The THC flow control capacity for the Lowers of the Amudarya River

1. Background

An original sediment concentration in the AmuDarya water was broken due to its accumulation in the reservoirs (Nurek and Tuyamuyun) and huge volume of water diverting to the irrigation canals in the mid-stream (KMK, ABMK and Karakum canal). Average monthly discharge (for the last 30 years) of the transported sediments along the river varies within the following ranges /UZGIDROMET /:

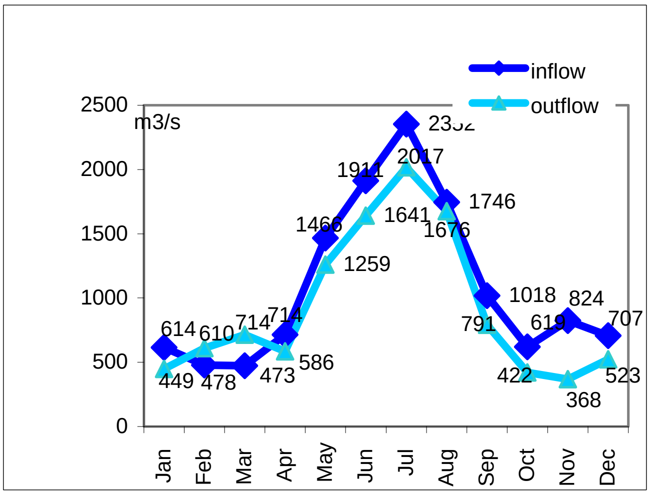
Kerki station - from 560 to 28,000 kg/s
Darganata station – from 250 to 8,000 kg/s
Tuyamuyun station – from 6 to 1,400 kg/s
Kipchak station – from 20 to 1,500 kg/s

Average monthly turbidity varies by the following:

Kerki station - from 0.72 to 19 kg/m^3
Darganata station – from 0.30 to 7.0 kg/m^3
Tuyamuyun station – from 0.02 to 1.8 kg/m^3
Kipchak station – from 0.04 to 0.89 kg/ m^3

Due to accumulation of sediments in the Channel reservoir the flow behind the dam has a low turbidity, the water is clarified. Turbidity is minimal (0.02-0.08 kg/m3) in winter time. In summer period turbidity is also low and water is clean.
In fig.1 water inflow to the reservoir and outflow (a) and accordingly sediment transportation (b) is presented.

a)



b)

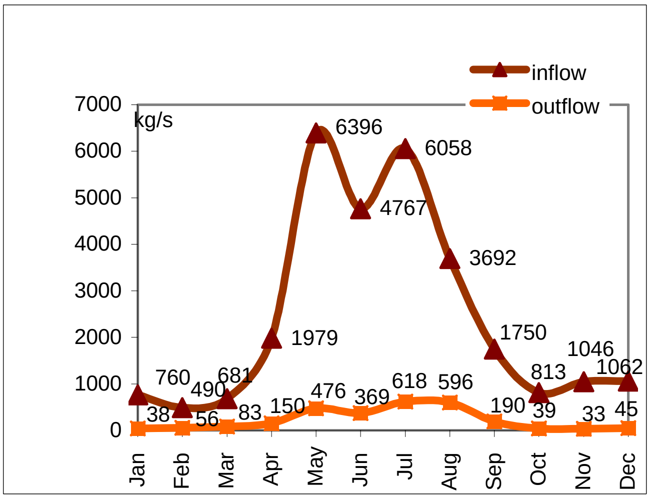


Fig. 1 - Average water and sedimentation inflow to the Channel reservoir and outflow for the period 1981-2005

If the outflowing surface elevation decreases lower than 118 m turbidity reaches to 1.10-8.0 kg/m3. Totally suspended matters and bed load varies from 4 to 10 Mio ton a year.

2 Analysis of sedimentation dynamics of the reservoir and its current state

The reservoir filling was started in 1981. During 25 years operation period the reservoir has been deformed significantly and lost almost 30% of operational capacity. The field investigations of the reservoir have been carried out by SANIIRI and the last by the BMC in 2005. The field investigations and data provided by the THC Management Unit allowed analyzing accumulation and removal processes in the Channel reservoir. In Fig.2.1 presented dependence of reservoir capacity on surface level according to the designed and measured data.

