the salinities in 1992 were 24·9‰ in the Small Sea and 36·5‰ in the Large Sea (Bortnik, unpublished report).

These differences probably arise for the following reasons. The lower salinity found on the northern side of the dam is probably due to the freshening effect of the Syrdar'ya river which enters nearby. The salinity immediately south of the dam is probably lower than that in the southern Aral because of filtration through the dam. The difference in level between the northern and southern water bodies is nearly 2 metres. Because of this and also because the dam is constructed from sand, a strong filtration of the lower salinity water from the Small Aral into the Large Aral is likely. Unfortunately, the dam built in July and August 1992 lasted less than 9 months. In March 1993 the level of the Small Sea level rose more than 1 metre and the dam was destroyed. However, the existence of the dam for this short time makes it possible to draw some conclusions. Blocking the flow of water from the Small Sea flow into the Large Sea had good as well as bad effects.

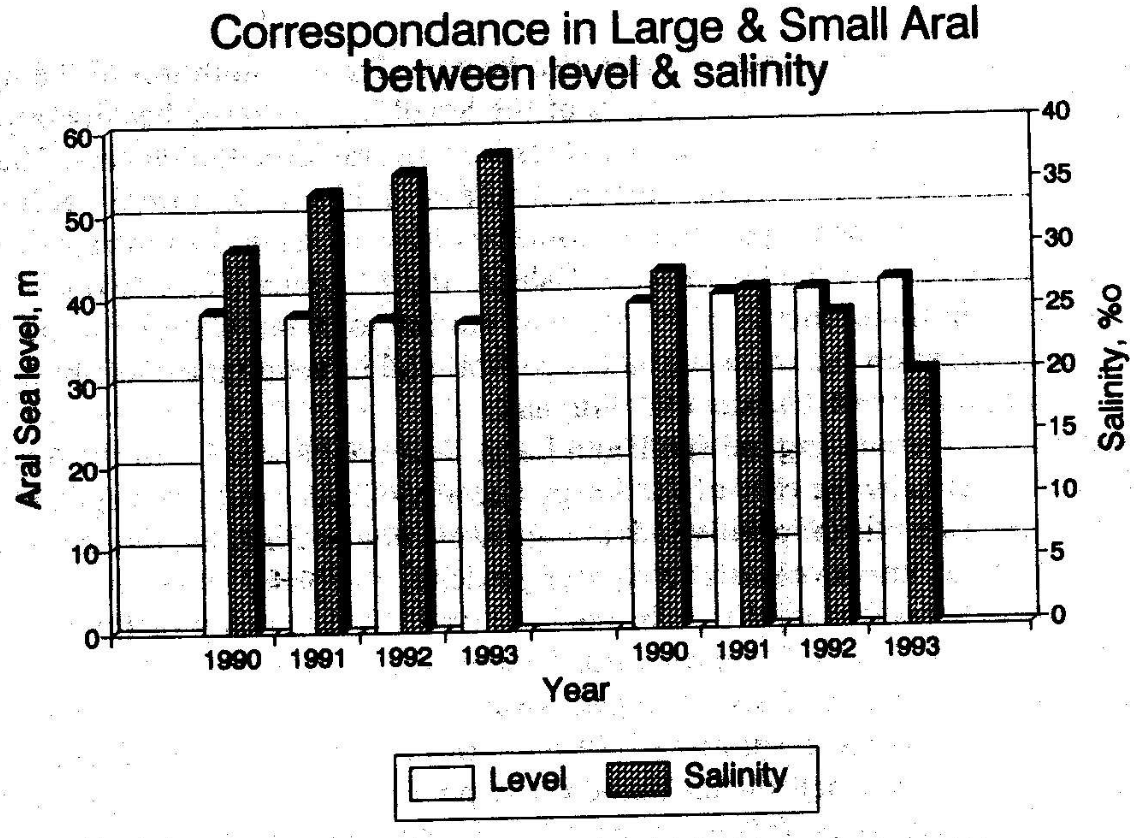

Figure 8. Levels and salinities in Large and Small Aral Seas 1990–1993

First, after the dam was constructed the fall in the level of the Small Aral sea was stopped for the first time for 30 years and, soon after that, a relatively rapid rise in level began (Figure 8). In less than 9 months the level rose by more than 1 metre.

Secondly, for the first time in the last 30 years the increase in the salinity of the Small Aral Sea was stopped and after a while the water began to freshen (Figure 8).

Thirdly, the danger that the artificial canal connecting the Small and Large Aral seas would cut down and drain the Small Aral Sea completely and divert the flow of the Syrdar'ya into the Large Sea was temporarily eliminated.

