ENHANCED RISK MANAGEMENT STRATEGIES FOR MITIGATING FUTURE DROUGHTS IN CENTRAL ASIA

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Introduction

Reliable and safe supply of fresh water resources is one of the most important global environmental challenges (Rechkemmer, 2004). Increasing demand for water, following a growing global population and extensive use of water for irrigation and industry, has raised the awareness of our vulnerability to drought. Any deficit or limitation in water supply will be most critical in drought periods, and competing water needs may be the cause of conflicts. The most severe social consequences of drought are found in arid or semi-arid regions where the availability of water is already low under normal conditions.

Glacial and snowmelt is essential for the well being of all Central Asian states and provides over 90 % of their water requirements. Climate change is causing rapid recession of the glaciers, which helps to meet short-term the states ambitious water requirements, but in the long-term decreased runoff and increased evapotranspiration from higher temperatures will result. Additionally, climate change has an effect on the frequency and intensity of extreme droughts, with the consequence of increased exceptional water deficits.

Dams and Reservoirs play a fundamental role in the water supply worldwide, and by contributing to the improvement of water resources management. Dams are practically the only solution for maintaining the present situation or improving it and they enable to reduce droughts and floods.

The existing reservoir system of the Tuyamuyun Hydro Complex (THC) offers highest capability for an adaptation of management strategies (Froebrich et al., 2007). At the lower part of the Amu Darya, in principle the THC reservoirs provide not enough storage capacity for keeping a strategic reserve for covering water deficits and irrigation demands during dry years. Nevertheless past results indicate enhanced reservoir operation for the THC as an effective measure for a rapid and comprehensive improvement of the water quality in water crisis regions (Olsson et al., 2007). The possibility to adapt the operation rules has been demonstrated the potential of the THC to supply the local population (of the lower Amu Darya region) with more potable water of higher quality even subject to a parallel reduction of water deficits.

Sedimentation reduces the storage capacity of reservoirs and thereby, the ability to conserve water for various intended purposes. Consequently, the frequency and magnitude of failures increases. Therefore, the effect of storage capacity losses on the water availability has to be considered within the management of available water resources, especially under water deficit conditions. At any dam or reservoir where sustainable long-term use is to be achieved, it will

be necessary to manage sediments as well as water (Morris and Fan, 1998). Sediment depositional patterns are mostly determined by storage operation of reservoirs. This means that reservoirs are operated to maximize water yield, without considering operational changes to limit storage capacity loss due to sedimentation (Basson and Rooseboom, 1997).
The focus of the study lies on the assessment of ongoing reservoir storage capacity losses of the Tuyamuyun Hydro-Complex (THC) and its effect on the compensation of water deficit volumes during exceptional drought events as occurred 2000-2002. The risk of reservoir storage capacity losses is a serious problem for the future water supply of the lower Amu Darya region. Especially the in-stream Channel Reservoir as the main reservoir of the THC, presents sedimentation processes strongly influenced by the seasonal variation of the Amu Darya inflow. The main proportion of inflowing suspended solids from the Amu Darya is silted in the Channel Reservoir.
The study assesses effects of past and developed reservoir operation strategies for dry years, on siltation processes in the Channel Reservoir, to evaluate the risk of storage capacity losses and the effects on the water availability. Therefore, criteria for applicable risk management strategies for water stress mitigation under dry year conditions can be provided.
The work presented was carried out within the project JAYHUN, funded by the European Commission-INCO program. The main aim of the project is to identify an adapted risk management in both the short and long term. A particular focus is given to develop improved reservoir operation and water management strategies to consider future decrease of available surface water resources in the allocation of transboundary water resources, and to identify a sustainable water resource management strategy for the basin that will ensure equitable allocation to all riparian needs including the environmental needs.

The Tuyamuyun Hydro-Complex (THC) in the lower Amu Darya River

The Amu Darya is with a total mean discharge of 79.3 km³/a the largest river in Central Asia. It is formed by the confluence of its main headwater tributaries, the Vakhsh and Pyanj Rivers. The total length of the Amu Darya from the head of the Pyanj River to the Aral Sea is about 2540 km, whereas the length from the river confluence accounts to 1415 km. (Froebrich and Kayumov, 2004). The catchment area (Figure 1) of the Amu Darya Basin comprises 309,000 km² and is shared by Afghanistan and four Central Asia Republics: Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan.

