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WATER STORAGE RESERVOIRS AND THEIR ROLE IN THE DEVELOPMENT, UTILIZATION AND PROTECTION OF CATCHMENT

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Reasons why water storage reservoirs are necessary in accordance with the sustainable development strategy are described in the paper. The main positive and negative impacts of reservoirs on the environment are analyzed. The most important are: the improvement of hydrological regimes (decreasing maximal and increasing minimal flows), the creation of optimal water management, utilization and protection of water, and the creation of better conditions for river and coastal ecosystems. Negative impacts and measures for its mitigation or elimination are also analyzed. The conclusion is that water storage reservoirs can be harmoniously incorporated into the environment. Serbia has a limited number of locations suitable for the construction of reservoirs, therefore it is necessary to retain these areas for storage in regional development plans and other legal acts.

Key words: water storage reservoirs, water as a resource, utilization of water, water protection, ecological aspects, social impacts, environment

INTRODUCTION

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

Strategic development plans in the water remit are defined in the Water Master Plan of the Republic Serbia and Water Master Plans of specific catchment areas. The Water Master Plan of the Republic of Serbia, completed in 2001, outlines the strategic development in this area (Maksin-Mićić et al., 2009). Locations for the realization of water resource systems can be defined on the basis of this document. After analyzing the strategic results of Water Master Plans a few important conclusions can be pointed out (Đorđević, 2002b): (a) contrary to previous opinions, Serbia lacks domestic water resources, (b) spatial and temporal distribution of water resources is unfavorable from the aspect of its utilization and protection, (c) Serbia is poor in water resources of high quality – high quality resources must be protected now so they could be used in the future, (d) future water demand can be met only with the realization of numerous water storage reservoirs, and their purpose will be the improvement of irregular water regimes. A general conclusion would be that complex problems of utilization, water protection and regulation will be solved only as part of integral systems, harmoniously incorporated in the environment and with planned measures for rationalization. Systems will be wider, better connected, with more goals in the area of utilization, regulation and water protection, and with higher required reliability. These objectives, especially the ones referring to higher reliability of water supply, flood protection and improvement of water regimes, cannot be accomplished without water storage reservoirs. These facts were also well known to ancient civilizations. Water storage reservoirs were built more than 4000 years ago. All developed civilizations based their progress and flourishment on the development of water resource systems, and the decline of each civilization began with neglecting and ruining these systems.

In recent times water storage reservoirs have become the bone of contention, supposedly because they have a negative impact on the surrounding area and the environment. This is an incorrect assumption! The main purpose of this article is to emphasize the following: (a) Integral water resource systems, with water storage reservoirs as their important part, are a key element for the regulation and protection of the area (water supply, sanitary settlements, flood protection, improvement of river banks, protection of catchments areas, improvement of conditions

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for better urban prosperity of settlements, etc.), (b) water storage reservoir redistributes water on time and over the given area in the best possible manner for the environment. By adequate management they can increase water regimes downstream from a dam or gate. This is of particular importance in low flow periods. In this way the actual concept of water protection is achieved: implementation of water resource management to help the 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. Firstly, ***development or stagnation of water resources directly affects the conditions and development of all other systems***. This is why it can be stated that the development of water resource systems act as an "engine of prosperity" for the development of all other systems. Some countries find their way out of great economic crises through the realization of complex systems in the water remit, especially the 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 fall through, and these are investments that start up different industries of a country.

Secondly, in line with the basic principles of maintenance development, there is a very strong connection between development and environmental protection (Vujošević, M., 2004). This is pointed out in a well-known document: *The Report of the World Commission on Environment and Development (1987).* A summary of this document in only a few sentences would read: "*Development should be relived. Poverty decreases the possibility to wisely use resources and increase impact on the environment...Economic and ecological goals (objectives) are interdependent*"[2]. Or, even shorter: ***environment cannot be properly protected without adequate economical development***. And economic development is not possible without adequate water resource systems, with water storage reservoirs as their key element.

