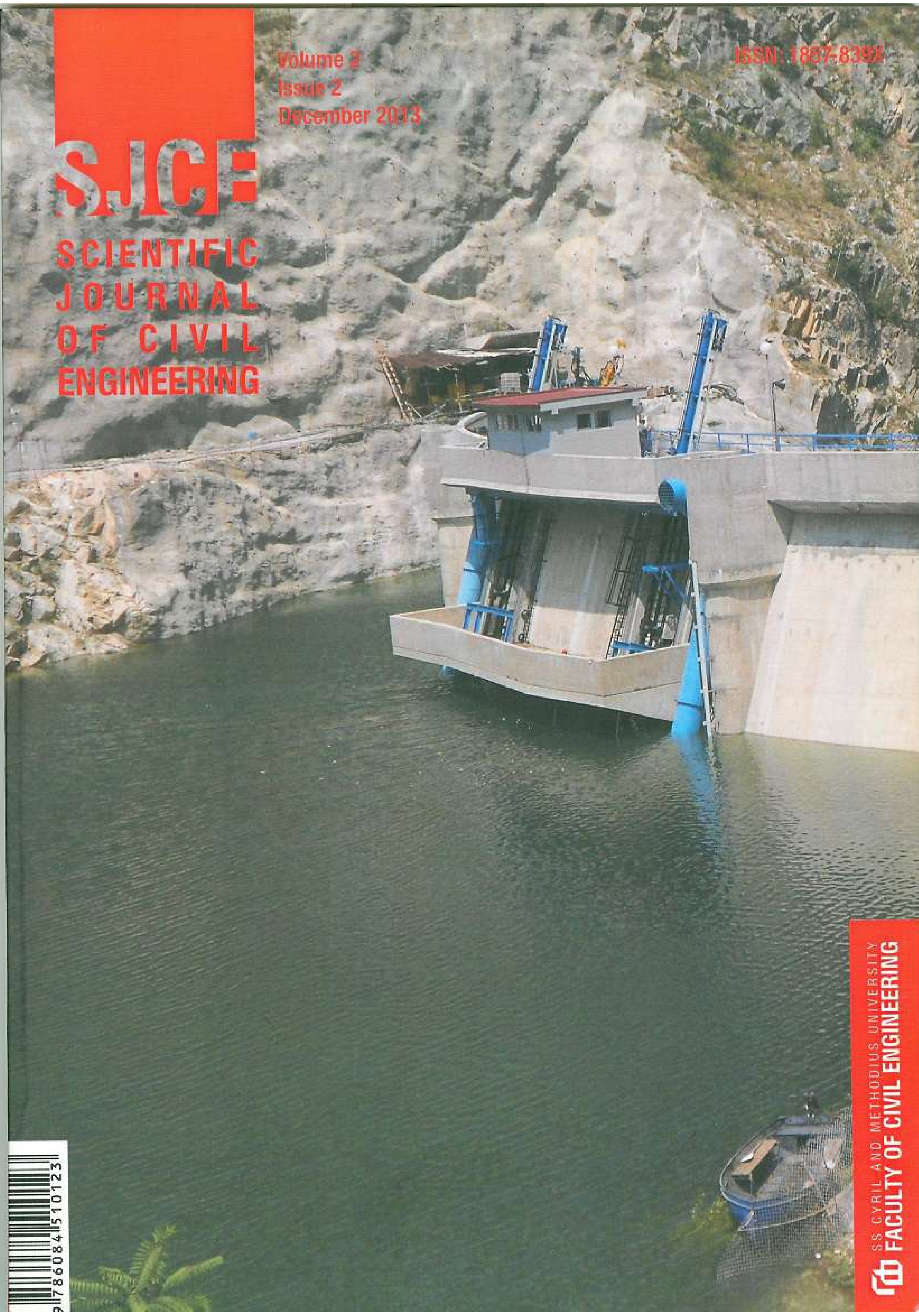

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INCORPORATION OF WATER STORAGE RESERVOIRS INTO THE ENVIRONMENT

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The construction of large dams and creation of water storage reservoirs have significant effect on the environmental and social surrounding. Although these impacts have been recognized in the first stage of modern dam construction period (period after Second World War), in the last decades they have become among the most debatable and for public opinion significant effects of the large dams. Water storage reservoirs are irreplaceable element of complex water resources systems, particularly having in mind climate changes - shorter and more intense rainy periods with floods threatening the man and his systems and long dry periods, when again, due to lack of water, whole ecosystem is endangered, as well as man. Reasons why water storage reservoirs are necessary are described in the paper. Main positive and negative impacts of reservoirs on the environment are analyzed and measures for neutralization, mitigation or compensation of negative impacts are summarized.