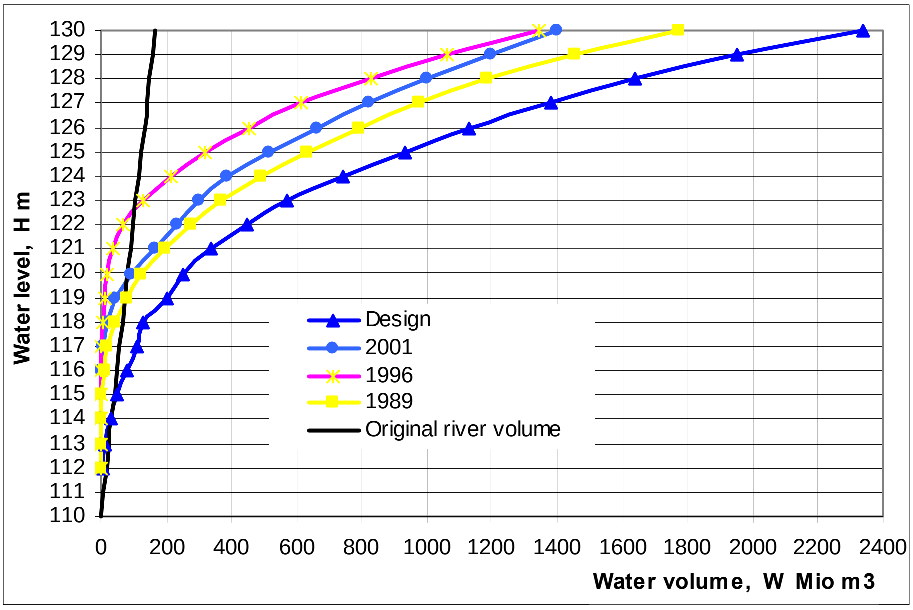


Fig - W=f(H) curve developed by measurements, Mio m3

Its surface level varies from 130m to 118 m according to design. In order to provide good quality drinking water to Kaparas (156 Mio m3 a year) a minimal surface elevation reaches to117m against designed 118m.

Analysis of the measurement data has resulted that the total designed reservoir capacity of 2340 Mio m3 was decreased to1287 Mio m3. The capacity loss dynamics for the period 1995-2005 and sediment accumulation is presented in table 2.1 and 2.2.

Table 2.1 - The Channel reservoir capacity change by elevations, Mio m^3

Elevation	Designed		SANIIRI field investigations								BMC
	Total	Operational	1995	1996	1997	1998	1999	2000	2001	2002	2005
130	2340	2090	1427	1346	1442	1334	1290	1369	1400	1316	1287
129	1950	1700	1143	1063	1165	1143	1100	1174	1195	932	994
128	1640	1390	906	826	938	956	912	988	1000	649	746
127	1380	1130	693	615	790	769	726	807	820	512	539
126	1130	880	528	452	642	590	546	656	660	380	372
125	930	680	393	320	520	438	393	527	515	252	263
124	740	490	285	215	399	296	252	377	385	161	188
123	570	320	195	130	280	242	199	297	300	115	129
122	450	200	125	65	170	193	152	227	231	85	87
121	340	90	75	35	110	145	105	172	163	60	58
120	250	0	50	20	68	98	61	124	95	40	36
119	200	Dead volume	29	10	44	55	30	84	40	25	20
118	130		14	4	21	16	8	56	20	15	9
117	110		5	0	7	5	3	31	6	8	3
116	80		1	0	1	1	0,8	8	2	3	1,6
115	50		0	0	0	0	0	0	0	0	0,5
114	30		0	0	0	0	0	0	0	0	0,1
113	10		0	0	0	0	0	0	0	0	
112	5		0	0	0	0	0	0	0	0	

Average annual sedimentation volume for operation period (from 1981 to 2005) consists of 22.0 Mio m3 a year. The most intensive accumulation of sediments took place in 1991-1992 (222 Mio m3) and in 1998 (108 Mio m3).

Maximum removal of sediments has been observed in 1986 (135 Mio m3) at the 20,8km3 runoff, 1997 (56 Mio m3) at the runoff of 18,3 km3 and 2000-2001 (110 Mio m3) at the runoff of 18,7 and 13,6 km3.

Table 2.2 – Sediment accumulation dynamics by elevations for the period 1995-2002, Mio m3

Elevation	1995	1996	1997	1998	1999	2000	2001	2002
130	913	994	898	1006	1050	971	940	1024
129	807	887	785	807	850	776	755	1018
128	734	814	702	684	728	652	640	991
127	687	765	590	611	654	573	560	868
126	602	678	488	540	584	474	470	750
125	537	610	410	492	537	403	415	678
124	455	525	341	444	488	363	355	579
123	375	440	290	328	371	273	270	455
122	325	385	280	257	298	223	219	365
121	265	305	230	195	235	168	177	280
120	200	230	182	152	189	126	155	210
119	171	190	156	145	170	116	160	175
118	116	126	109	114	122	74	110	115
117	105	110	103	105	107	79	104	102
116	79	80	79	79	79,2	72	78	77
115	50	50	50	50	50	50	50	50
114	30	30	30	30	30	30	30	30
113	10	10	10	10	10	10	10	10
112	5	5	5	5	5	5	5	5

The Channel reservoir was divided into 3 sections according to sedimentation rate (Fig.2.2).

