Water **2010**, *2*, 307-320; doi:10.3390/w2020307

OPEN ACCESS

water

ISSN 2073-4441

www.mdpi.com/journal/water

Article

Facts and Perspectives of Water Reservoirs in Central Asia: A Special Focus on Uzbekistan

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Received: 14 May 2010 / Accepted: 11 June 2010 / Published: 23 June 2010

Abstract: The political transformation of the Central Asian region has induced the implosion of the interconnected physical hydraulic infrastructure and its institutional management system. Land-locked Central Asian countries, with their climatic conditions and transboundary water resources, have been striving to meet their food security, to increase agricultural production, to sustain energy sectors, and to protect the environment. The existing water reservoirs are strategic infrastructures for irrigation and hydropower generation. Upstream countries (Tajikistan and Kyrgyzstan) favor the reservoirs' operation for energy supply, while downstream countries (Uzbekistan, Turkmenistan and Kazakhstan) push for irrigation use. This paper provides an overview of the current challenges and perspectives (technical, institutional, and legal regulations) and presents recommendations for the sustainable management of man-made water reservoirs in Uzbekistan.

Keywords: transboundary waters; dam management; water reservoirs; irrigation; hydropower; sedimentation; water policy

1. Introduction

After the disintegration of the former Soviet Union, transboundary water management and governance have become a hot topic in Central Asia over the last two decades [1-3]. In fact, the United Nations Development Program (UNDP) [4] report that the Central Asian region loses $1.7 billion per year, *i.e.*, three percent of the region's GDP (Gross Domestic Product), from the poor water management that lowers the agricultural yields. Moreover, some 22 million people depend, directly or indirectly, on irrigated agriculture in these countries [5]. The sustainability of irrigated agriculture is one of the main platforms for food security, employment, livelihoods, and environmental protection in Central Asia.

The Central Asia countries (Tajikistan, Kyrgyzstan, Kazakhstan, Turkmenistan, and Uzbekistan) have inherited an interconnected and sophisticated hydraulic infrastructure system from the Soviet era. As described by Libert *et al.* [6] and Rakhmatullaev *et al.* [7], from an engineering perspective, the hydraulic mission of the Soviet administration was set up to be based upon the construction of large dams and water reservoirs in the mountainous areas of upstream countries (Tajikistan and Kyrgyzstan). This was due to the areas' attractiveness of natural conditions and higher water accumulation per unit area in comparison to the conditions of the plains (lowland) within the downstream countries (Uzbekistan, Kazakhstan, and Turkmenistan). On the other hand, the lowlands were suitable for practicing irrigated agriculture and for growing water intensive agricultural crops (cotton, rice, and wheat).

The recent pivotal area of discussions is hydropower *versus* irrigation for the operation of reservoirs and dams in Central Asia, e.g., the Toktogul reservoir in Kyrgyzstan (Syr Darya River Basin) and the construction of the Rogun hydropower station in Tajikistan (Amu Darya River Basin).

In fact, in the region, various paramount technical, operational, and biophysical aspects that are not transboundary issues impact the sustainable operation and management of dams and their associated water reservoirs. Examples of these aspects include sedimentation, improper operation, overuse of hydraulic infrastructures against designed operational regimes, and the lack of national legal and institutional frameworks for dam safety. Moreover, there is no warning system for alerting downstream countries in the event of technical accidents or natural disasters. These acute issues have to be seriously addressed at the national and regional levels.

Some experts argue that within the region, global warming will have a severe impact on the formation of water resources in the mountain systems of the Tian Shan and Pamir-Alay because of the decrease in ice cover [8]. In fact, these mountain systems are major contributors to the watersheds of the region. Research reports that since the beginning of the 20th century, a general warming trend in Central Asia, on the order of 1–2 ℃, has been observed, which might have a potential impact on the regional temperature, evaporation, and precipitation regimes [9]. According to the estimates made by the Uzbekistan Hydro Meteorological Committee, the pessimistic scenarios of water resource transformations describe a reduction of the river discharges by 15–20% and 20–30% for the Syr Darya River and the Amu Darya River, respectively [10]. Water resources will be more stringent, and transboundary management of these hydraulic infrastructures has to be conducted in harmonious cooperation to meet the current concerns of all involved parties.