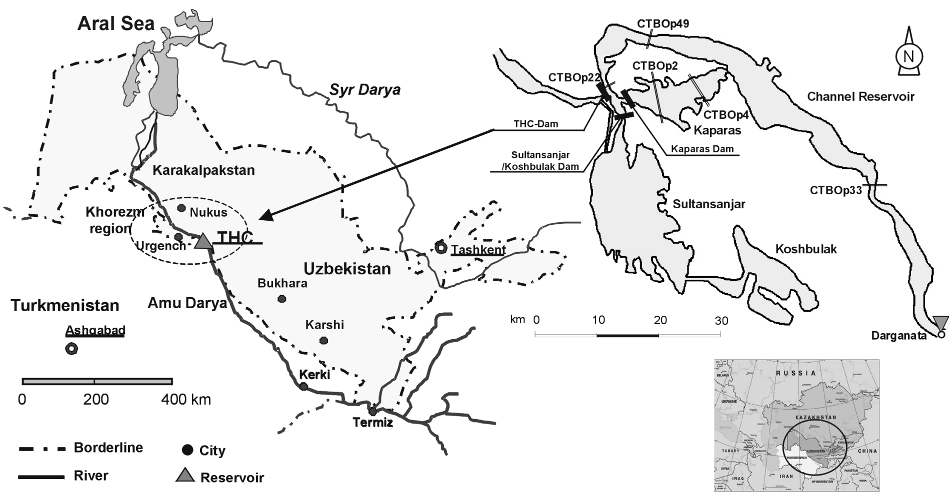


Figure 1. Location of the Tuyamuyun Hydro Complex (THC), with its multi-reservoir system and the inflow reference hydro post station Darganata, at the Aral Sea tributary Amu Darya.

The hydrologic regime of the Amu Darya River can be described by an uneven temporal distribution of the annual runoff volume, with about 80% within the period April to September. The greatest amount arises in mid summer due to the snow- and glacier melting in the Pamir-Alai Mountains. During the period from 1957 to 1980 the glaciers of the region have lost 126 km³ of ice (around 113 km³ of water) caused by climate change. The amount accounts for 19% of the total ice reserves in 1957 (National Commission of the Republic of Uzbekistan on Climate Change, 1999).

The annual flow regime of the Amu Darya is regulated upstream and downstream by large dams. In the upstream area this is the Nurek dam and the downstream area is characterized by the influence of the Tuyamuyun Hydroengineering Complex (THC) (Figure 1), which is located 300 km south of the Aral Sea on the territories of Turkmenistan and Uzbekistan, and is impounding the Aral Sea tributary Amu Darya. The complex consists of more than 30 main hydraulic structures including four interconnected reservoirs: the Channel Reservoir (Amu Darya main stream), the Kaparas reservoir, the Sultansanjar reservoir, and the Koshbulak reservoir. Initially, THC had a total storage capacity of 7.8 km³ but due to siltation losses, by 2001 the total storage was reduced to 6.9 km³. Water from THC is discharged to the lower Amu Darya and to an extensive canal system supplying the regions Khorezm, Karakalpakstan and Tashauz. The reservoir complex is used to redistribute the monthly water availability and the provided storage is mainly used for agriculture (around 98%), and partly for industry and drinking water supply (up to 2%).

The main reservoir the Channel Reservoir, with a design capacity of 2.3 km³, is the largest reservoir of the THC. It is more than 102 km long, with a surface area of over 303 km² and a maximum depth of 20 m. The reservoir bottom has a design level of around 110 m above sea level (a.s.l.), and the normal pool level (NPL) elevation is 130 m (a.s.l.). The operation of the Channel Reservoir is characterized by water level variations between the maximum operating level of 130 m (a.s.l) and minimum operating level of 120 m (a.s.l.). Within this range, the active regulation storage of the conservation pool is 2.1 km³, providing seasonal stream flow regulation of the lower Amu Darya River. In total, all THC reservoirs are able to provide an operational storage volume of 5.4 km^3.
Channel Reservoir is build by impounding the natural riverbed, whereas Kaparas, Sultansanjar and Koshbulak are designed as off stream reservoirs. From Channel Reservoir the water is either channeled into Kaparas or Sultansanjar reservoir, discharged to the downstream part of the river, or enters the different irrigation canals.

The Amu Darya River is one of the rivers in the world transporting the highest amount of suspended solids. Gwosdetsky and Michilow (1978) estimated a suspended solid concentration of 3300 mg/l and Letolle (1996) reported concentrations between 1000 and 3500 mg/l for the Amu Darya River. Generally, the main part of the annual sediment load is carried in the summer months. During the passing of the summer flood (May to September), maximum amount of debris is observed; the minimum is seen in November and December (Suslov, 1962). The suspended load of Amu Darya river is completely defined by erosive water activity in the river bed and on flood plains. In those places where loose sand comes up to the edge of a steep bank, the slightest movement of the air brings sand rolling down, thus increasing the amount of suspension debris in the water (Suslov, 1962).
The suspended sediment composition of the THC reservoir inflow can be described with a particle content of 15.5 per cent sand, 22 per cent silt, and 62.5 per cent clay.
For the lower Amu Darya also a significant annual variation can be obtained (Figure 2), at the THC reservoirs inflow reference station Darganata. The proportional distribution of the suspended solid on the seasonal discharge is shown in Figure 2. For the presented high