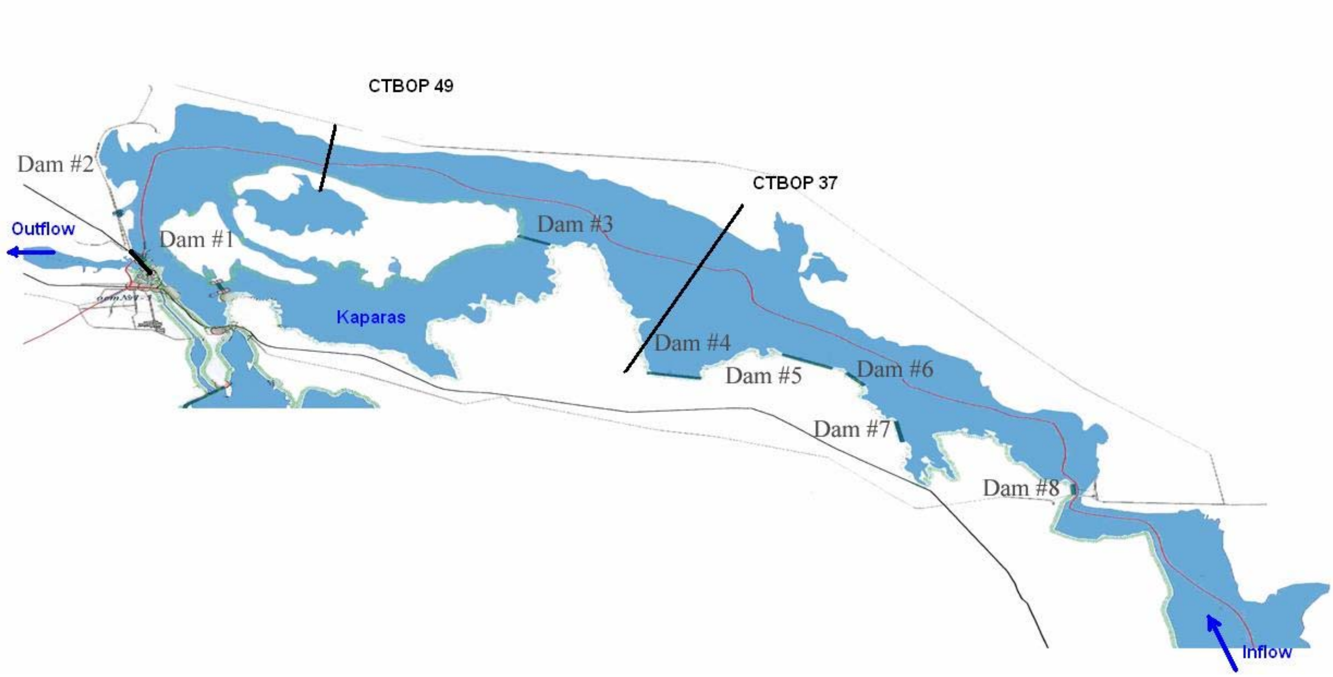


Fig. 2.2 - The Channel reservoir layout

The first section (from the dam to 49CTBOP - 15 km) consisting 110 Mio m3 of designed volume is totally covered by sediments. By 1995 an elevation of its bed has increased from 112m to 117m. Sediment volume consisted 11% of total accumulated volume in the reservoir (table 2.3).

The second section of the reservoir from 49 CTBOP to 37 CTBOP with length of 30 km (distance from the dam is 45 km) has 460 Mio m3 design volume. This section is characterized by fluctuation of the accumulated volume from 27% to 71% relatively the design volume. By the 2001 a sediment volume in this section consisted 36% of the initial volume. Sediments arriving from the third (upper located) section and its transition depend on the dam operation regime and inflowing and outflowing runoff(table 2.3).

