THE POLLUTION OF THE "IRON GATE" RESERVOIR

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ABSTRACT

The paper presents the characteristics of the Iron Gate I (the Djerdap) Water Power and Navigational System, one of the largest in Europe (completed in 1972 by joint efforts of Yugoslavia and Romania). In this paper the attention is devoted to review of the sediment monitoring program and impacts of reservoir sedimentation, as well as to the investigations of water and sediment quality. Special consideration is paid to the issue of sediment pollution research needs. Namely, the hot spot of the "Iron Gate" sedimentation represents a scarcely known pollution of sediment deposits. The present pollution probably is considerable, since the "Iron Gate" reservoir drains about 577000 km2, with over 80 million inhabitants, and developed municipal and industrial infrastructure. Therefore, in the thirty-year reservoir life various types of sediment-bound pollutants entered and deposited within it. Especially severe incidents happened during 1999 (as a result of NATO bombing campaign) and 2000 (two accidental pollutions in the Tisza river catchment). The study of the "Iron Gate" reservoir pollution should be prepared in order to enlighten the present state of reservoir sedimentation and pollution. The main objectives of the study are to enhance the government and public awareness of the present environmental state of the "Iron Gate" reservoir and to serve as a baseline for all future actions.

Kez words: water reservoir, pollution, bombing campaign

INTRODUCTION

The ″Iron Gate I″ (the Djerdap) Water Power and Navigation System is one of the largest in Europe. The aim of the Project (completed in 1972, as a result of joint efforts of Yugoslavia and Romania) was to utilize of the considerable water energy potential and improve the conditions of navigation on the Yugoslav-Romanian section of the Danube.

The "Iron Gate I" reservoir has some specific characteristics:

- It extends on a complex river system, consisting of the Danube river and its tributaries (Fig 1). The total drainage area upstream of the dam is 577 000 km2. The tributaries of the Danube within the reservoir range are the Tisza (catchment area 157 200 km2), the Sava (96 400 km2), the Morava (37 400 km2) and few minor rivers (with catchment area less than 2 000 km2).
- It has the variable height of water levels and extent of backwater zone, that depends on inflow and the power-plant operation. During high flow the water elevation at the dam site is 19 m and the backwater extends to the mouth of the Nera river (at km 1075 of the Danube). During periods of low flow (water height on the dam site is 33 m) the backwater spreads within 310 km on the Danube, 100 km on the Sava and 60 km on the Tisza river (Fig 1). The average volume of the reservoir is 3.5 109 m3 (2.1 109 m3 increase due to impoundment). The reservoir provides a daily and sometimes weekly flow regulation. The hydro-power plant operates as run-of-river, covering peak demands, which is enabled by the downstream reservoir (Iron Gate II System at km 862, completed in 1985).

Fig. 1: Layout of the "Iron Gate" System

The annual water inflow is 110 - 220 109 m3 (average discharge 3 500 to 7 000 m3/s). Low and high flow are about 2 000 and 15 000 m3/s, respectively. The suspended sediment concentration of the Danube river is relatively low (10-3 to 10-1 kg/m3), but the suspended sediment inflow is still considerable (annual amount between 7 and 30 million tons with an average of 17 million tons). The Danube river contributes about 41%, while the Tisza, the Sava and the Morava rivers bring 26%, 21% and 12%, respectively.

Construction of the "Iron Gate I" dam was an extraordinary endeavor creating large benefits in energy production and navigation. However, the impoundment caused many serious problems. One of them is siltation of the reservoir.

REVIEW OF THE SEDIMENT MONITORING PROGRAM

Anticipating that the impoundment will cause significant sedimentation, the first investigations and predictions of reservoir siltation were made within the project design (the Jaroslav Cerni Institute, 1962-1968). The forecast indicated considerable modifications in the sediment regime of the Danube river and its tributaries, which would generate a relatively slow development of sediment deposits. Therefrom arose the program of the sediment monitoring which started in 1974, after the reservoir impoundment. Annual monitoring programs were conducted the Jaroslav Cerni Institute and included the measurements and observations of water and suspended sediment, while special measurements of deposits and surveys of the reservoir were performed occasionally.

