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The reservoirs capacity assessment: the Tuyamuyun hydro complex in Khorezm region of Uzbekistan

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Abstract. The dynamic processes in water reservoirs depend on its morphological characteristics, i.e. bottom geology and relief, flow depth, intensity of water exchange, water and sediment features etc. The paper presents a capacity assessment of the Channel Reservoir of the Tyuyamuyun Hydro Complex located in Khorezm region of the Republic of Uzbekistan based on GIS tools. The study was aimed at determining of sedimentation dynamics of the Channel Reservoir during over 35 years dam operation and changes in the water storage capacity. The ongoing channel processes lead to regular reformation of the reservoir morphology. The data obtained allow determining the morphology of the reservoir, useful water volume, the capacity loss etc. and solving other issues related to management of water resources. The GIS technologies allows regular monitoring of the changes in capacity, make a prediction of future sedimentation processes, as well identify the stagnant water areas and volumes to be released to downstream for using in agriculture.

1. Introduction

The Tyuyamuyun Hydro Complex (THC) located on lower reaches of the Amudarya River aimed to irrigate over 500,000 agricultural lands in Khorezm and Karakalpakstan regions of Uzbekistan. The THC reservoir's total storage capacity is 7,2 km^3 containing of 4 reservoirs: Channel, Kaparas, Sultansanjar and Koshbulak functioning since 1981, and from that moment systematic process of sedimentation and siltation has been going on reducing its storage capacity (Figure 1). The Amu Darya River water with high turbidity (average 4-5 kg/m^3) flows into the Channel Reservoir where sediment is deposited, then, according to the water distribution scheme, the clear water is directed to other three reservoirs, irrigation canals and released to downstream. The initially designed capacity of the Channel reservoir was 2,340 Mio m^3 and it decreased for 585 Mio m^3 by 1985. From 1985 to 2002 the reservoir capacity decreased by another 355 Mio m^3. The siltation rate over 20 years (1985-2005) is averaged 22 Mio m^3 a year. According to measurements made by the State Unitary Enterprise ―Bathymetric Center‖ (SUEBC) in 2008, the siltation of the Channel Reservoir exceeded 1,200 Mio m^3. By end of 2018 the total siltation of the reservoir was estimated to be over 1,370 Mio m^3.
It is known, that during operation period the reservoir's design features undergo changes due to sediment deposition and erosion of the banks. Especially in flat irrigation reservoirs, which have large areas of water surface and not very deep, with the outflow of water into the downstream, large volumes of water remain in the newly formed drainless plots and cannot be used for intended purpose, which

happens with the THC Channel reservoir. To determine such phenomena that can accommodate up to 200 Mio m3 and more water it is necessary to have a clear morphological picture of the reservoir bottom, which can be obtained by bathymetric measurements. The bathymetric data are used to study the morphology and cartography of the Channel reservoir's bottom surface, to make analysis of the topography, determine the useful volume of the reservoir, and solve other applied problems.

At present, many methods have been developed for calculating the sedimentation/or siltation of reservoirs considering their specific features. The methods for calculating of reservoirs' siltation are divided into several groups. The methods of the *first group* are based on field study materials of siltation, i.e. on empirical dependencies [1-4]. These methods are based on a number of assumptions, in particular, that channel sediments in the first period settle equally along the entire length of the reservoir. At the same time, it is assumed that due to increase in depths and decrease in the flow rates in a reservoir, as flow moves to the dam, the rate of sediment deposition increases. The methods of the *other group* are based on the determination of siltation volumes by the difference in the transporting ability of the flow and do not consider the continuous change in the flow elements during silting. Most graphical dependencies are developed based on field investigations data on sediment volumes [5-8]. The main disadvantage of these methods is the assumption that during the time interval the hydraulic characteristics of the flow and siltation intensity are considered to be constant. The methods of the *third group* determine the amount of siltation taking into account the continuous change in the flow characteristics. The methods are called "balance method" considering a transporting ability of the flow in the reservoir. These methods are based on the sediment accumulation mechanism [2, 9-11]. With the development of GIS technologies, the *next group* of methods has been formed. It should be kept in mind that when modeling each unique hydraulic structure, including reservoirs, it must be considered all specific features [12-18].

