

Chapter 8

Irrigation in the Aral Sea Basin

Philip Micklin

Abstract Irrigation is highly developed 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, the area irrigated only increased slightly 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.

Keywords Irrigation • Soil salinity • Withdrawals • Cotton • Rice • Drainage • Kazakhstan • Uzbekistan • Turkmenistan • Kyrgyzstan • Tadjikistan

As discussed in Chap. 5, expansion of irrigation beyond the point of sustainability by the surface and groundwater resources of the Aral Sea Basin has been the primary cause of the post-1960s desiccation of the Aral Sea. In this chapter we

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delve more deeply into this critical topic, discussing its historical evolution as well as analyzing its modern development.

8.1 Pre-Soviet Period

For peoples of the world's arid regions, the well-known phrase, "without water there is no life," is a truism (Lunezheva et al. 1987). Irrigation was the driving force of settlement and civilization in the Aral Sea region since antiquity. Archeological evidence indicates the first settlements on the piedmont plains adjacent to the Kopet Dag Mountains in what is now southern Turkmenistan arose 8,000–10,000 years ago (Kostyukovskiy 1992; Karimov 1997, p. 7). Farmers cultivated wheat and barley, producing a harvest of near 12,000 centners (centner = 0.1 of a metric ton), enough to support 6,000 people. Soviet experts contended these crops were irrigated from small rivers exiting the mountains to the south, which would be one of the earliest examples of irrigation in the world. However, post-Soviet fieldwork by Western specialists at these sites casts doubt on this claim (O'Hara 2000). They contend the climate at the time was more moist than today and may have provided sufficient rainfall to grow crops without irrigation.

Nevertheless, it is clear that by the Bronze Age (2nd millennium, B.C.) farmers practiced irrigation in the oases along the middle and lower course of the Amu Darya and in the deltas of several terminal rivers in the Aral Sea Basin (Murgab in Turkmenistan and Zeravshan in Uzbekistan) (Kostyukovskiy 1992; Kes et al. 1980). Farmers, besides wheat and barley, raised grapes and beans. They dug distributary canals with widths up to 10 m, depths of 2–3 m and discharge capacities of 200–300 m³/day. The irrigated area may have reached 3,500 ha with water withdrawals of 12–13 million m³. This implies a water withdrawal rate of 3,400–3,700 m³/ha, an efficient use of water by modern standards. The population of these settlements may have reached 25,000–30,000. Irrigation in Khorezm, at the head of the Amu Darya Delta, first arose during the latter part of this period.

During the 1st millennium, B.C. (Iron Age), irrigation flourished along the Amu Darya, Zeravshan and Murgab (Kostyukovskiy 1992; Kes et al. 1980). The Khorezm oasis may have had 1.2 million ha under irrigation and a population of 200,000. Farmers of the Merv oasis in the delta of the Murgab irrigated some 500,000 ha, which supported a population of 300,000. The total area with irrigation systems in the Aral Sea Basin was huge, perhaps covering 3.5–3.8 million ha, about half the contemporary irrigated area. However, only a part of this area (probably less than half) was used in any given year. In the chief oases such as Khorezm irrigation technology advanced rapidly. They constructed large canals directly from the main channel of the river in earthen beds that stretched several hundred kilometers along with protective dikes to keep the river from overflowing its banks and flooding crops. The first evidence of irrigation on the lower Syr Darya dates to the middle of the 1st millennium, B.C. – a thousand years later than on the Amu Darya.

However, around the fourth and fifth centuries, A.D., the major irrigation systems of Khorezm were destroyed during a social and economic crisis (Kostyukovskiy 1992; Kes et al. 1980). Irrigation was restored by the seventh century, A.D., but was subsequently partially destroyed during the Arab invasion of 712. Irrigation again flourished during the twelfth and at the beginning of the thirteenth century when Khorezm became the center of a new feudal state whose government saw to the restoration of the canals and protective dikes. They irrigated large tracts of new land and built major canals far into the Kyzyl-Kum desert to unite the irrigated zones of the Amu Darya and Syr Darya. The irrigation experts of the time perfected the method of using diversion dams and storage basins to capture floodwaters for irrigation. The area with irrigation facilities during this period within the area controlled by Khorezm was near 2.5 million ha. Because of improved technology, such as the use of the “chigar” wheel, farmers were able to irrigate more efficiently and continuously than earlier. The “chigar” is a wooden wheel, some 2 m in diameter, with clay buckets arranged around the rim. The wheel is mounted on a horizontal axis in a pit with water in it. Draft animals (horse, donkey, camel) or the force of water can power the wheel to lift water from the pit to the fields. This device was widely used from ancient times until the Soviet transformation of agriculture in Central Asia during the late 1920s and 1930s (Karimov 1997, p. 13).

The Mongol invasion of Central Asia in 1220 led to the nearly complete destruction of irrigation systems along the Amu Darya and Syr Darya. (Kostyukovskiy 1992; Kes et al. 1980) Dikes and dams that controlled the rivers and allowed withdrawal of their waters for irrigation were ruined. The Amu Darya was purposely sent westward or diverted itself in this direction to the Sarykamysch Depression (as it had several times before) depriving the lower delta and Aral Sea of flow. (As noted in Chap. 2, diversion of the Amu Darya westward so that it flowed into the Sarykamysch hollow [and sometimes farther through the Uzboy channel to the Caspian Sea after it overtopped Sarykamysch] rather than the Aral Sea) have periodically occurred during the Holocene geological epoch. These diversions have been caused both by natural events [sedimentation of the bed and subsequent breaching of the rivers left bank during the spring floods] and by human actions such as the destruction of dikes and dams built to keep the river flowing to the Aral as noted above). Until the 1960s, these diversions were the primary cause for the fluctuations of the Aral Sea’s level (Kes et al. 1980; Kes and Klyukanova 1990). Subsequently, irrigation facilities were slowly rebuilt and the Amu Darya restored to its former course. By the early nineteenth Century the irrigated area was around 2 million ha, less than it had been prior to the Mongol attack.

The Russian Empire between the 1860s and 1900s, mainly by conquest, brought Central Asia, including the Aral Sea Basin, under its control (Brown et al. 1994, pp. 536–538; Clem 1992). The region was known as “Russian Turkestan” or just “Turkestan” (the land of the Turkic speaking peoples). A major expansion of irrigation began around 1900 focused on construction of new systems within the bounds of the traditional irrigated areas (Tashkent, Bukhara, Khorezm, Fergana and Zeravshan valleys) as well as expansion into desert areas that had never been irrigated, chiefly the Golodnaya (Hungry) Steppe (Fig. 8.1). By 1913, the irrigated

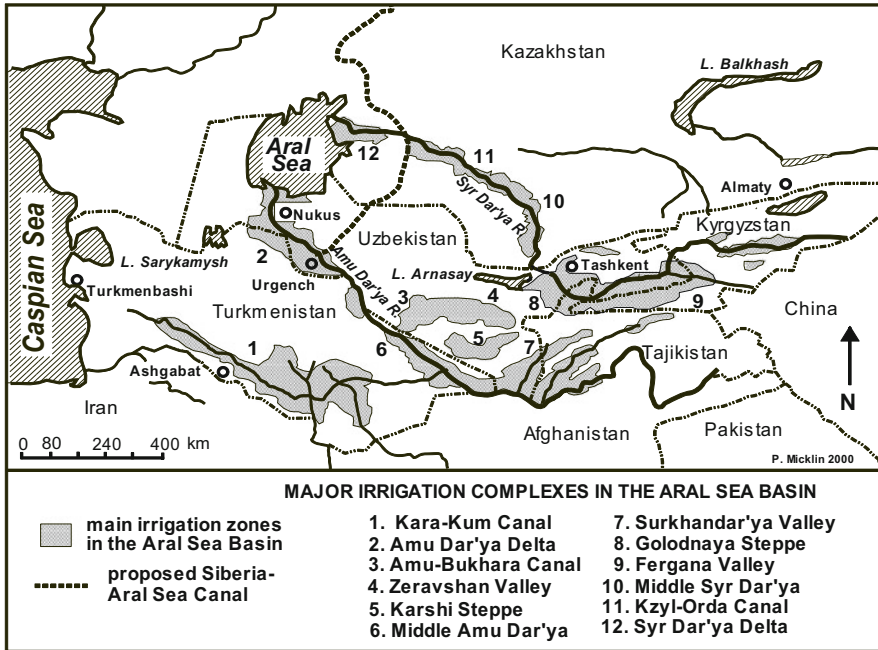


Fig. 8.1 Irrigation development in the Aral Sea Basin

area reached 3.2 million ha (Table 8.1). The newly irrigated lands permitted expansion of cotton sowing to 556,000 ha (17 % of the total irrigated). The major rationale was to meet needs of the growing textile industry in Russia (Clem 1992). However, cotton also displaced traditional food crops in portions of the older irrigated areas. For the Aral Sea Basin, yields of cotton averaged 12 centners/ha.