Fourthly, the 1 metre rise in the water level in the Small Aral Sea caused a partial filling of some of the gulfs which had earlier dried out. The centre of the gulf of Bolshoy Sarychaganak and some nameless small bays and gulfs were filled with water once again. It is noteworthy that the closing of the channel from the Small to the Large Aral delayed for some time the disintegration of the Small Aral into several separate small lakes. If the level falls much further, Butakov bay (and possibly Shevchenko bay) will become isolated from the body of the Small Sea. This might have already taken place if the dam had not been built.

Among the negative consequences the following are the most important. First, after the dam was constructed, rate of fall in the level of the Large Aral Sea increased to some extent. Unfortunately, because there are no continuous records, it is impossible to quantify this effect. The exact volume of the annual flow from the Small Sea into the Large Sea is not known. Using the measurements made in May 1992 the annual flow from the North to the South could be nearly 3 km^3 or about one-quarter of the total water income of the Large Aral.

Secondly, the damming has to some extent increased the rate of increase of salinity in the Large Sea. Nevertheless, in this case the negative effect was smaller than the effect on the level of the Large Aral. This is because the inflow from the Small Sea was not freshwater but saline water, although less salty than the water in the Large Sea. Direct salinity measurements in the canal in May 1992 gave salinity values of 21·2‰ to 24·5‰ while the Large Aral had an average salinity of 36·5‰.

A number of socio-economic factors must also be considered in addition to the hydrological benefits and disadvantages. Today, the coasts of the Small Sea are more heavily populated that those of the Large Sea. Around the Small Aral there are several large settlements. The largest are Aralsk city, and the villages of Birlestik, Tastubek, Akespe, Akbasty, Karateren, Karasholan and Bugun. They all play a significant part in the economy of Kazakhstan. In contrast, there are only two large settlements around the Large Aral: Ushsay and Muynak. These two settlements also play significant part in the economy of Uzbekistan but the total population on the coast of the Small Aral is larger than on the coast of the Large Aral and its economic contribution is greater than that of the population in Ushsay and Muynak.

The consequences of separating the Small and Large Seas on the wild life of the Aral Sea region must also be considered. In the case of the Large Sea any effects would be negligible but in the case of the Small Aral significant positive advantages were noted. First, the rise in water level by 1 metre has caused great improvements in Syrdar'ya delta. In spring 1993 there was a massive growth of reeds. As the water level rose in the river and the sea, many of the branches of the estuary filled with water. This led to more birds feeding and nesting in the delta. The number of pelicans (*Pelecanus crispus*, *P. onocrotalus*), swans (*Cygnus olor*, *C. cygnus*), flamingos (*Phoenicopterus ruber*), great cormorants (*Phalacrocorax carbo*), herons (*Ardea cinerea*, *A. purpurea*, *Ergetta alba*), various ducks (red-crested pochards *Netta rufina*, white-eyed ducks *Aythya nyroca*, tufted ducks *A. fuligula*, common teal *Anas crecca*, mallard *A. platyrhynchos*, goldeneys, *Bucephala clangula*), etc., all increased sharply.

Damming the flow of water from the north to the south significantly enlarged the brackish water zone of the Syrdar'ya. The abstraction of water from the Syrdar'ya for irrigation has inadvertently caused changes in the estuary which now flows mainly to the north of the dam. This has created a much wider zone of brackish water in the Small Sea. The zone has a very low salinity gradient, which has made it possible for freshwater fishes to leave the estuary and feed in the sea. Such behaviour has not been seen by local people for 10 or 15 years.

The rehabilitation of the Syrdar'ya estuary is beginning to affect not only the ichthyofauna but also the invertebrates. Many organisms of freshwater or brackish water origin found a refuge against the increasing salinity of the Aral sea in the freshwater or slightly brackish water branches of the Syrdar'ya delta.[14] The amphipod *Dikerogammarus aralensis* Ulljan. and the mysid *Paramysis lacustris* (Czern.) have now returned to the estuary. Thus the restoration of the biological diversity of the Syrdarya estuary and adjacent sea has begun.