Keywords: large dams, water storage reservoirs, water as a resource, ecological aspects, social impacts, environment

INTRODUCTION

In the Master Plans of all levels two space users have special priority: mines, especially ones with surface exploitation, and water resources systems. These users have very specific requirements for location, as their resources are located in specific and limited areas. So, the structures for their exploitation must be at those exact locations. If locations are not timely reserved and ensured for that specific utilization, they can be permanently lost. That is why these two users must prepare studies and designs, and precisely define areas necessary for realization of future systems.

In recent times water storage reservoirs became the object of contestation, supposedly because they have negative impact on the surrounding area and the environment. This is an incorrect conclusion! The main purpose of this article is to emphasize next:

(a) Integral water resource systems, with water storage reservoirs as their important part, are the key element for regulation and protection of the area (water supply, sanitary of settlements, flood protection, improvement of river banks, protection of catchments areas, improvement of conditions for better urban prosperity of settlements, etc.),

(b) Water storage reservoir redistributes water in time in the best possible manner for the environment. By adequate management they can increase water regimes downstream from the dam or gate. That is especially important in the low flow periods. In that way the actual concept of water protection is realized: Conduction of water resources management to help eco-system and preserve biodiversity in the best possible way.

In the process of water storage evaluation a few facts should be taken into account.

(1) Development or stagnation of water resources directly influences the conditions and development of all other systems. Some countries found their way out form big economical crises in realization of complex water resources systems, especially realization of water storage reservoirs (American "New Deal", polders, water storage reservoirs in Spain, Iran, Turkey, China, South Africa, etc.). It is well known that investment in water resources and hydro energy cannot be miss investment, and those are investments that start up different industries of a country.

(2) In line with basic principles of maintenance development there is very strong connection between development and environmental protection. That is pointed out in a well-known document: The Report of the World Commission on Environment and Development (1987). Summarizing that document in only one sentence, would state: "Environment could not be properly protected without adequate economical development." And economical development is not possible without adequate water resources systems, with water storage reservoirs as their key element.

(3) When analyzing the environmental impact of water storage reservoirs some important categories of impacts must be considered: soil as an area and resource, water as a resource and biotope, air as an area that should be protected, pollution with solid waste, pollution with liquid waste, thermal pollution, noise as pollution of the air, radiation, impact on biocenose, aesthetic of landscape. All alternatives should be compared and evaluated, including the "do nothing" choice, which often has a negative impact on the environment (considering the stated 10 impacts). If all defined impact categories are analyzed, hydropower plants - as renewable and clean energy source - has an incomparable advantage over all other energy sources.

WHY ARE WATER STORAGE RESERVOIRS NECESSARY?

There are numerous reasons why water storage reservoirs are a necessary element of water resource systems in Serbia. The most important ones are stated below:

Irregular temporal distribution of water flow in rivers

Lots of rivers in Serbia have torrent type flow. Very often 60□70% of summary annual water discharge runs in short flood period, succeeded with long dry periods. Average annual flow of all domestic water is around 509 m3/s. In low flow period it decreases ten times and is around 50 m3/s. That is not enough even for ecological needs of water ecosystem.

Ratio between minimal monthly discharge with occurrence probability of 95% and maximal annual discharges with occurrence probability of 1% are often greater than 1:1000. Variation coefficients of annual discharges are also high (Cv □ 0.5 for many rivers in Serbia), indicating variation of mean annual discharges, which are usually higher than 3:1.

Analysis of the coefficient of autocorrelation of annual discharges and spectral functions of those values indicates one unfavourable phenomena: accumulation of dry years joining in one long dry period, when discharges are very low on all rivers (catchments) and all water users are endangered as well as the rivers as ecosystems. Those extremely dry periods affect a wider region and without water storage reservoirs it would be impossible to provide water for normal human activities (settlements and economy). Those low flow periods are very dangerous for flora and fauna in the river.