discharges of the year 1992 with a maximum run-off of 4000 m^3/s in July, the graph describes high suspended solid concentrations with more than 4500 mg/l, during the first flood events of the summer period and low concentrations (around 500 mg/l) during the winter period. However, the presented dry year 1986 with a maximum discharge of 1800 m^3/s for July shows not such significant annual variation for the suspended solid concentrations. The graph describes a minimum concentration of 1800 mg/l in May and a maximum concentration of 3000 mg/l in January.

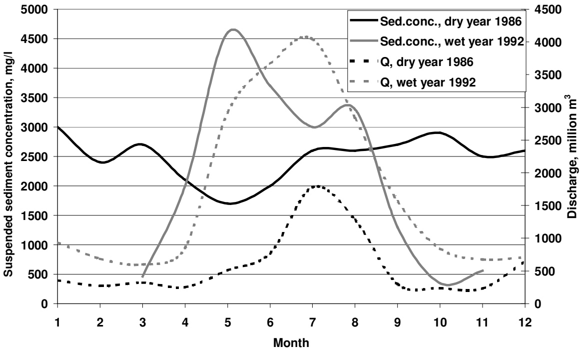


Figure 2. Monthly averaged suspended sediment concentration (mg/l) and monthly discharge (m^3/s) at Darganata station, for the wet year 1992 and dry year 1986

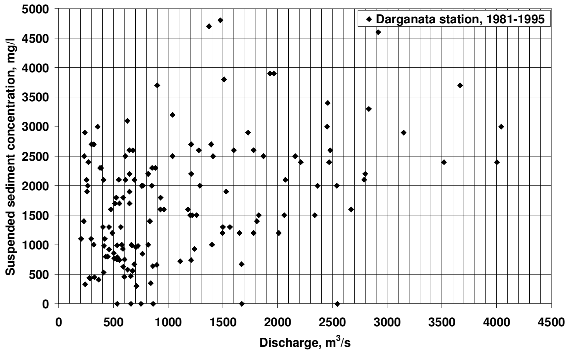


Figure 3. Distribution of suspended sediment concentration (mg/l) on the Amu Darya river discharge: Darganata station, 1981-1995

For the discharge of the lower Amu Darya River to the THC reservoir, the maximum concentration of suspended solids of 4800 mg/l was reached at a discharge of 1477 m^3/s and the minimum concentration of suspended solids of 300 mg/l at a discharge of 710 m^3/s (Figure 3) at the Darganata station 1981-1996.

Reservoir storage capacity and reservoir operation assessment

The study uses actual reservoir bathymetric data for its comparison with the design capacities, to assess the current storage capacity losses.

The storage capacity losses, SC_{loss} (million m^3), of the reservoir will be determined by the difference of the design capacity, SC_{design}, and obtained information on the reservoir bathymetry at time t, SC_t.

$$SC_{loss} = (SC_{design} - SC_t) \qquad \text{EQ 1}$$

where

SC_{loss}	:	Storage capacity losses (m^3)
SC_t	:	Storage capacity (m^3)
SC_{design}	:	Design capacity (m^3)

The current storage capacity losses of the reservoir will be described, by the volume elevation rating curves. The storage capacity losses, SC_{loss}, will also be used to describe the accumulated volume of sediments over the time.

The annual reservoir storage capacity loss, ASC_{loss} (million m^3/a), will be determined by the ratio of storage capacity losses, SC_{loss}, over the specific time period, Δt; from the initiation of impoundment to the investigated reservoir bathymetry at time t.

$$ASCloss = SCloss / \Delta t$$ EQ 2

where ASC_{loss} : Annual storage capacity losses (m^3/a)
SC_{loss} : Storage capacity losses (m^3)
Δt : Time period (t)