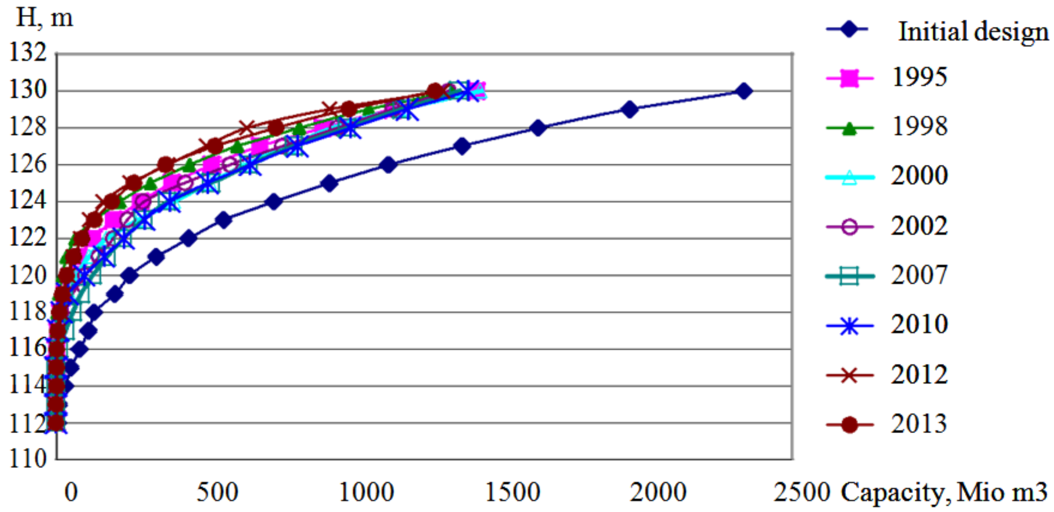

Figure 1. The Cannel Reservoir capacity change dynamics

2. Method

In Uzbekistan more than 50 large operated reservoirs were built in the last century. Reservoir siltation monitoring is always an urgent task. However, the THC reservoirs capacity measurement is associated with many difficulties including the fact that part of the reservoirs are located in the territory of another country - Turkmenistan. Moreover, in the country, introduction of GIS technologies in river hydraulics is not widely used.

Research analysis show that the main issue in developing of flow models in the reservoirs is associated with deficiency of necessary information, especially the measurement data in nature. The main difference in the present study is only in the methodology for taking into account the local characteristics of reservoir, descriptions of transverse and longitudinal hydraulic structures, taking into account their parameters, methods for visualizing the results and etc., according to which the model is subsequently calibrated.

Table 1. Sediment deposition in the Cannel Reservoir and their percentage relative to the design capacities of these zones (Mio. m3)

Years / Elevations		1985	1990	1991	1992	1995	2000	2001	2002	2007	2010	2012	2017
I	≤117	85	62	86	90	105	67	59	123	135	102	119	124
	Sedimentation % against design volume 110 Mio m^3	77	56	78	82	95	61	54	112	123	93	108	113
II	117-123m	155	118	136	210	244	123	106	287	353	346	386	389
	Sedimentation % against design volume 460 Mio m^3	34	26	30	46	53	27	23	62	77	75	84	85
III	123-130m	345	379	442	481	523	336	301	579	686	641	612	632
	Sedimentation % against design volume 1770 Mio m^3	19	21	25	27	30	19	17	33	39	36	35	36

Figure 2. The Channel reservoir layout

At the investigation the Channel reservoir was divided into 3 sections by sedimentation rate (Figure 2). Study of the sediment deposition process by altitude sections is presented in the Table 1. The I-section, from the dam to CS49 is 15 km (CS – cross section), consisting 110 Mio m^3 of totally covered by sediments. Elevation of its bed has increased from 112m to 117m. Sediment volume consisted 11% of total deposition in the Channel reservoir. Sediment removal from the reservoir in this area occurs when the reservoir operates at low water level and significant outflow releases to the downstream. The II-section is identified from CS49 to CS37 with length of 30 km. This section is characterized by fluctuation of sediment deposition from 27% to 71% of the total capacity against 460 Mio m^3 designed sedimentation volume. The III-section with a length of 45km at the upper side of CS37 is the main accumulation area of sediment arriving with water flow. Regular replacement of sediments takes place depending on operational regime of the dam. In this area often an accumulation process can be alternated with removal and vice versa. Sedimentation rate relatively to reservoir capacity as follows: 11% in the I-section, 18% in the II-section and 71% in the III-section.