The third section with a length of 30 km above the 37CTBOP is the most liable to water level change. In this area a backwater profile pinches out at the water level above 124m in the reservoir. There is the main sediment accumulation area arriving with water flow. Regularly 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. For example, according to the data from 1998-2001 the removal volume at the 32-36 CTBOP reached to 80-100 Mio m3, at the same time at the 31-35CTBOP took place a sedimentation up to 100 Mio m3. From the data of 2001 a percentage of sedimentation relatively to the total volume of the reservoir (940 Mio m3) were by the following: 11% in the I-section, 17,7% in the II-section and 71,3% in the III-section (table 2.3).

Table 2.3 – Accumulation of sediments (Mio m3) by elevations and its % relatively to designed volumes

Elevation \ Year		1985	1986	1987	1988	1989	1990	1991	1992	1993	1995	1996	1997	1998	1999	2000	2001
I	≤117m	85	71	73	85	89	62	86	90	100	105	110	103	105	107	79	104
	% relatively the initial volume of 110 Mio m^3	77	65	66	77	81	56	78	82	91	95	100	94	95	97	72	75
II	117-123 m	155	124	126	155	111	118	136	210	244	270	330	187	223	264	194	166
	% relatively the initial volume of 460 Mio m^3	34	27	27	34	24	26	30	46	33	59	71	40	48	57	42	36
III	123-130 m	345	255	329	345	365	379	442	481	523	538	514	608	678	679	698	670
	% relatively the initial volume of 1770 Mio m^3	19	14	18	19	20	21	25	27	29	30	29	34	38	38	39	38

3. The THC Channel reservoir sedimentation estimation method

The method is based on the method developed by Skrilnikov and a calculation can be carried out at a fixed level. The method described below was improved by SANIIRI for variable level regime taking into account the water cleaning (lightening) rate.

The initial capacity of the reservoir is $\mathbf{W_i = W_r}$, i.e if the dam is open. Then water volume in the reservoir is equal to the river volume. An original river volume W_r, where the flow transports all suspended matters, is

$$\mathbf{W_r = \Omega L,}$$

Here Ω is a river cross-section area, m2
L is a length of a dam impact (backwater lenghth)

In this case, at W_r / W_i =1, water cleaning (lightening) rate is **ε = 0.**
But in the case, if **Wi > Wr** and **Wr / Wi < 1** then **ε > 0**

Accordingly,

$$\varepsilon = f\,(Wr/\,Wi)$$

A water cleaning (lightening) rate is divided into two stages: at the 1-stage **ε =1.0,** at the 2-stage as the **Wr/ Wi** increases "ε"decreases from **1 to 0.**
Criteria of a transition from the 1-stage to the 2 – stage is **Wr/ Wi = 0.12.**

The calculation should be fulfilled by the following:

<u>Input the following data:</u>
Design volume of a reservoir - W_d, Mio m^3
The full volume of a reservoir by the beginning of a considering period (it may be the last measured volume) - W_m, Mio m^3
Inflow (average monthly) - Q m^3/s
Water level elevation by the 1 day of a considering period (month) - Hi , m
Water level elevation by the last day of a considering period (month) - H_l , m
Initial joint level elevation (see fig) - H_{ijl}, м
Calculated full volume of a reservoir (at 130m of the Channel) – W_c, $W_{c=1}$,…. $W_{c=n}$, here $W_{c=1}$= W_m

<u>Start the calculation</u>

1- Determine water volume in the reservoir on a joint level elevation – W_{jl}, Mio m^3

$$W_{jl.} = W_r\,(H_{ijl} - H_d)/(H_{nol} - H_d)$$

Here: W_r = 165 Mio m^3 is an original river flow volume on average discharge of 1800m^3/s for the period of the last 30 years on 110 km distance,
H_d= 110 м – dam invert level elevation,
H_{nol} = 130 м – normal operating level elevation

