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Research Article

Water Quantity and Quality Dynamics of the THC – Tuyamuyun Hydroengineering Complex – and Implications for Reservoir Operation*

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Abstract

Background. In the Aral Sea basin, safe water resources are scarce and steadily becoming scarcer. Particularly high quality water is going to become a rare good.
The object of the study was the Tuyamuyun Hydroengineering Complex (THC), a complex of artificial water reservoirs located in the lower Amu Darya River, which provides water for irrigation, industry, and drinking for the lower Amu Darya region. The focus was on operation of one of its four reservoirs, the Kaparas, which is mainly used for drinking water supply. The objective includes the investigation of impacts of conventional operation schemes on the reservoir water quality for improving drinking water quality (salinity). Basic operation rules for Kaparas, which can be considered as representative for conventional dam operation under dry year conditions, had to be identified and improved operation schemes derived.

Methods. Existing data archives were analysed, and further data were acquired from field surveys, data processing and modelling studies. Historical data were identified, which are appropriate to determine representative schemes for the conventional operation. For the simulation of time-dependent and depth-dependent changes of reservoir salinisation, the reservoir water quality model Lac was used and linked with the THC model.

Results and Discussion. Modelling results for the simulation of temperature dynamics and density stratification showed a sufficient congruence with the measured temperature profiles. The conformity of measured and calculated salt concentration is basically ensured. The reservoir, which fill with higher saline water at the end of the summer, aggravates the entrainment of high saline water in the entire water column.

Conclusions. The current conventional operation regime mainly leads to filling the Kaparas reservoir with high saline water during the winter months. Even in the event of starting with comparable low salinity levels, the simulation demonstrates the rapid deterioration of the reservoir water quality. Under dry year conditions, the WHO standards for drinking water will be exceeded by 30% after two years, so that the impact of dry years in the context of water stress becomes visible.

Recommendations and Outlook. Processed data and results are now available to identify enhanced reservoir operation strategies for salinity reduction by changing the period of reservoir filling and release, as well as to initiate a detailed analysis of how water deficits in dry years may be reduced by improved operation regimes. Using adapted and enhanced operation rules for THC reservoirs, the local population within the lower Aral Sea basin might be supplied with more potable water of higher quality in future.

Keywords: Aral Sea; quality modelling; reservoir water quality model; salinity; Uzbekistan; water quality; water supply

Background and Scope

The Amu Darya watershed stretches across the territories of Turkmenistan, Afghanistan as well as the Republics of Tajikistan, Uzbekistan and Kyrgyzstan. In total, the Amu Darya catchment covers an area of about 227,800 km² with a river length of 2,620 km from the confluence of the Pyandj and Vaksh River to the Aral Sea (UNEP/GRID-Arendal 2005, IWLP 2005). After passing the mountainous upstream part, the Amu Darya meanders through a desert region until it reaches the Tuyamuyun Hydroengineering Complex (THC). The annual water flow of the Amu Darya ranges from 58.6 km³ to 109.9 km³ with an average flow volume of about 78.4 km³/a (Froebrich and Kayumov 2004).

The reservoir complex studied is situated 300 km to the south of the former Aral-Sea shoreline, at the beginning of the lower Amu Darya region, which ranges from the Tuyamuyun Hydroengineering Complex (THC) downstream from the Aral Sea. This region has seen a continuous increase of intensive irrigation activities based on an extended canal and collector system during the last 50 years.

By extreme overstressing, safe water resources in the Aral Sea basin are scarce and steadily becoming scarcer. In particular, high quality water is and will continue to be a rare good, considering high population growth, increasing agricultural withdrawal and rising requirements to water quality. The past environmental destruction has also led to endangered human existence in the Aral Sea deltas. More than 3 million people have no access to a satisfactory drinking water supply. Child mortality is comparatively very high and diseases, such as typhoid fever, viral hepatitis, anaemia, respiratory diseases, and different types of cancer, are widespread (Elpiner 1999). In Khorezm, for example, 51% of the population rely on drinking water from open wells and pumps with salt concentrations up to 3,000 mg/l, partly even exceeding 4,000 mg/l (Herbst 2004).

Against this background, a particular focus is provided in this paper on the operation of the Amu Darya reservoirs, primarily the dams of the Tuyamuyun Hydroengineering Complex (THC), which stores and provides water for irrigation, for industrial needs, and for drinking in the lower parts of the Amu Darya, the regions Khorezm and Karakalpakstan in Uzbekistan, and Dashoguz in Turkmenistan.