Irrigation expansion in the early part of the twentieth century mainly occurred in the alluvial fans where rivers exited the mountains and downstream in the river valleys and deltas (Karimov 1995; Pankova et al. 1996, pp. 74–91). This allowed development of the most fertile parts of the piedmont plain and dry sections of river deltas using gravity diversions that did not require construction of head-works facilities (dams, pumping stations, etc.). The main task was building of main delivery canals. In the drier parts of the Amu Darya Delta, farmers used a system of deepened earthen canals with ‘Chigar’ wheels to lift the water to the fields. These canals simultaneously fulfilled the role of distribution network for irrigation water and collector network for drainage water. Initially, these efforts went well and substantially increased production. But after 10–15 years, the first signs of water logging and secondary soil salinization (from over-irrigation, lack of proper drainage and irrigation of naturally saline soils) appeared in the Golodnaya Steppe, leading to the loss of 60 % of the newly irrigated area here.

Table 8.1 Irrigation data for the Aral Sea Basin for 1913–2010

Year	Irrigated area (million ha)	Withdrawals for irrigation (km ³)	Withdrawals for irrigation (m ³ /ha)	Cotton area (million ha)	Cotton % of total irrigated area	Cotton yields (centnars/ha) ^a	Water use for raw cotton (m ³ /centnar) ^b
1913	3.2	25.6–43.2	8,000–13,500	0.556	17.4	12	950
1922	1.7	16	9,400	0.100	5.9	7	1,230
1933	3.5	40	11,500	1.800	51.4	5	1,800
1940	3.8	49	13,000	1.369	36.0	14	1,800
1945	no data	no data	15,000	1.110	no data	10	1,350
1950	3.8	57	15,000	1.580	41.6	20	800
1965	4.8	82	17,000	2.287	47.6	23	800
1980	6.3	107.1–126	17,000–20,000	2.869	45.5	29	750
1985	7.0	112–133	16,000–19,000	3.051	43.6	26	700
1990	7.25	109	14,600–17,000	2.907	41.0	8.3	no data
1995	7.94	100	12,594	2.354	29.6	7.3	no data
2000	8.1	75	9,180	2.236	27.6	5.89	no data
2005	8.1	91	11,258	2.537	31.3	6.91	no data
2010	8.2	92	11,169	2.300	28.0	6.39	no data

Sources: Data from 1913 through 1985 taken from Micklin (2000), Table 3, p. 28

Data for 1990 through 2010 from Micklin (2000), Tables 10.2, 10.3 10.4, and 10.5 this chapter and Index Mundi for Uzbekistan, Kazakhstan, Tadjikistan, Kyrgyzstan and Turkmenistan <http://www.indexmundi.com/agriculture/?country=uz&commodity=cotton&graph=area-harvested> (Accessed 31 January 2012)

^aCotton yield data for 1950–1985 probably are significantly exaggerated owing to underreporting of area cropped and over reporting of harvests

^bWater use for raw cotton is probably significantly underestimated for 1950–1985; see footnote 1

8.2 Soviet Period

During the Civil War (1919–1924) following the Bolshevik seizure of power, irrigation systems were destroyed or idled (Karimov 1995; Pankova et al. 1996, pp. 76–77). The irrigated area decreased from 3.2 million ha in 1913 to 1.7 million in 1922. The cotton area shrank to a little over 100,000 ha and average yields fell to near 7 centnars/ha. With the solidification of Soviet power in Central Asia, Moscow ordered the restoration and repair of irrigation systems, which was completed between 1925 and 1928. At this time, although there were significant variations from one place to another, the crop structure for the Aral Sea Basin in terms of the total area sown was grains, 30–40 %, perennial grasses, 30 %, rice, 5–25 %, and cotton no more than 20–25 % (Pankova et al. 1996, p. 78).

The traditional system of irrigated agriculture in the Aral Sea Basin was essentially preserved until the mid 1920s. This system, developed over thousands of years, had survived wars, social collapse, natural catastrophes, and the Tsarist conquest of the region. It had both a land use and administrative component. In terms of the former, some 90 % of the irrigated area consisted of small, individually managed farms of 2–3 ha (Siprozhidnikov 1991). Extended families, some of whom

owned the land and some of whom rented the land or worked it as tenants of large landowners for a share of the crop, typically operated these farms. The farms were divided into irrigated fields of 0.3–0.8 ha with permanent low walls lined with trees. Farmers used primitive irrigation technologies based on hand labor supplemented by draft animals. Animal wastes were used as fertilizer. Filtration losses in the irrigation system were as much as 30 %. Irrigation systems were not built according to any overall plan and they lacked control structures, drainage canals and discharge canals to convey runoff from fields.

We might expect such systems to be unsustainable as a result of rapid water logging, soil salinization and falling crop yields. But they obviously weren't. The principles of irrigated farming developed by trial and error over the centuries were sound. The small size of the flooded fields ensured even distribution of the water and the absence of any wasteful runoff. The low walls that surrounded these sectors acted to absorb and accumulate salt, preventing soil salinization. The trees planted along the walls transpired excess water and thereby acted to control water logging as well as lowering wind speeds over the fields, which reduced evaporative losses from the soil. The trees also served as a fuel source. Water was used efficiently. Average withdrawals, including filtration losses on the fields and in delivery canals, are estimated to have been 10,700–11,500 m³/ha.

The administrative-governance system of irrigation had also evolved over a lengthy period. The basic principle was central government control of water management but local responsibility for operation and maintenance of the water management system (Karimov 1997, pp. 8–11; Karimov 1998). Islamic law (*Sharia*) saw water as social property and did not allow private ownership of it. Local authorities assigned water use rights to farmers and ensured the maintenance of irrigation facilities for distributing water to them. Higher levels of government made sure that local officials fulfilled their responsibilities and handled disputes between regions (e.g., Samarkand and Bukhara on the Zeravshan River) or that couldn't be resolved by local leaders.

The government required water users to both build and maintain the irrigation system. This was managed through a complicated system of obligatory annual work to clean canals of sediments, repair dams and other facilities, and deal with any other maintenance or construction issues that needed attention. Authorities also collected taxes for water used in irrigation and fines from those who didn't appear for their obligatory duties. They used the collected funds to finance construction and maintenance of the irrigation systems.

The irrigation water management system operated through a hierarchy of water technicians/bureaucrats (Karimov 1997, pp. 8–11, 1998). For example, during the nineteenth century in Bukhara Khanate the chief Vizier of the state (known as the *Atalyk*) was in charge of irrigation. The *Mirab* (manager) of the main irrigation canal was subordinate to him and responsible for water distribution from and maintenance of this facility. The *Mirabs* of the main distributary canals were next in the hierarchy and had the same responsibilities for the facilities under their control. The *Mirabs* of the canals for distribution of water to individual fields were at the bottom of the management system. There were also "observers"

(*Panzhbegi* and *Obron*) to ensure that the withdrawals at critical diversion points along the distributary canals were according to the limitations set by higher authorities and personnel known as *Obandozy* who were assigned responsibility to make sure the orders of the *Atalyk* were delivered to the *Mirabs* of the main canals. This system made it possible to determine who was responsible for problems in the system and to punish the guilty (sometimes severely).

The traditional system of irrigated agriculture was adjusted to the environmental constraints of an arid environment and provided strong incentives for farming families to cooperate in the maintenance of irrigation systems as well as to use both land and water carefully (Siprozhidnikov 1991; Karimov 1998). The Soviets could have kept the best aspects of this system while carefully and judiciously introducing more modern technology, where appropriate, and pursuing a program of land reform and redistribution to give land to the landless peasantry. Instead, they chose to institute historically unprecedented changes in irrigated agriculture in the Aral Sea Basin that radically and permanently changed the face of agriculture and peasant life here (An excellent treatment of the devastating changes wrought on farmers and agriculture in Uzbekistan under the Soviets is provided in Thurman 1999).

The primary motivations were two: (1) deeply held beliefs among the Bolshevik leadership and intelligentsia that the traditional (in their view 'feudal') irrigation and agricultural system in Central Asia was primitive, backward, and inefficient, as well as exploitative and oppressive of the peasantry that formed its basis and (2) the need to institute state control of irrigation and agriculture, as well as individual farming, in order to dramatically expand production of cotton (Askochenskiy 1967, pp. 13–20; Siprozhidnikov 1991). Thus, in the view of the Bolsheviks this 'corrupt and worthless' system had to be entirely destroyed and replaced by centrally controlled, modern, large-scale, equipment intensive irrigation on the industrial model with tight government oversight where the peasantry rather than owners/managers of the land and water were simply employees executing the state economic plan. The first steps, instituted by decree in 1925, nationalized all lands and began confiscation of large landholdings for redistribution to small landholders and landless peasants (Karimov 1995). For example, in Uzbekistan, which accounted for the largest share of the irrigated area in the Aral Sea Basin, large landholders controlled more than half the irrigated territory.