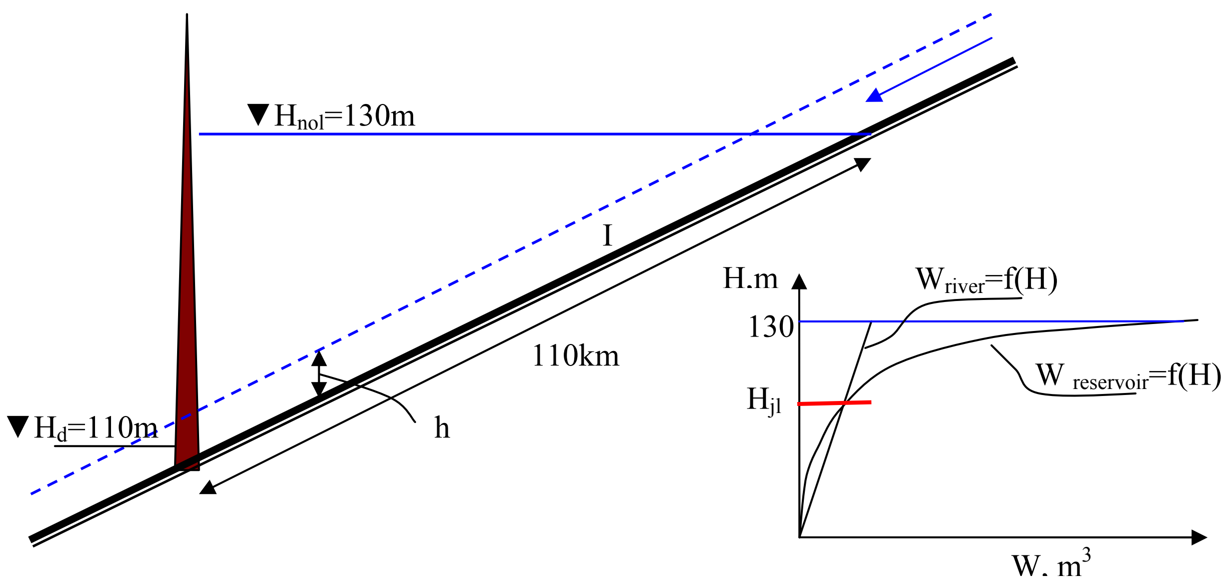


Fig 3. 1 - Scheme for the calculation

2- Width of a considering part of the river stream - B, m

$$B = Q /(V h)$$

Here: V = 1.2 m/s - average flow velocity for Amudarya / by Altunin and Skrilnikov/
h = 2.5 m - average flow depth at the THC, .

3 - Turbidity of an inflowing discharge - ρ , kg/m^3

$$\rho = K Q^{0,9}$$

Here: К- a turbidity coefficient: for the January-May period K=0.0035; June-December K=0.0025 / by SANIIRI/

4 - River runof for a considering period (month) -R , Mio m^3

$$R = Q t$$

Here: t – period, s.

5 - Inflowing sediment runoff for a considering period (month) - R_s, Mio m^3

$$R_s = 0.0012V\rho$$

6 - Total sediment volume in the reservoir by the beginning of a calculation (according to the last measurement) **- W_s,** Mio m^3

$$W_s= W_d – W_m$$

7 - Average sedimentation level elevation by the beginning of a calculation - H_{Ws}, m

as for the Channel reservoir W_s>1000 Mio m^3

$$H_{Ws} = -10^{-6}W_s^2 +0.0067W_s+119.66$$

8 - Calculated volume of water in the reservoir - W_i, Mio m^3

$$W_i = W_c (H_i- H_d)(H_i-H_{jl})/(H_{nol}-H_{jl}) (H_{nol}- H_d)$$

i=1, 2…n

9 - Additional turbidity (in the case of a sediment removal) – ρ_{add}, kg/m^3

at $H_i < H_{jl}$ and $H_f < H_{jl}$ then $\rho_{add} = 0.83B\mu (H_{Ws} – H_f) / IQ$

Здесь: μ=0.0008 – sediment removal intensity, mm/s.
I = 0.00018 – river slope

10 - Water lightening coefficient – ε

If $H_i \le H_{jl}$ and $H_f \le H_{jl}$ then **ε=0**

If $H_i > H_{jl}$ then $\varepsilon=0.041(W_r (H_{nol} – H_{jl})/ W_c (H_i – H_{jl}))^{-1.5}$

11 - Sedimentation / removal volume <u>at filling up</u> for the considering period (month) - W_{st}

If $H_i > H_{Jl}$ and $H_f > H_{Jl}$ and $H_i < H_f$ (filling) then $W_{st} = 1,2_\rho(R-(VW_i (1- \varepsilon)/W_f))$

If $H_i < H_{Jl}$ and $H_f > H_{Jl}$ and $H_i < H_f$ (filling) then

until H_{Jl} $\mathbf{W_{sr} = 1{,}2\ \rho_{add}\ ((R(H_i-H_{jl})/(H_i-H_f))+(W_i-W_{jl}))}$,

above H_{Jl} $\mathbf{W_{st} = 1{,}2\ \rho((R-R(H_i-H_{jl})/(H_i-H_f)) - (V-VW_{jl}(H_i-H_{jl})/W_f(H_i-H_f))(1-\varepsilon))}$

Here you can see until H_{Jl} – removal, higher H_{Jl} – sedimentation, so two processes are taking place.