The assessment of suspended sediment balance in the reservoir relies upon daily observations on ten monitoring profiles: four at the entry of the Danube and its tributaries in the reservoir, five profiles within the reservoir range and one profile at the dam site (Fig. 2). The sediment balance in the "Iron Gate" reservoir is determined per annum, as a difference of the sediment inflow and outflow. The quantities recorded on monitoring profiles within the reservoir range determined the nature of changes on the related reservoir sections. The assessment is based on:
Daily observations suspended sediment concentrations. The sediment concentration is derived from samples (volume of 10 l on the Danube or 5 l on tributaries), taken from the fixed point at the water surface. The surface concentrations were than converted into average values, by applying empirical relationships established from the measurements of water and sediment discharge.

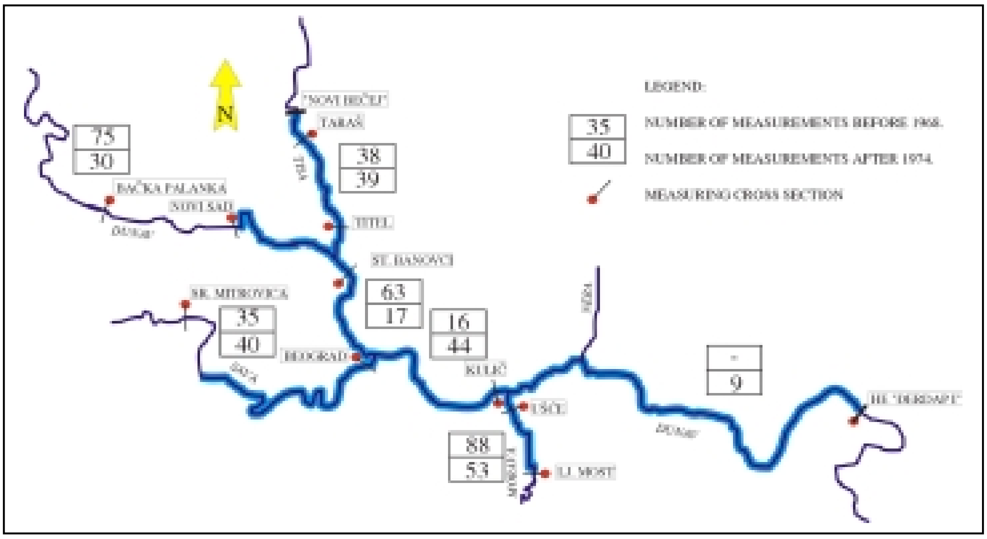

Fig 2: Sediment measuring profiles in the "Iron Gate I" reservoir

Measurements of water and sediment discharge. More than 300 measurements of water and suspended sediment discharge were performed in the preceding period (locations of measuring profiles presented on Fig. 2). Techniques of suspended sediment measurement and laboratory testing were carefully evaluated during the design phase of the Project and confirmed by later comparative analyses.

Some results of water and sediment balance assessment are presented on Fig 3. In the period of observations the total inflow of sediment into the reservoir was about 475 million tons, while the outflow is estimated to about 79 million tons. Thus, around 380 million tons of sediment was trapped in the reservoir (14 million tons per year). The trap efficiency varied from 69% (in rainy years) to 92% (in dry years), with an average of 83%.

As a complement to the assessment of reservoir sediment balance, the modifications of river channel within the reservoir were periodically recorded by survey of numerous cross-sections. Namely, the survey determines the position and magnitude of morphological changes, while the estimates of sediment balance show the nature of the deformation process (local displacement of sediment forms or general process of deposition/erosion). The survey data are also used for backwater level calculations and management of the navigable waterway. The reservoir part downstream of the mouth of the Nera river (where the most significant morphological changes were expected), is furnished with a dense net of cross-sections (total of 134, at average distance of about 1 km). The surveys and calculations were performed in 1981, 1984 and 1988. After a long pause, a new survey has been performed in 1998.