3. Results and Discussions

The data analysis based on the Channel Reservoir measurement conducted by the THC Operation Unit, SUEBC and other institutions conducted field investigations data showed an increase in the bottom elevations of the initial channel and intensive siltation of the floodplains which leaded to formation of many ―water blocked plots‖ due to sediment deposition. The storage capacity of these volumes are considered at the reservoir capacity estimation, however at discharging of the reservoir this water remains unused. The reservoir filling modes estimation has been based on the regulating water volume data. The calculation results depend on the reliability of the following initial data: inflow to the THC, water turbidity and the initial ―base‖ volume curve. To represent a filling state of reservoir, a database has been compiled and a GIS model has been developed identifying interdependence of volumes and water level, sedimentation and erosion areas and waterways among them, bottom level elevation data, water flow and sediment movement tracks and etc. (Figure 3 and Table 2).

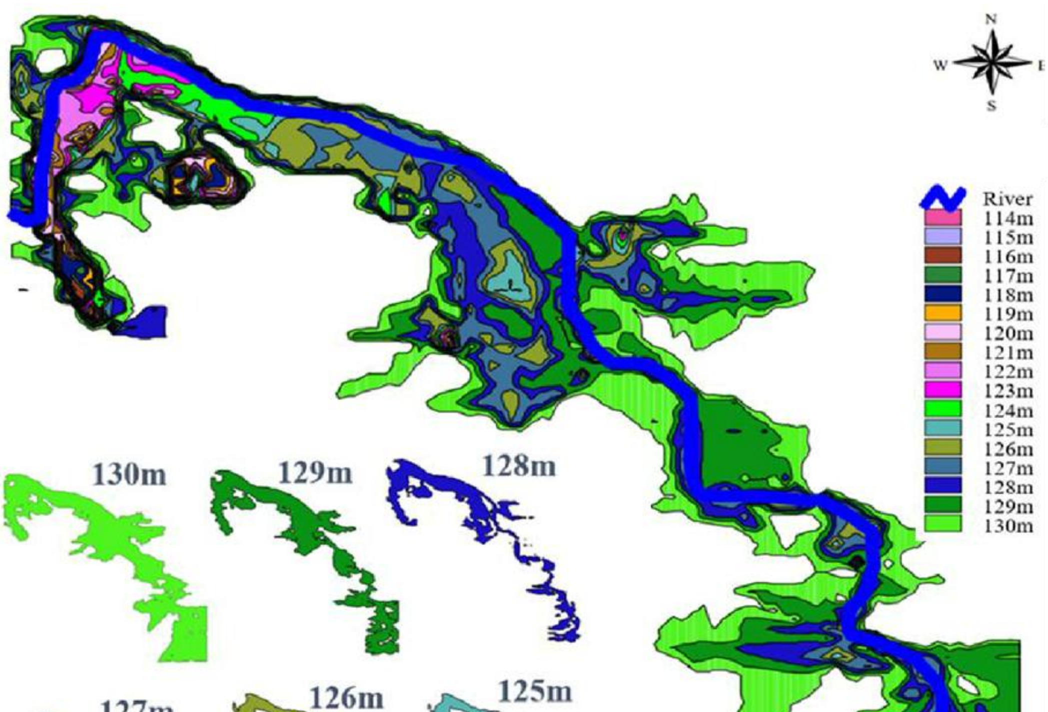

Figure 3. GIS model of the THC Channel reservoir capacity at various water levels

Table 2. The reservoir capacity at different level of water surface: field investigations and model results