Furthermore, the three-dimensional water quality model MOHID will be used to analyse the effect of past and enhanced reservoir operation on the inside sedimentation processes. Herewith, the applicability of the enhanced reservoir operation, developed for the water quality improvement can be assessed, by using MOHID simulation results.
MOHID Water consists of a three-dimensional numerical model to simulate surface water bodies such as rivers, reservoirs, estuaries, coastal areas or the ocean. It is one of the main programs in MOHID Water Modelling System, written in FORTRAN 95 using an object oriented programming phylosophy. It is currently maintained and developed by the MARETEC (Marine and Environmental Technology Research Center) group of the Instituto Superior Técnico (IST) at the Technical University of Lisbon. Up to now, it has been constantly enhanced by additional features and modules. It is composed of a series of modules, which are mainly responsible for computing physical or biogeochemical process, e.g. Module Hydrodynamic, and Module WaterProperties.
MOHID Water was designed in order to be able to simulate aquatic systems dividing them into three compartments or media: air, water and land. Thus it was constructed assuming: one model consisting of two main interfaces: the water-sediment interface and the water-air interface, dividing three well defined compartments, the atmosphere, the water column and the sediment. The two interfaces should be able to communicate by handling the fluxes between the three compartments. To do this, two modules were created: Module InterfaceSedimentWater and Module InterfaceWaterAir.
The MOHID model has been applied to several coastal and estuarine areas and it has showed its ability to simulate complex features of the flows. More recently MOHID has been applied to the several Portuguese fresh water reservoirs Monte Novo, Roxo and Alqueva, (Braunschweig, 2001), in order to study the flow and water quality.

Assessment of the Channel Reservoir storage capacity

The Central Asian Scientific Research Institute of Irrigation (SANIIRI) has carried out yearly field investigations of the Channel Reservoir, since the reservoir filling was started in 1981. Available data on the storage capacity volumes of the Channel Reservoir provides a notion about the annual values, but the obtained bathymetric information were not able to illustrate the internal dynamics of reservoir sedimentation processes.
The most recent information on the Channel Reservoir storage capacity was obtained by a bathymetric survey from the Bathymetric Center (BMC) of the Ministry of Agriculture and Water resources Uzbekistan and the EC project Jayhun, in 2005. These information have described a reduction of reservoir storage capacity from 2 340 million m^3 to 1 287 million m^3 at the maximum water level of 130 m a.s.l., since the initiation of impoundment of the Amu Darya in 1983. This is comparably a storage capacity loss, SC_{loss}, of 1 053 million m^3 or 45 % respectively, and an average ASC_{loss} of slightly over 48 million m^3/a. For illustration, the Figure 4 shows the original design capacity (dashed line) compared to the storage capacity in 2005 (bold line) of the Channel Reservoir for different water levels. The useful storage volume was reduced from 2070 million m^3 to 1251 million m^3, which means that it has been silted by 819 million m^3. The volume of deposits within the dead storage below elevation of

120 m (a.s.l.) is about 234 million m³ and describes a storage reduction from 270 million m³ to 36 million m³.

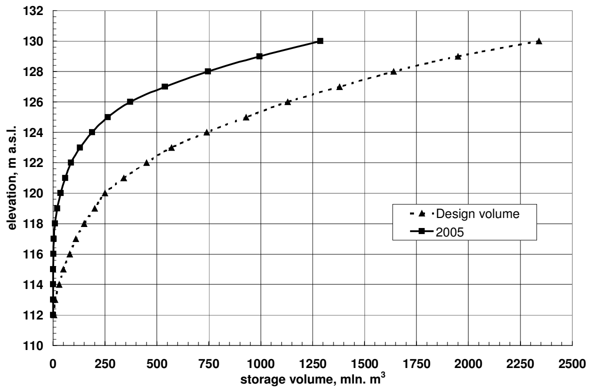


Figure 4. Volume elevation rating curves Channel Reservoir (THC).

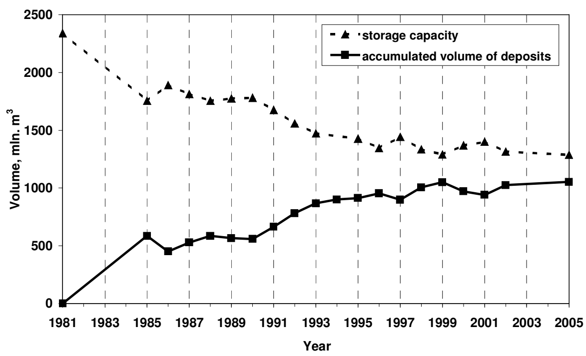


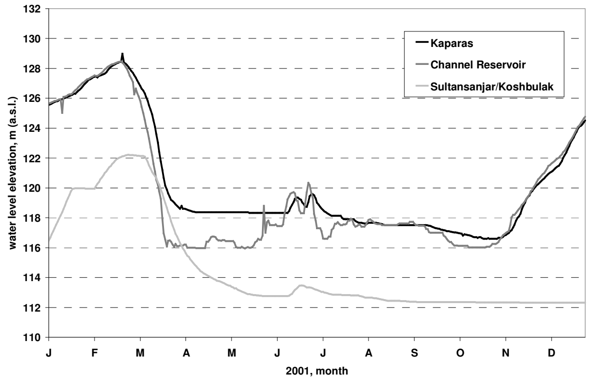
Figure 5. Variation of storage capacity and accumulation of sediments, Channel Reservoir, 1981-2005