Thirdly, when analyzing the environmental impact of water storage reservoirs some important categories of impacts must be considered: (1) soil as an area and resource, (2) water as a resource and biotope, (3) air as an area that should be protected, (4) pollution with solid waste, (5) pollution with liquid waste, (6) thermal pollution, (7) noise as a form of air pollution, (8) radiation, (9) impact on biocenosis, (10) aesthetic of the 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 ten impacts). If all defined impact categories are analyzed, hydroelectric power plants – as a renewable and clean energy source – have an incomparable advantage over all other energy sources (Đorđević, 2001b).

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:

- Temporal distribution of water flow in rivers is irregular. Lots of rivers have torrent type flow. Very often 60–70% of summary annual water discharge runs in a short flood period, succeeded with long dry periods. The average annual flow of all domestic waterways in Serbia is around 509 m^3/s. In a low flow period it decreases ten times and stands at around 50 m^3/s. This is insufficient even for ecological needs of the water ecosystem. The relation between the minimum monthly discharge with the occurrence probability of 95% and the maximum annual discharges with the occurrence probability of 1% are often greater than 1:1000. Variation coefficients of annual discharges are also high ($C_v > 0.5$ for many rivers in Serbia), indicating a variation of mean annual discharges, which are usually higher than 3:1. An analysis of the coefficient of autocorrelation of annual discharges and spectral functions of those values indicates one unfavorable phenomenon: accumulation of dry years creating 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. These extremely dry periods affect a broader region and without water storage reservoirs it would be impossible to provide water for normal human activities (settlements and economy). These low flow periods are detrimental for river flora and fauna. The only way to mitigate it is to discharge water from water storage reservoirs in the upstream part of the river.
- This area is also characterized by extreme spatial irregularity. Specific water flows of domestic waterways vary in a wide range, from only around 1 $L/s \cdot km^2$, to over 50 $L/s \cdot km^2$ in the area of the Dinarides. The lowest specific flows are in the lowland areas with the highest density of population and with fertile land which should be intensively irrigated. Taking all this into account, it can be concluded that water storage reservoirs are the only structures that can deal with temporal and spatial water irregularities. Without them it would be impossible to transfer water from the water source area to the consumer area.
- Around 2/3 of underground water in Serbia is in river alluvium, meaning that the quantity and quality of this water directly depends on the river flow. That is the reason why settlements supplied with water from wells in the river alluvium have huge problems with water supply. Many settlements (Vranje, Kruševac, Kragujevac, Užice, Čačak, Aleksinac, Leskovac etc.) changed their water supply systems from groundwater to more reliable supply – from water storage reservoirs. The source of the water supply system for Belgrade has changed in a similar manner. Water demand could not be satisfied from wells near the two large rivers, so the source was changed, and it now uses the water from Sava Lake – a special form of water storage reservoir.
- There is an important difference between the two categories of water: water existing in catchment areas and water that can be treated as a water resource. An imperceptible difference between these categories can lead to serious errors in the evaluation of water resources of some catchment areas or regions. ***Water existing*** in the area/catchment (V) is exclusively a geophysical category, and it can be defined as: $V = \langle L,Q,K \rangle$, with the matrix structure defining location (L), quantity (Q) and quality (K) of water (Đorđević, 1990). ***Water resource*** (VR) is a social, economic and ecological category, because beside the previously mentioned three attributes, it also has to possess another very important one – the existence of conditions for catching, utilization and protection of water (US). This means that when defining the water resource matrix, the structure of the "existing water" has to be enlarged with the conditions for utilization (Đorđević, 1996), and it can be defined by the relation:

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

Based on the same system logics, ***water demand*** in an area/catchment can be defined

[2] "The goal of sustainability requires that all countries rethink their policies and actions with respect to their impact on world ecology and economic development. Critical objectives in this process include:

- Reviving growth. Poverty reduces peoples' capacity to use resources wisely and intensifies pressures on the environment. The stagnant or declining economic growth trends of this decade must be reversed, especially in developing countries, where the links between economic growth, elevation of poverty, and improvement of environmental conditions are most apparent.
- Ecological and economic concerns are interdependent. Therefore the environment and economy must be integrated in the decision making process from the very start, not just to protect the environment but also to promote long-term economic and social development."