Nevertheless, most of the irrigated area remained under private management. Over the next few years, the Soviet government instituted other major changes. Individual farms were amalgamated into larger, supposedly more efficient units (Siprozhidnikov 1991). As a part of this process, and contrary to promises made, the small irrigation fields of 0.3–0.8 ha were combined into larger units, averaging 3.5 ha, resulting in the destruction of the earthen walls separating them and the uprooting of the trees growing on them. The area of irrigation grew, mainly by conversion of lands formerly used for growing trees or kept in fallow within the bounds of irrigation systems. Owing to such actions, water logging and soil salinization significantly worsened. The area devoted to cotton grew rapidly, but because yields were far below pre-Revolutionary levels the harvest remained less than in

1913. Average irrigation water withdrawals in Uzbekistan rose from 10,000 to 13,000 m³/ha. Water waste and losses in irrigation sharply increased.

As elsewhere in the USSR, massive collectivization of agriculture began in Central Asia in 1929. Soviet authorities forced individual farms to combine into *Kolhozy* (Collective Farms), while *Sovkhozy* (State Farms) were established on newly irrigated lands. Farmers' use of distinct, separate portions of the land was abolished and people were organized into 'teams', working the land in common. The main goal was to reach 'cotton independence' by the end of the first 5-year Plan in 1933 (Pankova et al. 1996; pp. 78–81; Karimov 1995). Cotton plantings grew to over 50 % of the sown area and domestically produced cotton rose from 59 % to 97 % of national needs. However, yields remained below 8 centners/ha while water use per centner skyrocketed to 1,800 m³ compared to around 1,200 m³ in the early 1920s (Table 8.1).

The situation improved during the remaining years of the decade as authorities eased the more onerous aspects of collectivization and slowed the pace of its implementation. Renovation of irrigation systems and mechanization of fieldwork slightly lowered water use. By 1940 the irrigated area rose to 3.8 million ha but cotton's percentage of that total fell to 36 %. Average cotton yields in the Aral Sea Basin nearly tripled.

By the end of the decade collectivization was firmly in place. The lasting legacy of this social and economic transformation was destruction of traditional irrigation in the Aral Sea Basin, which converted irrigated agriculture here into a completely state controlled enterprise and set the stage for subsequent developments in irrigation for the rest of the Soviet period.

Even though Central Asia suffered no invasion, the war years (1940–1945) saw deterioration of irrigated agriculture (Pankova et al. 1996, p. 74; Karimov 1995). The irrigated area shrank, cotton plantings dropped nearly 20 % and yields of cotton fell to 10 centners/ha as water use per centner declined sharply. Irrigation more than recovered by 1950 as the irrigated area regained prewar levels, cotton hectareage increased to 1.6 million ha (42 % of the irrigated area), cotton yields doubled to 20 centners/ha, and water use per centner of cotton dropped to 800 m³.

Irrigation in the Aral Sea Basin underwent steady expansion from 1950 to 1965, reaching nearly 5 million ha (Table 8.1) (Pankova et al. 1996, pp 76–77; Karimov 1995). The Soviet government emphasized expanding irrigation in older irrigated areas such as the Bukhhara Oasis, the Fergana Valley, and the lower Amu Darya and Syr Darya as well as in the zones of more recent irrigation (e.g., Golodnaya and Karshi steppes) (Fig. 8.1). Construction on the Kara-Kum Canal, the largest capacity and longest irrigation canal in the former USSR, started in 1954. Irrigation during this period expanded onto the lower lying portions of the piedmont plains which have poor drainage and are natural accumulators of salt flowing in groundwater from higher territory. This exacerbated the already serious problems of water logging, and soil salinization.

What to do with increasing amounts of saline irrigation drainage water became a serious problem. Much of it was simply dumped into rivers, worsening their water quality. Drainage water also began to flow into desert depressions forming

permanent lakes. Today, the largest of these are Sarykamysb in Turkmenistan and Arnasay in Uzbekistan, each of which has grown to several thousand km² in area (Fig. 8.1). From 1950 to 1965, irrigation water withdrawals in Uzbekistan, the republic with by far the largest irrigated area, rose 1.25 fold while irrigation drainage flows grew more than threefold.

Construction of very large irrigation systems encompassing hundreds of thousands of hectares (e.g., Golodnaya and Karshi steppes of Uzbekistan) and extending well into the deserts started during these years. These were built on an industrial basis and included social amenities and infrastructure (houses, stores and entertainment and recreational facilities) and communication networks (roads, telephones lines etc.). To facilitate use of larger tractors and other equipment, individual field size was dramatically increased to as much as 100 ha (Siprozhidnikov 1991). These new systems were supposed to improve irrigation conditions and performance. However, they did the opposite. The huge fields were impossible to irrigate evenly, requiring application of excessive quantities of water. This in turn led to soil erosion, rising ground water levels and water logging, secondary salinization, increased water use and lowered yields. Furthermore, some of the areas had naturally saline soils, which required annual applications of water to leach the salts prior to the start of the irrigation season. Another major problem was that the push to expand the irrigated area took precedence over ensuring the proper construction of irrigation systems. Construction brigades frequently disregarded the requirement to install drainage facilities in the drive to bring on-line the maximum newly irrigated area.

The Cotton hectareage grew to 2.3 million or 48 % of the irrigated area by 1965 (Table 8.1) (Pankova et al. 1996, pp. 76–85). Yields slowly increased to 23 centners/ha. During this period, fertilizer use for cotton rose rapidly. Average water withdrawals in the Aral Sea Basin rose to around 17,000 m³/ha with about 11,000 m³/ha (64 %) ‘lost’, i.e., not going for plant growth needs. Similar figures for the mid-1920s, prior to the Soviet transformation of irrigated agriculture, are around 10,000 and 5,000, respectively.

The next 20 years, 1965–1985, saw rapid development of irrigation in the Aral Sea Basin, with the irrigated area approaching 7 million ha by the end of the period (Karimov 1995).

The period from 1980 to 1985 was characterized by very rapid growth as irrigators attempted to maintain cotton harvests in the face of declining yields and also expand the irrigated area devoted to grains. The main emphasis was on expanding irrigation in newly irrigated zones, including the Golodnaya, Djizak, Karshi and Kashka Darya steppes, and along the Amu-Bukhara Canal (which was under construction) in Uzbekistan and in the Yavansk Valley in Tajikistan (Fig. 8.1). They also continued extension of the Kara-Kum Canal in Turkmenistan.

This was the era of large (and very large) dam and reservoir construction along the Amu Darya, Syr Darya and their tributaries (Pankova et al. 1996, p. 76; Micklin 1991, pp. 30–32; Dukhovnyy 1993, pp 260–261). The largest of these are the Toktogul, Andizhan, Kayrakkum, Charvak and Chardarya along the former river and its main tributaries, the Naryn, Karadarya, and Chirchik, and the Tyuyamuyun

and Nurek on the latter river and its chief tributary, the Vakhsh. The fundamental purpose was flow regulation to provide more water for irrigation (by storing spring high flows for use during summer) and provision of hydropower, much of which would be used for powering irrigation pumps. By the 1980s, they had nearly completely regulated the Syr Darya's flow whereas the flow of the Amu Darya was largely controlled.

The Soviet government devoted much attention to installing collector-drainage networks to cope with the growing problems of rising groundwater levels, water logging and secondary salinization. However, this increased return drainage flows into rivers substantially, worsening their quality. Another major goal was raising the efficiency of irrigation systems. Until 1980, withdrawals increased, reaching a peak somewhere between 17,000 and 20,000 m³/ha, but by 1985 they fell to around 16,000–19,000 (Table 8.1). Water losses in irrigation systems peaked in the 1970s between 11–12,000 m³/ha and fell to around 10,000 m³/ha by 1985 (Pankova et al. 1996, p. 84, Fig. 14). In an attempt to maintain cotton yields, the use of mineral fertilizers and pesticides grew enormously, also contributing to river pollution owing to return flows from irrigated fields. Cotton's percentage of the irrigated area fell slightly to 44 % by 1985. Yields rose to a peak 29 centners/ha in 1980 (in the 1930s, they had been as low as 5) but dropped to 26 centners/ha by 1985. However, the late 1970s and early 1980s were the time of the infamous 'cotton scandals' when harvest and yield data were purposely exaggerated; hence the 1980 figure may be high by as much as 20 % (Thurman 1999, pp. 41 and 46–47)

With the rapid growth of withdrawals for irrigation, the water resources of the Amu Darya and Syr Darya were approaching exhaustion. As a result, little river flow reached the Aral Sea and its level steadily fell. Central Asian political leaders and national and regional water managers in the late 1960s began to push hard for implementation of a grandiose plans to divert huge quantities of water from Siberian rivers (Ob and Irtysh) to Central Asia (see Chap. 16 for a detailed discussion of this project). The major purpose was to provide water to continue expanding irrigation, not replenish the drying Aral. Experts completed the design of this project by the late 1970s. Although there was considerable opposition to the endeavor from nationalist writers, environmentalists, and scientists in Russia, it appeared on the verge of implementation by the early 1980s. However, after Gorbachev assumed leadership in 1985, these plans were vehemently attacked as environmentally dangerous and economically unjustified. The project was put on permanent hold in 1986. Moscow told Central Asians they would and could get along with the water available within the region. Central Asian political leaders and water managers remain bitter about the cancellation of the Siberian project which they believe was promised them by Moscow in exchange for growing ever more cotton.