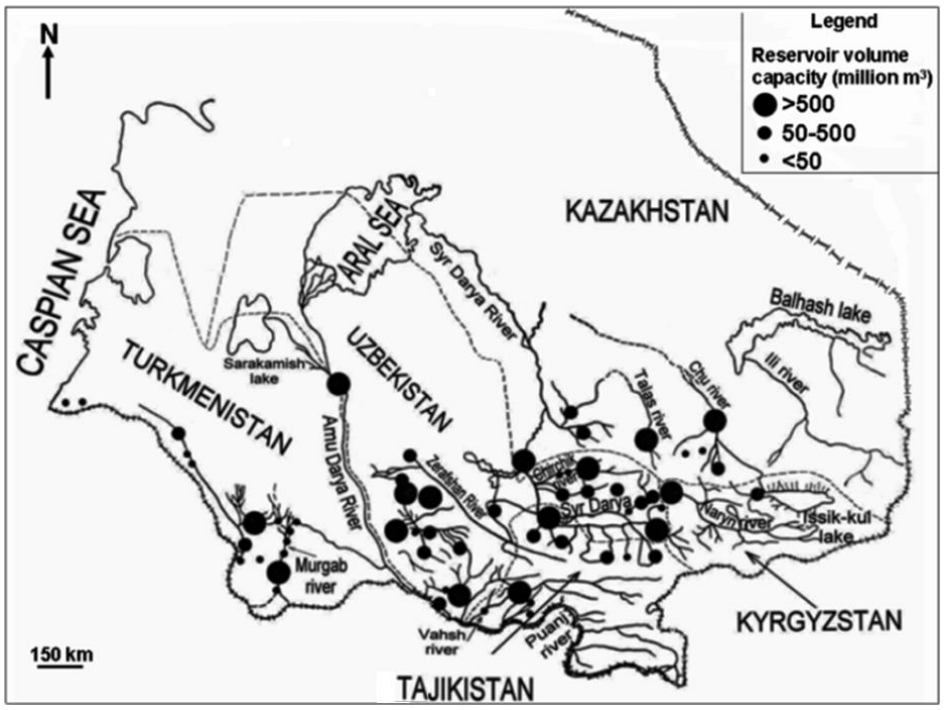
The World Commission on Dams (WCD) [11] outlines that large hydraulic infrastructures, such as dams and their associated water reservoirs, have played an important role in the regional development of many parts of the world. In the Central Asian region, where natural precipitation is erratic or seasonal, with uneven spatial and temporal water resource distribution, and arid climatic conditions, man-made water reservoirs play a particularly paramount role [12]. In fact, reservoirs store water during wet periods to make it available during dry periods, and in so doing, regulate floods, generate hydropower, and enable irrigation [13]. Thus, it is important to discuss the technical, management aspects of dams and the dams' associated water reservoirs.

The primary objective of this paper is to review the situation on dams and water reservoirs in terms of the technical, legal, and institutional aspects of the new geopolitical realities within the region. Special attention will be paid to the Uzbekistan experience and on improving the country's large hydraulic infrastructure safety framework. Perspectives and recommendations are given for improving hydraulic infrastructure operation and management in Uzbekistan, and for examining, on a Central Asian level, the regional dialogue for cooperation.