("Our Common Future – Sustainable Development", The Report of the World Commission on Environment and Development, 1987) by the matrix $V_z = \langle L_z, Q_z, K_z \rangle$, with L_z – the location where water is demanded, the required quantity Q_z and demanded water quality K_z. Now, the planning of water resources systems can be presented by the logical structure S:

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

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

Conditions for water utilization (US) are of multidimensional structure, with many components on which the realization of water utilization depends. In each water resource alternative certain conditions have 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 environmental protection (ZU) and conditions that result from international obligations (MU). US can be decomposed into the 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 these parameters we can emphasize impracticability or practicability only under particular circumstances of water utilization in an area. If only one of the mentioned parameters in the matrix (3) is given a value defining the impracticability of the design for water utilization (for example GU=0, because a karstified valley cannot provide water tightness), the entire design becomes impracticable because an appropriate water resources system (VS), necessary for the transformation from "existing water" into "water demand" (equation (2)) cannot be achieved. In this case, water existing in the area cannot be considered as a water resource and it should not be taken into account for future use. Because of all the abovementioned reasons, real water resources are considerably lower than those estimated by analyzing the water existing in the catchment area, or analytically:

$$VR \ll V \qquad (4)$$

Equation (4) is simple, but fundamentally important. The fact that the quantity of water that can be defined as a water resource is much lower than the water existing in the catchment area (sign **<<**) is the main reason for misunderstandings between the public and designers. Usualy, public opinion about water is much more optimistic. This is why the broader public does not understand that key elements for water utilization are water storage reservoirs.

• ***Reliability of water delivery*** is the main reason why water storage reservoirs have become such an important element in water supply systems. The expansion of settlements into the large urban centers requires an increase in the reliability of water supply. Presently, reliability of water supply systems is required to be over 97%. Lack of water in big cities with high-rise buildings and a high concentration of population, without a stable and secured water supply source, is one of the most serious issues that can occur. The situation is similar when it comes to providing water for technological needs for heavy industry and thermal power plants, where the required level of water supply reliability exceeds 97%. This is the result of a close interrelationship between production processes and integration in one unique production circle, where failure of one basic capacity affects other production processes in a chain reaction, thus practically affecting the entire production circle. It is for these very reasons that water storage reservoirs are absolutely necessary: only water storage reservoirs with a large relative volume can provide high reliability of water supply for settlements and technological systems. Analyses performed with simulated synthetic series of flows with different stochastic characteristics (Đorđević, 1990) indicate one typical 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 the required relative water supply is $\alpha = 0.7$ (delivered quantity of water is 70% of average multiyear flow), then an increase of reliability from P=80% to P=90% requires an increase of the water storage volume 2.5 times higher! In order to achieve higher reliability, the situation is even more drastic: an increase of reliability from P=90% to P=97% requires an increase of water storage volume of 2.2 times. An enormous increase of the necessary water storage volume implies a higher price for increased water supply reliability. However, the reliability of around P=97% is within the range of system saturation, and further increases of reliability practically cannot be realized without system of reservoirs with multiyear regulation.

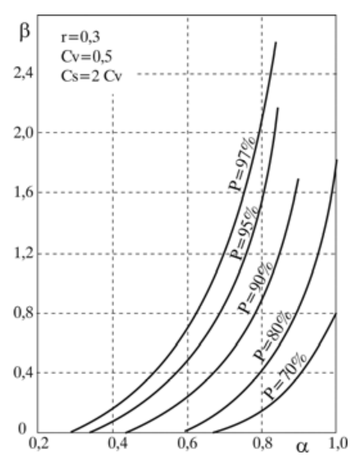

Figure 1. Relation between relative water storage volume, relative water supply and reliability $\beta = \beta(\alpha, P)$