The decades-long expansion of irrigation in the Aral Sea Basin greatly slowed during the last years of the Soviet regime (1985–1991) (Pankova et al. 1996, pp. 60–82; Karimov 1995). The formerly powerful and rich water management establishment composed of the national Ministry of Water Management in Moscow

and its republican affiliates that for decades had successfully lobbied for more irrigation lost its influence. With the open approval of the new Gorbachev regime it was publicly, and often bitterly, attacked for squandering state funds on economically and ecologically questionable water development projects and for destroying the Aral Sea through the massive expansion of irrigation in Central Asia. The fresh water resources of the region, given current irrigation practices, were exhausted and there would be no rescue from Siberian rivers. Hence, it was time to cease initiation of major new projects and concentrate on improving irrigation efficiency and dealing with the very serious problems of soil salinization and water logging in already irrigated zones. Another stated government goal was to provide more water to the Aral Sea.

The new emphasis on irrigation improvement had some success (Pankova et al. 1996, pp. 78–84; Karimov 1995, 1998). Cotton decreased to 40 % of the sown area by 1990 with average basin-wide yields rising slightly to 27 centners/ha (Table 8.1). Beginning in the early 1980s, water withdrawals per hectare steadily declined. Renovation and improvement of irrigation systems played a role in this but the main factor was a series of dry years in the 1980s that forced institution of strict limitations on water use. On the negative side, ground water levels continued on the rise, worsening the problems of water logging, as did the process of soil salinization. By 1989, 3.6 million ha, equaling 50 % of the irrigated area in the Aral Sea Basin, suffered from salinization. The volume of drainage return flows was still growing rapidly and composed over 40 % of irrigation withdrawals. Part of this flow reentered rivers, causing average salinity in the lower Amu Darya and Syr Darya to rise to 2–3 g/l by 1990.

8.3 Post-Soviet (Contemporary) Irrigation

The new states of Central Asia formed from the USSR after its collapse at the end of 1991 inherited an irrigation system developed over a 65 year period under the principles of state ownership and tight control, centralized top down management, which allowed little initiative at the local level, a focus on cotton as the chief crop, and the need for large-scale facilities. As independent entities since 1991 they have dealt with this legacy individually. However, given their common history and the integrated nature of the irrigation systems, they face similar problems in adapting what they inherited to the future. This section provides a description and analysis of irrigation in the Aral Sea Basin over the past two decades, including an evaluation of the potential for solving the most serious irrigation issues faced by the basin nations that were formerly part of the USSR.

Table 8.2 Irrigated areas in the Aral Sea Basin in 1995 (million ha)

Country	Amu Darya Basin	%	Syr Darya Basin	%	Aral Sea Basin	%
Uzbekistan	2.48	53	1.80	55	4.28	54
Turkmenistan	1.74	37	0.00	0	1.74	22
Tajikistan	0.43	9	0.29	9	0.72	9
Kazakhstan	0.00	0	0.74	22	0.74	9
Kyrgyzstan	0.00	0	0.46	14	0.46	6
Total	4.65	100	3.29	100	7.94	100

Source: Adapted from World Bank (1998), Table 2
Afghanistan and Iran are excluded from the calculations

Table 8.3 Water withdrawals for Irrigation in the Aral Sea Basin in 1995 (km³)

Country	Amu Darya Basin	Syr Darya Basin	Aral Sea Basin	% of Aral Sea Basin withdrawals	Specific withdrawal (m ³ /ha)	Total basin water withdrawals	Irrigation % of total
Uzbekistan	33.2	19.8	53.0	53.0	12,383	58.0	91
Turkmenistan	22.4	0.0	22.4	22.4	12,874	23.1	97
Tajikistan	7.0	3.3	10.3	10.3	14,306	12.0	86
Kazakhstan	0.0	9.7	9.7	9.7	13,108	11.0	88
Kyrgyzstan	0.0	4.6	4.6	4.6	10,000	5.1	90
Aral Sea Basin	62.6	37.4	100.0	100.0	12,594	109.2	92

Source: Adapted from World Bank (1998), Table 2

8.3.1 Changes in Irrigated Area and Water Withdrawals

The key to improving management of the Aral Sea Basin's water resources (including provision of substantial additional quantities of water for the Aral Sea, the deltas of the Amu Darya and Syr Darya, and for expanding economic uses) is irrigated agriculture. A 1998 World Bank report, based on data provided by the Aral Sea Basin countries that were formerly part of the USSR, cited the irrigated area in the basin in 1995 (excluding Afghanistan and Iran) at 7.94 million ha (World 1998). At that time Uzbekistan had the majority of the irrigated area with Turkmenistan a distant second followed in close order by Tajikistan and Kazakhstan with Kyrgystan somewhat farther back (Table 8.2 and Fig. 8.1). In 1995, irrigation was far and away the chief source of water withdrawals in the basin, accounting for 92 % of the total (Table 8.3). As one would expect, Uzbekistan was also far ahead in water withdrawals followed in order by Turkmenistan, Tajikistan, Kazakhstan, and Kyrgyzstan. The average withdrawal for the Aral Sea Basin was slightly more than 12,500 m³/ha with Tajikistan the highest at 14,306 m³/ha, followed by Kazakhstan, Turkmenistan, Uzbekistan and Kyrgyzstan in descending order.

What has happened to the size of the irrigated area and volume of withdrawals since 1995 is not clear, mainly owing to the difficulty of obtaining comprehensive, consistent data for these parameters by country. An authoritative source, the

Scientific Information Center (SIC) of the Interstate Coordinating Commission for Water Resources (ICWC), the intergovernmental agency whose responsibility is to provide reliable information on the water management situation in the Aral Sea Basin, provides a table on their CAWaterinfo website showing a slight decline in the irrigated area to 7.896 million ha by 2000 and then slow growth of the irrigated area to 8.120 million ha by 2004 (Basic Indicators of Water and Land Use in the Aral Sea Basin 2012). Withdrawals for irrigation are cited as 94 out of a total of 106 km³, for 2000 and 93 out of 104 km³ for 2004. Based on these figures, irrigation accounted for around 91 % of all withdrawals for each year. Dividing withdrawals for irrigation by the irrigated area gives withdrawals per hectare of 11,904 m³/ha in 2000 and 11,453 m³/ha in 2004. The latter figure represents a 9 % reduction from 1995. Victor Dukhovnyy, the head of SIC in a presentation at a major Aral conference in 2008, cited a specific withdrawal figure for the Aral Sea Basin of 12,300 and 11,500 m³/ha for 2006 and 2007 respectively (Dukhovnyy 2008).

A detailed, comprehensive set of data on the irrigated area and irrigation water withdrawals for different years in the Aral Sea basin by country from 1980 to 2010 is provided in a table on the CAWaterinfo website (Dynamics of General Indicators of the Aral Sea Basin States 2012). This table is periodically updated. Unfortunately the figures presented are not entirely consistent with the data discussed above. Tables 8.4 and 8.5 are adapted and modified from this table. According to these data, the irrigated area for the entire Aral Sea Basin rose from 8.09 to 8.201 million ha from 1995 to 2010, an increase of 1.62 %. Turkmenistan had the largest increase over this period at 11.78 % followed by Tajikistan at 7.36 %. The other states showed small decreases in their irrigated areas. The ranking of countries by irrigated area remained the same over the 15-year period with Uzbekistan far ahead, Turkmenistan a distant second, followed in order by Tajikistan, Kazakhstan and Kyrgyzstan. Uzbekistan's, Kazakhstan's and Kyrgyzstan's share of the total irrigated area dropped slightly Turkmenistan and Tajikistan increased their portion of the total a small amount. But according to the area irrigated, the picture of the Aral Sea basin in 2010 was essentially the same as in 1995.

Aggregate water withdrawals for irrigation remained essentially unchanged comparing 1995–2010. They were 90.1 km³ in 1995 and 91.6 km³ in 2010 and constituted, respectively 80 % and 84 % of total withdrawals. The low figure shown for 2000 of 74.6 km³ reflects the severe drought that occurred in 2000 and 2001 forcing a considerable reduction in withdrawals. According to the “Dynamics. . .” (2012) data, there was an even lower withdrawal of 70.8 km³ in 2008 during another period of serious drought. Throughout this period Uzbekistan far and away accounted for the largest share of withdrawals followed by Turkmenistan, Tajikistan, Kazakhstan and Kyrgyzstan. For the basin as a whole, withdrawals per hectare were nearly the same comparing 1995 (11,165 m³/ha) and 2010 (11,169 m³/ha), but showed, as you would expect, significant declines in drought years. Thus, in 2000 these figures were 9,180 and in 2008 equaled 8,638. Comparing 1995 to 2010, all states except Uzbekistan show sizeable drops in withdrawals per hectare. Uzbekistan's withdrawals, on the other hand, grew by nearly 17 %. However, this may not be accurate. The 1995 total withdrawal figure and related per hectare measure for Uzbekistan appears

Table 8.4 Irrigated area in the Aral Sea Basin 1995–2010 (million ha)

Country	1995	%	2000	%	2005	%	2010	%	% change 1995–2010
Uzbekistan	4.466	55.3	4.439	54.6	4.404	54.3	4.373	53.3	–2.1
Turkmenistan	1.672	20.7	1.738	21.4	1.818	22.4	1.869	22.8	11.8
Tajikistan	0.747	9.3	0.750	9.2	0.763	9.4	0.802	9.8	7.4
Kazakhstan	0.758	9.4	0.770	9.5	0.714	8.8	0.750	9.1	–1.1
Kyrgyzstan	0.427	5.3	0.429	5.3	0.411	5.1	0.407	5.0	–4.7
Aral Sea Basin	8.070	100	8.126	100	8.110	100	8.201	100	1.6

Source: Adapted from Dynamics of General Indicators of the Aral Sea Basin States (2012)
Iran and Afghanistan are excluded from the calculations

unrealistically low. If we use the figure from the World Bank study cited above for 1995 (12,383 m³/ha) and compare it to the 2010 figure from Table 8.5 (11,800 m³/ha), then Uzbekistan had a 4.7 % decrease in withdrawals.