Only way to mitigate it is to discharge water from water storage reservoirs in the upstream part of the river.

Spatial irregularity of water flow

Water flows in Serbia are also characterized by extreme spatial irregularity. Specific water flows of domestic water vary in wide range, from only around 1 L/s□km2, to over 50 L/s□km2 in Dinaric mountain areas. The lowest specific flows are in the lowland areas with the highest density of population and with the fertile land which should be intensively irrigated. Taking all this into account it can be concluded that water storage reservoirs are only structures that can deal with temporal and spatial water irregularity. Without them it would be impossible to transfer water from the water source area to the consumer area.

Underground water mainly from river alluvium

Around 2/3 of underground water in Serbia is in river alluvium, meaning that quantity and quality of that water directly depends on the river flow. That is the reason why settlements providing water from wells in river alluvium have huge problems with water supply. Many settlements (Vranje, Kruševac, Kragujevac, Užice, Čačak, Aleksinac, Leskovac, etc.) changed their water supply system from groundwater to more reliable supply - from water storage reservoirs. Source of water supply system for Belgrade has changed similary. Water demand could not be satisfied by using wells near two big rivers, so the source was changed, and now it uses water from Sava lake - the special form of water storage reservoir.

Difference between water resource and water existing on the catchment area

There is an important difference between two categories of water: water existing on the catchment area and water that can be treated as a water resource. Unnoticing difference between those categories can lead to big mistakes in evaluation of water resources of some catchments areas or regions.

Water existing on the area/catchment (V) is exclusively geophysical category, and it can be defined as: $V = \langle L,Q,K \rangle$, with matrix structure defining location (L), quantity (Q) and quality (K) of water [3].

Water resource (VR) is social, economic and ecological category, because beside previously mentioned three attributes it has to possess one more, very important one - existence of conditions for catching, utilization and protection of water (US). So, when defining the water resource matrix, the structure of "existing water" has to be enlarged with the conditions for utilization, and it can be defined by the relation:

$$VR = \langle\langle V,US \rangle\rangle \qquad (1)$$

Following the same system logic water demand on some area/catchment can be defined by the matrix $Vz = \langle Lz,Qz,Kz \rangle$, where Lz - location where water is demanded, demanded quantity Qz and demanded water quality Kz. Now, planning of water resources systems can be presented by the logical structure S:

$$S: \quad V \xrightarrow{US} VR \xrightarrow{VS,U} V_z \qquad (2)$$

Relation (2) means that water existing on the catchment (defined by the matrix V) can be considered as a resource only after including utilization conditions (US). Through the appropriate water resource system (VS) and appropriate management (U) it can be transformed into matrix structure of water demand (V_z).

Conditions for water utilization (US) are of multidimensional structure, with lots of components on which the realization of water utilization depends. In each water resource alternative some conditions has to be analyzed: geotechnical conditions (GU), hydrotechnical conditions (HU), economic conditions (EU), conditions of interaction with social and urban environment (SU), interactions with cultural-historical and other properties (KU), conditions for ecological environmental protection (ZU) and conditions that results from international obligations (MU). US can be decomposed in following structure:

$$US = \langle\langle GU, HU, EU, SU, KU, ZU, MU \rangle\rangle \qquad (3)$$

Some parameters in equation (3) can be defined with appropriate quantitative or qualitative valuations. With those parameters it can be emphasized practicability, impracticability or practicability only under particular circumstances of water utilization on some area. If only one of the mentioned parameters in matrix (3) gets a value defining impracticability of the design for water utilization (for example GU=0, because karstified valley can't provide water tightness), whole design becomes impracticable because appropriate water resources system (VS), necessary for transformation from "existing water" in "water demand" (equation (2)) can't be achieved. In that case water existing on the area can't be considered as water resource and it shouldn't be accounted for future use. For all mentioned reasons real water resources are considerably lower than those estimated by analyzing water existing on the catchment area, or analytically:

$$VR << V \tag{4}$$

Equation (4) is simple but fundamentally important. Fact that the quantity of water that can be defined as water resource is much lower than the water existing on the catchment area (sign <<) is the main reason for misunderstandings between the public and designers. Usualy, public opinion about water is much more optimistic. That is why public do not understand that key element for water utilization are water storage reservoirs.