• Requirements in the area of flood protection are more severe (strict) and often cannot be met without active use of water storage reservoirs. Namely, modern flood protection systems require a high protection level (for example protection from flood water with occurrence probability of 1%). Such demands can be met only with a combination of passive protection measures (linear systems – embankments and regulatory works) and active measures. Active protection measures imply a mitigation of flood water especially in reserved areas (volumes) of multipurpose reservoirs, but also influence the entire reservoir volume – very efficient for this purpose. A high level of protection for settlements with urban parts entirely defined in relation to the river cannot be accomplished without active retention effects of a water storage reservoir. One of the examples is Leskovac, a town reliably protected only after the water storage reservoir Barje on the Veternica River has been completed. Another example is the town of Skoplje, for which the required high level of protection (P ~ 0.3%) was accomplished after completing the water storage reservoir Kozjak on the Treska River. A similar situation can be observed in numerous other towns in the world. Fast urban development was realized after managing flood water in reservoirs in the catchment area. The Seine River used to flood Paris until its flood water was mitigated by a water storage reservoir.

Figure 2. Center of Paris (Rue de Lion) during a flood in 1910 before the realization of reservoirs on the River Seine catchment area

• Water quality protection, one of the primary objectives of an organized society, can be accomplished only by one or all of the following actions (measures): (a) technological, (b) water resources and (c) organizational-economical measures. Water resource measures become the crucial protection measures as without them it is almost impossible to accomplish the required high quality levels in rivers, especially during low flow periods. These measures take into account the so called improvement of low flows by discharging water during low flow periods. During this period, river biocenosis and ichtiofauna are endangered as a result of a synergetic influence of several ecological factors, each of them near its pessimum (simultaneous effects of low flow, high temperature and low concentration of dissolved oxygen in the water). If under such conditions water can be discharged from the water storage reservoir, water of high quality, desired temperature, with a high concentration of dissolved oxygen – water quality can be managed and maintained within the boundaries suitable for the survival of river biocenosis. To accomplish this, structures for discharging guarantied ecological flow are built as selective inlets, with the possibility of taking water from the layer with the most suitable temperature (Figure 4). It is an active way to utilize thermal stratification of a lake. This way, water storage reservoirs become an irreplaceable element for water quality protection. They are also the only protection activity in incidental situations, when the designed discharge of quality water can mitigate dangerous consequences of those incidents.

• The recent electric energy situation in the world has been guiding energy development in the direction of complete utilization of hydro potential, as a renewable and ecologically one of the cleanest sources of energy. Such a situation is the result of several facts. (a) The rise of fossil fuel prices makes energy from thermal plants more expensive. In addition, conditions for the control of GHG (green houses gasses) are stricter which, increases the price of thermal plants. (b) The criteria for nuclear power plants are even stricter in all countries; in some they are even forbidden, so that an imbalance between a demand for and supply of energy becomes more pronounced (severe). (c) The criteria for economic utilization of hydro potential have also changed. As a result of the soaring prices of fossil fuels and energy from thermal plants, coefficients of HPP (hydro power plants) energy value increase (Đorđević, 1980, 2001c). This is why some HPPs previously judged as economically unfavorable, have become economically viable when compared to TPPs (thermal power plants). The criteria for economic acceptability for HPP are quite simple: it suffices that the energy price of some HPP is lower than the energy price of the highest price TPP that will be ejected from the system. (d) Building huge aggregates in TPPs increases the problem of providing the spinning reserve capacity and stand-by reserve. Hydropower plants are the most favorable type of plants for providing both reserves, because of its mobility and for operational reasons. (e) An electric power system with more HPPs is economically more stable (Dašić, Đorđević, 2008) (f) Complex water utilization in multipurpose systems enables the utilization of a part of the potential that would be too expensive in one purpose systems. (g) Technological prosperity in equipment production, especially different types of Tubular turbines, enables the utilization of small gross head, on the alluvial rivers, previously impossible to utilize by classical Kaplan turbines. This part of hydro energy potential was not utilized, although it passed into the category of economical potential (Đorđević, 2003).