A more significant phenomenon can be observed during exceptional flood and drought events, like in high and low water years. Investigations on the Channel Reservoir siltation have shown that the biggest volume of sediments with 222 million m³ accumulated in the high water years of 1991 - 1992 and with 108 million m³ in 1998. In contrast to high water years the bathymetric data describe a reduction of deposit accumulation and an increase of the storage capacity for all low water years since the reservoir impoundment. Furthermore, the removal of sediments can be observed for the Channel Reservoir, with a maximum deposit volume of 135 million m³ during the low water year (THC inflow, 20.8 km³) in 1986, with 56 million m³ during 1997 (18.3 km³) and with 110 million m³ during the exceptional drought period 2000-2001 (18.7 and 13.6 km³).
The velocity and the turbulences are varying according to the water level of Channel Reservoir, which ranges between 115 m a.s.l. and 130 m a.s.l.. If the reservoir is filled, flow velocities are low and silting processes occur. If the reservoir is not filled completely, higher flow velocities occur resulting in higher turbulences and lower sedimentation.

The results of the storage capacity assessment characterise flushing effects caused by past reservoir operation, with channelling the scarce water through the Channel Reservoir to the lower river without any storage, in dry years. Furthermore, the results indicate an increased risk of storage capacity losses for the conventional management in wet and high water years, by complete impounding of the reservoir.

Boundary conditions for simulating the cohesive sediment transport

The aims of the following modelling exercises are the definition of the different reservoir operation effects on the cohesive sediment concentration and sedimentation in the Channel Reservoir. This was done in order to assess the risk of reservoir storage capacity losses and therefore to evaluate the applicability of the enhanced reservoir operation developed for dry years. Applying the concept of enhanced reservoir operation it was planned to store mainly the low salinity summer flood. The results have identified the most suitable combination of water level regimes for all reservoirs of the THC, which are indicated in Figure 7.



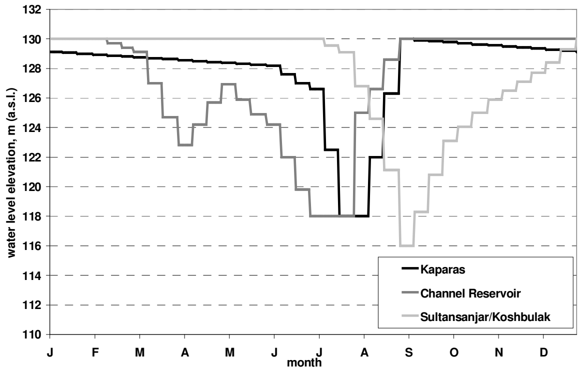


Figure 6. Reservoir operation of the Channel Reservoir, Kaparas, Sultansanjar and Koshbulak during the dry year (2001), water level elevation m (a.s.l.).

Figure 7. Developed water level elevation (m a.s.l.) of the THC reservoirs, under dry conditions.

Discretisation

Based on the xyz coordinates from the bathymetric survey, 2005, the orthogonal grid has been discretised with a side length of 52 km and a grid size of 104 to 104 cells. Therefore the reservoir system has 10816 cells with a grid step 500 to 500 m.

The model of the reservoir system (Figure 8), including Channel Reservoir and Kaparas, has a river inflow at the bottom of the model, an outflow at the dam site to the lower river and a combined in- and outflow to the Sultansanjar reservoir.

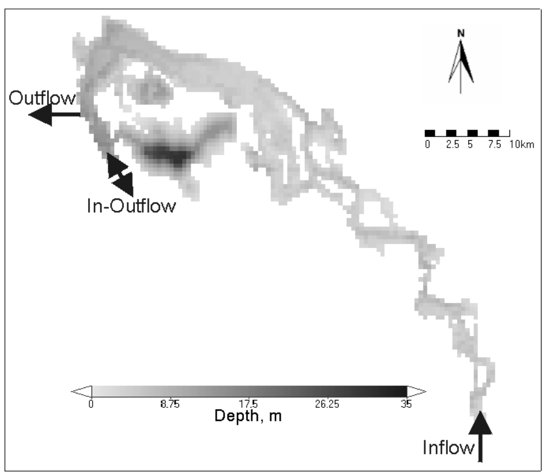


Figure 8. Reservoir bathymetry of the Channel Reservoir and Kaparas reservoir of the Tuyamuyun Hydro-Complex used for the cohesive sediment simulation with mohid water model.