Elevation, m	Design capacity, Mio m^3	BMC, field measurements, Mio m^3	Model, Mio m^3
130	2340	1287	1223,6
129	1950	994	944,7
128	1640	746	718,4
127	1380	539	512,15
126	1130	372	333,4
125	930	263	241,85
124	740	188	158,6
123	570	129	122,5
122	450	87	72,6
121	340	58	56,1
120	250	36	35,2
119	200	20	19,4
118	130	9	8,5
117	110	3	2,8
116	80	1,6	1,2
115	50	0,5	0,5
114	30	0,1	0,1
113	10		0
112	5		0

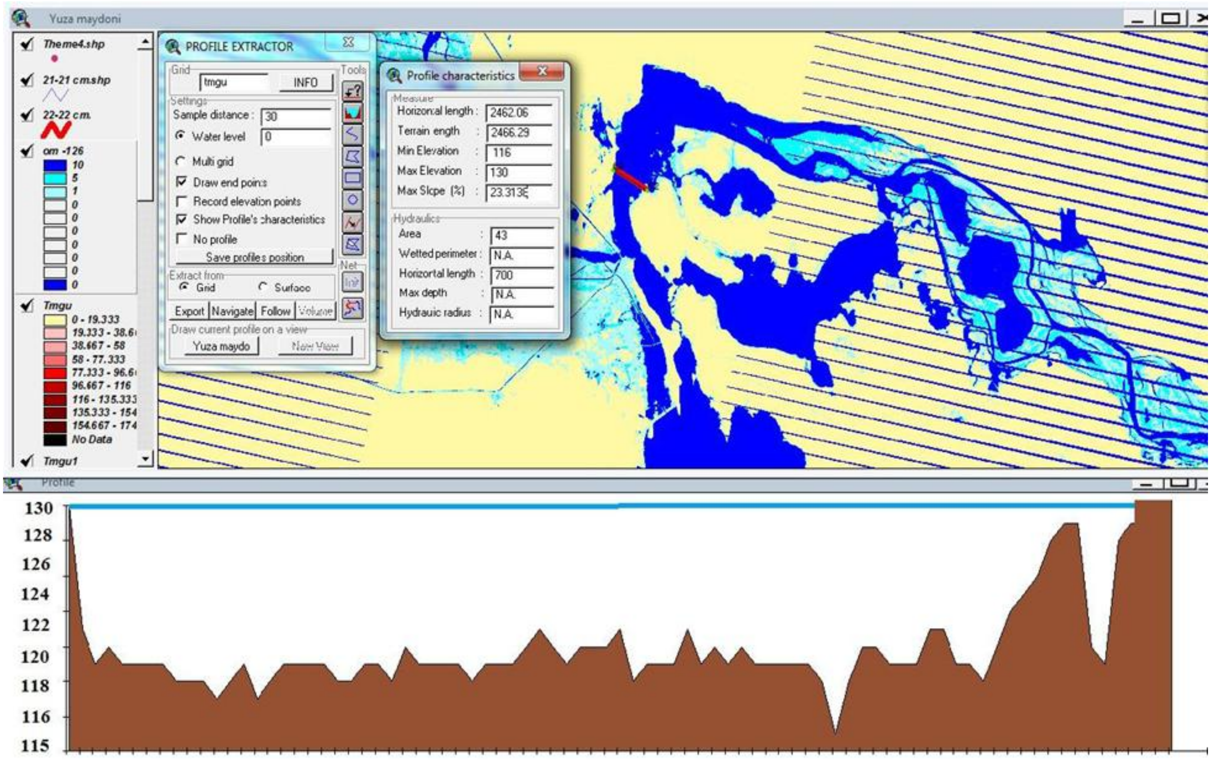

Figure 4. GIS model and cross section of the reservoir

As a software tool, ArcView GIS 3.2a version and modules as PE6.0 for 3D spatial analyst were used. The hydrological database was created and stored in a cartographic semantic form, an interface and data verification was developed. A selection of primary materials with statistical data processing is performed. In terms of determining and refining the morphometric characteristics of reservoir areas at different levels of the water surface, linear and area indicators (length and width of the reservoir, coastlines, area, volume, depths, etc.) of the identified taxonomic units are calculated.
The modeling includes 2 main directories - cartographic and attributes data. The cartographic database consists of digital layers: contours of the coastline and water-covered sections of the reservoir, islands, boundaries of morphological units, depth marks (elevations), bottom topography based on a regular (GRID) and triangulated irregular network (TIN), which are formed into isobaths. The database makes possible to process the available material and simulate siltation or erosion processes occurring in the reservoir. The cartographic material is divided into the following scales: 1: 25000, 1: 200000. The attributive database contains morphometric characteristics introduced at modeling the spatial dynamics of the morphological regime elements, i.e. thematic and model characteristics are stored. Model data consists of generalized tables of various statistical characteristics (Figure 4).
Using the GIS model, it was revealed, that with a decrease of water level from 127m to 118m at the dam area (section I) suspended sediments are transported with the water flow to the downstream, and at the same time erosion of sediments is also observed which can reach up to 31 Mio m^3 a year. When the water level is high, in the high-altitude zones of this section from 118 to 130 m, processes of both silting and erosion are taking place. During wet seasons with a flow rate from 2700 m^3/s to 4450 m^3/s and water levels from 126.4m to 129.5m, the percentage of siltation ranged from 71% to 100% of the total siltation in this section of the reservoir. At elevations of 120-124m a siltation reaches up to 45%, and at 124-130m siltation amount consists of 45-70%. In dry years the erosion process is observed at 118-124 m elevation.
