Reservoir Sedimentation as a Consequence of Land Use in the Catchment

MILANKO LJUJIĆ, MILENA DJURIĆ, SRECKO CURCIC*, MILAN PAVLOVIĆ, NEDA NIKOLIC
1 Public Enterprise Gornji Milanovac, Vojvodina Misica 23, 32300 Gornji Milanovac, Serbia
2 University of Kragujevac, Faculty of Agronomy, Cara Dusana 34, 32000 Cačak, Serbia
3 University of Kragujevac, Faculty Technical Science Cačak, Svetog Save 65, 32000 Cačak, Serbia
4 University of Novi Sad, Technical faculty- Mihailo Pupin-, 23000 Zrenjanin, Serbia

Reservoir sedimentation is a very complex problem. Natural conditions and anthropogenic activities have strong influence on sedimentation intensity and hydrological processes, which is represented at the experimental watershed of the Dicina River, in Western Serbia. Reservoir of 340000 m³ was formed after construction of a 17 m high dam, in 1966. Sedimentation of the Velika Dicina reservoir was determined on the basis of a survey from October 1966 to October 2011, along longitudinal profile, 750 m upstream from the dam, with 15 cross section profiles (at a spacing of 50 m). Land use changes were analyzed on the basis of a comparison of watershed conditions in 1966 and 2012, using the CORINE methodology and the MapInfo software. Sediment yield of the area and intensity of erosion processes were estimated on the basis of the Erosion Potential Method (EPM). The hydrological conditions in 1966 and 2012 (after the performed Erosion and Torrent Control Works-ETCWs) were assessed on the basis of a historical overview of land use changes and their impact on computed maximal discharges. Total quantity of deposited sediment in the reservoir amounts to 18750 m³. Intensity of sedimentation has continuously been decreasing since 2002 as the consequence of land use changes, performed ETCWs and depopulation. The realization of restoration works contributed to a decrease in the annual yield of erosive material from Wa=16007 m³ to Wa=1930 m³. Presented are the comparative results of sediment trans-sport for ri-vers in Serbia, with catchment area smaller than 1000 km².

Keywords: catchment area, sedimentation, erosion processes, depopulation, land use, sediment yield

Dams and accumulations have been successfully used for collecting, storage and managing of water resources throughout history. Today, there are a large number of constructed dams with multiple functions, including the production of electric power, flood protection, water supply, irrigation, recreation, fishery and many others. Reservoir siltation is a very complex problem in Serbia, both in big and small reservoirs. The huge Djerdap reservoir in the Danube River, on the border between Serbia and Romania, has a volume of 2.10¹⁰ m³, and traps 15.10⁶ m³ of sediment every year. However it has not been significantly endangered due to sedimentation yet [8]. In contrast to that, the small Gvozdac reservoir at Goè mountain in Central Serbia, has a volume of 60-10⁶ m³ that is completely filled with sediment and out of function for water storage [13]. Sediment yield due to soil erosion depends on the complex interaction among a number of factors, including the natural characteristics of the area, population growth and fall rates, educational and cultural issues, the institutional conditions, as well as environmental and agricultural policy [1,2]. The intensity of erosion processes varies depending on storm conditions, hillslope aspect, lithological properties and human impact [12].

In the 60s of the 20th century over one hundred small reservoirs were formed in the hilly-mountainous regions of Serbia. These reservoirs were faced with a serious risk of sedimentation due to intensive anthropogenic activity in the watershed areas [5]. However, already in the 80s of the last century the process of depopulation of rural areas was initiated as a result of the migration of people to cities, which reduced the pressure on the forest and agricultural areas. In the same period, Water Resources Management of Serbia performed large scale erosion and torrent control works (ETCWs), including technical works (check dams, bank protective structures, torrent training) and biotechnical works (afforestation, forest protective belts, silt-filtering strips, grassing, terracing and contour farming). In addition, spontaneous restoration of forests in large areas of abandoned arable land was observed in the hilly-mountainous areas characterized by intensive depopulation [10]. The large-scale land use changes have produced some favorable effects, including decrease of sediment yield, less intensive reservoir sedimentation and reduced watershed potential for the formation of fast surface runoff. These phenomena were measured and analyzed at the experimental watershed of the Dicina River in Western Serbia.