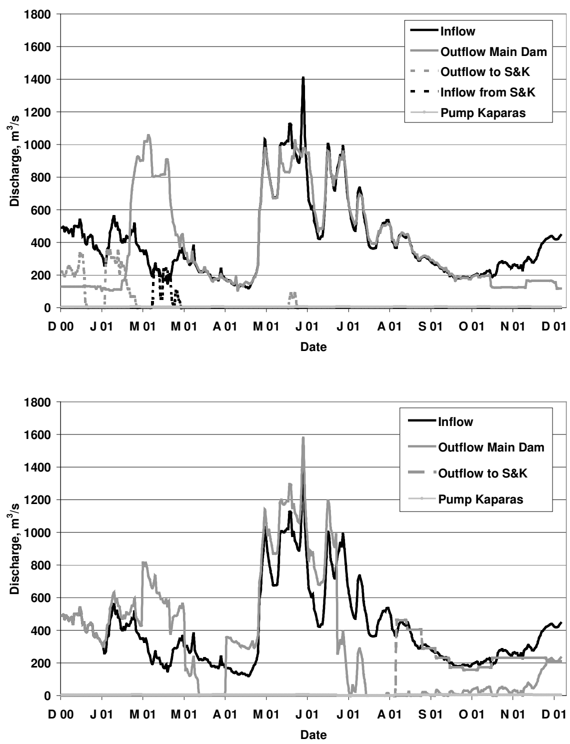


Figure 9. Boundary conditions for cohesive sediment simulations with inflow to the reservoir system, releases at the main dam, in-outflow Sultansanjar dam and withdrawal in the Kaparas reservoir, for conventional (above) and enhanced operation (bottom).

The effects of conventional and enhanced operation modes have been investigated using the estimated reservoir inflow and releases as boundary conditions (Figure 9) and the established representative cohesive sediment inflow concentration for a dry year (Table 1).

Table 1. Boundary conditions for cohesive sediment simulations, developed average cohesive sediment inflow, dry year .

Past practised operation 2001 and Enhanced operation mode												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cohesive sediment inflow mg/l	834	817	516	467	606	1640	910	665	490	302	344	495

Both applications have been used as basic input data measured cohesive sediment concentrations of 6 mg/l, recorded at the middle Section of Channel Reservoir in January 2001. The simulation of the conventional operation starts with a water level of 125.64 m (a.s.l.) in the Channel Reservoir, as recorded on 1. January 2001, whereas the enhanced operation starts with a water level of 130.0 m (a.s.l.). The use of different initial water levels is based on the method of the enhanced reservoir operation to fill Channel Reservoir to its maximum water level of 130 m (a.s.l.) each year and it assumes that the reservoir was filled up to this maximum water level in the summer months of the preceding year. Past records of climate data from 2001 have been used as input.

Impact of enhanced reservoir operation on sedimentation processes in the Channel Reservoir in dry years

The simulation results of the conventional operation, as depicted in Figure 10 (grey line), show a continuous sedimentation of cohesive sediments up to 28,200,000 kg for the Channel Reservoir and Kaparas during one year of operation. This describes an average sedimentation of around 13,000,000 kg/a for the conventional operation as occurred during past dry years, as in 2001.

The conventional operation, with continuous low water levels resulting higher flow velocities and higher turbulences from March up to November is responsible for the continuous lower reservoir sedimentation. Partial sluicing effects occur for the inflowing water with high cohesive sediments concentration during the summer months.

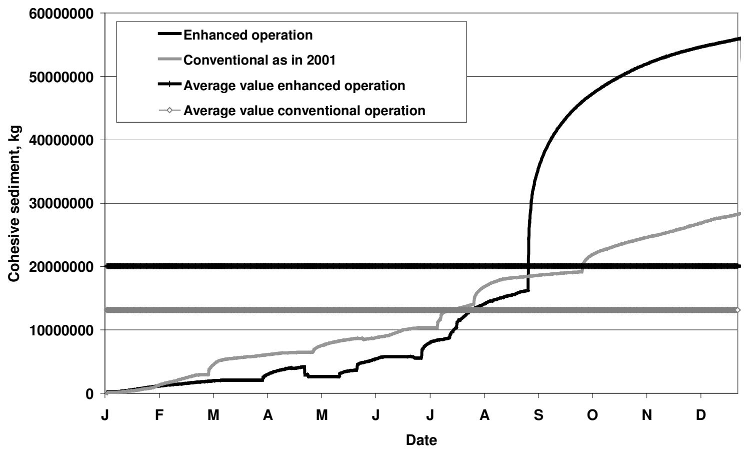


Figure 10. Simulation results for the cohesive sediments at the reservoir bottom, in total and average for the conventional and enhanced reservoir operation.