2. Water Reservoirs in Central Asia

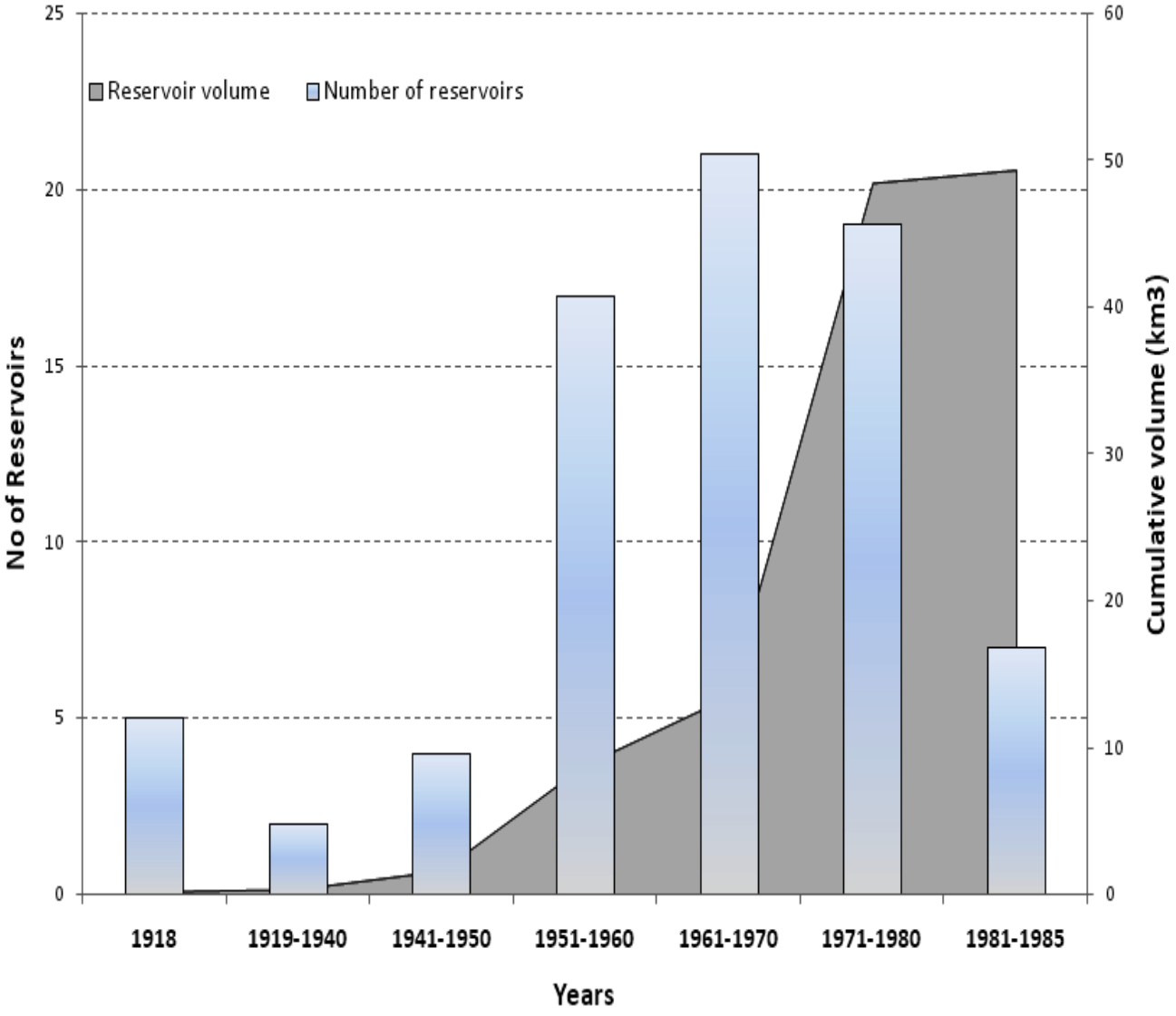
In the Central Asian region, the first water reservoirs were constructed as early as the tenth through 11th centuries [14,15]. For the regulation of the region's rivers, hundreds of man-made water reservoirs were constructed to mitigate the natural shortage of water resources. Additionally, these reservoirs generated hydropower, irrigation, and water supplies for municipalities and industry, and provided water for recreational purposes (Figure 1).

Figure 1. Schematic location of the main water reservoirs and their volume capacities in Central Asia (excluding reservoirs in the central and northern region of Kazakhstan), adopted and modified from [15].



The era of massive water reservoir construction was documented in the late 1900s. From 1950 to 1980, more than 60 large reservoirs were constructed in the region (Figure 2). The gross reservoir volume has increased by 50-fold, from 0.17 to 49.3 km^3, as a part of the unprecedented increase of water storage capacities around the globe. Most of the dams and water reservoirs in the region have been constructed for irrigation purposes, with a few for hydropower generation. As a result, over a period of 90 years (1913–2003), the areas under irrigation have increased three-fold in Central Asia, e.g., from 4.51 million ha in 1960 to 6.92 million ha in 1980, and to 7.85 million ha in 2000 [16,17]. The peak of dam construction is dated to the Soviet period, when the USSR's policy was aimed at expanding irrigated lands for the mass production of cotton [18].

Figure 2. The number of reservoirs constructed and the cumulative volume capacity in Central Asia during the last century [18].



At the moment, there are more than 290 water reservoirs in Central Asia, with a total volume capacity of over 163 km^3. They regulate more than 50% of the monthly regional river flow, and the area occupied by the reservoirs constitutes roughly 6% of the irrigated areas of Central Asian countries (Table 1) [19]. For example, on average, about 30% of irrigation water is delivered from reservoirs in

the region. The percentages range up to 54% in Turkmenistan and down to as low as 13% in Kyrgyzstan.

Table 1. Distribution of water reservoirs by total volume and numbers in Central Asian countries. CA = Central Asia.

Country	Total reservoir volume capacity (km^3)	Number of reservoirs	Irrigation water from reservoirs (%)
Kazakhstan *	88.8	180 *	32
Kyrgyzstan	23.5	18	13
Tajikistan	29	19	28
Turkmenistan	2.89	18	54
Uzbekistan	19	55	24
Total in CA	163.19	290	Average 30

* The number of reservoirs represents the whole of Kazakhstan.

There are 45 large-scale hydropower stations, with a gross capacity of 36.7 GWh/year, on large water reservoirs in the Central Asian region [20]. However, only 11% of the hydropower is generated in Uzbekistan, whereas more than 90% is produced in Tajikistan [21]. Kyrgyzstan and Tajikistan have about 78% of the total hydropower potential of the region, but utilize only 10% of that potential.