The II section of the reservoir with length of 30 km, at a distance from the dam from 15rv to 45 km. This area is featured by annual variability of sediment volumes from 27% to 71% relative to the design capacity of 460 Mio m^3. Vertically, by elevations the deposit amount change is negligible. Sediment comes from the overlying third section. The movement of sediments towards the dam or their deposition depends on the operation terms of the reservoir, on flow rate and the amount of water, discharged into the lower sites of the hydraulic system, i.e. on the channel processes occurring in this section of the river.
The III section of the reservoir is most affected by changes in water levels. On this site wedging areas of backwater levels fluctuate around 124m. This is the main sediment deposition zone in the reservoir, inflowing along with the river water. The reservoir morphology reformation in this area is associated with periodic runoffs and fillings and play a significant role in the siltation of the reservoir and the creation of an additional backwater curve directed upstream of the river. In this area, the erosion zones alternate with sedimentation zones. For example, in dry years, the erosion volumes can reach 80-100 Mio m^3, while at the average and wet years this section is featured by a large volume of deposits reaching over 100 Mio m^3. At this point a regulated volume of water is considered, used within certain time frame. The obtained results depend on the initial data accuracy consisting of the following indicators: inflow to the reservoir and outflow, water withdrawals to irrigation canals, water turbidity, the design volume curve etc. As the input data is received, the operational model for calculating the reservoir siltation should be corrected.
The GIS model of the Channel reservoir and database developed based on bathymetric measurements allow to achieve the following results:
i) based on the water inflow data to the Channel Reservoir, the amount of sediment inflow, deposition and erosion volume in the monthly section were determined. The Figure 5 presents these characteristics for the average water year (2017).
ii) at the dam area at elevation 125m an intensive movement of water stream with high turbidity is observed within 1/8 part of the CS22. Large sediment deposed area identified at the elevation of 127m including on the upper slope of the dam #3. The area near by the dam#2 is completely silted up to

elevation 125m. Within CS51 and CS35 at level of 125m due to specific sediment deposition morphology many stagnant water areas and ducts are observed (Figure 5).
iii) the area at CS34 is silted up to elevation 127,5m. At the area of CS34 a place with depth of 10-18m is observed. At the same time, the right half part of the site is silted up to 127 m.