12 - Sedimentation / removal volume <u>at outflowing</u> for the considering period (month) - W_{st}

If $H_i > H_{Jl}$ and $H_f > H_{Jl}$ and $H_i > H_f$ (outflowing) then $\mathbf{W_{st} = 1{,}2\ \rho V\ \varepsilon}$

If $H_i > H_{Jl}$ and $H_f < H_{Jl}$ and $H_i > H_f$ (outflowing) then

until H_{Jl} then $\mathbf{W_{st} = 1{,}2\ \rho\ \varepsilon\ R(H_i-H_{jl})/(H_i-H_f)}$,

below H_{Jl} then $\mathbf{W_{sr} = 1{,}2\ \rho_{add}\ (R-(R(H_i-H_{jl})/(H_i-H_f))+(W_{jl}-W_f))}$

In this case outflowing until H_{Jl} sedimentation, lower – removal is take place, so also two processes.

13 - Joint level elevation by the end of the considering period (month), m

At sedimentation process $H_i > H_{jl} < H_f$

$$\mathbf{H_{jl(i)} = H_{jl(i-1)} + \Delta h_s}$$

Here $\mathbf{\Delta h_s = W_s I\ /\ (3B_r(H_{jl(i-1)}-H_d))}$ – sediment layer height, m

At removal process $H_i < H_{jl} > H_f$

$$\mathbf{H_{jl(i)} = H_{jl(i-1)} - \Delta h_r}$$

Here $\mathbf{\Delta h_r = W_{sr} I/\ (B_r(H_{jl(i-1)}-H_d))}$ – removed sediment layer thickness, m

4. The Channel reservoir sedimentation and future trends

Firstly, the estimation was carried out based on the hydrological data and real operation regimes of the reservoir. Next, the similar estimation was fulfilled based on the improved operation regime (by SANIIRI team) considering runoff rate in the years from 1996 to 2003. In that case 1996, 1999, 2002 and 2003 were average water availability years, 1997, 2000 and 2001 – dry and 1998 was wet year.

According to field investigations by the end of 1995 a useful volume of the reservoir at the elevation of H=130m reached 1427 Mio m3. This volume was accepted as an initial volume to start the calculation. The volume of the stable channel was determined by the following:

$$\mathbf{W_r = Q/VL = 165\ Mio\ m3,}$$

here Q=1800 m3/s,
V=1-1.2 km/s (averaged velocity of the river at this area
L=110 km, length of the reservoir

At the river slope i=0.00018 hydraulic elements of the river are B=600m, h=2.5m

The initial elevation of the bed covered by sediments was accepted 124,83 by the end of 1995 (fig 3.1). The data by the end of 1995 was accepted as initial data in order to start the calculation for 1996.

In order to assess an accuracy of the calculated results the actual data for 1996 and 2006 were compared as given in the table 4.1 and Fig 4.1, which showed its precision and the method developed was used for prediction.

Table 4.1 - Calculated and actual volumes of the reservoir

Year	The reservoir capacity, Mio m3		Sedimentation volume, Mio m3	
	calculated	measured	calculated	measured
1996 (initial)	1427	1427	913	913
1996	1376	1346	964	994
1997	1416	1442	924	898
1998	1265	1334	1075	1006
1999	1252	1290	1088	1050
2000	1350	1369	990	971
2001	1429	1400	911	940
2002	1346	1316	994	1024
2003	1246	-	1094	-
2004	-	-	-	-
2005	-	1278	-	1062

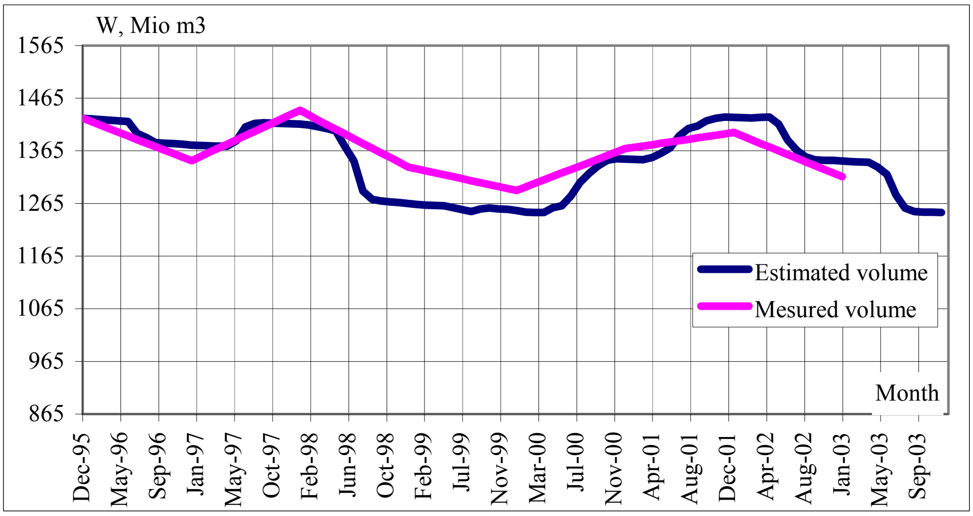


Fig.4.1 - Comparison of measured and estimated capacities of the reservoir from 1995 to 2003