From the above it can be concluded that the construction of water storage reservoirs continues to be the most instrumental part in the development of electric systems.

• The struggle for food becomes the struggle for irrigation of agricultural land, at least of the highest quality land. However, even in the fertile valley of large rivers (Velika and Zapadna Morava Rivers) there are no conditions for mass irrigation by river water in natural conditions. The reason, as previously mentioned, is the irregular flow distribution – there is not enough water during the periods when intensive irrigation is necessary. The river flow on the Velika Morava drops to below 30 m^3/s, which is hardly enough for the ecological survival of river during low flow periods. This is why irrigation cannot be achieved without seasonal replenishment of water flow from water storage reservoirs.

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 survival. As ecological impact of water storage reservoirs is often a subject of discussion, their role from the environmental point of view will be discussed. It should be analyzed comprehensively, in time and space in which their entire impact must be evaluated. Only the most important positive ecological impacts, crucial for water storage reservoir valuation, are discussed.

• Healthy drinking water is provided, waterborne epidemics are prevented – an important ecological impact.

• Production of hydro energy – ecologically the cleanest form of 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. This is one of the most important ecological impacts. At the same time, ecological pressure on lower quality land is weaker and it can be used for reforestation and other purposes.

• Flood water flows are decreased and flood risk is smaller. Human population is free of the fear of floods, but the environment is also protected from floods which can easily be termed one of the biggest environmental catastrophes.

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

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

• The construction of water storage reservoirs is accompanied by anti erosion works, especially the 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.) and are an ecologically important contribution to the eco-environment of the area.

• The construction of water storage reservoirs is always followed by improved sanitary arrangement, sewerage system and wastewater treatment plants, to protect the reservoir and the river from the process of eutrophication. These water quality protection measures are financed from dam and reservoir designs.

• Finally, large water storage reservoirs create favorable conditions for tourism and recreational valorization of the area.

NEGATIVE IMPACTS OF WATER STORAGE RESERVOIRS AND MEASURES FOR THEIR MAINTENANCE

The construction of each water storage reservoir is followed by certain negative impacts. Most of these negative impacts could be maintained, mitigated or completely eliminated by adequate design solutions. The most important negative impacts are the following:

• On the riparian area as a result of changed groundwater regimes. This impact is especially visible at reservoirs on alluvial rivers, with low riparian area. It can be successfully neutralized by constructing a suitable drainage system. These systems become an inseparable part of the area and enable the management of groundwater regimes – maintenance of groundwater levels within the defined boundaries appropriate for urban systems and agricultural production. These systems can be of two purposes – drainage and irrigation, when a negative impact transforms into a positive one. It was performed in the riparian area of the HPP Đerdap, and the same principles of managing groundwater regimes are planned for the riparian area of the Velika Morava River, Mačva and Semberija after the construction of integral systems on the Morava and Drina Rivers.

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

• The change of ecological factors can jeopardize the survival and development of some biocenoses in the backwater zone. Altered water regimes in backwater zones bring about changes in the living conditions for biocenoses in that zone. Conditions for the development of reobionits – species adapted to living in fast-flowing waters – change very unfavorably. Survival of these species can be secured if some parts of the river, out from the backwater zones, remain in their natural condition.

• Dams are barriers for fish migration. This negative impact can be successfully overcome if special structures for fish migration are provided. For lower barriers – fish paths, and for higher ones – 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 serious problems causing water quality degradation if protection measures are not implemented. These negative impacts can be neutralized and controlled if control of inflow water quality is performed. There are mathematical models for predicting water quality. These models, with appropriate research studies, can predict the changes of water quality. This enables the designer to make some changes in reservoir design and to predict adequate protection measures (Dašić, Đorđević, 2009). There are numerous examples of successful revitalization of reservoirs in an advanced phase of eutrophication and water quality degradation. Reservoirs were returned to oligotrophic state by adequate measures of nutrient income, especially of phosphorus. This means that water storage reservoirs can maintain ecologically favorable quality conditions by adequate protection measures.