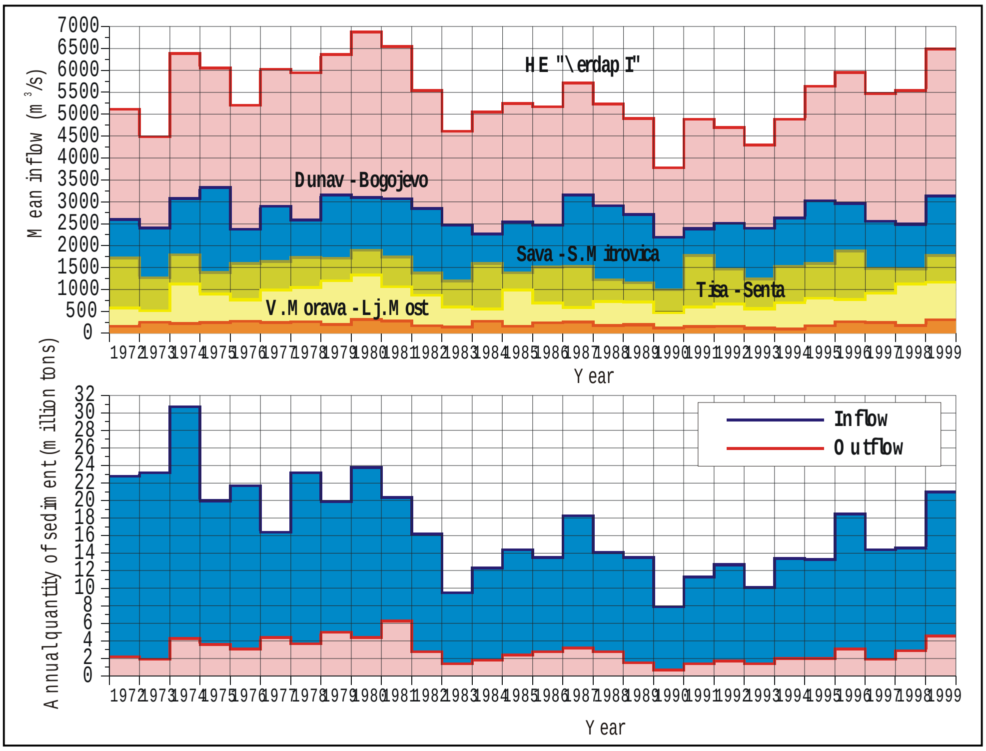

Fig. 4: Results of the reservoir balance assessment (1972-1999)

Surveys indicated that the most of the sediment deposition occurred between the dam and km 1075 (in the Yugoslav-Romanian part of the reservoir). Particularly intense sedimentation is present in one part of the Djerdap gorge (between km 970 and km 1003), which acts as a natural sediment trap (see Fig 5). Upstream of the Morava river mouth, no apparent trend of sediment deposition was noticed so far.