Experimental part
Materials and methods
Study site description
Reservoir sedimentation and the hydrological effects of land use changes should be assessed at watershed scale, on the basis of complex investigations, including a historical overview of the process of erosion and land use changes, intensity of sedimentation, computations of sediment yield and hydrographic characteristics of the watershed. This paper presents an investigation carried out at the experimental watershed of the Dicina River, profile P at the Velika Dicina dam, (fig. 1).

The dam Velika Dicina (made of stone with clay core) was built in the 1965-66 period, above the village of Gornji Banjani, as a water retention area for flood protection with...
a continuously open outlet. The main characteristics of the dam and reservoir are as follows: construction height of the dam, \( H_{br} = 17.0 \) m; dam crown width, \( B = 3.50 \) m; dam crown length, \( L_d = 65.20 \) m; and volume of the reservoir, \( V = 340000 \text{ m}^3 \).

The main hydrographic characteristics of the experimental Dièina River watershed (up to the control profile \( P \) at the Velika Dicina dam), are presented in table 1.

### Methodology

The intensity of sedimentation was surveyed from October 1966 to October 2011. Sediment yield was measured by survey along longitudinal profile, 750 m upstream from the dam, with 15 cross section profiles (at a spacing of 50 m). The measurements were taken in 1966, 1997, 2001 and 2011, using a theodolite (from 1966 to 2000) and a laser total station (Topcon GPT-3100N) from 2001 to 2011.

Land use changes were analyzed on the basis of the existing technical documentation and the data collected from 1966 to 2012, field investigations, usage of aerial and satellite photo images, as well as topographic, geological and soil maps. Land use classification was made on the basis of the CORINE methodology \[3\] using the MapInfo software. The area sediment yield and the intensity of erosion processes were estimated by the Erosion Potential Method (EPM). This method was created, developed and calibrated in Serbia \[4\] and it is still in use in all the countries which originated from former Yugoslavia.

The aim of this investigation is to show how land use changes caused by ETCWs and lowered anthropogenic pressure can help improve the hydrological conditions in watersheds, mitigate erosion processes, decrease deposition of sediment and reduce the risk of torrential floods.

### Results and discussions

#### Land use changes

The land use changes were determined on the basis of comparison of land use maps from 1966 and 2012 in figures 2a and 2b.

There are no settlements in the watershed. However, the villages of Kostunici and G. Banjani are located in the vicinity (fig. 1). The inhabitants of these villages are the owners and the users of the land. The anthropogenic pressure on the soil in the watershed was very strong during the 1960s of the last century, because the population of the neighboring villages amounted to more than 1473 people or 67 persons per 1 \( \text{km}^2 \). In 2011, there were 747 inhabitants or 34 per 1 \( \text{km}^2 \) \[14\].

The erosion and torrent control works (ETCWs) in the watershed started in the mid-60's of the 20th century. In the 1966–2012 period a wide scope of biological and biotechnical activities were performed. Dominant biological and biotechnical activities included: afforestation of bare land with \textit{Pinus nigra} and \textit{Pinus silvestris} (219 ha; steep, deforested and eroded slopes; 700-1100 seedlings per ha, two to three years old); systems of wattlings (197 wattlings were built in 21 gullies; average height - 0.8 m; material - \textit{Salix alba}). The autochthonous forest cover dominantly consists of beech and oak trees. The beech forests are located at northern exposures, whereas the oak forests can mostly be found in the south.

### Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mark</th>
<th>Unit</th>
<th>Dièina River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude</td>
<td>A</td>
<td>km²</td>
<td>21.98</td>
</tr>
<tr>
<td>Perimeter</td>
<td>P</td>
<td>km</td>
<td>23.64</td>
</tr>
<tr>
<td>Peak point</td>
<td>Pp</td>
<td><em>m.a.s.l.</em></td>
<td>794</td>
</tr>
<tr>
<td>Confluence point</td>
<td>Cp</td>
<td>m.a.s.l.</td>
<td>497</td>
</tr>
<tr>
<td>Mean altitude</td>
<td>Am</td>
<td>m.a.s.l.</td>
<td>654.10</td>
</tr>
<tr>
<td>Length of the main stream</td>
<td>L</td>
<td>km</td>
<td>8.20</td>
</tr>
<tr>
<td>Absolute slope of river bed</td>
<td>Sa</td>
<td>%</td>
<td>3.68</td>
</tr>
<tr>
<td>Mean slope of river bed</td>
<td>Sm</td>
<td>%</td>
<td>2.05</td>
</tr>
<tr>
<td>Mean slope of terrain</td>
<td>Smat</td>
<td>%</td>
<td>23.99</td>
</tr>
<tr>
<td>Density of hydrographic network</td>
<td>D</td>
<td>km km⁻²</td>
<td>2.57</td>
</tr>
</tbody>
</table>

*m.a.s.l.* - meters above sea level
The process of erosion and sediment yield

Dispositions of different categories of destructivity of erosion processes (classification by EPM) in 1966 and 2012 are presented in figures 3a and 3b.

Some characteristic outputs of computations of sediment yield are presented in table 2, as well as the representative values of the coefficient of erosion Z, before the ETCWs (1966) and at present (2012), including \( W_a \) - annual yield of erosive material and \( W_{asp} \) - specific annual yield of erosive material.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before ETCW-1966</th>
<th>Actual conditions-2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W_a ) [m³]</td>
<td>16007</td>
<td>1930</td>
</tr>
<tr>
<td>( W_{asp} ) [m³ km⁻² year⁻¹]</td>
<td>728.3</td>
<td>87.8</td>
</tr>
<tr>
<td>Z</td>
<td>0.439</td>
<td>0.187</td>
</tr>
</tbody>
</table>

Reservoir sedimentation

The sedimentation of the Velika Dicina reservoir was determined on the basis of a survey conducted from October 1966 to October 2011 along longitudinal profile, 750 m upstream from the dam, with 15 cross section profiles, at a spacing of 50 m (fig. 4). The total quantity of deposited sediment in the reservoir amounts to 18750 m³, i.e. 15800 m³ (509.6 m³/yearly on average), in the 1966-1997 period, 2280 m³ (570 m³/yearly on average), in the 1998-2001 period and 670 m³ (67 m³/yearly on average) in the 2002-2011 period. The maximal depth of deposited sediment close to the dam amounted to 3.1 m. The process of reservoir sedimentation starts at the distance of about 450 m upstream from the dam (profile 9, fig. 4).

The levels of reservoir sedimentation were measured in 1966, 1997, 2001 and 2011. Cross section profile 2, at the distance of 100 m upstream from the dam (fig. 4, 5) has a deposited surface of 44.32 m² and a maximum thickness of deposited material of 2.1 m.

Compromise of research results with data for other basins in Serbia

Data-base on sedimentation in the territory of Serbia includes the results of measurements of suspended sediment in several larger and smaller rivers, as well as results of reservoir siltation monitoring. This database is analyzed by Petkovic [6]. Table 3 presents the comparative results of measurement and calculation of sediment transport (formula by Petkovic) for some rivers in Serbia, with catchment area smaller than 1000 km².

Based on the results from table 3, a diagram of a specific correlation between sediment transport (\( g \)) and water shed area (\( F \)) is obtained, shown in figure 6. On the diagram are specified the range of values \( g(F) \), obtained on the basis of sediment measurement applied to a number of river flows in Serbia.