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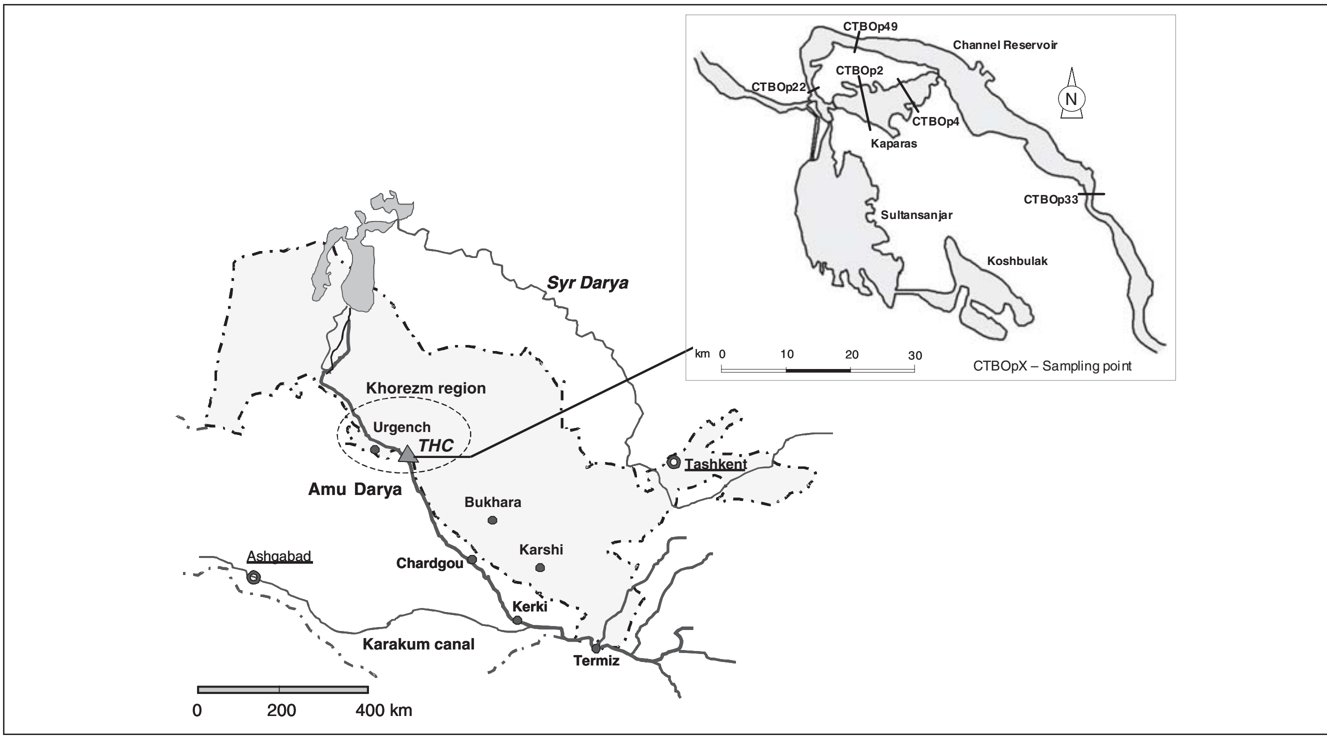

Fig. 1: Amu Darya and Syr Darya – the Aral Sea tributaries and location of the Tuyamuyun Hydroengineering Complex (THC)

The focus was on the operation of one of its four reservoirs, Kaparas, which is mainly used for drinking water supply. Using revised operating rules for existing reservoirs, the local population might be supplied with more potable water of higher quality in future. The reservoir system provides a valuable case to demonstrate ways for improving the regional water supply by changing operation strategies, using the given advantageous situation that Kaparas reservoir is an off-stream reservoir, and can be operated independently.

Whereas incoming river water rarely exceeds salinity concentrations of 1,000 mg/l, the water stored in the Kaparas reservoir often exceeds this *guidance value* for safe drinking water (WHO 2004), in particular in dry years.

The scope of this paper is therefore to investigate the impact of the conventional operation regime on the Kaparas water quality also under more severe conditions. Of particular interest for securing water supply are the conditions which are met during dry years. While in wet years and median years, water quantity is sufficiently available, the availability of high quality is limited during dry years and its storage is affected by various constraints. Therefore, this paper concentrates on the investigation of dry year scenarios and potential effects, if a sequence of dry years occurs. As currently there are no formal operation plans used to manage THC under dry year conditions (Djoraev and Babajanov 2004), the paper is also devoted to identify a basic operation scheme that can be considered as representative for conventional dam operation under dry year conditions.

Salinity is used in this study to demonstrate general patterns of contrary temporal trends in water quantity and quality; as a conservative substance, salinity clearly indicates the impact of reservoir operation, inflows, mixing and density stratification.

1 Methods

The study was executed in the framework of the INTAS/DFG project IWMT 'Development of integrated water management tools for the Tuyamuyun reservoir complex – Improvement of drinking water supply and public health in the disaster zone of lower Amu Darya'. It is related to the downstream part of the Amu Darya and covered, basically, data acquisition from existing data archives (mainly from Glavgidromet), field surveys, data processing and modelling studies. Historical data on reservoir level changes from the years 1990/1991 and 2000/2001 are used to determine representative schemes for the conventional management. Runoff data and flow have been used from the monitoring stations Darganata (about 80 km upstream from THC) and Tuyamuyun (8 km downstream to THC). The water quality data have been used from Lebab station (70 km upstream of THC) and at different locations (CTBO points as in **Fig. 1**) at the THC.

For estimating basic trends in reservoir salinisation, the use of climate data of the station Urgench (distance 70 km) was considered as sufficient. Using monthly representative data for wind speed (m/s), air temperature (°C), humidity (%), cloud cover (n/10), and precipitation, daily data are generated within the simulation by linear interpolation.