Analysis of sediment estimation by the developed method for the real dam operation regime in 1996-2003 - ***scenario I*** and the regime improved by SANIIRI – ***scenario II*** are given below:

A. S***cenario I.*** In 1996 (average water) and 1998 (wet) the accumulated sediment volume was 51 Mio m3 and 151 Mio m3 accordingly. In 2002 (average) and 2003 (wet) the volumes were 83

Mio m3 and 143 Mio m3 accordingly. And only in 1997, 2000, 2001 (dry) it was fixed an increase of a capacity of the reservoir, due to removal of sediments at low level operation, accordingly to 40 Mio m3, 98 Mio m3 and 79 Mio m3.

However, the followed operation regime at high elevations in 2002 and 2003 has brought to decrease a capacity for 83+143= 226 Mio m3.

Totally an accumulated sediment volume from 1996 to 2006 consisted of 298 Mio m3, removed volume was 217 Mio m3.
Comparison of the estimated results with accumulated and removed sediment data for the period 1996-2002 where Ws=317 Mio m3 and Wr=206 Mio m3 (table 4.2) has shown its good accuracy what confirmed applicability of the method for determination the reservoir capacity and its trend for the future. As was indicated above, the method considers possible changes of sedimentation and removal processes taking place at its level variation and hydrological terms of river.

B. Analysis of ***the II Scenario*** results has shown that increase of operational capacity of the reservoir by 81 Mio m3 took place in 1996. This amount is less than in the *I scenario* (81 Mio m3< 217 Mio m3). But sedimentation volume is for the considering period is 189 Mio m3, significantly less than the other one 298 Mio m3 for the same period. An advantage of the *II scenario* is in that, according to SANIIRI recommendations the most loaded with sediments flow in March-June period must be passed through dam keeping low elevations of surface level. This operation brings to reduction of the accumulated sediments volume and at the same time promotes removal of sediments out of the reservoir. Such operation terms (developed) bring to saving of a capacity 298-189=207 Mio m3.

Table 4.2 – The reservoir capacity by the *I* and *II scenarios*

Year	Reservoir capacity, Mio m^3		Reservoir capacity change regarding to the previous year, Mio m^3	
	I scenario	*II scenario*	*I scenario*	*II scenario*
1995	1427	1427	-	-
1996	1376	1508	-51	+81
1997	1416	1495	+40	-13
1998	1265	1436	-151	-59
1999	1252	1396	-13	-40
2000	1350	1386	+98	-10
2001	1429	1381	+79	-5
2002	1346	1349	-83	-32
2003	1246	1317	-100	-32
Total			+217 -398	+81 -191