From figure 6 it can be concluded that the sediment transport in the Velika Dicina basin, registered at the dam, is lower than the range for the territory of Serbia, which...
The processes of erosion and sedimentation are related to the conditions in a watershed, including climate, topography, geology and soil characteristics, hydrology, population density and land use. The natural conditions in the watershed of the Dicina River are favorable for the development of the process of erosion, fast surface runoff formation and sediment transport. These natural conditions include frequent rainfall events of a short duration (2-3 hours) and strong intensity, I > 1 mm·min⁻¹ [11], steep slopes of the terrain (Sₘₜ = 23.99%) and river bed (S = 3.68%). In addition, the dominant part of the experimental watershed consists of waterproof rocks (serpentine) or erodible rocks (marls and sandstones, dolomite, porphyritic breccias, tuffs with porphyritic flows, claystones and diabases). The existing soil types (Eutric Leptosol and Calcic Cambisol) are characterized by a moderate water storage capacity and resistance to erosion under sustainable land use (dense vegetation cover, contour and terrace farming, limited number of live stock, controlled urbanization and forest cuttings). However, a significant part of the soil (39%) was eroded, during the 1960s of the last century, due to inadequate land use (massive clear forest cuttings, overgrazing, and straight row farming down the slope). The consequences were reduced water infiltration capacity and intensive sheet, furrow and even gully erosion.

The average population density in the vicinity of the watershed amounted to 67 persons per 1 km² during the 1960s of the last century and 34 per 1 km² in 2011. The comparison of the land use maps from 1966 and 2012 shows great differences in the structure of surfaces (fig. 2a and 2b). Until the end of 1960s, the watershed of the Dicina River was covered with bare lands on 18.06% of the total area (0.84 km²). In the same period, the broad-leaved forest area increased from 43.58% of the total area (9.58 km²) to 57% of the total area (12.53 km²). In addition to that, new coniferous forests were established in almost 9.96% of the total area (2.19 km²), mostly on the former bare lands and abandoned arable land.

The depopulation caused a decrease in the anthropogenic pressure on the agricultural and forest surfaces in the watershed, so that the pastures and grasslands were reduced from 24.97% (5.49 km²) to 14.79% (3.25 km²) of the total area. In addition, 13.42% of the total area (2.95 km²) containing mostly bare land, abandoned arable land and pastures became spontaneously overgrown with trees and shrubs.

The establishment of stable forest stands on bare land is a key anti-erosion measure applied to protect reservoir storage capacity from sedimentation. The effects of this measure are the following: increase of transpiration and interception, reduction in the loss of water by evaporation, the development of the soil and its infiltration capacity, as well as lower, but longer specific runoff. Pinus nigra on serpentine rock produced the above effects, 7 years after planting in the experimental site at Goè mountain in Central Serbia [9]. The performed ETCWs in the watershed of the Dicina River (afforestation of 219 ha of deforested and eroded slopes, systems of wattlings for gully restoration) helped decrease the sediment yield and balance the runoff regime.

Total sedimentation in the Velika Dicina reservoir in the 1966-2011 period, amounts to 18750 m³ or on average 416.7 m³/yearly, i.e. 19 m³·km⁻² expressed as specific annual intensity of sedimentation. Deposition of the reservoir was more intensive (570 m³/yearly on average, or 25.9 m³·km⁻²) in the 1966-1998 period (509.6 m³/yearly on average, or 23.2 m³·km⁻²), as the consequence of the highly intensive and uncontrolled forest exploitation on steep slopes. The intensive afforestation of bare lands and restoration of gullies with wattlings, as well as better control of cuttings and depopulation, contributed to a decrease in the intensity of deposition in the 2002-2011 period to 67 m³/yearly on average (3.05 m³·km⁻²). The total loss of reservoir volume in the 1966-2011 period amounts to 5.51%, or on average 0.122% yearly.