• A change of aesthetic values of some spatial natural characteristic. Some reservoirs, especially the ones in deep gorges, after their formation turn into a different kind of biotope and can be experienced as a different aesthetic ambience. This change cannot be mitigated, and this is the most important problem facing the construction of some very attractive water resource systems in canyon parts of some rivers (Tara, Morača, Studenica). But, this new aesthetic view is not unpleasant, moreover, for many people it is of special aesthetic value. This is a matter of personal experience of some elements in space. It can be demonstrated by the fact that most of the time, the biggest problem after filling the reservoir is how to prevent the construction of settlements on its coastal areas.

• A change of microclimate conditions in the narrow zone around the reservoir is another impact. Analyses performed over recent years in a number of countries indicate that microclimate changes are of a much lesser degree than previously thought. The case of the Studenica River reservoir, for which the most detailed analysis were conducted, indicates that all impacts in terms 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 reservoir water level have certain negative impacts. One is aesthetic, because bare coasts in backwater zones are an unpleasant sight. The second impact is ecological: fluctuations of water levels can cause the destruction of fish spawn laid in the shallow zones. The third is from the point of view of tourist and recreational usage of the reservoir: lowering water levels decreases the possibility for its exploitation. These negative impacts cannot be neutralized, but can be alleviated if an additional criterion is implemented in management rules – the criterion for maintaining water level in some periods of the year (periods of fish spawning, summer when the reservoir is used for recreation and tourism). Furthermore, in numerous cases, especially in the case of reservoirs for hydro energy production, reservoirs are full and levels are stable during that period of the year.

• Altered water regimes downstream from the dam and its impact on biocenoses is another important effect. It can be neutralized by designing adequate guarantied ecological flow. The methodology for defining guarantied ecological flow in Serbia already exists (Đorđević, Dašić, 2007). According to this methodology, downstream parts of the river are permanently maintained in the state needed for undisturbed development of the aquatic ecosystem. During certain periods of the year, intentional additional discharge from the reservoir may create conditions better than the natural ones (without the reservoir).

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

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

• Reservoir parameters, especially water levels, should be defined in line with the ecological criteria, considering the behavior 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 to the development of submerged plants and intense eutrophication processes in the lake.

• Design of all infrastructure of the system (dam, intakes, valves, powerhouse etc.) should be architecturally implemented and horticulturally enhanced in such a way that they fit into the environment as harmoniously as possible. On rivers with special ambience values, all of these structures, except dams, can be placed underground. An example of a harmonious integration of a dam into the ambience is the Marathon Dam which supplies water to Athens.

Figure 3. Marathon Dam for water supply of Athens

• Excavations and borrow pits should be subsequently submerged, or, if impossible, later on shaped and "cured" by biological measures, or even used for the improvement of ambience values.

• Each water resource design has to be accompanied by detailed ichthyological studies, which should define if there is a need to incorporate structures for providing fish migration (fish paths, navigation locks and elevators). Water storage reservoirs are a 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 the reservoir with fish and the disposition of structures for fish protection should be planned.

• The dynamics of the 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 unfavorable effects of the 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 the flow should be designed as a selective intake structure with a possibility to manage the quantity and quality of discharged water. Discharged water should be accommodated to the needs of downstream biocenoses (discharge from the adequate water level, the one most appropriate for the specific development phase of downstream biocenoses, Figure 4)[3]. Valves have to be of regulatory type to enable water flow management. Dispositions and types should also envisage the best possible aeration of the stream (the best are Howler-Bunger valves, Figure 5) to enable the control of the oxygen content in water. Summary: outlets should be designed in such a way as to enable the management of the temperature and oxygen regimes downstream from the dam.

[3] Function of the outlet must be adjusted to temperature constant according to which the product of temperature (t) and time (v) of the development of fish spawn until the hatching is constant: v×t=const. For example, temperature constant for trout is v×t=410, meaning that at the temperature of 2 °C smaller fish (subyearlings) hatches after 205 days, at the temperature of 5 °C after 82 days and at the temperature of 10 °C it lasts only 41 days. This means that proper management of water temperature discharged from the reservoir through selective intake from the most appropriate level can accelerate the development of fish populations, in line with the objectives of anthropogenic guided successions.