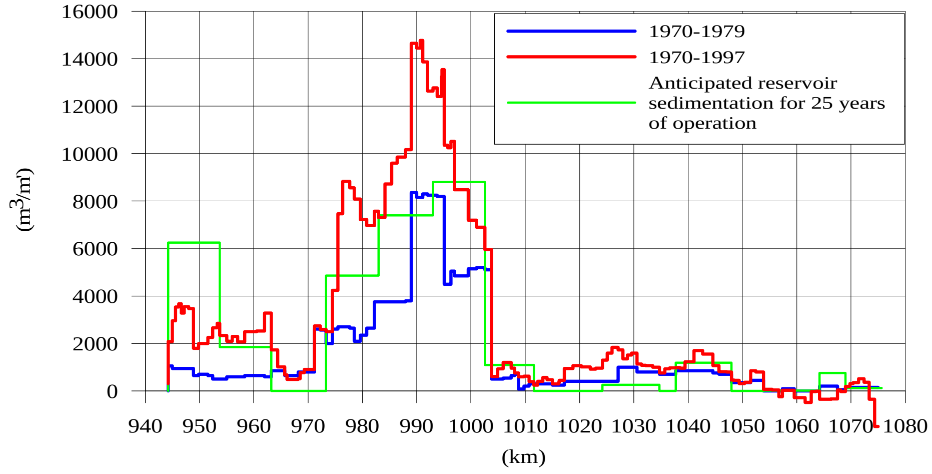

Fig. 5: Distribution of riverbed changes along the reservoir

The bulk density of deposits was determined from undisturbed samples. The last sampling was performed in 1980 (Fig 6).

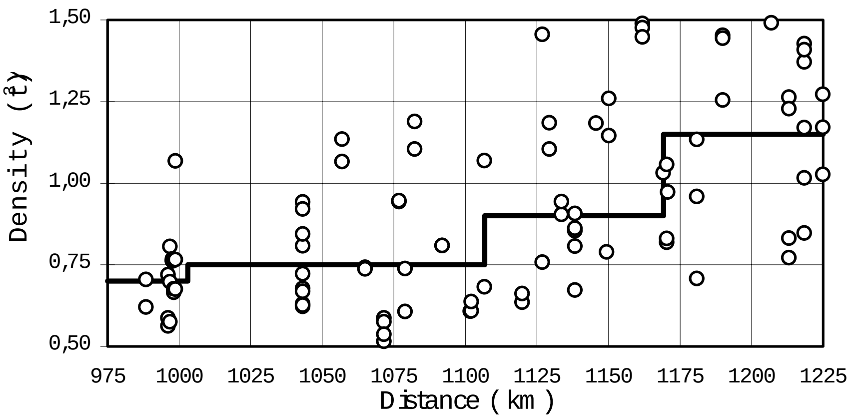

Fig. 6: Bulk density of sediment deposits

ENGINEERING AND ECONOMIC IMPACTS OF RESERVOIR SEDIMENTATION

Engineering and economical impacts of "Iron Gate" reservoir sedimentation are considerable. A gradual increase of high water levels, that can reduce the safety of the existing flood protection system, is viewed as a very important one from the engineering point of view. The deposition-caused increase of water levels differently affects the flood protection system along the reservoir (depending on characteristics of the riparian land, protective structures and location of deposits). In the Djerdap gorge (up to km 1030 of the Danube river) the water level increase is considerable but harmless because of the actual hydropower plant regime (flood levels are lower than normal backwater). Upstream (betwe-en km 1030 and 1075), the increase of high-water levels is endangering some cities on the Yugoslav bank, but the problem can be alleviated by upgrading local protective structures. In the future, the elevation of levees may be necessary upstream of km 1075, where flood protection system protects lowland areas, if the supplementary level increase grow to be significant. This measure is still not necessary at present (all the levees are built to provide protection against the 100 years flood, with 1.2 to 1.7 m of additional free board).
Other impact of sedimentation stem from changes of hydraulic connection between surface and ground water, which affects the drainage systems and aquifer capacity. Nevertheless, particular investigations of sedimentation effects on operation of drainage systems and utilization of ground water resources in the riparian zone, which may provide reliable information on these impacts were never performed. The impact of sediment deposition on energy production was not investigated in the past period, but it is probably significant.

REVIEW OF THE WATER AND SEDIMENT QUALITY MONITORING PROGRAM

The regular investigations on water quality changes within the common Yugoslav-Romanian sector of the Danube river (between the Iron Gate Dam and km 1075) have been performed between 1985–1991, with the basic programme that was settled with Romanian part in Bucharest (1985). After a long pause (1992- 2000), the investigation restarted in 2001 with regular programme and adopted methodology, which includes hydrobiology and radiology analyses.