8.3.2 Improving Water Use Efficiency in Irrigation

There are three major technical approaches to reduce the quantity of water used in irrigation. Taking substantial areas out of this activity would be the quickest to implement. But this is not considered a wise idea as irrigation is the most important economic activity in the Aral Sea basin and major reductions in it would have severe economic and social welfare impacts. Indeed, as shown above, the irrigated area since the mid-1990s has not shrunk but grown, although at a slow pace. A key argument used to justify increasing the irrigated area is the need to expand food production to meet population growth. Hence, significant water savings through reduction of the irrigated area are unlikely for the foreseeable future. The other two methods for saving significant amounts of water in irrigation are improvements in irrigation efficiency, and switching from higher to lower water use crops. Both of these are considered to have substantial promise.

Determining possible savings from raised efficiency entails estimating the minimum water withdrawal required in a given area for optimal (or near optimal) growth of a specific crop mix. The difference between this figure and what is actually withdrawn represents potential gross savings. However, the net additions to usable water resources would be less, as corrections are necessary to take account of reduced drainage water return flows to rivers associated with reduced aggregate withdrawals. Calculating the “minimum”, (or norm in Soviet irrigation parlance still used in Central Asia) is not easy as it depends on the availability of detailed and accurate data on climate, soil conditions, and crops at a scale sufficiently large to reflect the regional variability in the Aral Sea Basin as well as calculating the minimum obtainable losses in the irrigation water delivery system.

Table 8.5 Water withdrawals for Irrigation in the Aral Sea Basin, 1995–2010

State	1995 (km ³)	% of total	withdrawal per ha (m ³)	2000 (km ³)	% of total	withdrawal per ha (m ³)	2005 (km ³)	% of total	withdrawal per ha (m ³)	2010 (km ³)	% of total	withdrawal per ha (m ³)	increase 1995–2010	withdrawal per ha % increase 1995–2010
Uzbekistan	45.2	50.2	10,121	35.7	47.9	8,042	49.9	54.7	11,331	51.6	56.3	11,800	16.59	
Turkmenistan	24.1	26.7	14,414	20.0	26.8	11,507	22.7	24.9	12,486	22.5	24.6	12,039	-16.48	
Tajikistan	9.6	10.7	12,851	10.2	13.7	13,600	9.7	10.6	12,713	9.3	10.2	11,596	-9.77	
Kazakhstan	8.3	9.2	10,950	6.1	8.2	7,922	6.5	7.1	9,104	5.9	6.4	7,867	-28.16	
Kyrgyzstan	2.9	3.2	6,792	2.6	3.5	6,061	2.5	2.7	6,083	2.3	2.5	5,651	-16.79	
Aral Sea Basin	90.1	100	11,165	74.6	100.0	9,180	91.3	100	11,258	91.6	100.0	11,169	0.04	

Source: Adapted from Dynamics of General Indicators of the Aral Sea Basin States (2012).
Afghanistan and Iran are excluded from the calculations

USSR irrigation experts intensively investigated the question of minimum possible withdrawals under Aral Sea basin climatic conditions and cropping patterns. An authoritative figure cited at the end of the Soviet period for the minimum average field application rate obtainable was 8,500 m³/ha (Polad Zade 1989). Assuming the average losses in the delivery canals could be lowered to 20 % (they remain far higher than this), meaning that 80 % of the water would reach distribution points to the fields, the overall withdrawal would be 10,600 m³/ha. Subtracting this figure from the basin-wide withdrawal shown in Table 8.3 for 1995 of 12,594 m³/ha shows possible savings of 1,994 m³/ha. If we use the withdrawal number for 2010 shown in Table 8.5 of 11,169 m³/ha savings would be considerably lower at 569 m³/ha. The 1995 savings figure, assuming an irrigated area of 7.94 million ha, would translate into a basin-wide gross reduction of 15.8 km³/year. The same calculation made for the 2010 number assuming an irrigated area of 8.2 million ha, would be 4.7 km³/year. Net savings (corrected for reductions in return flows to rivers) would be less. Taking the 1995 case and assuming return flows to rivers at 24 % of withdrawals, typical for the first half of the 1990s, and that they would be reduced by the same percentage as irrigation withdrawals for 1995 (15.8 %), net savings would equal 12 km³/year. The same calculation made for 2010 conditions results in net savings of 3.6 km³/year. The gross figure for 1995 falls within the range of estimated feasible water savings (12.7–18.3 km³) made by the countries of the region in the mid-1990s and the net figure is slightly less than the lower end of the range (World Bank and the ICWC 1996, pp. 24–25).

The savings noted above are based on implementation of modern technologies for reducing irrigation water usage such as lining delivery canals to reduce water losses owing to exfiltration and more precise leveling of fields using lasers to ensure even distribution of water. Combining these techniques with Western best management practices (BMP) that include irrigation scheduling using computers and specialized software along with real-time monitoring of soil moisture and crop water needs to determine exactly when and how much water to apply, accurate measuring of the exact amount of water being used, genetic engineering of crops to lower water requirements, and precision farming using satellite imagery and GPS [Global Positioning System] technology could lead to substantially greater savings (Texas Water Development 2012). Thus Israel, with similar climatic conditions to the Aral Sea Basin, but technologically sophisticated irrigation practices, had in the mid 1990s an average withdrawal of 5,590 m³/ha (ICAS 1996, Table 4.1). Such a figure is probably out of reach in the Aral Sea Basin because of the much longer length of water-losing delivery canals and the different crop mix. However, if average water withdrawals for the basin could be lowered to 8,000 m³/ha, as Victor Dukhovnyy, a leading Central Asian irrigation expert during both the Soviet and post Soviet eras (and currently head of the Scientific Information Center of the Interstate Coordinating Water Management Commission) proposed in 1985, gross savings of 36.5 km³ and net savings of 27.7 km³ (27 % of withdrawals) would accrue using the 1995 water withdrawal data (Dukhovnyy 1985). Using the 2010 data, gross savings would be 26 km³ and net savings 19.8 km³ (21.6 % of withdrawals).

One means to obtain considerable water savings in irrigation would be to replace a substantial part of the inefficient furrow irrigation systems, which serve 70 % of the irrigated area in the Aral Sea basin, with drip irrigation that uses much less water per hectare irrigated. However, drip systems are very expensive, require a high level of maintenance, and the drip emitters would be subject to severe plugging problems here owing to the high sediment content of water in the Amu Darya and Syr Darya (Jones 2000). Sprinkler irrigation, widely used in the United States, is also a more efficient irrigation method than the use of furrows. But in the extremely arid conditions of the Aral Sea basin, there would be excessive losses to evaporation from the spray before the droplets reached the ground. Partial mitigation of this problem might be possible through the use of “downcomers” that release the spray close to the ground.

In spite of the reality that irrigation in the Aral Sea basin for the foreseeable future will be based heavily on the existing system dominated by the use of furrows, water savings from implementation of aggressive efficiency improvement efforts could well be significantly larger than indicated by the calculations presented above. This owes to the fact that water wastage and inefficient use is likely considerably greater than reported. There is compelling evidence that official figures provided by the basin states for their irrigation withdrawals are underestimated for several reasons (Schapp 1996/1997). The system of measuring deliveries to “cooperative” users (the former collective and state farms), inadequate during Soviet times, has significantly deteriorated. Usage by the variety of ‘private’ farming types that have developed in the Aral Sea Basin countries since independence (see Chap. 12 for information on these) is even more of a mystery. In the majority of instances, no organized system exists to measure withdrawals.

Frequently, what is reported as farm usage is not based on actual measurement (because measuring equipment is absent or not working) but is an educated guess derived from the established water use “norms” (standards) for the region and farm crop mix left over from Soviet times. It represents the quantity of water that should be delivered to the farm; not what is actually supplied. An Uzbekistan water management expert, relying on careful farm-level studies conducted between 1996 and 2000, clearly and forcefully points out the level of irrigation water wastage:

A dramatic feature of the current situation in water use in the region is that under conditions of water supply limitation (water quotas), the water deficit is aggravated by extremely irrational water use at the on-farm level. Basic water losses take place in the on-farm irrigation network and in a field. At the same time, over-normative water losses at both levels, on average, amount to approximately 4,440 m³ per hectare or 37 percent of total water supply at farm boundaries (Sokolov 2006, p. 65).