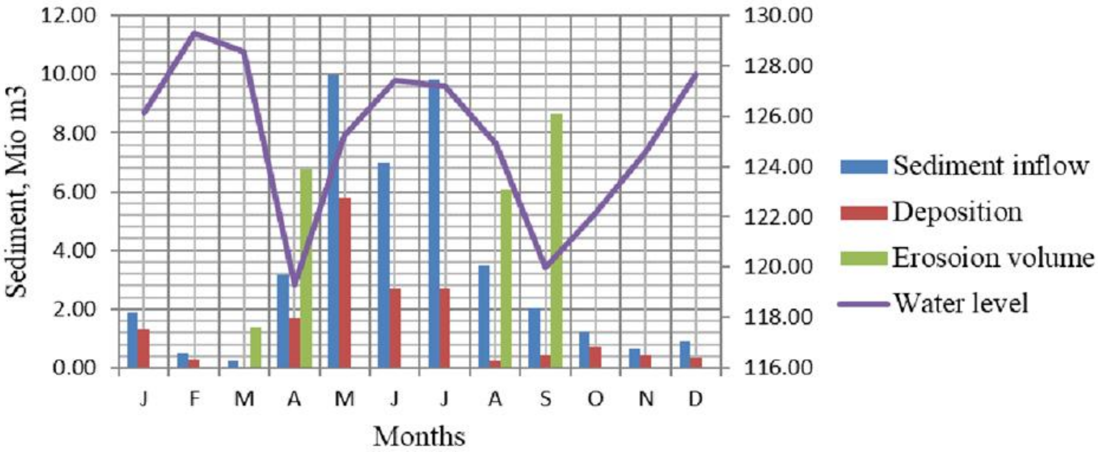

Figure 5. Sediment inflow-outflow and deposition depending on water level in the Cannel reservoir

This situation is linked with intensive and huge amounts of siltation of the lower located area, which leads to decrease the flow velocity in the upper site, especially at the Lebap Bridge, many ducts formed due to siltation. Part of these ducts is blocked by the created small silt bars. By the model data, considering water flow was 120 m^3/s at Lebap bridge section located 58 km upper the dam.
Using the GIS model, the water volumes, distance to/and between ducks can be determined. Location of the blocked water bodies and their cross sections in every 1m, presented in the Figure 6, allow calculating water volumes (borders of the blocked water plots are highlighted in red).

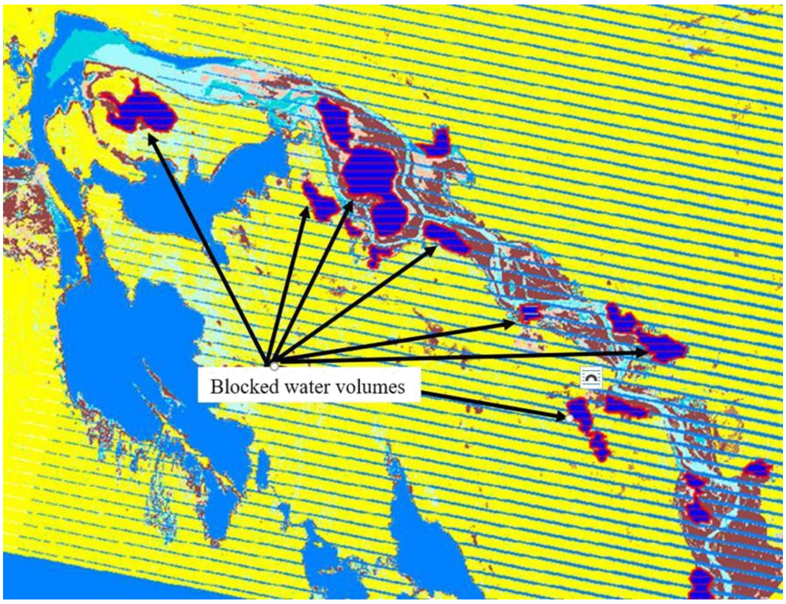

Figure 6. Location of blocked water areas

4. Conclusions

The study results have shown that, depending on the reservoir morphology the water stagnation zones can be formed, volumes of which change from 200 to 450 Mio m^3, water from which can be directed downstream by using dredgers by open of flow paths. The developed GIS model with database consider the reflection of real processes occurring during the operation of the THC reservoirs, allow to determine the following parameters: water discharge and water level features at the river flow and accumulated in the Channel reservoir water allocation and redistribution among other reservoirs as Kaparas, Sultansanjar and Koshbulak, water abstraction to irrigation canals and discharge to the lower streams of the Amu Darya River; sediment deposition volumes in the Channel Reservoir and value of turbidity in the downstream of the THC; the amount of evaporation and filtration water loss from reservoirs; the intensity of the Channel Reservoir useful capacity changes due to sediment deposition, and erosion and removal to the lower reaches of Amu Darya River.

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