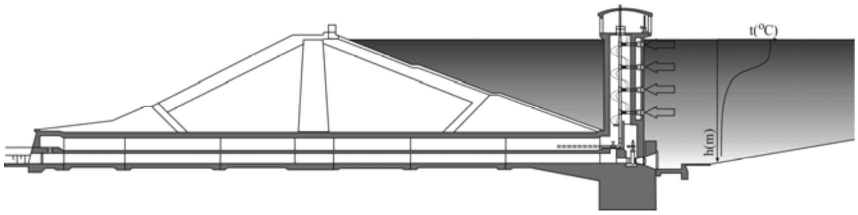

Figure 4. Discharge of guarantied ecological flow from adequate water level

Figure 5. Howler-Bunger valve

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

• Groundwater levels in affected land should be controlled by drainage systems, which should be designed as management systems to enable better water regimes than those in natural conditions. These systems should also be adapted to water resources and ecological objectives (irrigation, touristic valorization of the area). A good example of such a system is the design of Srebrno Jezero Lake on the Danube River, as a part of the protection of the riparian area of HPP Đerdap, which became a popular tourist and recreational centre thanks to managed water regimes. Systems for the protection of riparian areas should be designed as multipurpose systems, so that they can be used for drainage as well as for irrigation, control of salt regimes, etc.

• Antierosion protection of the reservoir should be considered as a wider measure of catchment area cultivation. Particularly important are biological measures (afforestation, drainage of pastures). It should be treated not only as an ecological parameter, but also as a stabilizing economical parameter for the survival of people on catchment areas with poor soil quality.

• Water level management should be adapted to ecological and tourist requirements. For example, maintaining stable water levels in the periods of fish spawning to prevent the destruction of fish spawn laid in shallow zones, or maintaining stable water levels during the summer in the reservoirs used for tourism purposes.

• All biological interventions in the system (afforestation, stocking reservoir with fish) should be carried out only after detailed ecological studies, to prevent destabilization of the already established ecological equilibrium.

• Guarantied ecological flow should be defined in line with ecological requirements, considering it as dynamic category. It should be adaptable to the stage of development of a biotope downstream from the dam (discharging more water in a warmer part of the year, Đorđević and Dašić, 2000).

• To maintain reservoir water quality at the best possible level, the quality of inflow water should be protected. Adequate observation of reservoir water quality, with mathematical models for water quality prediction, enables the prediction of processes of degrading water quality. In this case certain 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 crossing over the water barrage.

• Hydraulic engineering structures in towns and settlements should be planned with special care, from the viewpoint of harmonious functional and aesthetical incorporation into the urban framework. Reservoirs constructed in populated areas should be utilized for a harmonious connection of settlements and the body of water (examples are some parts of Belgrade, which are urbanisticaly adequately connected with the Sava and the Danube – these rivers are part of the Đerdap reservoir, Kladovo, Golubac, Bečej in central parts of these towns).

CONCLUSION

Summarizing water resources, the economic, social and other aspects of water storage reservoirs, it can be concluded that there is an unambiguously clear answer to the question of whether they should be built. They have to be built because economic and social progress and even the survival of the civilization depends on water storage reservoirs. The main question to be asked is the following: what protection measures should be implemented to harmoniously incorporate water storage reservoirs into the environment. Harmonious integration of reservoirs into the environment is not a 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 the process of building water storage reservoirs, significantly improved. In addition to past experiences, the criteria for developing an optimum solution must be extended to include optimizations of economics, of the technical know-how, and only elements necessary for the system's functionality should be built. Now, optimization of integral solutions must be performed, with a complex structure of objectives, in which the technical solution is reached by defining sets of social, economical, ecological, urban and other objectives, criteria and constraints. Future water resource systems should be built only as part of integral systems, meaning that complex solutions are optimally incorporated into the requirements of other users of space.

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