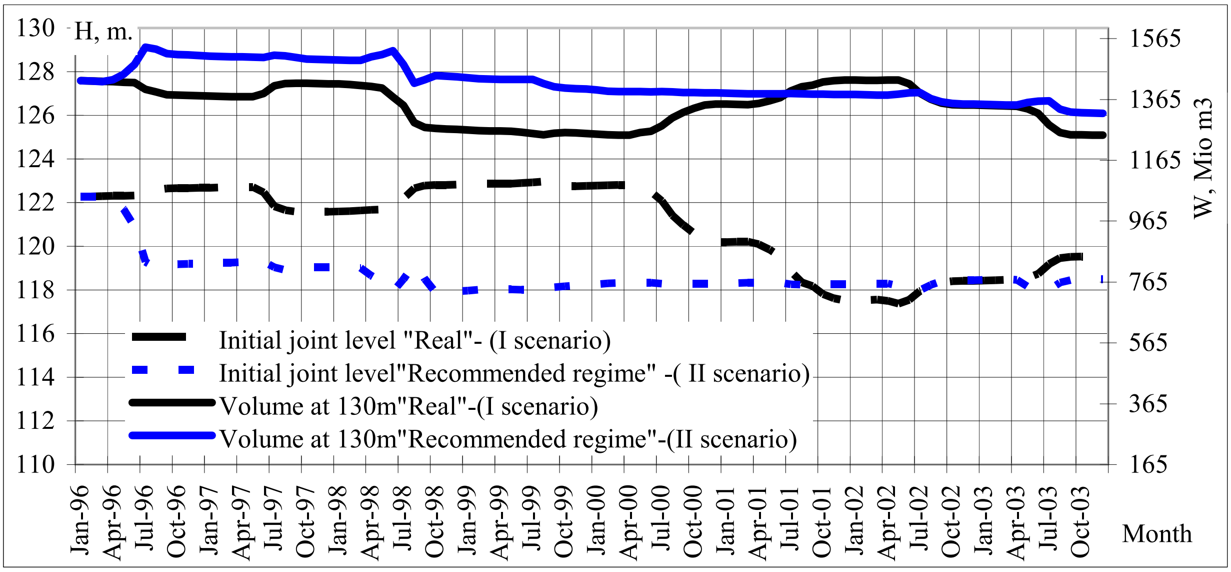


Fig. 4.2 – Comparison of change of the useful volume of the reservoir depending on the dam operation terms

In order to estimate the future trends of sedimentation in the reservoir we have considered next two scenarios from 1996 to 2034. The first is at the existing dam operation terms, the second one – at the improved by SANIIRI operation terms.

The scenario III is based on real hydrological terms of the river and operation regime of the reservoir in 1996 which is expanded to the all period. ***The IV scenario*** is also based on real hydrological terms of the river as in the *III scenario* but in this case the developed operational regime was accepted.

Calculation results for an average water year are shown in table 4.3 and Fig. 4.3.

Table 4.3 - The reservoir capacity by the *III* and *IV scenarios*

Year	Reservoir capacity, Mio m^3		Reservoir capacity change regarding to the previous year, Mio m^3	
	III scenario	*IV scenario*	*III scenario*	*IV scenario*
1995	1427	1427	-	-
1996	1376	1508	-51	+81
1997	1327	1498	-49	-10
2000	1193	1400	-134	-98
2010	869	1114	-324	-286
2015	730	985	-139	-129
2017	663	936	-67	-49
2024	484	774	-179	-162
2030	362	647	-122	-127
2034	295	568	-67	-79
Total:			-1132	+81 -940

Comparison of the estimation results carried out to choose of effective dam operation regime showed that at the operation regime recommended by SANIIRI the reservoir sedimentation intensity for 1.5 times lower than at the real one and a stabilization of the reservoir, i.e.

beginning of an stable balance of incoming and outflowing volume of sediments from the reservoir, will take place at the capacity of 700-800 Mio m3 by 2023. This period can be prolonged due to realization a regular flushing.

But at the existing now real operating regimes it will happen in 2012-2014.

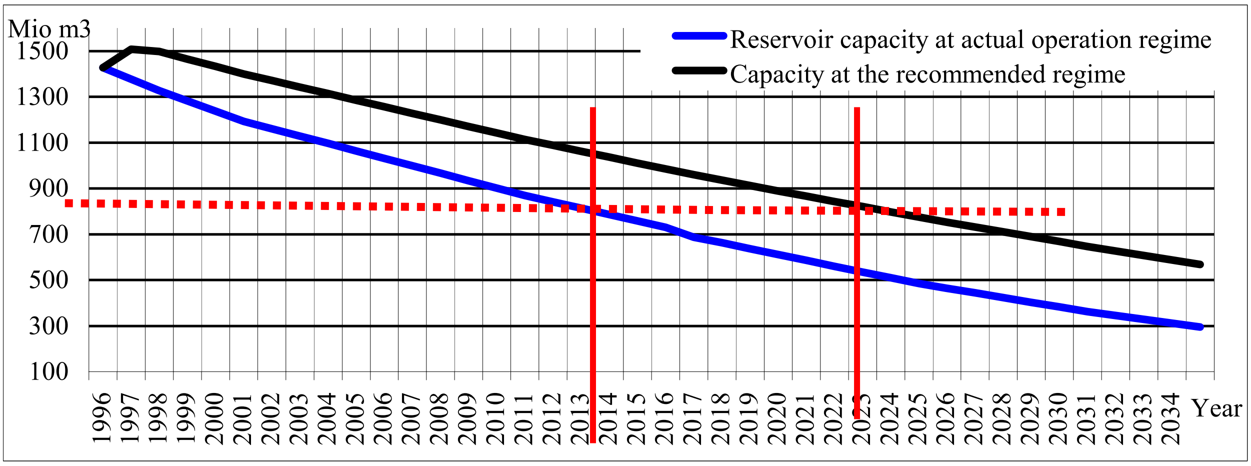


Fig.4.3 – Dynamics of the reservoir capacity change and its prognosis to 2034