He went on to note that most of the water losses in the middle and lower reaches of river basins occur in the conveyance systems’ unlined canals leading from the farm boundaries to the fields and account for 15–35 % of the water delivered to the farm.

The situation has probably not improved in any major way since and may have deteriorated. A 2009 study of Asian Irrigation by the International Water

Management Institute (IWMI) that was funded by the Asian Development Bank (ADB) concluded that poorly maintained and under funded irrigation systems threaten the future of agriculture in Central Asia (IRIN 2009). Victor Dukhovnyy in his PowerPoint presentation at the International Aral Conference held in Tashkent Uzbekistan in 2008 provided a list of the key problems plaguing irrigation in the Aral sea basin (Dukhovnyy 2008): (1) lack of attention to water conservation; (2) decreased accuracy of water accounting; (3) deterioration of water infrastructure in all chains of [the]water hierarchy that leads to loss of controllability; (4) small investments in reconstruction and modernization; (5) increased number of water users; and (5) lack of financing of operational services and, hence, loss of personnel.

Another factor contributing to underreporting of water usage per hectare is exaggeration of the area irrigated as it represents the lands with completed irrigation facilities but is not reduced for those systems that are under repair, not working, or have been removed from production (for example, because of excessive soil salinization or lack of water). Farms and the agricultural/water management hierarchy have an incentive to over-report the area irrigated and under-report water withdrawals as it makes them look better in terms of efficiency, i.e., water use per hectare.

Implementation of a large-scale program for technical improvement of irrigation in the Aral Sea basin would be a gigantic undertaking and require a long period for completion. For the basin as a whole in 1994, the length of main and inter-farm irrigation channels was around 48,000 km; only 28 % of these were lined to reduce filtration (World Bank and the ICWC 1996). The situation was even worse for on-farm canals: over 268,000 km with 21 % lined. In Uzbekistan in the mid 1990s, 10,000 km of main and inter-farm canals needed lining, and nearly 2 million ha with older irrigation systems, nearly one-half the irrigated area, needed reconstruction (Antonov 1996).

8.3.3 Soil Salinity and Drainage Problems

Soil salinization is one of the most serious problems faced by irrigation in the Aral Sea basin. It not only lowers yields but also increases water use owing to the need to flush (leach) salts from the soil prior to spring planting. A 1996 study reported that 50 % of irrigated lands in the basin suffers from this affliction (Pankova et al. 1996, pp. 85–87). The problem does not appear to have diminished in subsequent years. Reportedly, the share of salinized irrigated lands in Uzbekistan increased from around 48 % to around 64 % between 1990 and 2003 (Schillinger 2003). At the 2008 International Aral Sea conference in Tashkent, Dr. Herath Manthritilake, head of the Central Asian section of the International Water Management Institute, reported that over 4 million ha or 55 % of irrigated lands in Kazakhstan, Uzbekistan and Turkmenistan were damaged by salinity (Manthritilake 2008). As a result, cotton and wheat harvests as well as water productivity (yields per cubic meter) in these zones were 20–40 % lower than on non-saline lands. According to a 2001

World Bank study 66 %, 97 %, 80 %, 38 % and 29 % of irrigated lands were salinized to one degree or another in Uzbekistan, Turkmenistan, Kazakhstan, Tadjikistan, and Kyrgyzstan, respectively (World Bank 2001).

Large portions of irrigated lands also suffer from high water tables as a result of the lack of drainage facilities or ones that are inadequate or not working properly. Drainage systems that keep the water table sufficiently deep are exceptionally important for irrigation in dry areas with saline ground water such as are common in the Aral Sea Basin. Field experiments conducted at the end of the Soviet era showed, for example, that in Bukhara Oblast of Uzbekistan, one of that nation's most important irrigated oblasts, it took 26,000 m³/ha to grow cotton and prevent secondary soil salinization where the depth to groundwater was 1 m or less but only 8,000 m³/ha when the water table stood at 3 m or more (Micklin 2000, p. 40). In the former case, most of the water was used to flush salts from the upper layers of the soil rather than for irrigating the crop. Again, since the collapse of the USSR, matters have not improved but grown worse. A detailed and excellent 2003 World Bank report stated that:

Since the collapse of the Soviet Union, both government budgets and farm incomes have fallen dramatically, water management institutions have weakened, and infrastructure maintenance has in many places come to a standstill. Irrigation and drainage (I&D) infrastructure is beginning to fall apart. Canals are silted up or damaged, gates broken or non-existent, and pumps held together by improvised repairs and parts cannibalized from other machinery. Across vast areas, water supply has become erratic, and land salinized and waterlogged (World Bank 2003, p. i).

As drainage systems have deteriorated, vast tracts of land have become either salinized or waterlogged over the last decade, with a corresponding drop in crop yields. Salinization forces farmers to apply ever-greater quantities of water in an attempt to flush the salt out of the soil, making water application even more wasteful than it was before. This raises water tables further, and increases water logging, which further reduces yields and in some areas even damages buildings (World Bank 2003, p. ii).

Of the major irrigation zones, only the Golodnaya Steppe and Khorezm Oasis in Uzbekistan have adequate drainage facilities. Ground water levels are rising nearly everywhere, exacerbating water logging and soil salinization. Disposal of the huge volumes of salinized and polluted (with agricultural chemicals and fertilizers) irrigation drainage water remains a serious problem, although the level of pollution has decreased owing to lower use of toxic chemicals on fields than during Soviet times when these were applied with reckless abandon. These discharges reached 43 km³ annually by the mid-1990s (ICAS 1996, Chap. 6).

An Uzbekistani expert in 1996 estimated the rehabilitation costs for the older irrigation systems in the Aral Sea Basin at \$3,000–4,000/ha (Djalalov 1996). A World Bank sponsored study of the same vintage indicated renovation of irrigation and drainage systems could run to \$3,000/ha (World Bank and the ICWC 1996, p. 25). This document also estimated that 5.4 million (68 %) of the 7.94 million ha of irrigated lands in 1995 needed reconstruction. At \$3,000/ha this would cost \$16 billion and at \$4,000/ha nearly \$22 billion. Considering inflation, the cost of such rehabilitation today would be considerably greater.

Uzbekistan and Turkmenistan with the largest areas under irrigation and the largest share of the systems needing reconstruction would bear the brunt of the bill. It is extremely doubtful that the states of the basin, individually or collectively, have the funds now, or will in the near or mid-term future, to fund so costly a project. Furthermore, the condition of irrigation systems in the basin has deteriorated since independence as funds for maintenance and repair have plummeted; responsibility for system maintenance has fallen between the cracks or been dumped on farm units who are incapable or unwilling to conduct the necessary work; and the supply of replacement parts and equipment that formerly came from other republics of the USSR has dried up. Hence the size of the job to repair the irrigation infrastructure is increasing with time and is another factor driving the cost upward.

One disturbing result of the deteriorating condition of irrigated lands in the Aral Sea Basin has been a steady decline in the yields of most major irrigated crops (ICAS 1996, Chap. 10, Table 8.2). This owes primarily to salinization and water logging and began toward the end of the Soviet period. It has continued and probably accelerated since formation of the independent states of Central Asia. Between 1990 and 1994 yields of cereals fell 19 % in Uzbekistan, 37 % in Kazakhstan, 23 % in Turkmenistan, 50 % in Kyrgyzstan and 59 % in Tajikistan. Cotton yields declined 7 % in Uzbekistan, 31 % in Kazakhstan, 2 % in Turkmenistan, 24 % in Kyrgyzstan and 31 % in Tajikistan. Vegetable yields rose by 23 % in Turkmenistan, held steady in Uzbekistan but fell between 33 % and 68 % for the other states. Other factors such as poor seed quality, a sharp drop in usage of fertilizers and pesticides, poorly timed agricultural operations and ill-timed harvests, and lack of proper crop rotation also contributed to these declines in yields.

8.3.4 Saving Water by Changing the Crop Mix

Switching the crop mix from high water use crops (rice and cotton) more toward lower (grains, vegetables, melons, fruits, and soybeans) could be a relatively low cost means of reducing water use compared to massive technical rehabilitation. In arid regions such as the Aral Sea Basin, rice may require up to 25,000 m³/ha and cotton up to 13,000 m³/ha (Grand Solution 2012). On the other hand, wheat and Sorghum maximally require only 6,500 m³/ha, soybeans 7,000 m³/ha, and tomatoes 8,000 m³/ha. Melons on average need 6,000 m³/ha (FAO 2012, Table 5). Licorice is a crop native to Central Asia that shows considerable promise. It not only has relatively low water needs but field experiments in the first decade of this century have shown that it has the ability to significantly reduce soil salinity. In heavily saline areas of the Fergana Valley in Uzbekistan, salinity in licorice cropped fields fell from 215 to 185 t/ha and yields of cotton in rotation with licorice rose from 0.3–0.6 to 1.5–1.89 t/ha (Manthrithilake 2008). Similar results were obtained with winter wheat.