The reservoir water quality model Lac was used and linked with the THC model. Lac is a dynamic, deterministic model and permits the simulation of time-dependent and depth-dependent changes of relevant quality processes within reservoirs and lakes (Froebrich 2000). The special characteristic of the model is the detailed collection of hydraulic, hydrothermal, and biological processes, enabling, amongst other things, a reliable investigation of density stratification and its influence on salinity dynamics. The model has two main compartments: (i) different sub-models enabling the hydrophysical simulation and (ii) the water quality sub-model for simulating the variation of hydrochemical constituents and biological variables, where time and depth dependent changes of state variables were calculated by using an explicit difference scheme.

Vertically, the model is distributed in a number of water layers in the lake. For each layer, the surface area has to be determined in correspondence to the volume/depth ratio of the reservoir. The depth of the layers has to be chosen by the user and ranges, usually, between 1 and 2 m. The model is not restricted for a specific water depth, and has been applied for deeper, (up to 40 m depth) as well as shallower impoundments (up to 2 m depth). While lakes and deep reservoirs show significant vertical mass and energy gradients, longitudinal differences might be comparably low and occur mainly between the inflow point and the lacustrine zone. Exceptions can be met at very shallow reservoirs or reticulated water bodies.

Equations incorporated in the Lac model for calculation of heat and radiation balance at the water surface are adapted from Hurley Octavio et al. (1977). In a first step, the several components of long and short wave radiation are estimated, and the net heat flux at the water surface is calculated. Heat and density changes in deeper strata are calculated according to the continuous exponential decline of radiation with depth.

Sequences of turnover and stratification are simulated by a continuous comparison of potential energy, determined by the density stratification and kinetic energy depending on the entrainment of wind energy at the water surface. The change of potential energy is calculated by an approach described in Hurley Octavio et al. (1977). It is assumed that the rate of change of potential energy is proportional to the rate of working of the shear stress due to the wind. Advection is simulated using an approach from Schwerdhelm (1992). For each time step, the mass flux through the layer boundaries is calculated by the water balance in each layer, starting from the bottom. If inflow and outflow for a given layer are not balanced, positive or negative flows across the layer boundaries are assumed accordingly.

Geogenic salt release from the bottom can play an important role. Within this study, the bottom salt release was simulated by assuming a salt mass flux (Kg/d) entering the bottom layer.

Water quality inflow data for the Kaparas reservoir have been calculated with the THC model (Sorokin and Ikramova, 2005). While Lac focuses on detailed water quality changes within a single reservoir, the THC model is supporting the combinative operation of the entire THC complex, by considering each reservoir as a complete mixed reactor and establishing salt balances for each of them.

2 Results and Discussion

2.1 Design and operational features of the THC System

The THC was constructed to impound the Amu Darya in order to provide water for irrigation, industry, and the drinking water supply for the lower Amu Darya region (Kayumov et al. 1997). With an initial total storage capacity of 7.8 km³ in 1983, the THC complex lost about 1.0 km³ of this until 2001, due to siltation.

The Channel Reservoir was built by impounding the natural riverbed, whereas Kaparas, Sultansandjar, and Koshbulak are constructed as off-stream reservoirs. From Channel Reservoir, the water is either channelled into Kaparas or Sultansanjar reservoir, discharged to the downstream part of the river, from where it flows down the river or enters the irrigation canals. In Channel Reservoir, a minimum water level of 117 m a.s.l. is required for enabling inflow into Kaparas or Sultansanjar reservoir, because the water exchange between the reservoirs is based on free surface slope. Separation gates allow an individual management of the single reservoirs.

Actual discharge for filling of Kaparas depends on the water level difference between Channel Reservoir and Kaparas. The intake structure is designed for a maximum discharge of 320 m³/s, which would require a water level difference of 13 m. Given a water level at Channel Reservoir of 123.5 m and 117 m at Kaparas, a discharge of 150 m³/s is obtained.

2.2 Inflow conditions – discharge and salinity

There is a strong temporal variation of the annual drainage volume in the basin, with about 80% of the annual drainage occurring during April to September. The greatest amount arises in mid summer due to the snow and glacier melting in the Pamir-Mountains. Due to strong dilution effects, a broad salinity decrease occurs during the summer months, whereas the highest concentrations of dissolved minerals can be observed in the winter and spring (October to April) (Crosa et al. 2005).

Table 1 indicates the monthly flow of the Amu Darya for selected years used in this study and gives the average flow for wet, median, and dry years (estimated for 1991). Com-

Table 1: Mean monthly discharge (m³/s) for selected years and averages for dry, median, and wet years

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	475	555	387	567	1,870	1,810	2,340	1,495	1,240	930	664	816
1991	885	650	400	885	1,400	2,400	2,050	1,499	1,364	884	477	990
2000	781	443	349	249	608	563	807	567	440	319	318	427
2001	438	428	257	230	307	928	701	495	352	206	233	356
Mean monthly discharge (m³/s)												
Dry year	540	381	358	450	681	950	1,184	1,087	525	320	372	522
Median year	629	473	506	838	1,557	1,919	2,457	1,965	1,156	727	639	772
Wet year	761	754	744	924	2,396	3,095	4,181	2,704	1,569	805	686	800

pared to average conditions in dry years, the year 2000 corresponds to an exceptionally dry year with a discharge maximum of only 807 m^3/s. Similarly, 2001 can also be characterised as below the average. Together, 2000 and 2001 are considered as representative to derive an idealised operation scheme for conventional management under dry year conditions.