Reliability of water delivery

Reliability of water delivery is the main reason why water storage reservoirs became such an important element in water supply systems. Expansion of settlements into the big urban centres requires the increase in reliability of water supply. Presently, reliability of water supply systems is required to be over 97%. Similar situation is in providing water for technological needs for heavy industry and thermoenergetics. Those are the reasons why water storage reservoirs are absolutely necessary: only water storage reservoirs with large relative volume can provide high reliability of water supply. Analyses performed with simulated synthetic series of flows [4] demonstrate one characteristic relation: for flow series with stochastic parameters close to those common for rivers in our country (variation coefficient Cv=0.5, relation between coefficients of asymmetry and variation C_s/C_v = 2, autocorrelation coefficient of annual flows r=0.3) if demanded relative water supply is α = 0,7 (delivered quantity of water is 70% of average multiyear flow), then increase of reliability from P=80% to P=90% requires increase of water storage volume of 2.5 times! (Figure 1) For higher reliabilities situation is even more drastic. Enormous increase of necessary water storage volume is that high price must be paid for increased water supply reliability. However, reliability of around P=97% is the area of system saturation, and further increase of reliability practically cannot be realized without system of reservoirs with multiyear regulation.

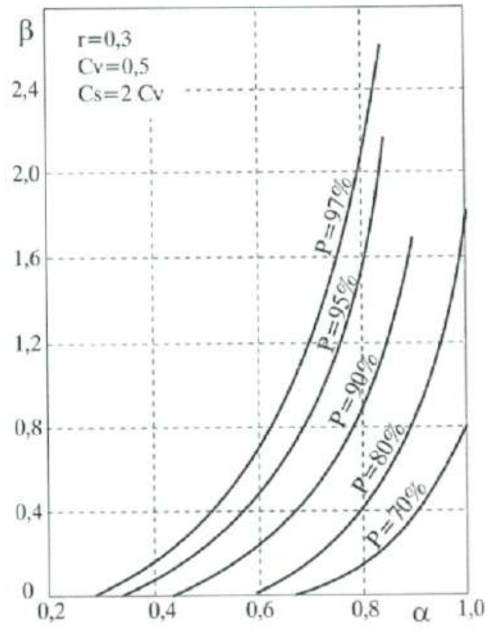

Figure 1. Relation between relative water storage volume β, relative water supply α and reliability P

Requirements in the area of flood protection are more severe

Requirements in the area of flood protection are very strict and often cannot be satisfied without active use of water storage reservoirs. Namely, modern flood protection systems require high protection level (for example protection from flood water with probability occurrence of 1%). Such demands can be satisfied only with combination of passive protection measures (linear systems - embankment and regulatory works) and active measures (mitigation of flood water in especially reserved areas (volumes) of multipurpose reservoirs). High level of protection for settlements with urban parts entirely defined in relation to the river cannot be accomplished without active retention effects of water storage reservoir. One of the examples is Leskovac, town reliably protected only after completing water storage reservoir Barje on Veternica River. Another example is town Skoplje whose high required protection (P ~ 0,3%) was accomplished after completing water storage reservoir Kozjak at Treska River. Similar situation can be found in numerous towns in the world. High urban development was realized after managing flood water in the reservoirs in the catchment area. Sena River used to flood Paris (Figure 2) until those flood water were mitigated by the water storage reservoir.

Figure 2. Paris downtown (Rue de Lion) during flood in 1910. before realization of reservoirs in River Sena catchment area

Water quality protection

Water quality protection can be properly accomplished only by the following measures: technological, water resources and organization-economical measure. Water resource measure are very important protection measure as without them it is almost impossible to accomplish the required high quality levels in rivers, especially during the low flow periods. Those measures consider so called *improvement of low flows*, by discharging water during the low flow periods. During that period river biocenoses and ichtiofauna are endangered as a result of synergetic influence of few ecological factors each of them near its pessimum (simultaneous effects of low flow, high temperature and low concentration of dissolved oxygen in the water). In such conditions if water can be discharged from the water storage reservoir, water of high quality, desirable temperature, with high concentration of dissolved oxygen - water quality can be managed and maintained within the boundaries favourable for existence of river biocenoses. To accomplish this structures for discharge of guarantied ecological flow are built as a selective inlet, with possibility to take water from the layer with the most appropriate temperature (Figure 4). It is an active way to utilize thermal stratification of lake.