Reservoirs in Uzbekistan

The total number of man-made water reservoirs in Uzbekistan is 55 (Table 2) [22].

Table 2. Distribution of water reservoirs in Uzbekistan by administrative boundaries.

Province	Number	Useful Volume Capacity (km^3)	Province	Number	Useful Volume Capacity (km^3)
Amu Darya River Basin			*Syr Darya River Basin*		
Khorezm	1	4.5	Andijan	3	1.7
Kashkadarya	14	2.3	Tashkent	5	1.9
Samarkand	7	1.1	Fergana	4	0.25
Surkhandarya	4	0.9	Namangan	7	0.23
Navoi	2	0.8	Jizzak	4	0.18
Bukhara	2	0.4	Syrdarya	2	0.01
Total	30	10.1		25	4.45

In Uzbekistan, the total gross volume capacity of all reservoirs is about 19 km^3, and the useful volume capacity is about 14.5 km^3, whereas the total surface area of reservoirs is estimated at *ca.*, 1,450 km^2. The total reservoir volume capacity is defined as the maximum amount of water stored, whereas the useful volume capacity is the actual available water storage. The arithmetical difference between the two values is defined as the dead storage of a reservoir. In other words, the dead volume storage in a reservoir is determined as the storage volume between the stream bed and the lowest elevation from which water can be withdrawn by gravity [23]. The difference observed between the total capacity and the useful capacity is an indicator of the efficiency of dam and water management.

The 4.5 km^3 difference represents a loss of 26% that is due to topographic peculiarities, *i.e.*, most of the water reservoirs are constructed in the lowlands of Uzbekistan.

Nine major reservoirs constitute about 86% (16.8 km^3) of the total reservoir volume capacity, and about 94% (1362 km^2) of the total surface area (Table 3) [24]. Almost 90% of all dams are used for irrigation purposes, whereas two are used for hydropower (Andijan and Charvak). About 75% of dams were constructed in the 30-year period from 1961 to 1990, with 93% of the total reservoir capacity coming from a time known as the "Soviet Period". At the moment, three water reservoirs, for increasing the water storage capacities, are being constructed in the Namangan, Jizzak, and Samarkand provinces of Uzbekistan.

All dams and their associated water reservoirs are aging, and numerous biophysical, technical, and management issues need to be addressed in order to attain a sustainable management of water resources and hydraulic infrastructures. For hydraulic structures which have a transboundary importance, these issues should be addressed, in particular, at the national level.

3. Threats to Water Reservoirs in Uzbekistan

Almost all the hydraulic infrastructures in Uzbekistan, but particularly dams and their associated water reservoirs, are aging (constructed during the 1930–1940 period) [25]. Thus, there is some urgency to perform operations that would improve the safety of such structures in order to avoid devastating emergency situations in the event of technical operational failures or natural phenomena, such as earthquakes. For example, the civil engineering of the dams, in terms of life cycle and survey, and also water practices and legal aspects, are linked to the management of the dams and resources, at different steps and scales. This management is a key point of discussion at the national level, and is very often problematic at an international one (*i.e.*, case of the transboundary rivers).

3.1. Reservoir Sedimentation

A reduced reservoir volume capacity, due to sedimentation, triggers operational and maintenance issues. These issues are exacerbated by uncertainty over the economic feasibility of corrective measures and by environmental and social concerns [26]. Sedimentation is a natural geomorphologic process, but human interference increases its rates. Sedimentation reduces the main reservoir asset, *i.e.*, its volume capacity, over time because of the feeding rivers. It is reported that globally, sedimentation has been observed to cause an annual average of 0.5–1% loss with respect to the volume capacities of small and large reservoirs [11,23]. Palmieri *et al.* [27] reports that the loss in volume capacity requires an annual replacement cost of 13 billion US dollars.

The most recent reports indicate that the average annual reservoir volume loss is estimated at 0.5% in Uzbekistan (Table 3) [24]. The total volume capacities of major reservoirs have decreased by about 20% and the nation's dams' dead storage capacities have decreased by 55%. For example, the dead volume capacities of seven reservoirs decreased by more than 75%. This is an alarming signal that in the future, the sedimentation rates can be unprecedented, with several operational and maintenance problems.

Due to the naturally high turbidity of the watercourses, reservoir sedimentation is an acute issue in Central Asia. In fact, most of the reservoirs have been silted to a great extent. Sedimentation impacts

the guaranteed water supply for the different water users (irrigation, industry, and hydropower) at the national and regional levels.