The simulation results for the enhanced operation, as depicted in Figure 10 (black line) show an increase in sedimentation of cohesive sediments up to the maximum of 55,900,000 kg at the end of the year, with an average sedimentation of 20,000,000 kg/a for a dry year. Due to continuous increase in sedimentation, occurs an increase to 16,200,000 kg by the end of August followed by a sharp rise to the annual maximum at the end of December.
The results demonstrate the impact of the enhanced operation on variation of water levels, with the refill of the Channel Reservoir and Kaparas in August/September to provide water of low salinity flow velocities fell and sedimentation rise to its maximum. However, for the time period from January to August the results of the enhanced operation fall below the values of the conventional operation.

The outcomes indicate that, the past practice operation will lead to an average annual sedimentation rate of 13,000,000 kg/a in the Channel Reservoir and directly connected Kaparas reservoir. On the other hand applying the recommended enhanced operation scheme will achieve an increase of annual cohesive sediment deposition of 7,000,000 kg/a, or 53% respectively. Whereas the main reason for this difference lies on the high sedimentation rates during the refill of Channel Reservoir and Kaparas on their maximum water levels from August to December.

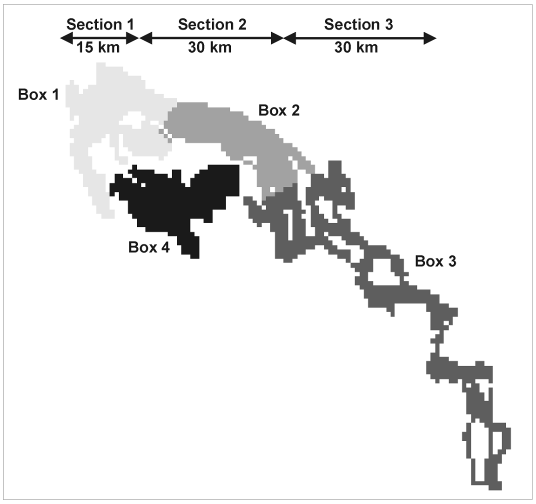


Figure 11. Channel Reservoir sections as pre-defined boxes 1 to 4 in MOHID, for the investigation of cohesive sediment transport.

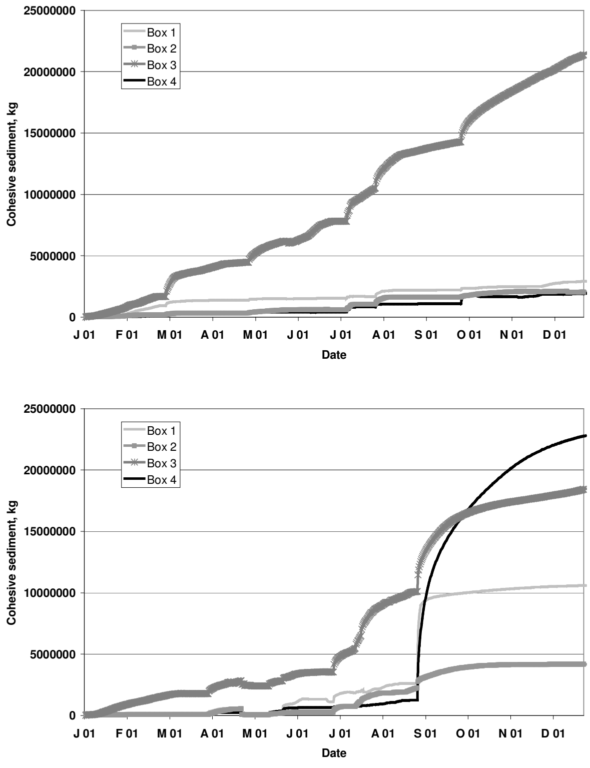


Figure 12. Cohesive sediments at the reservoir bottom, for box 1-4, conventional operation (above) and enhanced operation (bottom).

For a better understanding of the Channel Reservoir sedimentation processes, it is necessary to investigate more detailed information on the location of deposits in the reservoir. For the analysis of the internal reservoir processes the Channel reservoir was divided into 3 sections, Box 1 to 3 and an additional Box 4 for Kaparas reservoir (Figure 11).