POSITIVE IMPACTS OF WATER STORAGE RESERVOIRS

From the previous part of the article a number of positive impacts can be perceived. They indicate that water storage reservoirs are irreplaceable structures for human survivor. As ecological impact of water storage reservoirs are often subject of discussion, their role from the ecological point of view will be discussed. It should be analyzed comprehensively, in time and space in which all their impact must be evaluated. Only the most important positive ecological impacts, important for water storage reservoir valuation are discussed.

- Healthy drinking water is provided, hydric epidemics are prevented - an important ecological impact.

- Production of hydro energy - ecologically the cleanest energy - decreases pollution with solid, liquid, gas, thermal and radioactive waste from alternative thermal and nuclear power plants (these should not be built at the expense of hydro power plants).

- Production of food is intensive in the irrigation condition. That is one of the most important ecological impacts. At the same time, ecological pressure on the land of lower quality is weaker and it can be used for reforestations and other purposes.

- Flood water flows are decreased and flood risk is smaller. Human population is free of fear of floods, but the environment is also protected from floods as the biggest ecological destruction.

- River flows increase in warm part of the year (improvement of low flows), when conditions for survival of biocenoses in the river are limited as a result of synergetic influence of low flows, high temperature, low concentration of dissolved oxygen.

- A water regime becomes managed: low flows can be increased and flood water decreased, with positive impact on ecological state downstream from reservoir. With better water regimes, regulation and organization of river banks settlements (earlier suffered from floods and low flows) can come down to the river banks and incorporate them in the urban city framework. Through the settlements river regulation should be done on the bases of natural regulations - one of the most important measures for harmonious incorporation and arrangement of river banks part of the settlements.

- Construction of water storage reservoirs are accompanied by anti erosion works, especially rehabilitation of erosion areas of I and II category (excessive and strong erosion). Biological protection measures are particularly important (reforestation, restoration of degraded forests, drainage of meadows, etc.) - ecologically important contribution to the areas eco-environment.

- Construction of water storage reservoirs are always followed by improved sanitary arrangement, sewage system and waste water treatment plants, to protect reservoir and river from process of eutrophication. Those water quality protection measures are financed from the dams and reservoirs designs.

- Finally, big water storage reservoirs create favourable conditions for tourism and recreational valorisation of the area.

NEGATIVE IMPACTS OF WATER STORAGE RESERVOIRS AND MEASURES FOR THEIR MAINTENANCE

Construction of each water storage reservoir is followed by some negative impacts. Most of those negative impacts could be maintained, mitigated or completely eliminated by adequate design solutions. The most important negative impacts are:

- Impact on riparian area as a result of changed groundwater regimes. That impact is specially seen at reservoirs on alluvial rivers, with low riparian area. It can be successfully neutralized by constructing suitable drainage system. Those systems become inseparable part of the area and enable managing groundwater regimes - maintenance of groundwater levels within defined boundaries appropriate for urban systems and agricultural production. Those systems can be of two purposes - drainage and irrigation, when negative impact transforms into the positive. It was performed in riparian area of HPP Đerdap, and the same principles of managing groundwater regimes is planned for riparian area of Velika Morava, Mačva and Semberia after construction of integral Systems on Morava and Drina River.

- Reservoir sedimentation as a result of disturbed regimes of deposit flow is negative impact that cannot be neutralized, but can be mitigated and maintained by adequate anti erosion works and selection of adequate discharge objects.

- Change of ecological factors can endanger survivor and development of some biocenoses in the backwater zone. Changed water regimes in backwater zones change living conditions for biocenoses in that zone. Conditions for development of reobionts - species adopted living in fast waters, change very unfavourable. Survival of those species can be provided if some parts of the river, out from the backwater zones, remain in their natural condition.

- Dams are barriers for fish migration. That negative impact can be successfully solved if special structures for fish migration are provided: for lower barriers - fish paths, and for higher - fish navigation lock and fish elevators. In some cases disturbance in fish reproduction can be solved by special spawning zones in backwater.

- Eutrophication of lakes is one of the most serious problems causing water quality degradation if protection measures are not implemented. Those negative impacts can be neutralized and controlled if control of inflow water quality is performed. There are mathematical models for predicting water quality. Those models, with appropriate investigation, can predict changes of water quality. That enables designer to make some changes in reservoir design and to predict adequate protection measures [3].