For example, the direct loss of reservoir volume capacity leads to lower hydropower production capacity available for sale, less irrigated land for food production, and a reduced flood routing capacity. Moreover, the deterioration of water quality in reservoirs can be a major issue, with increasing levels of various contaminants from agriculture, industry, and natural sources, whether organic (pesticides, PCBs, PAHs) or inorganic (trace metals) [12,26]. Dam cavitation and abrasion of conduits, valves, sluice gates, and hydropower turbines dramatically impact hydraulic facilities and structures. Moreover, social aspects can result. For example, the region may be rendered less attractive for tourism, and recreational opportunities can be lost.

Table 3. Loss of reservoir volume (total and dead) of selected major reservoirs in Uzbekistan.

Reservoir	River Basin	Total Volume (Mm^3)	Silted volume (%)	Started to operate (Year)
Talimarjan	Amu Darya	1,525	3.9	1985
Janubiy Surkhan	Surkhan Darya	800	37	1967
Kuyimazar	Amu Darya	310	11.2	1958
Tudakul	Amu Darya	1,200	13.7	1983
Andijan	Kara Darya	1,900	13.4	1970
Kattakurgan	Zerafshan	900	22.5	1953
Chimkurgan	Kashka Darya	500	22.7	1963
Ruslovoy *	Amu Darya	2,340	44.9	1980
Kaparas *	Amu Darya	960	1.9	1983
Average			19	

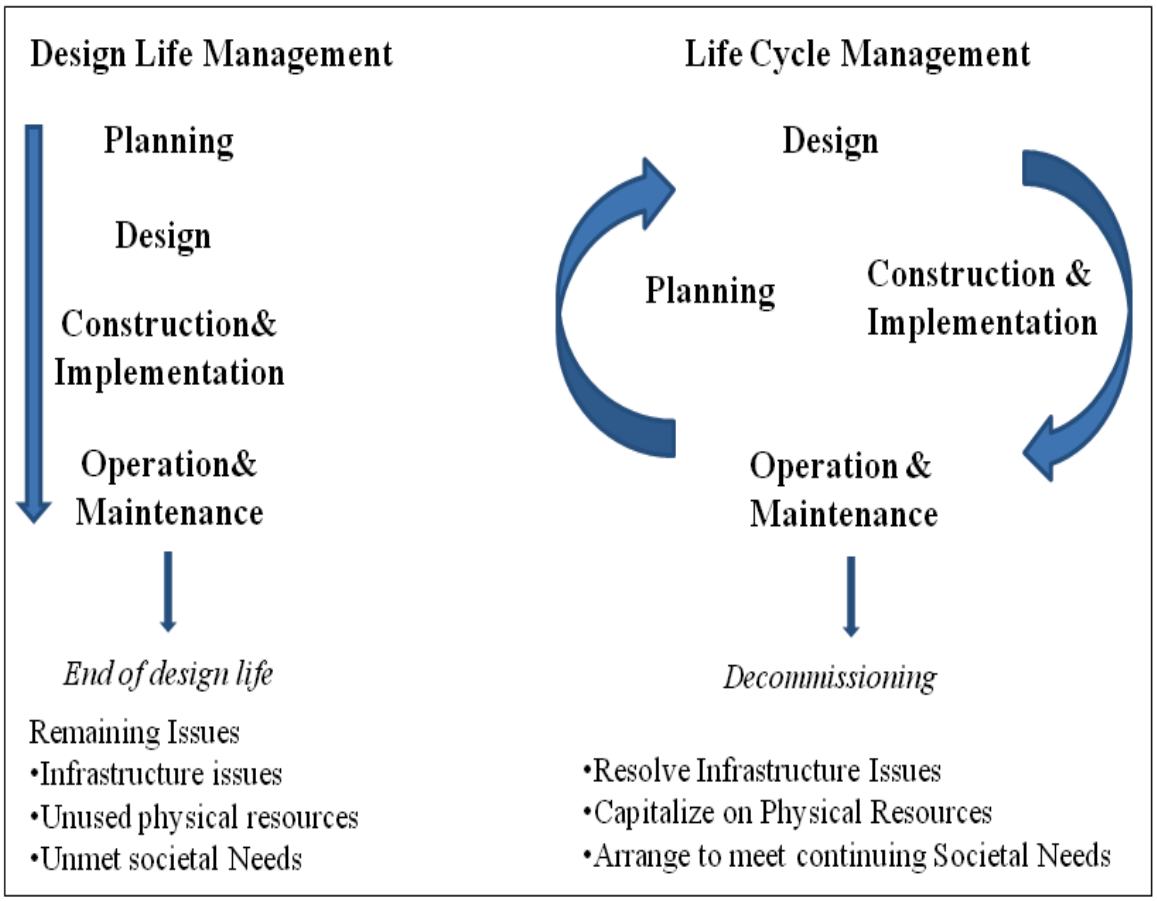
* Tuyamuin is composed of four reservoirs: (1) Ruslovoy—2.34 km^3; (2) Sultansanjar—2.69 km^3; (3) Kaparas—0.96 km^3; (4) Koshbulak—1.81 km^3.