In fact, the reason irrigation withdrawals per hectare substantially dropped between 1990 and 1995 primarily owed to cropping changes (Table 8.1). The

area devoted to cotton and rice was reduced while the area planted to winter wheat increased. Over this period, Uzbekistan, by far the largest grower of cotton in the Aral Sea basin, shrank its cotton hectareage from 1.83 to 1.491 million ha, a decline of 19 % (Index 2012a). At the same time, the area planted to wheat tripled from 433,000 ha to 1.3 million ha (Index 2012b). Between 1995 and 2011, the pace of decline in cotton hectareage in Uzbekistan greatly slowed with the cotton area falling to 1.34 million ha in 2011, a 10 % decrease. The wheat area for the same time period grew to 1.4 million ha, only an 8 % rise.

Turkmenistan, the second in cotton production, had 623,000 ha under cultivation in 1990. This shrank to 450,000 ha by 1995 (28 % decrease), but then increased to 575,000 ha by 2011, 8 % less than in 1995 (Index 2012c). Wheat area in 1990 was a paltry 60,000 ha but grew rapidly to 437,000 ha by 1995 (a sixfold growth) (Index 2012d). By 2011, the wheat hectareage had doubled to 860,000 ha compared with 1995. The purpose of these changes, however, was not so much water savings but strengthening the national food bases. Significant further reductions in the area planted to cotton is unlikely in either of these countries in the near (or probably even mid-term future) as cotton is an important foreign currency-earning export crop.

In Uzbekistan, the sizable reduction in the area devoted to cotton resulted in a significant reduction of output. In 1990, output of baled cotton was 1.5 million metric tons (mt), by 1995 it had dropped to 1.3 million mt and by 2011 to 981,000 mt (Index 2012e). The 40 % drop in production from 1990 to 2011 is significantly more than the 27 % decline in planted area and indicates a drop in average yield of 33 %. Turkmenistan's 1990 production was 410,523 mt of baled cotton; by 1995 it had shrunk 43 % to 235,227 mt and by 2011 rose 22 % to 286,364 (Index 2012f). From 1990 to 2011, there was a 30 % reduction in production whereas the area planted only decreased by 8 %. Thus the accompanying decline in yields was 73 %. There are, to be sure, year-to-year swings in cotton production owing to changes in climatic and other factors, but the trend since the 1990s is clearly downward in both of these two most important cotton producing countries in the Aral Sea Basin. This is another clear indicator of the general deterioration of irrigated cotton agriculture.

The area given to rice production in the Aral Sea basin also decreased significantly. Kazakhstan, the major rice producer, had 124,000 ha under this crop in 1990. By 1995, rice plantings had fallen to 95,000 (a drop of 23 %) and by 2011 diminished slightly further to 94,000 ha (Index 2012g). Uzbekistan, with the second largest area under rice in the Aral Sea basin, had 145,000 ha planted to this crop in 1990 (Index 2012h). There was little drop in this figure by 1995, but a precipitous decline from 1996 to 2001, with the area falling to 40,000 ha (a 72 % drop). A severe drought afflicted Uzbekistan in 2001 and little water was available in the major rice growing regions in the downstream part of the Amu Darya so they had to make major cutbacks in the area planted to this water intensive crop. The rice hectareage rose in subsequent years, but then again fell reaching 30,000 ha by 2011, only 20 % of what it was in 1990. Certainly the reduction in the area devoted to rice, the most water intensive crop in the Aral Sea basin, has helped reduce aggregate water withdrawals for irrigation and improve the average water use figures for the

mix of crops grown here. Given the very high water needs of rice, shrinkage of the planted area also made a significant contribution to reducing water withdrawals from the Syr and Amu rivers. The contraction of the rice growing areas along the lower course of the Syr Darya has been one of the major factors increasing inflow to the Small Aral Sea and allowing its partial rehabilitation (see Chap. 15).

Owing to the major reductions in the area planted to rice, its production has substantially dropped in both Kazakhstan and Uzbekistan. In 1990, the former nation produced 376,000 mt; by 1995 this had fallen to 120,000 mt, a 68 % drop (Index 2012i). However, the harvest rose to 220,000 t by 2011, an 83 % rise over 1995, even though the area planted essentially remained the same. Average yields would have risen by the same percentage. This likely reflects improved growing practices and the taking out of production of the least suitable lands. For Uzbekistan, the 1990 harvest was 351,000 mt (Index 2012j). By 2001 this had contracted to 44,000 mt, an 87 % drop. By 2011, rice production rose to 75,000 t, a 79 % decrease from 1990. The percentage decline in area planted to rice and the production of rice in Uzbekistan were the same in Uzbekistan between 1990 and 2011, indicating that average yields were essentially the same for these 2 years.

A promising program that has been implemented on a pilot basis in the Fergana Valley, location of intensive and productive irrigation, which includes parts of Uzbekistan, Kyrgyzstan, and Tajikistan, utilizes the concept of Integrated Water Resource Management (IWRM). IWRM is an approach to handling water resources that has been around for decades, but has received renewed attention since the 1990s. A useful definition provided by the Technical Committee of the Global Water Partnership is “a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (Wikipedia 2012).”

8.3.5 Other Measures to Improve Irrigation

The Fergana Valley program was initiated in 1999 with the intent to account for all available water sources within the hydrologic basin, take into account the interests of different water using sectors, involve all stakeholders in decision making and to promote efficient water use in order to benefit public welfare and promote environmental stability (Sokolov 2006). According to Victor Dukhovnyy, introduction of IWRM principles to the management of the Southern Fergana Canal reduced water use during the vegetation period from 1.063 km³ in 2003 to 0.643 km³ in 2007 (Dukhovnyy 2008).

Adoption of governmental policies and laws promoting irrigation water pricing, privatization of land, and giving rights of self-governance and responsibility for management of on-farm and inter-farm irrigation systems to farmer-irrigators would without doubt encourage introduction of water saving practices in the

Aral Sea Basin without massive governmental expenditures (Micklin 1996/1997, p. 228, 1997a, b). The governments of Kazakhstan, Tajikistan, and particularly Kyrgyzstan, have taken some serious steps in terms of these reforms. The leaders of Uzbekistan have certainly talked about these subjects but made few moves toward implementing meaningful policies. Turkmenistan has done practically nothing. Among the key problems hindering further advancements along these lines are governmental resistance based on fear of losing social and economic control, opposition from the former collective (now cooperative) farms and local officials, fear of land speculation and exacerbating rural underemployment and unemployment, lack of means to measure water deliveries to farmers, and the impoverished state of the farming economy (Micklin 2000, pp. 54–67).

The major burden for reducing irrigation usage must rest on Uzbekistan as it has the majority of the irrigated area and irrigation withdrawals in the Aral Sea Basin. Turkmenistan which accounts for a significant share of the irrigated area and withdrawals in the Amu Darya Basin could also make substantial contributions to water savings, particularly given that it had the highest per hectare withdrawals of the five Aral Sea Basin states. The remaining states that were part of the USSR (Tajikistan, Kazakhstan and Kyrgyzstan) irrigate much smaller portions of the basin and withdraw considerably less water. Their possible contributions, although not insignificant, would be much smaller. Afghanistan and Iran withdraw little from the basin; their possible contribution to water savings is nil. This may change in the future for Afghanistan as it has the right under international water law to substantially increase its withdrawals from the Amu Darya.

References

- Antonov VO (1996) Concerning the program for further development of irrigation in Uzbekistan. *Vestnik Arala* 1:7–10
- Askochenskiy AN (1967) Irrigation and watering in the USSR. Kolos, Moscow (in Russian)
- Basic Indicators of Water and Land Use in the Aral Sea Basin (2012) http://www.cawater-info.net/bk/water_land_resources_use/english/docs/table6.pdf. Accessed 11 Jan 2012 (in Russian and English)
- Brown A, Kaser M, Smith G (1994) *The Cambridge encyclopedia of Russia and the former Soviet Union*. Cambridge University Press, Cambridge
- Clem RS (1992) The Frontier and Colonialism in Russian and Soviet Central Asia. In: Lewis RA (ed) *Geographic perspectives on Soviet Central Asia*. Routledge, New York, pp 19–36
- Djalalov GN (1996) Report given by Mr. G.N. Djalalov, Deputy Minister of Water Management for Uzbekistan, at the working meeting of representatives of the water-energy services of Kazakhstan, Uzbekistan, Tajikistan and Kyrgyzstan for preparation of recommendations for the efficient use of the resources of the Naryn-Syr Darya Cascade of reservoirs over the long-term, Almaty, Kazakhstan, 1–2 Oct
- Dukhovnyy V (2008) Water and environmental stability in Central Asia. PowerPoint presentation at the international conference on the problems of the Aral, their influence on the genefund of the population, vegetation and animal world and measures of international cooperation to mitigate their consequences, Tashkent, 12 Mar 2008 (in English)