The initial state of the process of erosion (1966) was characterized by the coefficient of erosion Z = 0.439 (medium erosion). ETCWs were carried out in order to decrease the yield of erosive material, increase water storage capacity of the soil and reduce flood runoff. The present state of the process of erosion is characterized by the coefficient of erosion Z = 0.187 (very weak erosion). The realization of restoration works helped decrease the
annual yield of erosive material from \( W = 16007 \text{ m}^3 \) to \( W = 1930 \text{ m}^3 \) (table 2). The comparison of erosion maps from 1966 and 2012 shows great differences in the intensity of the process of erosion (fig. 3a and 3b). Until the end of the 1960s, the watershed of the Dicina River was endangered by excessive erosion (the hardest category of terrain destruction with deep gullies, landslides, and removed soil) on the 11% of the total area (2.42 km²), while in the spring of 2012 it amounted to 1.64% of the total area (0.36 km²).

Comparing erosions parameters of the catchment area of the river Velika Dicina with other river basins in Serbia, it was found that only Gvozdac river is more beneficial to the erosion factor. This means that only the basin of this river has a smaller percentage of areas under severe erosion of the basin Velika Dicina. In terms of annual values of sediment transport in the basin (g) has the lowest specific transport of sediment from the basin, expressed in m³/2 km²/year. Compared with, the size and decline, similar river basin Grošnica river four times lower value of specific transport of sediment from the basin of Velika Dicina. Catchment area of the river Velika Dicina has the lowest specific sediment transport.

**Conclusions**

The experimental watershed of the Diëina River still has the natural potential, in terms of climate, topography, geology and soil characteristics and hydrology, for the development of intensive processes of erosion, sediment yield and reservoir sedimentation. Soil erosion in the watershed, during the 60s of the last century, was initiated by the removal of forest (clear cuttings, trunk transport down the slope) and inadequate agricultural activities (straight row farming down the slope, overgrazing). In addition to that, population density, educational and cultural conditions contributed to the process of degradation.

The anthropogenic impact was significantly reduced after the ETCWs and the change towards sustainable land use. The depopulation contributed to a significant decrease in the pressure on agricultural and forest surfaces in the watershed. The ETCWs in the watershed of the Dicina River (afforestation of 219 ha of deforested and eroded slopes, systems of wattlings for gully restoration) helped decrease the sediment yield and balance runoff regime. The establishment of forest stands on degraded surfaces and appropriate technical works in the hydrographic network are effective anti-erosion measures for the protection of reservoir storage capacity from sedimentation [7].

Once extremely disturbed watershed with intensive sediment yield is now restored after large-scale biological and biotechnical ETCWs, which were performed in the 1966-2010 period. Land use changes in the watershed helped balance the runoff regime by increasing the low discharges (their amount and duration) and decreasing the maximal discharges. The intensity of the process of erosion has been reduced from medium erosion (Z=0.439) before the ETCWs, to very weak erosion (Z=0.187). Most of the former bare land, abandoned and degraded arable land and pastures were transformed into forest surfaces or transitional woodland-shrub land. This transformation and the restoration of 21 gullies with systems of wattlings helped decrease the sediment yield about 8 times.

The natural conditions in the watershed of the Dicina River are favorable for the development of the process of erosion. Because of this, be applied erosion protection based on biotechnology works and increasing the forest coverage of the watershed. The afforestation should be done with appropriate types and form a stable stand, at least 7-10 years before the exploitation of the dam. Afforestation and increase the area under vegetation allows for the preservation of biological diversity. Protective function of the vegetation is reflected in the creation of favorable hydrological conditions in the basin, the development of land and the infiltration capacity, mitigation of erosion, reducing the maximum flow and volume of flood, reduce sediment accumulation in the reservoir and the risk of torrential floods.

Large forest fires a frequent occurrence in the region. The last fire was in 2012, destroyed more than 100 ha forest and raised plantations. The basic network of fire protection on the ground should make the fire streaks associated with roads and watercourses. Water for fire fighting should be provided from capped sources, and in the upper reaches of streams and rivers form a microaccumulations. In unpopulated places should raise watchtowers of the dominant points and arrange service monitoring and alert.

**References**


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