Common engineering practice advocates for a "design for life" approach for dam and reservoir conception. The design for life approach assumes a finite project life, which means that future generations should bear all occurring costs and profits [11,23,26].

Palmieri *et al.* [27] proposed a new "life cycle management" approach for the sustainable management and use of hydraulic infrastructures (Figure 3). The ultimate goal of this approach is sustainable use, where the major functions of the dam are preserved, through good management and maintenance. It means that these hydraulic infrastructures should be considered as economic assets and that through proper mitigation measures, there should be long-term benefits generated for the local populations.

The design life approach follows a linear time-line and assumes that the project will have served its purpose at the end of its design life. In contrast, the concept of life cycle management encourages a cyclic time-line and sustainable use. The main element in this approach is decommissioning. In the design life approach, the financial costs for decommissioning are not foreseen, whereas in the life cycle management, such costs are taken into consideration through a retirement fund, *i.e.*, contributions from benefits and other sources.

Figure 3. The main elements of the "design life" *versus* "life cycle" management approaches (modified from [27]).



3.2. Water Reservoirs Operation Guidelines

It is known that all large scale hydraulic infrastructures, in particular dams and water reservoirs, are designed and constructed according to a design operation regime, which safeguards the durability of the operations. However, the real situation is quite different in Uzbekistan. The weighted decision for the operation of water reservoirs lies in the hand of local government authorities (hokimiyats, *i.e.*, governors), who are responsible for the agricultural production of cotton and wheat [28]. The water management organizations are left with only a technical assistance role for water supply matters. In most cases, the design operation regime is violated. These violations create severe circumstances for the hydraulic infrastructures. Infrastructure fatigue puts additional pressure for the proper management of scare water resources.

3.3. Institutional and Legal Frameworks of Water Reservoirs

The hydraulic infrastructures, in particular dams and their associated water reservoirs, are managed, rehabilitated, and operated by the Ministry of Agriculture and Water Resources of Uzbekistan [29]. The hydropower plants are managed and operated by the State Joint Stock Company, UzbekEnergo. For example, about 11.5% of the power generation is produced through 29 hydropower plants and two

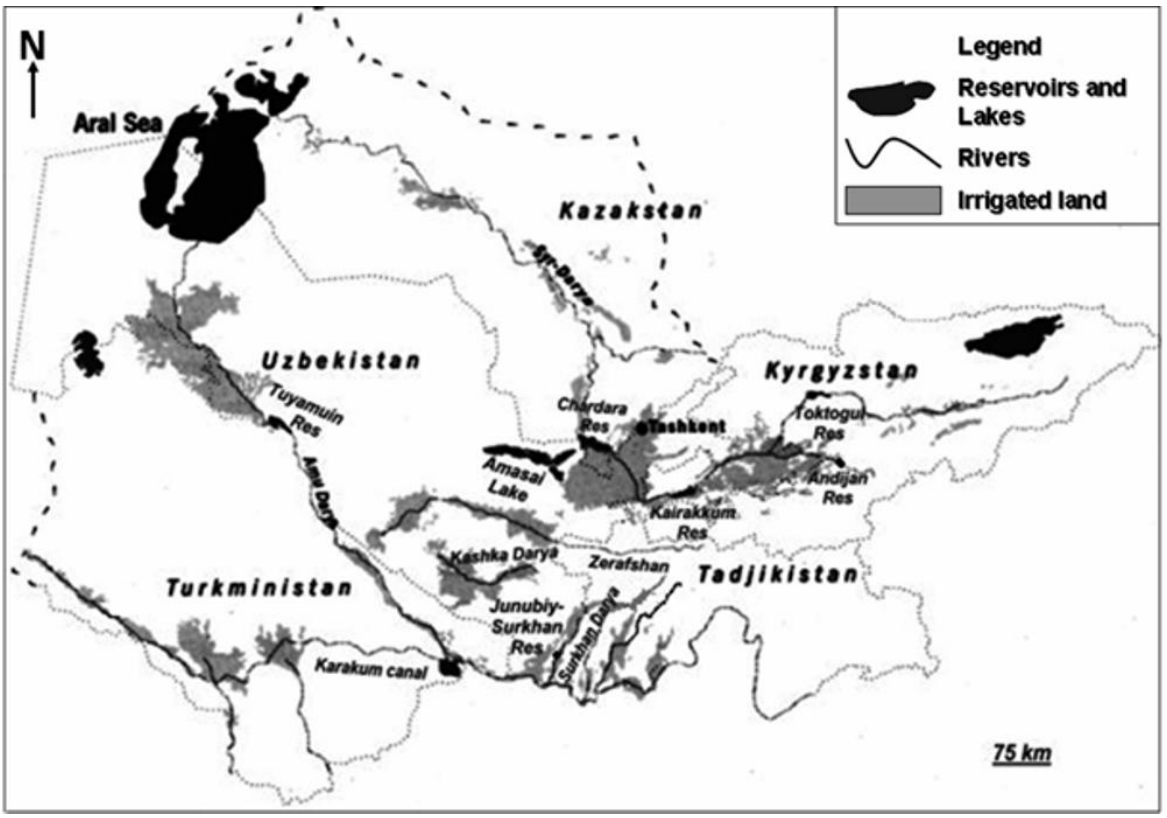
large dams (Charvak and Andijan). There is an overlap of responsibilities of these two state agencies on the management of dams and their associated water reservoirs.