The investigation results between 1985 and 1991 indicated that:

- Changes of water composition are influenced by the incoming pollution, retention time and water temperature.
- Changes of water characteristics are conditioned by sedimentation, biochemical degradation of organic matter, decrease of primary production, sorption and accumulation of toxic matter (heavy metals and organic micro pollutants) on the deposited sediment (silt).
- There is a significant consumption of dissolved oxygen through transformation processes in sediment, which is also being the potential source of harmful and dangerous substances, although these processes are not yet completely understood.
- In the period of low waters, oxygen deficit is recorded near km 1075 with a downstream increasing trend.
- The noticed changes concerning composition and structure of plankton mass have great impact on water quality changes in this sector.

- Most of the indicators of specific pollution (heavy metals) were below the MCL (maximum contaminant level) while the concentrations of mineral oils were occasionally above the limit.

The most recent research of water quality in the Danube river from October 2001 states that:

- There is no temperature stratification in the Iron Gate reservoir, because maximal vertical variation of water temperature in the stream midpoint is less then 1 oC.
- Minor oxygen deficit (ranging between 3,9 and 12,5%), which didn't increase downstream, has been recorded.
- According to all physico-chemical parameters of water quality, it corresponds to the specified II class (with some exceptions like the BOD value on km 1075, where the highest oxygen deficit has been recorded).
- All specific water pollution parameters (heavy metals and specific groups of micro organic pollutants as phenols, detergents, PCB, PAH and total hydrocarbons) are within the permissible limits.
- Global radioactivity (total alpha and beta radioactivity) is also within the permissible limits.
- There is no significant downstream tendency of the measured parameters. An exception is water transparency, which is increasing towards the profile of the Dam. It was accompanied by decrease of chlorophyll "a" content and increase of IFA (Index of phosphatase activity).
- Nitrogen and phosphorus are not limiting elements for bioproduction.
- Hydrobiological analyses have confirmed previous results and indicated further changes in qualitative composition of plankton community in the reservoir:
- While previously the phytoplankton was composed of 6 groups with total number of 20 species, only a very small number of species (from the same groups) was found in 2001. The Saprobity Index (based on qualitative composition and relative abundance of phytoplankton) was within the limits of beta-meso-lymnosaprobic quality status of water, varying from 1,66 (km 1075, midstream) to 1,94 (below the Dam, at right bank).
- Qualitative composition zooplankton changes in the same manner as the composition of phytoplankton. Namely, the number of zooplankton species (only three species of *Protozoa*, six species of *Rotatoria*, one species of *Cladocera* and two species of *Copepoda were found*) is much smaller than before. The Saprobity Index was within the limits of beta mesosaprobic quality status of water.
- Based on analysis of macrozoobenthic community, the Saprobic Indices were found to be within the values characteristic for poorer lymnosaprobic water quality status, i.e. within the alpha mesosaprobic status (III class of quality).

In the same time, the investigation of quality of the upper sediment layer revealed the following:

- The sediment contains a significant portion of accumulated organic matter. The content of organic matter expressed by means of COD is ranging from 81000 ppm dry weight (at km 1059) to 64000 ppm (below the Dam).
- The measured ratio of total nitrogen to total phosphorus content ranges from 2,3 to 3,8. Organic nitrogen is the most dominant amongst all present nitrogen categories.

- The sediment contains a large amount of accumulated heavy elements, with the average values of 81 ppm for lead, 1.98 ppm for cadmium, 3.51 ppm for arsenic and 0.58 ppm for mercury, dry weight. The metals content is higher than in the Tisza river sediment. Cadmium and lead are pointed out as critical pollutants for their toxicity and elevated concentrations.
- The specific analyses of organic matter content in the surface sediment layer show that a native organic substance is in question i.e. the recent pollution made by oil derivatives has not been detected.
- The total content of PCBs ranges from <0.010 to 0.940 ppm (average 0.603 ppm). The average content of total PAH compounds is 1.37 ppm and average content of total hydrocarbons is 7.88 ppm dry weight.