In 1992–1993 every species represented in other parts of the Aral Sea were found in zooplankton near the mouth of Syrdar'ya and in former Berg's strait. Species found were the copepods *Calanipeda aquaedulcis* Kritch. and *Halicyclops rotundipes aralensis* Bor., harpacticoids *Halectinosoma abrau* Kritch., cladocerans *Podonevadne camptonyx* (G. Sars), larvae of bivalve mollusks *Cerastoderma isthmicum* Issell and *Syndosmia segmentum* (Phil.), rotifers *Synchaeta* sp. The studies showed that very high levels of zooplankton biomass (up to 600 mg/m^3) were found in the spring in this region. *C. aquaedulcis* formed more than 75 per cent of biomass, though in other parts of the Small Aral Sea the larvae of the bivalve mollusks *C. isthmicum* and *S. Segmentum* were the most important part of the zooplankton in the spring.[15] The high biomass of zooplankton in this region may be related to the high concentration of suspended organic matter, mainly detritus, supplied by the river flow and from bottom sediments. This would encourage the detritus and phytoplankton eating *C. aquaedulcis*. The reduction in salinity in this region may also favour it. This region was formerly characterized by higher zooplankton biomass.[16]

In our opinion the balance of advantages and disadvantages which resulted from damming the flow of water from the Small Sea into the Large Sea demonstrates the necessity of reconstructing this dam. The positive ecological, economical and social changes in the whole Small Aral greatly surpass the disadvantages to the Large Sea.,

Unfortunately, the dam between the Small and Large seas lasted only 9 months and in March and April 1993, because the level in the Small Sea rose by more than 1 metre, the dam was broken in three places. The main outflow was once again on the site of the former channel with weaker outflows in the centre of the dam and on the side of Syrdar'ya mouth (Figure 4). In the middle of May 1993 depth of the first outflow was nearly 1 metre, the second less than 0·5 metre and the last only a few centimetres. It should be noted that by the end of May the third stream had practically dried up. The total outflow into the Large Aral, after the dam broke, appears to have been small. Possibly in the days after the dam broke the outflow may have been more substantial, but by the middle of May the discharge into the Large Aral through all three breaches was not more than 20 or 30 cumecs and by the end of May local specialists estimate that it had decreased to 15 or 20 cumecs (oral communication from local hydrotechnical authorities). Even after the dam was destroyed the flow from the north to the south never reached 100 cumecs, as it did in the spring of 1992.

At first, after the artificial channel was filled up by sand and the embankment was constructed, the area was subject to strong wind erosion. Especially strong sand accretion was observed on the south side of the dam. All the area between the coast of the Large Sea and the southern side of the dam was covered with sand-hills up to 2 or 3 metres high. These significantly reinforced the dam on its southern side and reduced the flow to the Large Sea, after the dam partially collapsed.

Furthermore, the Small Sea in front of the dam is extremely shallow and the wave action has formed numerous sand banks running parallel to the embankment. These shoals have also reinforced the northern side of the dam. They hindered the downcutting of channels and reduced the flow into the Large Aral after the dam collapsed. Even in its semi-destroyed state the dam still keeps the water level in the Small Aral more than a metre higher. Although the Kazakhstan government has now begun to reconstruct the dam, there is no long term plan to rehabilitate the Small Sea and there is no engineering survey to determine the most appropriate design for the dam. Theoretically, if the Syrdar'ya flow could be increased to a reasonable level, it would be possible to fill the Small Sea up to the level of 1970 or even higher. However, this would require a dam 12 to 14 metres high. It would also be necessary to construct a sluice in the dam to prevent the dam being overtopped. It is unlikely that the western strait, Auzykokaral, could become the natural regulator of the level of the Small Aral Sea because after more than 20 years without water the bottom has undergone considerable morphological changes. Conspicuous chains of sand-hills have developed which would interfere with the outflow through the Auzykokaral strait if the level in the Small Sea were to reach +51 m. In our opinion there is an urgent need to develop a full scientific and engineering programme to regulate the level of the Small Aral Sea. It will be necessary to enlist the support of international scientific and investment organizations, such as the UN, the World Bank, the International Waterfowl and Wetlands Research Bureau, etc., to develop this work.

Other proposals have already been made to divide the Small and Large Aral Seas. The other authors[6,7,17–19] all proposed to construct a dam in the narrowest part of Berg's strait, where it is not more than 12 to 14 km wide. In the light of the 1992 experiment we consider that it is more desirable to construct the dam 8 km south-east of the narrowest place in Berg's strait. In this case the dam would be 22 km long, 8 km longer than at the narrowest point, but it would be easier to construct on dry ground. If built on this site the dam also will be reinforced from the south by blown sand.