In Uzbekistan, a national law for the safety of hydraulic structures was adopted in 1999. Gosvodkhoznadzor, under the Cabinet of Ministries of the Republic of Uzbekistan, is a state inspection agency that controls and monitors the technical conditions and safety operations of large-scale hydraulic infrastructures [30]. There are almost 273 large hydraulic infrastructures (55 water reservoirs, 35 pumping stations, 29 hydropower plants, 60 irrigation main canals, 64 water-intake schemes, 24 main collectors, and 7 riverbank protection structures). Gosvodkhoznadzor inspects the safety of large hydraulic infrastructures and sanctions the Ministry of Agriculture and Water Resources of Uzbekistan for proper actions and mitigation measures. Unfortunately, in most cases, the recommendations of Gosvodkhoznadzor are only conceived of as suggestions by the Ministry.

4. Transboundary Issues of Water Reservoirs for Uzbekistan

Uneven spatial and temporal water resources, and a Soviet inherited unified hydraulic infrastructure, have raised transboundary reservoir management issues over water resource allocation among the countries of the region (*i.e.*, Kyrgyzstan, Tajikistan, Kazakhstan, Uzbekistan and Turkmenistan). The rivers, such as Syr Darya and Amu Darya, are already regulated by more than 78% and 94% respectively, and attempts for new reservoir projects upstream raise increased concerns for the downstream countries (e.g., the Rogun hydropower station in Tajikistan and the Toktogul reservoir in Kyrgyzstan) (Figure 4).

Figure 4. The major transboundary rivers in Central Asia, modified from [10].



Competition for water resources is prioritized by the downstream countries (Uzbekistan, Turkmenistan, and Kazakhstan) for irrigation, whereas upstream countries (Tajikistan and Kyrgyzstan) use them mainly for hydropower generation [5,14]. There has been a serious conflict related to the water resource management of some hydraulic infrastructures, like the Toktogul reservoir located in Kyrgyzstan in the recent post-Soviet period.

This water storage infrastructure serves the needs of the entire Syr Darya River basin. Its main purpose is to regulate and secure the Syr Darya River flow during the growing season (April–September) for irrigation. It was designed to release 8.5 km^3 of water during the growing season and about 2.8 km^3 during the non-growing season (October–March).

The Toktogul dam's surplus hydropower generation in the summer is transmitted into the former Central Asian Power System Grid for use by the downstream countries of Kazakhstan and Uzbekistan. For compensation, Kazakhstan supplied fossil fuels, and Uzbekistan provided electricity, to Kyrgyzstan for electricity needs in winter months.

However, the situation has significantly changed due to the end of the former Soviet Union. During 1990 to 2000, summer releases declined to 45% and winter releases increased to 55% of the annual discharges [25].

5. Regional Institutional and Legal Frameworks

One important bottleneck, for the sustainable and cooperative management and operation of dams and their associated water reservoirs, lies in the absence of national legal frameworks and appropriate institutions in all the Central Asian countries, except Uzbekistan [9]. After the dissolution of the former Soviet Union, large hydraulic infrastructures have been left without proper attention from the Central Asian countries. For example, in Kazakhstan, hydropower plants are managed by semi-private entities, whereas reservoirs are still operated by the government water management authorities. Therefore, there is always a dispute for the coordinated operation and maintenance of hydropower plant and dam.

International assistance programs have tried to support regional dialogue on the cooperative use and operation of transboundary hydraulic infrastructures, but little success was achieved, due to the cost-sharing of operation and the maintenance price of such transboundary structures. UNECE (United Nations Economic Commission for Europe) is actively participating in the development of a regional agreement on cooperation on dam safety, and in particular, in the information exchange and notification of other countries (in case of accidents with dams) [8].