- Change of aesthetic values of some spatial natural characteristic. Some reservoirs, especially ones in deep gorges, after forming reservoir becomes different kind of biotope and also is experienced as different aesthetic ambience. That change can not be mitigated, and that is the most important problem facing construction of some very attractive water resources systems in canyon parts of some rivers (Tara, Morača, Studenica). But, that new aesthetic view is not unpleasant, further more for many people it is of special aesthetic value. That is the matter of personal experience of some elements in space. It can be demonstrated by the fact that the biggest problem after filling the reservoir is, most of the time, how to prevent building of settlements on its coastal areas.

- Change of microclimate conditions in the narrow zone around reservoir is another impact of reservoir. Analyses performed in resent years in lots of countries indicate that microclimate changes are of much lesser degree than previously considered (thought). In the case of Studenica reservoir, for which the most detailed analysis were done, indicate that all impacts in the aspects of temperature and humidity were negligibly small and measurable only in the distance of 600 m to 800 m from the reservoir coast.

- Oscillations of reservoirs water levels have few negative impacts. One is aesthetic, because bare coasts in the backwater zones are unpleasant view. Second impact is ecological: changes of water levels can cause destruction of fish spawn laid in the shallow zones. Third is from the point of view of tourist and recreational usage of reservoir: lowering the water levels decrease possibility for that use. Those negative impacts can not be neutralized but can be mitigated if an additional criterion is implemented in management rules - criteria for maintain water level in some periods of the year (periods of fish spawning, summer period when reservoir is used for recreation and tourism). Furthermore, in lots of cases, especially in the case of reservoirs for hydro energy generation, reservoirs are full and levels are stable during that period of the year.

- Changed water regimes downstream from the dam and its impact on biocenoses is another important impact. It can be neutralized by designing adequate guarantied ecological flow. Methodology for defining guarantied ecological flow in Serbia exist [9]. According to that methodology downstream parts of river are permanently maintained in the state needed for undisturbed development of aquatic ecosystem. During periods of year intentional additional discharge from reservoir may create better conditions than it would be in natural conditions (without reservoir).

DESIGN MEASURES FOR INTEGRATION (FITTING) OF RESERVOIRS IN THE ENVIRONMENT

From the master planning point of view wider question is asked: can water storage reservoirs be harmoniously incorporated in social and ecological environment with adequate design and management measures? Answer is affirmative and some of the measures will be tabled.

- Reservoir parameters, especially water levels, should be defined in line with ecological criteria, considering behaviour of the reservoir as a biotope in the period of exploitation. Dispositions with wide shallow zones should be avoided, because such reservoirs are very prone (likely) to develop of submerged plants and intensify eutrophication processes in the lake.

- Design of all infrastructures of the system (dam, intakes, valves, powerhouse, etc.) should be architecturally implemented and horticulturally arranged in such a way that they fit as harmoniously as possible into the environment. At rivers with special ambiental values all those structures, except dam, can be placed under ground. Example of harmonious integration of dam into the ambience is Marathon dam made for water supply of Athens (Figure 3).

- Excavations and borrow pits should be subsequently submerged, or, if impossible, these areas should later on be shaped and "cured" by biological measures, or even used for improvement of ambient values.

- Each water resource design has to be accompanied by detail ichthyologic studies. Those studies should define if there is a need to incorporate structures for providing fish migration (fish paths, navigation locks and elevators). Water storage reservoirs are new aquatic biotope in which the desired development of fish population can be realized by anthropologically guided successions. In line with this fact all activities on stocking reservoir with fish and disposition of structures for fish protection should be planned.

Figure 3. Marathon dam for water supply of Athens

- Dynamism of first filling of the reservoir should be planned and performed in line with ecological demands. Submerged areas of the reservoir should be carefully cleaned just before the filling to avoid unfavourable effects on eutrophication process.

- The design of outlets (capacity, number of inlets, elevation, etc.) should respond to ecological requirements. To provide the best quality of guarantied ecological flow - structures for discharging that flow should be designed as a selective intake structure with possibility to manage quantity and quality of discharged water. Discharged water should be accommodated to needs of downstream biocenoses (discharge from adequate water level, the one most appropriate for the specific development phase of downstream biocenoses, Figure 4). Valves have to be of regulatory type to enable management of water flow. Dispositions and types should also envisage the best possible aeration of the stream (the best are Howler-Bunger valves, Figure 5) to enable controlling the oxygen content in the water.