2.3 Water levels and water salinity under dry conditions

The annual variation of the salt concentration shows an opposite seasonal fluctuation compared to the flow regime, as low concentrations occur at high discharges (**Fig. 2**). Especially in the summer months, from June to September, the concentrations are below the guidance value for drinking water of 1,000 mg/l (WHO 2004) hydrological conditions, whereas the salinity varies during the summer month only between 600 mg/l and 800 mg/l. Higher salinity values, but also a higher variability, occur during the autumn months.

Whereas 1998 and 1999 correspond to a wet and a median year, respectively (**Fig. 3**), 2001 is well visible by the exceptional deep water level lowering at both Sultansanjar and Koshbulak reservoir, for providing additional irrigation water to the Amu Darya downstream reach.

Water levels at Kaparas reservoir appeared very low during the years 2000 and 2001. In both years the operational regime was very similar. While the highest storage level was obtained between January and February, the release period was significant until the end of March in 2001 and June in 2000. A significant refilling did not start before September.

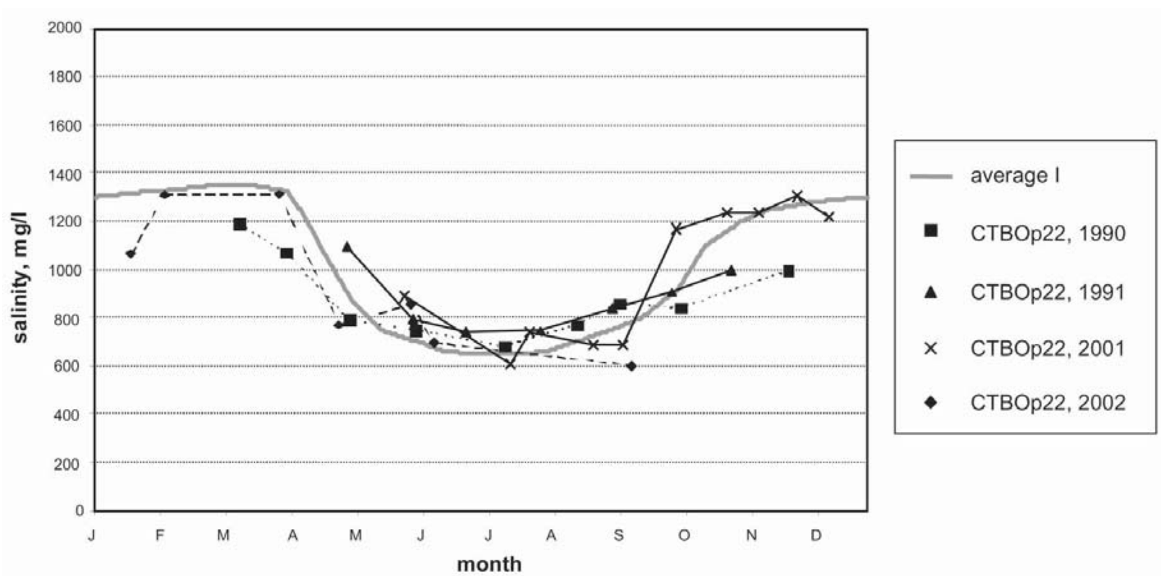

Fig. 2: Measured and average salinity for different years at Channel Reservoir near outlet and water intake to Kaparas (CTBOp22)

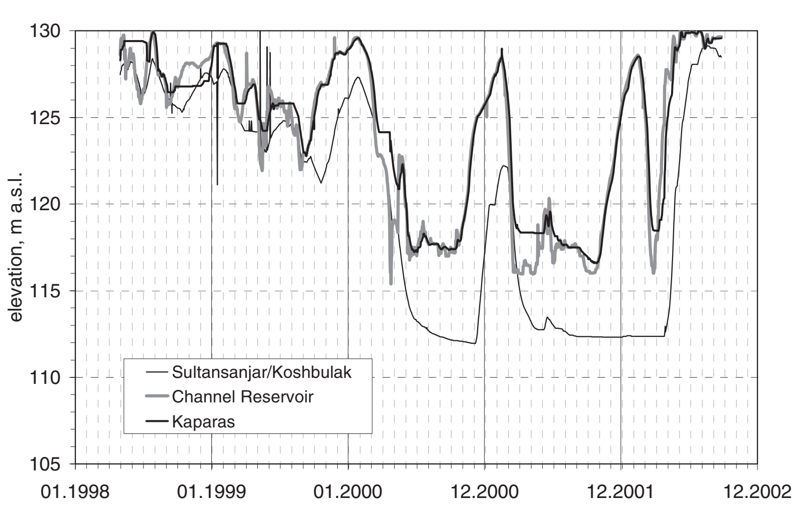

Fig. 3: Measured water levels of the THC complex for the dry years 2000 and 2001 and comparative situation for 1998 (wet year) and 1999 (median year)

Table 2: Conventional reservoir operation regimes (Tuyamuyun Hydroengineering Complex)

	Channel Reservoir	Kaparas	Sultansandjar/Koshbulak
Inflow	Throughout the whole year	From September to January / February	From September to January / February
Storage	From September to January / February	March to September under dry years, variable in other years	Variable
Emptying	February to April From May to September, the flow from Amu Darya river is channelled through the reservoir without storage	February to May (or shorter period in dry years)	February to June
General characteristics	Provision of supply for Kaparas and Sultansandjar / Koshbulak reservoirs During wet years, the water can be retained during the summer (June / July)	Low storage volume from May to August Filling dependant on water level at Channel Reservoir Independent release control by operational intake structure	During wet years, inflow also during summer (June, July, August)

Based on the measured values for water levels and salt concentrations, the operation strategies for the single reservoirs can be derived (**Table 2**).