6. Perspectives and Recommendations

The following key perspectives and recommendations are discussed for the sustainable management of the water reservoirs and dams in the region and Uzbekistan.

6.1. Mini Hydropower Schemes

In the light of hot negotiations among and between riparian states over the water-energy nexus, small hydropower schemes should be advocated in all Central Asian countries as compromises.

The small hydropower schemes are attractive in terms of financial, technical, management, and environmental feasibility aspects. These mini hydropower schemes would not significantly alter, for different water uses upstream and downstream, the hydrological regimes of the main transboundary watercourses. Furthermore these schemes are financially attractive for the international donor communities, and are less environmentally impact-oriented for upstream and downstream riparian ecosystems. Almost all the attractive potential sites for large dam and water reservoirs are used in the region. Another argument for the small hydropower schemes is the issue of seismological conditions at upstream sites. In the event of tectonics, the small hydropower schemes have less devastating effects for local communities, ecosystems, and for states (in terms of financial burdens).

6.2. Institutional and Legal Framework

For a regional cooperation on dams and water reservoirs management in Central Asia, the authors recommend the creation of a regional chapter of the International Commission on Large Dams (ICOLD), which can play a role as a neutral key regional institution on dam safety issues. Under the umbrella of the Central Asia ICOLD, national working groups can cooperate and discuss various topicalities regarding the development of mutually beneficial procedures, regulation norms, and standards on the monitoring of hydro infrastructure safety. The mandates of such an organization could be the harmonization of the cooperation of Central Asian states on dam safety, monitoring procedures, information exchange, and the development of a comprehensive database. This can be a first step to the creation of a regional platform for the discussion of current issues on planning, design, operation, maintenance, and management of large hydraulic structures.

In order to synchronize cooperation on the management of dams and their associated water reservoirs, each country should develop its own laws on safety of hydraulic infrastructures. Only Uzbekistan has adopted such a law in 1999. Only after each country has its own law can a regional legal framework be developed through consultations.

6.3. Mitigation Measures

For a regional cooperation on dams and water reservoirs safety, proper technical and management activities should take place at the national level in order to sustainably operate and manage these sophisticated infrastructures. It is time to review and assess the present technical conditions of all large infrastructures for each country.

The best practices (mitigation measures) can then be shared and duplicated among other regional countries. For example, in Uzbekistan, a new GIS (Geographic Information System), in combination with depth measurement systems, are being used for the operative estimation of reservoir sedimentation volumes [17].

As the infrastructure fatigue will be reached in this century, appropriate planning programs should be designed and implemented, such as a retirement fund for dam and water reservoirs [31]. The retirement fund is intended to accumulate annual contributions made during the life of the dam to pay for any actions required at its retirement, for example, a change of purpose (e.g., recreation, farming, environment creation) from its present irrigation or hydropower generation, and in extreme cases, the partial or complete removal of the dam. However, the partial or full decommissioning of dams would

not be economically feasible in the region, due to the high financial costs, and the lack of existence of real local expertise. A practical approach that can still be attractive to local authorities is to change the dam's or reservoir's purpose.

7. Conclusions

Large hydraulic infrastructures have played an important role for the Central Asian region's development and have brought many benefits, regionally and nationally, through irrigation, hydropower generation, and water supply for industry and recreation. However, these hydraulic structures are facing numerous problematic issues, such as infrastructure fatigue, biophysical issues, and problems with operation and maintenance on national levels, due to the decrease of substantial financial assistance programs.

As the infrastructure fatigue is unavoidable, the new life cycle management approach should be recommended to all national authorities for the sustainable operation of such engineering infrastructures and for the use of scare water resources.

With new geopolitical realms in the region after the collapse of the former Soviet Union and the emergence of new independent states, regional and transboundary issues have arisen for the cooperative management of water resources and the cost sharing of operation and maintenance. In the domain of large hydraulic infrastructure safety issues, transparent legal and institutional frameworks should be developed and adopted, reflecting a transnational good spirit of cooperation.

A regional platform should be developed, such as a branch of the ICOLD, which will serve as a professional union for the harmonized management and the joint operation of dams and water reservoirs on transboundary watercourses.

Acknowledgements

The authors would like to thank the French Embassy in Tashkent for supporting the French-Uzbek cooperation in the field of water sciences. This study has also been supported by INTAS fellowship No. 04-83-3665 and by the French Ministry of Foreign Affairs via the Eiffel fellowship program No. 530909C. However, the views expressed in this paper do not necessarily reflect those of the funding agencies, and no official endorsement should be inferred from it.

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