Besides the above-mentioned investigations, which were performed by "Jaroslav Cerni" Institute, only two relevant examinations were done.

The first report named *"Report on consequences made by NATO bombardment on quality status of water, sediment and biota in the Danube river* ", dealt with the quality of water and sediment in the Iron Gate reservoir (profile Ram on km 1075) immediately after the cease of bombing (July 8th and August 12th 1999). It concluded that:

- No values above the permissible limits are measured in water for lead, mercury, mineral oils, PAH and PCB compounds.
- The consequences of oil and mercury pollution are recorded in the river sediment, while no traces of PCB compounds and EDC (1,2-dichlorethane) are found.

The second one was *BTF Report (Balkans Task Force)* which concluded that on Ram profile (August 28th 1999) the measured concentrations of PAH compounds are homogenous in the surface and in deeper water layers, and correspond to the content measured prior to NATO aggression:

- Increased concentrations of PCB compounds were not found in water, while concentrations of volatile HC (hydrocarbons) were below the minimum method detection limit. Dissolved Pb and Hg were not found either.
- The sediment analysis revealed the increased concentrations of total HC content in the surface level, but analyses of fragmented sediment core showed significant content of adsorbed hydrocarbons, PCBs and mercury. That pollution is said to originate from earlier pollution emission over the whole drainage area upstream of Ram profile.

PROPOSAL FOR ADDITIONAL INVESTIGATIONS OF THE RESERVOIR POLLUTION

It can be seen from abovementioned data that the hot spot of the "Iron Gate" sedimentation represents a scarcely known pollution of sediment deposits, along with the insufficiently investigated water quality changes. Namely, the previous investigations of sediment quality were reduced to only few locations in the reservoir (mostly to Ram profile on km 1075), while sediment deposits in deeper parts of the reservoir were never examined. Also, only the quality of surface layer was investigated, while deeper layers' quality is entirely unknown. Their pollution is probably considerable, since the "Iron Gate" reservoir drains

about 577000 km2, with over 80 million inhabitants, and developed municipal and industrial infrastructure. Therefore, in the thirty-year reservoir life various types of sediment-bound pollutants entered and deposited within it. Especially severe incidents happened during 1999 (as a result of NATO bombing campaign) and 2000 (two accidental pollutions in the Tisza river catchment).
Therefore, the study of the "Iron Gate" reservoir pollution should be prepared in order to enlighten the present state of reservoir sedimentation and pollution.
The main objectives of the study are to enhance the government and public awareness of the present environmental state of the "Iron Gate" reservoir and to serve as a baseline for all future actions. Therefore, the study of the "Iron Gate" reservoir pollution should:

- Determine up-to-date sediment accumulation within the reservoir,
- Document the occurrence of specified pollutants,
- Describe long-term trends of selected chemical constituents,
- Estimate total and average annual mass input of these chemicals into the reservoir,
- Render environmental aspects of reservoir sediment pollution and
- Initiate further investigations concerning the reservoir pollution and possible protective or remedial measures.

The study must be based on the actual reservoir pollution data. Therefore, the first task should be to assess the sediment characteristics and the total sediment deposition over the reservoir life. The last survey of the common Yugoslav-Romanian part of the reservoir was performed in 1998, before the most dangerous contamination of the reservoir (in 1999 and 2000). Therefore, a new bathymetric survey should be organized to provide a present contour map and enable a calculation of the total volume of sediment deposited in the latest period.
The second task should encompass field and laboratory activities related to the acquisition of sediment pollution data. For this purpose, sediment cores should be taken and analyzed in order to obtain data on physical and chemical characteristics of reservoir deposits. Chemical analysis of sediment cores will also provide a baseline for monitoring of future changes in the water quality or watershed activities.