2.4 Measured salinity at Kaparas reservoir

Historical data for salinity at different water depths were available in 1990, 1991 and, with less density, in 2001. Salinity values of Kaparas waters range mostly between 700 mg/l and 1,700 mg/l. Maximum values above 1,500 mg/l were reached in the lower water layers, and the significant level for drinking water of 1,000 mg/l is almost permanently exceeded (**Fig. 4**).

The depth-dependent salt concentration in October 1991 indicates a distinctive salt stratification. Also, in the second half of 1990, an indication for a stable stratification is given with the depths increasing salt concentrations. Values in different months of November, however, characterise the subsequent complete mixing of the reservoir.

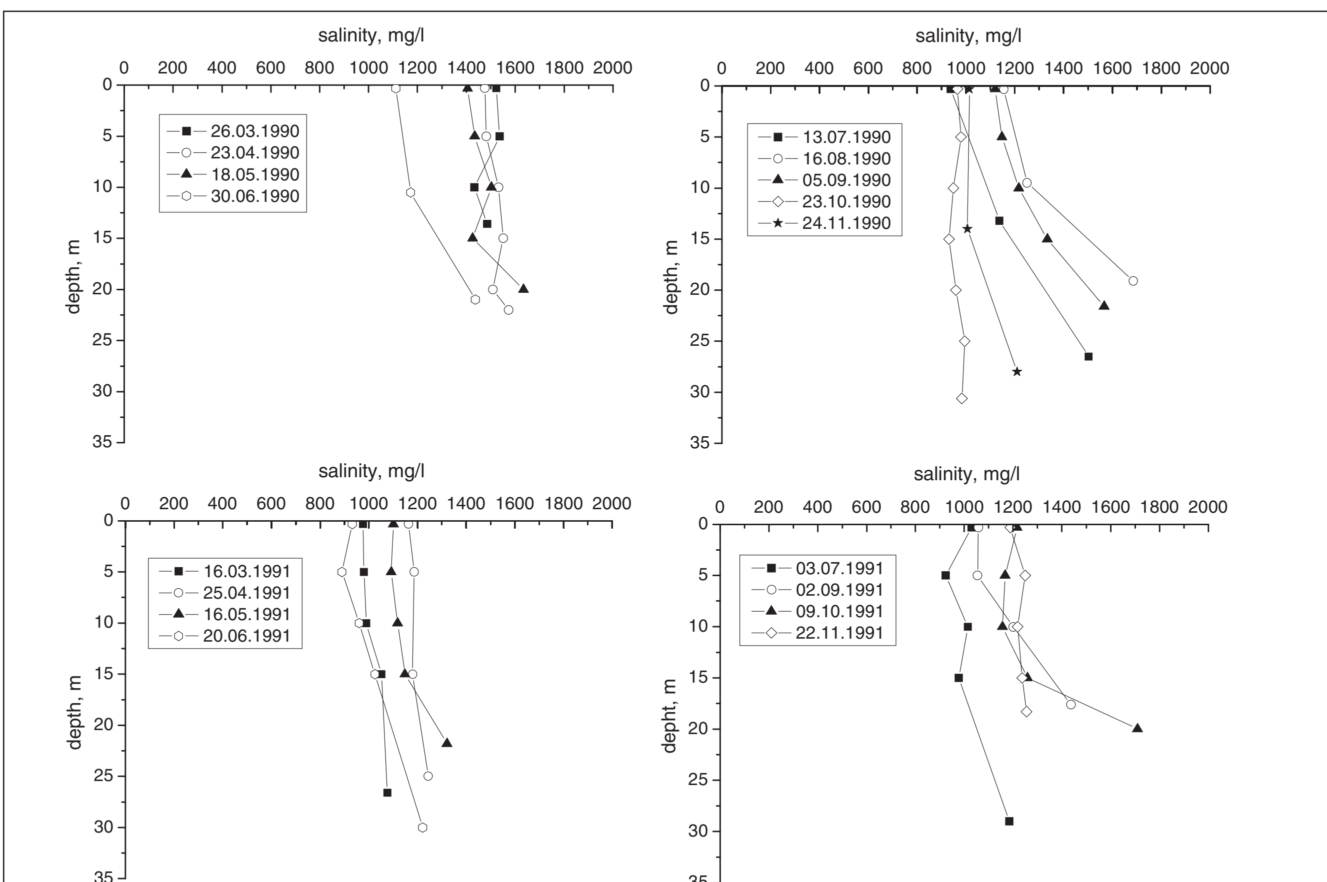

Fig. 4: Salinity profiles for Kaparas reservoir in median years 1990, 1991 (validation period)

2.5 Simulation of past reservoir salinity and validation of the model Lac

Modelling of temperature dynamics is done based on physical and empirical equations and does not necessarily require a calibration of the parameters. Basic settings as shear stress coefficient and light transmission have been adopted from the literature and were already tested in the case of the Sidi Salem reservoir in Tunisia (Froebrich 2000). Transferring the parameters, the simulation of the Kaparas reservoir has been used as a validation of the model by using a two-year time series (1990 and 1991). The choice of this validation period was determined by the available data of at least monthly intervals at several water depths. Starting on 15. March 1990, the end of the simulation and validation period is defined by the beginning of the construction work at the water intake structure of Kaparas. Due to the influence of the hydraulic properties and reservoir water quality dynamics, the end of the investigation period is set for 31. December 1991.