If a substantial dam is built on this site it would raise the level of the Small Aral. Both the human population and the wild life of the northern Aral region would benefit greatly while the damage to the southern Aral region would be minimal. Were such a dam constructed the overflow of surplus water into the Large Aral Sea would gradually lower the salinity. If the flow of the Syrdar'ya river was increased to several cubic kilometres each year the Small Aral Sea could rapidly become a freshwater lake. Some engineering work to divide the flow of the river into the Large and Small Aral Seas might be necessary in the longer term. A reduction of the salinity to around the 6‰ level, which prevailed in the first half of the twentieth century, would be wholly desirable. The Aral Sea has suffered not only from dessication but also from the mistaken attempts to naturalize marine species in the Aral.[20] Some marine species such as the annelid *Nereis diversicolor* and the small crab *Rhithropanopeus* have flourished at the expense of the native fauna. If the salinity were reduced, some, at least, of the alien species might disappear and be replaced by the native species, restoring the originally more fertile lake ecosystems.

REFERENCES

1. Bortnik, V. N. 'Water balance' *in Hydrometheorology and Hydrochemistry of the Seas of the USSR. VII. The Aral Sea*, Leningrad, 1990, pp. 34–42 (in Russian).
2. Ahmedsafin, U. N., Sadykov, Zh. S., Polomoshnova, M. G., *et al.* 1983. Underground water and saline flow in the Aral Sea basin. State and prognosis. Alma-Ata: 159p. (in Russian).
3. Chernenko, I. M. 'Income of underground waters into the Aral Sea and its significance to solve the Aral problem', *Problemy osvoyeniya pustyn*, **4**, 28–38 (1970) (in Russian).
4. Chernenko, I. M. 'About underground water income, water-saline balance and the Aral problem', *Problemy osvoyeniya pustyn*, **2**, 32–42 (1972) (in Russian).
5. Rogov, M. M., Hodkin, S. S. and Revina, S. K. 'Hydrology of the mouth region of Amudarya', *Trudy GOIN*, **94**, 268 (1968) (in Russian).
6. Chernenko, I. M. 'Water-saline balance and using of the dessicating Aral', *Problemy osvoyeniya pustyn*, **3**, 18–25 (1983) (in Russian).
7. Micklin, P. 'The water Management Crisis in Soviet Central Asia', The Cark Beck papers in Russian and East European Studies, No. 905, University of Pittsburg Center for Russian and East European Studies, 1991.
8. Aladin, N. V. and Williams, W. D. 'Recent changes in the biota of the Aral Sea, Central Asia', *Verh. Internat. Verein. Limnol.*, **179**, 1–4 (1993).
9. UNEP. 'Diagnostic study for the development of an action plan for the Aral Sea', Unpublished report, UNEP, Nairobia, Kenya, 1992.
10. Smerdov, B. A. 'Sea level' *in Hydrometheorology and Hydrochemistry of the Seas of the USSR, VII. The Aral Sea*, Leningrad, 1990, pp. 29–33 (in Russian).
11. Aladin, N. V. 'Studying of water salinization in separating gulfs of the Aral Sea on the hydrobionts', USSR Academy of Sciences, Proceedings of the Zoological Institute, Leningrad, 1991, v. 237, pp. 4–13 (in Russian).
12. Solovyeva, N. F. 'On the problem of dynamics of the Aral Sea saline balance' *in Materials on Ichtyophauna and Water Regime in the Aral Sea Basin*, Moscow, 1950, pp. 62–69.
13. Blinov, L. K. *Hydrochemistry of the Aral Sea*, Leningrad, 1956, p. 252 (in Russian).
14. Filippov, A. A., Petukhov, V. A. and Komendantov, A. Yu. 'Zoobenthos of Berg's strait (the Aral Sea) in 1992', Russian Academy of Sciences, Proceedings of the Zoological Institute, Leningrad, v. 250 (in Russian).
15. Plotnikov, I. 'The Aral Sea zooplankton in 1992', Russian Academy of Sciences. Proceedings of the Zoological Institute, Leningrad, v. 2501 (in Russian).
16. Andreev, N. I. 'Zooplankton of the Aral Sea in the initial period of its salinization', USSR Academy of Sciences, Proceedings of the Zoological Institute, Leningrad, 1989, vol. 1991, pp. 26–52 (in Russian).

17. Bortnik, V. N. *Present and Future of the Aral Sea*, Obninsk, 1978, p. 11 (in Russian).
18. Bortnik, V. N. 'Studies on the structure of longstanding average changes in some elements of hydrometheorological regime of the Aral Sea', *Trudy GOIN*, **159**, 119–126 (1980) (in Russian).
19. Lvovich, M. I. and Tsigelnaya, I. D. 'The Aral Sea water balance management', *Izvestiya AN SSSR, seriya geograficheskaya*, **1**, 42–54 (1978).
20. Aladin, N. V. 'Studying of water salinization in separating gulfs of the Aral Sea on the hydrobionts', USSR Academy of Sciences, Proceedings of the Zoological Institute, Leningrad, 1991, v. 237, pp. 4–13 (in Russian).