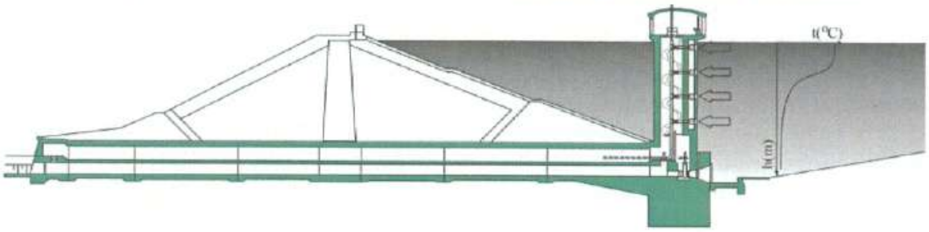

Figure 4. Discharge of guarantied ecological flow from adequate water level

Figure 5. Howler-Bunger valve

- Bottom outlets should be of high discharge capacity to allow pre-emptying of the reservoir for efficient mitigation of flood waves.

- Groundwater levels in the affected land should be controlled by drainage systems. Those systems should be designed as management systems to enable better water regimes comparing to those in natural conditions. Those systems should also be adapted to water resources and ecological objectives (irrigation, touristic valorisation of the area). Good example of such system is design of Srebreno jezero on Danube River, as a part of protection of riparian area of HPP Djerdap, who become popular touristic and recreational centre thanks to managed water regimes. Systems for protection of riparian area should be designed as multipurpose systems, so they can be used for drainage as well as for irrigation, control of salt regimes, etc.

- Antierosion protection of reservoir should be considered as wider measure of catchment area cultivation. Especially important are biological measures (afforestation, drainage of pastures). It should be treated not only as ecological parameter, but also as stabilizing economical parameter for survivor of people on catchment areas with low soil quality.

- Water levels management should be adapted to ecological and touristic requirements. For example maintaining stable water levels in periods of fish spawning to prevent destruction of fish spawn laid in shallow zones, or maintaining stable water levels during the summer in the reservoirs with touristic utilization.

- All biological intervention in the system (afforestation, stocking reservoir with fish) should be done only after detailed ecological studies, to prevent destabilization of some already established ecological balance.

- Guarantied ecological flow should be defined in line with ecological requirements, considering it as dynamic category. It should be adaptable to development stage of biotope downstream from the dam (discharging more water in warm part of the year [9]).

- To maintain reservoir water quality in the best possible level (state) quality of inflow water should be protected. Adequate observation of reservoir water quality, with mathematical models for water quality prediction enables predictions of processes of degrading water quality. In that case some measures for water quality protection could be undertaken

- Envisage protective forest corridors, in the areas of new reservoirs, for the migration of animals and to provide safe cross over the water barrage.

- Hydraulic engineering structures in towns and settlements should be planned especially carefully from the viewpoint of the harmonious functional and aesthetical incorporation into the urban framework. Building of reservoirs in the settlements area should be utilized for harmonious connection of settlements and water body (examples are some parts of Belgrade, which are urbanisticaly adequate connected with Sava and Danube - those rivers are part of Djerdap reservoir, Kladovo, Gloubac, Bečej in central parts of those towns).

CONCLUSION

Summarizing water resources, economic, social and other aspects of water storage reservoirs it can be concluded that there is unambiguously clear answer to question whether they should be built. They have to be built because the economic and social prosperity and even the survivor of civilization depend on water storage reservoirs. The main question to be asked is: what protection measures should be implemented to harmoniously incorporate water storage reservoir into the environment. Harmonious integration of reservoirs into the environment is not technical matter. It was pointed out that technically the majority of negative impacts can be neutralized, mitigated or compensated, and some of the other components of eco-system (environment), in process of building water storage reservoirs, significantly improved. Criteria for developing optimal solution must be extended. Optimization of integral solutions must be performed, with complex structure of objectives, in which the technical solution is reached through defining sets of social, economical, ecological, urban and other objectives, criteria and constraints. Future water resource systems should be built only as a part of integral systems, meaning complex solutions optimally incorporated in requirements of other users of space.

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