Modelling results for the simulation of temperature dynamics and density stratification showed a sufficient congruence with the measured temperature profiles. While field and simulation data correspond well during the summer period, the values on the water surface at the end of October 1990 differ by only some degrees. In November 1990, these deviations have disappeared and the data fit well again. However, on the surface, the measured and calculated values correspond better. In some cases, the calculated temperatures from May to September at lower water layers are higher than the measured values.

The time-depth plots of the calculated and measured salinities for the years 1990 and 1991 are shown in **Fig. 5**. Some differences in the graphics can be attributed to the specific characteristic of the interpolation method of the post-processing tool for visualisation, but the conformity of measured and calculated concentration is basically ensured.

In the winter period from October 1990 to March 1991, the salt concentrations range between 900 mg/l and 1,000 mg/l. In the summer period, stratification appears in reality as well as calculated by the Lac model. While water salinity of the lower layers varies between 1,400 mg/l and 1,600 mg/l, values from 1,000 mg/l to 1,400 mg/l can be found in upper layers. Summer stratification is influenced by high water level fluctuations in the reservoir.

The correspondence of the measured and calculated salinity is more satisfactory for the year 1990 than for 1991, as inflow salinity data from November 1990 to February 1991 had to be interpolated, because no other field data had been available. Additionally, differences between simulation and measured data may be influenced by the fact that salinity at CTBOp22, which represents inflow conditions, was only measured at 0.3 m water depth. Density currents and higher salinity levels at bottom layers passing from Channel Reservoir to Kaparas have not been considered so far.