The simulation results of the cohesive sediment deposition for the boxes 1 to 3 of the Channel Reservoir and for the box 4 of the Kaparas reservoir (Figure 12) show the distribution of deposits within the several reservoir sections for the conventional and enhanced operation.
The separation of the simulation results for the two reservoirs presents sedimentation processes within Channel Reservoir with a total maximum of 26,300,000 kg, and annual average of 12,000,000 kg/a, for the conventional operation and with a maximum of 33,100,000 kg, and annual average of 13,600,000 kg/a, for the enhanced operation. This describes a difference of not more than 1,600,00 kg/a instead of the 7,000,000 kg/a for the results in total (Figure 10) and describes therefore lower differences in storage capacity losses for the Channel Reservoir.
The results for the Kaparas reservoir (Figure 12, black line) demonstrate that with a total maximum of 1,900,000 kg, and annual average of 820,000 kg/a for the conventional operation and with a maximum 22,700,000 kg, and annual average of 6,500,000 kg/a, for the enhanced operation, the box 4 was the main reason for the sharp rise within the results of total sedimentation (Figure 10) from August to December.
This indicates that Kaparas with a difference in annual average of 5,680,000 kg/a affects mainly the assessment results of the enhanced reservoir operation on total storage capacity losses. Furthermore the results demonstrate the impact of the past practice operation on reservoir sedimentation processes with minimum variation of lowest water levels in the summer months and a predominantly filling during December to February.
The objective of the enhanced reservoir operation was to fill Kaparas as an off-stream reservoir with water of low salinity levels from the summer flood in September. However the refill on maximum water levels takes place in a period with higher sediment concentrations and additionally after this refill no further water level variations, resulting in higher velocities and turbulences will prevent the deposition of cohesive sediments.

The preliminary simulation results of the cohesive sediment process for the Channel Reservoir describe a first approximation on the siltation processes and storage capacity losses and provide a first estimation on the reservoir operation effects.
Currently the cohesive sediment processes will be simulated and tested with adapted initial and boundary conditions, e.g. shear stress, critical shear stress for erosion and deposition.
This will provide more realistic values for the assessment of storage capacity losses by reservoir operation. Nevertheless this study provides tendentiously evaluation outcomes for the applicability of enhanced reservoir operation under drought conditions.

Conclusion

The THC significantly influences the sediment regime of the lower Amu Darya as a sediment trap. The results illustrate that a huge amount of sediments is stored at the THC reservoirs. Initially, THC had a total storage capacity of 7.8 km^3 but due to siltation, by 2001 the total storage was reduced to 6.9 km^3. Since the initiation of impoundment of the Amu Darya in 1983, at the normal pool level of 130 m (a.s.l.), Channel Reservoirs storage capacity has been reduced by 45%. This is an average of slightly over 2% to 3% per year. In consideration of the results for the potential reservoir capacity losses it can be assumed, that Channel Reservoir with a currently available total storage volume of 1 287 million m^3, will be able to operate without silt removal for at least another 25 years.
However, already the total design capacity, 7.8 km^3, of the THC reservoirs provide not enough storage volume for keeping a strategic reserve for covering water deficits and irrigation demands of 20.2 km^3 for the lower Amu Darya region, during dry years as 2001 (with an average discharge of 12.8 km^3). Furthermore, the assessment results for the risk of

storage capacity losses and therefore the opportunity to compensate water deficits by drought events indicate currently an increased risk of failure for the THC storage volume.

The applicability of developed enhanced reservoir operation for the THC reservoirs to provide water of higher quality even subject to a parallel reduction of water deficits has been assessed in relation to siltation processes and the impact on ongoing storage capacity losses. The assessment of the reservoir operation strategies has identified an increase in annual sedimentation of 13% for the Channel Reservoir and of 53% for the system Channel Reservoir-Kaparas by enhanced operation during dry years. However, Kaparas provides a sufficient volume for sedimentation, because of the big dead storage volume of 320 mln. m³.
The loss in Channel Reservoir storage capacity can be assumed as a comparably minor effect if simultaneously a reduction of water deficit from 21.5% (conventional operation) to 9.9% can be achieved by applying the enhanced reservoir operation during dry years.

The results presented give a first approximation to the total storage capacity losses and the sedimentation processes of the THC. Without further comparative information in reservoir bathymetry of Sultansanjar and Koshbulak, it is impossible to have a more reliable estimate of the total THC capacity losses and to reduce discrepancies in the volume calculations. This is of particular importance if water level variations are used to estimate the actual inflow volumes accounting for evaporation losses and recorded releases.

The results shows the need for sustainable sediment management for the reservoir in order to avoid further capacity losses. It should be proofed which sediment management is applicable for the special characteristics of the Channel Reservoir and how it can be implemented in an enhanced reservoir operation method. The sediment management method of flushing and sluicing could be appropriate, by application in high or normal water years.
The study has emphasized that a more precise understanding of reservoir sedimentation processes and resulting storage capacity losses provides necessary background information for assessing management options during drought events and the impact of climate change on water availability during the next 50 years.

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