- Dukhovnyy V (1993) Reclamation and water management of the arid zone. Mekhnat, Tashkent (in Russian)
- Dukhovnyy VA (1985) Save irrigation water! *Gidrotekhnika i melioratsiya* 5:40–43
- Dynamics of General Indicators of the Aral Sea Basin States (2012) http://www.cawater-info.net/analysis/water/asb_dynamics_en.pdf. Updated 5 Dec 2011. Accessed 13 Jan 2012
- FAO (2012) Chapter 2: Crop Water Needs. <http://www.fao.org/docrep/S2022E/s2022e02.htm>. Accessed 23 Jan 2012
- Grand Solution Manual (2012) <http://aboutcivil.com/water-requirements-of-crops.html>. Accessed 23 Jan 2012
- ICAS (1996) Fundamental provisions of water management in the Aral Sea Basin: a common strategy of water allocation, rational water use and protection of water resources, prepared with the assistance of the World Bank, Oct
- Index Mundi (2012a) Uzbekistan cotton area harvested by year. <http://www.indexmundi.com/agriculture/?country=uz&commodity=cotton&graph=area-harvested>. Accessed 23 Jan 2012
- Index Mundi (2012b) Uzbekistan wheat area harvested by year. <http://www.indexmundi.com/agriculture/?country=uz&commodity=wheat&graph=area-harvested>. Accessed 23 Jan 2012
- Index Mundi (2012c) Turkmenistan cotton area harvested by year. <http://www.indexmundi.com/agriculture/?country=tm&commodity=cotton&graph=area-harvested>. Accessed 23 Jan 2012
- Index Mundi (2012d) Turkmenistan wheat area harvested by year. <http://www.indexmundi.com/agriculture/?country=tm&commodity=wheat&graph=area-harvested>. Accessed 23 Jan 2012
- Index Mundi (2012e) Uzbekistan cotton production by year. <http://www.indexmundi.com/agriculture/?country=uz&commodity=cotton&graph=production>. Accessed 23 Jan 2012
- Index Mundi (2012f) Turkmenistan cotton production by year. <http://www.indexmundi.com/agriculture/?country=tm&commodity=cotton&graph=production>. Accessed 23 Jan 2012
- Index Mundi (2012g) Kazakhstan milled rice area harvested by year. <http://www.indexmundi.com/agriculture/?country=kz&commodity=milled-rice&graph=area-harvested>. Accessed 23 Jan 2012
- Index Mundi (2012h) Uzbekistan milled rice Area harvested by year. <http://www.indexmundi.com/agriculture/?country=uz&commodity=milled-rice&graph=area-harvested>. Accessed 23 Jan 2012
- Index Mundi (2012i) Kazakhstan milled rice production by year. <http://www.indexmundi.com/agriculture/?country=kz&commodity=rice&graph=production>. Accessed 23 Jan 2012
- Index Mundi (2012j) Uzbekistan milled rice production by year. <http://www.indexmundi.com/agriculture/?country=uz&commodity=rice&graph=production>. Accessed 23 Jan 2012
- IRIN (2009) CENTRAL ASIA: poorly maintained irrigation systems threaten agriculture. www.irinnews.org/printreport.aspx?reportid=85771. Accessed 19 Jan 2012
- Jones N (2000) Conversation with Mr. N. Jones, Meredith Jones Group, London, 25 (2000)
- Kostyukovskiy VI (1992) Dynamics of the natural complexes of the plains of Turkmenistan under conditions of natural and anthropogenic variations of moisture. *Vodnyye resursy* 4:85–92 (in Russian)
- Karimov A (1998) Water regimes in Central Asia. A paper given at the Aral Sea Basin Workshop, Tashkent, 19–21 May 1998, sponsored by the Social Science Research Council, New York
- Karimov A (1997) Managing water resource scarcity. GFNTI, Tashkent, p 7 (in Russian)
- Karimov E (1995) Man and nature: time to unite. *Ekonomika i statistika* 3:48–50 (in Russian)
- Kes AS, Klyukanova IA (1990) concerning the causes of the fluctuation of the Aral Sea level in the past. *Izvestiya Akademii Nauk SSSR, seriya geograficheskaya* 1:78–86
- Kes AS, Andrianov BP, Itina MA (1980) Dynamics of the hydrographic network and variations of the Aral Sea level. In: *Fluctuation of the moistness of the Aral-Caspian region in the Holocene*. Nauka, Moscow, pp 185–197 (in Russian)
- Lunezheva MK, Kiyatkin AK, Polishchuk VP (1987) Central Asia and Kazakhstan – an ancient region of irrigation. *Gidrotekhnika i melioratsiya* 10:65–70 (in Russian)

- Manthrithilake H (2008) Land and water management issues in Central Asia. PowerPoint presentation at the international conference on the problems of the Aral, their influence on the genefund of the population, vegetation and animal world and measures of international cooperation to mitigate their consequences, Tashkent, 12 Mar 2008 (In Russian and English)
- Micklin PP (2000) Managing water in Central Asia. Central Asian and Caucasian Prospects. The Royal Institute of International Affairs, London
- Micklin PP (1996–1997) Information acquired by the author during a one year assignment as Resident Advisor on Water and Environmental Management Policy to the Government of Uzbekistan, under USAID's Environmental Policy and Technology Project, Sept 1996–Oct 1997
- Micklin PP (1997a) Development of self-governing irrigation systems in Uzbekistan: problems and prospects. Draft final report on the training seminar held in Tashkent, 29–30 Apr 1997, prepared for the Central Asia Mission U.S. agency for international development, Almaty, Kazakhstan under contract No. CCN-0003-Q-14-3165-00 of the Environmental Policy and Technology Project, 25 May 1997
- Micklin PP (1997b) Developing water pricing systems for Uzbekistan: key policy issues and initial steps. Draft final report on the training seminar held in Khodjikit, Uzbekistan, 28 July–1 Aug 1997, prepared for the Central Asia Mission U.S. Agency for International Development, Almaty, Kazakhstan under Contract No. CCN-0003-Q-14-3165-00 of the Environmental Policy and Technology Project, 11 Aug 1997
- Micklin PP (1991) The water management crisis in Soviet Central Asia, The Carl Beck papers in Russian and East European studies, No. 905. The Center for Russian and East European Studies, Pittsburgh
- O'Hara S (2000) Conversations with Dr. S. O'Hara, Department of Geography, University of Nottingham, London, 25 Jan
- Pankova YeI, Aydarov IP, Yamnova IA, Novikova AF, Blarovolin NS (1996) Natural and anthropogenic salinization of soils in the basin of the Aral Sea (geography, genesis, evolution). Rossiyskaya Akademiya Sel'skokhozyaystvennykh Nauk, Moscow
- Polad Zade (1989) Interview with Mr. Polad-Polad Zade, First Deputy Minister of Minvodstroy (Ministry of Water Management Construction for the USSR) Moscow 14 Sept 1989
- Schapp O (1996–1997) Conversations with Mr. Onno Schapp, on-farm irrigation management specialist, WARMAP Project of the European Union's TACIS Program, during the period Oct 1996–Aug 1997 when Philip Micklin worked director of a USAID project in Tashkent
- Schillinger W (2003) Cropping systems research needs in Uzbekistan: a report to the World Bank. As cited in Environmental Justice Foundation (EJF), *white gold: the true cost of cotton*, section titled "Draining the Aral Sea" footnote 25, p 27 (London, 2005)
- Siprozhidnikov KS (1991) Concerning the apparent causes of the falling level of the Aral Sea. *Problemy osvoyeniya pustyn* 6:23–28
- Sokolov V (2006) Experiences with IWRM in the Central Asia and Caucasus Regions. *Water Int* 31(1):59–70
- Texas Water Development Board (2012) Agricultural water conservation, irrigation water use management, best management practices, no date. http://www.twdb.state.tx.us/publications/brochures/conservation/doc/AgBrochure2_irrigation.pdf. Accessed 16 Jan 2012
- Thurman J (1999) The "Command-Administrative System" in cotton farming in Uzbekistan 1920s to present. *Papers on inner Asia*, No. 32, Indiana University Research Institute for inner Asian studies. Bloomington, pp 2–34
- Wikipedia (2012) Integrated water resources management. http://en.wikipedia.org/wiki/Integrated_Water_Resources_Management. Accessed 25 Jan 2012
- World Bank (2003) Irrigation in Central Asia: social, economic and environmental considerations. [siteresources.worldbank.org/ECAEXT/Resources/publications/Irrigation-in-Central-Asia/Irrigation_in_Central_Asia-Full_Document-English](http://www.worldbank.org/ECAEXT/Resources/publications/Irrigation-in-Central-Asia/Irrigation_in_Central_Asia-Full_Document-English) Accessed 21 Jan 2012

- World Bank (2001) Water and environment management project. Sub-component A1. National and regional water and salt management plans. Regional report No. 2. Phase III report – Regional needs and constraints. Supporting volume (Nov). Tashkent: World Bank. As cited in Environmental Justice Foundation (EJF), *white gold: the true cost of cotton*, section titled “Draining a Sea: How Cotton Emptied the Aral” footnote 14, p 27 (London, 2005)
- World Bank (1998) Aral Sea Basin Program (Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan) Water and environmental management project. World Bank, Washington
- World Bank and the ICWC (1996) Developing a regional water management strategy: issues and work plan. Aral Sea Basin Program Technical Paper Series, Washington, April