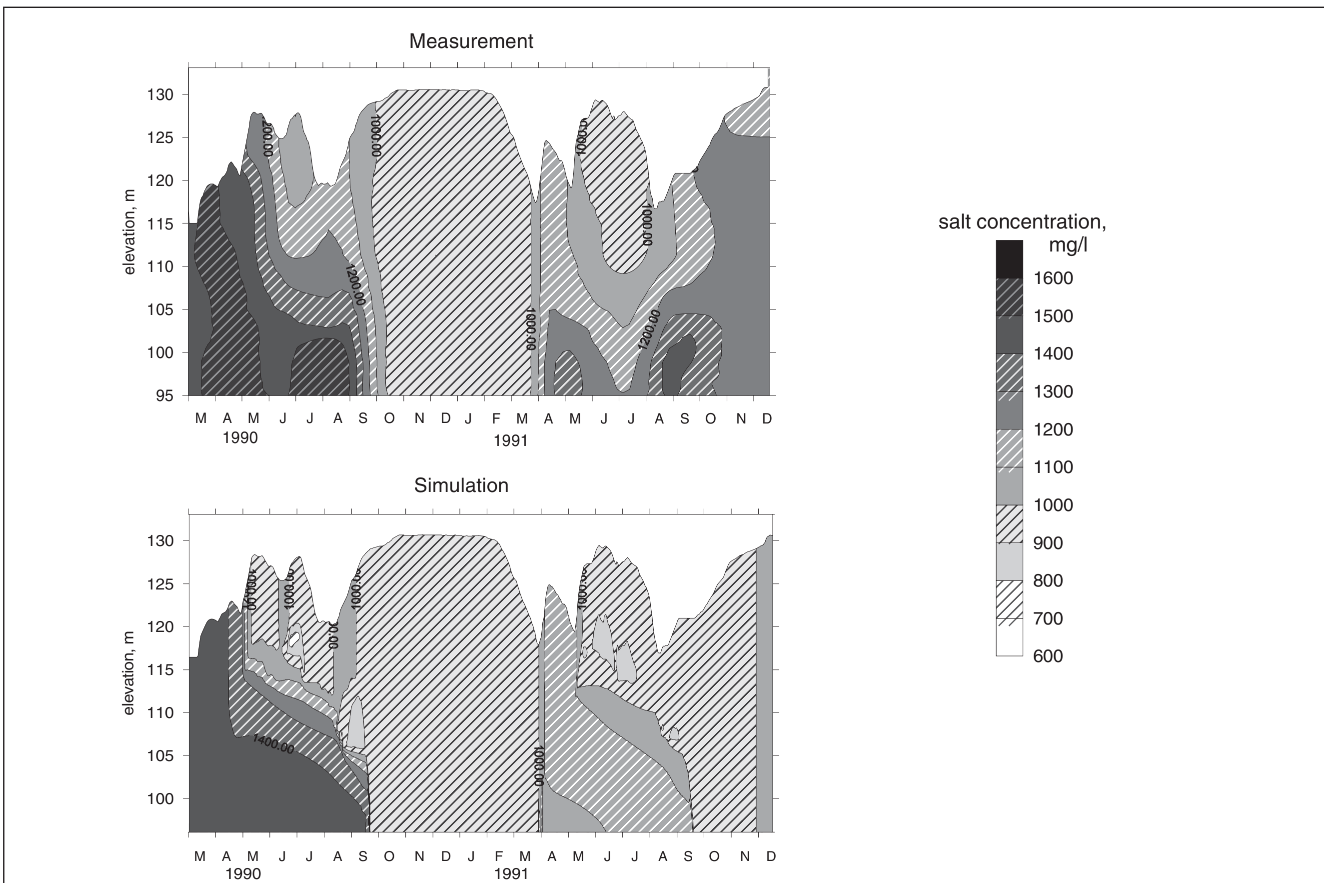

Fig. 5: Measured and calculated salinity for Kaparas reservoir, time-depths plots for the period 1990/1991

2.6 Impact of conventional management on water quality deterioration in dry years

Because of the critical conditions for agriculture and for direct human consumption in terms of low quality, especially during dry years, a sequence of three consecutive dry years has been chosen as a boundary condition, in order to represent a realistic but severe case of water scarcity. The basic settings determining initial conditions for the simulation by using the model Lac are summarized in **Table 3** and **Table 4**. If dry years follow in sequence of a wet or average year, the originally satisfying conditions, the intensity of the dry conditions, and time-dependant deteriorations are of interest. Measured salt concentrations data from 28. May 2001 range from 717 mg/l at the bottom up to 732 mg/l at the surface and represent the mostly low salinity. These data have been used as basic input data within this application to illustrate an expected negative trend of increased salinity concentrations in Kaparas reservoir, resulting from inflow salinity concentrations between 1,190 mg/l to 1,392 mg/l. Past records from 1990 must be of use as input climate data, because no other data were available. It is assumed that the salinity is more sensitive to changes in inflow salinity than to different evaporation in dry years and median years during the summer months.

For representing a conventional operation regime, inflow data had been calculated with the THC model, assuming water level differences between Channel Reservoir and Kaparas accordingly. The major inflow is considered within December to February, reaching a maximum of 293.1 million m³/month. Results obtained from the THC-model for estimated inflow salinity values range between 1,456 mg/l in April and 1,004 mg/l in August. Compared to past records for the Channel Reservoir station CTBOp22, the salinity level is higher, but still in accordance with data reported for Darganata Station at dry years.

The simulation results, as depicted in **Fig. 6**, show a reasonable variation of water levels with increase during the winter months and decrease starting from March. Calculated salinity starts with about 800 mg/l at the beginning of the simulation and reaches levels of 1,100 mg/l within the first year. The second year is characterised by an increase up to 1,300 mg/l, while at the end of the third year more than 1,400 mg/l are reached.

It is demonstrated that the influence of comparably low salinity starting/input levels only affects the availability of low saline water during the first 6 months. Especially in periods with lower salinity, as assumed in the first year, the influence of salt release at bottom layers is significant and contributes during the onset of the destratification towards an entrainment of high saline water in the entire water column.

During the filling with higher saline water at the end of the summer, this effect is aggravated and leads to a visible dete-

Table 3: Basic settings used for simulation of salinity in dry years

Start water level	125.55 m (measured water level on 1. January 2001)
Simulation period	1. January 2004 to 31. December 2006
Weather / climate data	Measurements 1990, Urgench
Reservoir Bottom	95.0 m a.s.l.
Initial conditions	Kaparas, middle section, station 9, measurements from 28. May 2001
Salt release	Constant daily flow of 0.9 m³/s with salt concentration of 2,100 mg/l

Table 4: Boundary conditions for salinity simulation, values obtained from THC model results

Kaparas	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Inflow (million m³)	293.1	101.6	0.0	0.0	0.0	13.6	0.0	0.0	0.0	0.0	45.5	155.4
Outflow (million m³)	0.0	0.0	275.8	191.5	2.2	0.0	18.6	18.3	5.8	20.3	0.0	0.0
Inflow salinity (mg/l)	1,190	1,285	1,393	1,456	1,384	1,255	1,118	1,004	1,041	1,109	1,291	1,392

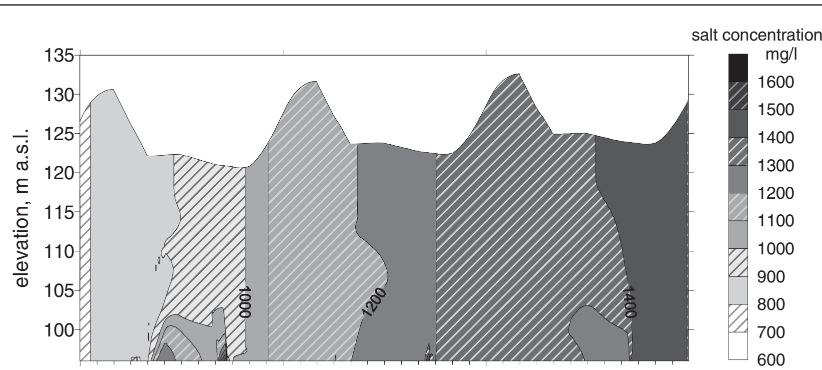

Fig. 6: Predicted time – depth development of salinity for three subsequent dry years

rioration of water quality. As the filling occurs predominantly during December to February, even lower salinity during the Amu Darya summer discharge would not bring a notable difference.

3 Conclusion

The results show that the conventional operation regime currently used is mainly based on filling Kaparas with high saline water during the winter months. Basically, this is determined by the need to transfer water of the low saline summer flood to the downstream irrigation areas. Another important constraint is the requirement to fill Kaparas by preceding higher water levels in Channel Reservoir. Even in case of starting with comparably low salinity levels, the simulation results demonstrate the rapid deterioration of water quality. Under dry year conditions, the WHO standards are exceeded already during one dry year, and will be exceeded after two years by 30–40%. The impact of dry years in the context of water stress becomes apparent. Not only the amount of usable water is restricted and leads to significant water scarcity and crop losses downstream, but also a water supply with satisfactory quality cannot be provided anymore.

The conventional operation practice does not consider the potential for taking in higher quality drinking water, which is provided by the low saline summer floods even under dry year conditions, when comparably low salinities between 800 mg/l and 1,000 mg/l can be expected. Here, improving the reservoir operation can capitalize the options provided by the fact that the Kaparas reservoir is an off-stream reservoir, and may also be operated independently from Sultansanjar and Koshbulak reservoir.

Processed data and simulation results are now at hand to identify enhanced reservoir operation strategies by changing the period of filling and release, as well as to initiate detailed analyses concerning how existing water deficits in dry years may be reduced by improved operation regimes.

Acknowledgements. The work presented is the outcome of an intensive collaboration between several researchers from Europe and Central Asia within the framework of the DFG/INTAS project IWMT 'Development of integrated water management tools for the Tuyamuyun reservoir complex – Improvement of drinking water supply and public health in the disaster zone of lower Amu Darya'. The successful collaborative work led to intensive friendship and mutual understanding of different aspects in the field of integrated water resources management in Central Asia. For this achievement, the stimulating work of Prof. Davide Calamari contributes definitively with the largest amounts. In particular in the starting phase of the project, his expertise and happiness provided the important swing in scientific and personal terms. The whole team does regret that Prof. Davide Calamari did not experience the satisfactory moment of a successful termination of the project and publishing of the results in the professional work, as well as in the establishment of the warm personal relationships.

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References

Crosa G, Froebrich J, Nikolayenko V, Stefani F (2005): Spatial and seasonal variations in the water quality of the Amu Darya River (Central Asia). Water Research (in press)

Djoraev Z, Babajanov K (2004): Water resources management in Uzbekistan. Managing Water Supply Security and Food Quality, Joint workshop by INTAS and University of Hannover, 18./19. November 2004, Hannover, Germany

Elpiner L (1999): Public health in the Aral Sea coastal region and the dynamics of changes in the ecological situation. In: Glantz MH (ed), Creeping environmental Problems and Sustainable Development in the Aral Sea Basin. Cambridge University Press, United Kingdom

Froebrich J, Kayumov O (2004): Water management aspects of Amu Darya. In: Nihoul JCJ et al. (eds), Dying and Dead Seas – Climatic Versus Anthropic Causes. Nato Science Series: IV, Earth and Environmental Sciences, Volume 36. Kluwer Academic Publishers, Dordrecht

Froebrich J (2000): Vorhersage der mehrjährigen Wassergüteentwicklung in Speichern mittels eines deterministischen Modells. (Prognosis of water quality dynamics in reservoirs by use of a deterministic model), Cuvillier Verlag Goettingen, Germany

Herbst S (2004): personnel communication

Hurley Octavio KA, Jirka GH, Harleman DRF (1977): Vertical heat transport mechanisms in lakes and reservoirs. Report No. 227, R. M. Parsons Laboratory for Water Resources and Hydrodynamics, Department of Civil Engineering, Massachusetts Institute of Technology

Ikramova M, Sorokin A, Khodjiev A, Misirkhanov H, Karimov B (2004): High quality water to the Amudarya Lower's population. Uzbekistan Agriculture, No. 12, Tashkent

IWLP (2005): International Water Law Project 2000–2005. Available at <http://www.internationalwaterlaw.org/>

Kayumov O, Ikramova MR (1997): Influence of Tuyamuyun Hydrosystem on bed processes and water intake in Amu Darya lowers. Uzbekistan Agriculture, No. 2, Tashkent

Schwerdhelm R (1992): Daten und Gleichungen zur Berechnung der Guetevorgaenge in Gewaessern. (Data and equations for the computation of the quality procedures in water bodies.) Unpublished internal documentation, Water quality protection and management, University of Hannover, Germany

Sorokin A, Ikramova M (2005): Modelling studies Tuyamuyun Hydro Complex model. Internal report

UNEP/GRID-Arendal (2005): National Report of Uzbekistan for Nature Protection 2000. Available at <http://enrin.grida.no//htmls/uzbek/report/index.htm>

Wegerich K (2004): Coping with disintegration of a river-basin management system: multidimensional issues in Central Asia. Water Policy, Vol. 6, pp 335–344

World Health Organization (WHO) (2004): WHO Guidelines for drinking-water quality, third edition. World Health Organization (WHO) 2004, ISBN 9241546387, 515 pages. Available at <http://www.who.int/water_sanitation_health/dwq/gdwq3/en/index.html>

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