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THE EFFICIENCY OF HYDROTECHNICAL WORKS IN THE GURGHIU HYDROGRAPHIC BASIN

Iulia Diana ARION[1], Felix ARION[2], Irina Maria MORAR[1]

[1]University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca, Department of Forestry, 3-5 Manastur Street, Cluj-Napoca, Romania
[2]University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca, Department of Economic Sciences, 3-5 Manastur Street, Cluj-Napoca, Romania

Corresponding author email: felixarion@usamvcluj.ro

Abstract

The characterisation and knowledge of the Gurghiu drainage basin represents a realistic analysis of the current state of the drainage basin. This analysis led to the obtaining of information on morphometric parameters specific to the drainage basin and the Orşova, Fâncel and Sirod sub-drainage basins; the current state, together with the effects and efficiency of torrent correction works in these sub-drainage basins and the knowledge of the grain size of the alluviums accumulated behind the hydrotechnical works. To analyse the profitability of the hydrological management work in the sub-drainage basin Fâncel, a series of specific indicators were used: specific investment, duration of the recovery of the investment, updated net value, internal rate of return and profitability index. The total amount of alluvium retained in the valleys of the Gurghiu hydrographic basin is 24,960.3 m^3, with direct retention accounting for 6,774.55 m^3 and consolidation for 8,185.8 m^3. The analysis reveals that the costs associated with extracting torrential alluvium would have been roughly 1,859.55 thousand lei. Recommendations are to urgently restore essential repairs to damaged, broken, or detached parts of the work, to cover infiltrations and cracks and to complete masonry in places affected by degradations.

Key words: *forest management, rural development, sustainable development.*

INTRODUCTION

The study starts from the assumption, that, the management of water resources will soon involve planning and constructing new water supply systems as well as analysing the financial performance of the current ones. The instability and lack of the predictability of the water amount in time and space will cause more and more efforts to be focused on solving water scarcity and reducing water conflicts. In such an assumption, the hydro-economic models depict integrated systems that consider the infrastructure already in place and management choices based on economic values (Turner et al., 2000). The processes for allocating and managing water within these integrated tools are to be determined either by the known economic value of water or by its estimation based on economic value.

Within these integrated tools, the processes of water allocations and management are to be determined either by the known economic value of water or by its estimation based on economic value on specific time and place. A basic concept considers that water demand is not uniform, and therefore, it depends on the quantities of water used at a given time, so its total and marginal economic value can differ greatly (Harou et al., 2009).

The increase in disaster-related losses is slower than the increase in wealth, according to research cited in a 2012 World Bank Policy Research Working Paper by Hallegatte (Hallegate, 2012). A straightforward model demonstrates that this trend can outweigh the impact of risk reduction measures in many countries where rising incomes have also contributed to increased migration and investment in high-risk areas. This assessment may be understated because it ignores the production losses brought on by the destruction of assets, which are indirect losses brought on by natural disasters. In the case of major disasters, indirect losses may be comparable in size to direct losses.

In Romania, research on how the hydrological disturbances generate, as an inevitable effect, the reduction of the area's natural potential has also been carried out. The information on water management in Wallachia dates to 1576, and the oldest writing reference about flood protection is known as the "Canalul Ipsilantis", dating from 1774 (Mititelu, 2010). Currently, other scholars (Hâncu & Nițescu, 2016) think that, overall, the water management must be considered a distinct branch of the economy and it must be approached accordingly, and it has not to be integrated within other branches, such as environmental economics or forestry economics.

It is undeniable that traditional engineering and hydrological models of water management issues are integrating more and more economic and social concepts and methods (Toscani et al., 2020). For better results and information for decisions and policies regarding water management, economic management concepts and performance indicators should be combined with an adequate engineering level of understanding of a hydrological system (Sun & Vose, 2016). Such models can serve as a basis for a common understanding of water issues as a foundation for management solutions and negotiated public policies when they are created and used with stakeholder involvement. Integrated hydro-economic models can offer creative solutions that decision-makers can take into account when they are put into practice using optimization software. Their applications to watershed management problems are constantly being reviewed. The economic and integrated modeling of the economy-engineering-hydrology triplet is then discussed in relation to the European Water Framework Directive (Heinz et al., 2007). Cost recovery and water pricing, the effectiveness of water management strategies in terms of cost, and public participation in decision-making are all pertinent factors.

In a situation where there is competition for scarce water resources, combined hydro-economic models of river basins are essential tools for assessing management and infrastructure strategies to increase the economic effectiveness of water use. The physical behaviour of the system must be accurately modeled in integrated hydro-economic models, including interactions between the various surface and groundwater resources as well as the spatial and temporal variability of resource availability. However, according to Pulido-Velazquez et al., these models must consider the value of water for various urban, agricultural, and industrial uses and users (Pulido-Velazquez et al., 2008). Economic values for water use are established in accordance with the marginal residual value of water for production (for agricultural and industrial uses) or the accessibility of payment for urban supply and other end uses of water.

The current inability to provide pertinent information required to achieve the necessary coherence in various government policies can be partially resolved by integrated research on hydrological aspects combining the social and natural sciences. A comprehensive framework for watershed research has been developed (Lindroth et al., 1994) contends that combining economic analysis with integrated modelling, stakeholder analysis, multi-criteria assessment, and stakeholder analysis can yield complementary insights into wetland management, policy optimization, and welfare maximization. Each part of this integrated wetland research is then examined and connected to wetland management strategy.

Constructions utilizing hydrotechnical methods have a wide range of significant environmental effects, both good and bad. Because of this, they should be examined using a sophisticated tool that incorporates techniques unique to economic sciences. That is a prerequisite (Mititelu, 2010) for them to agree with those established at the Conference of Nations United of June 1972 from Stockholm, which defined environmental impact as any impact that human activity has on the environment, including the safety and health of wildlife, plants, soil, water, climate, landscapes, and historical structures like monuments.

The direct protection of the objectives threatened by torrential floods, as well as an important ecological effect, can be ensured by the retention of alluvium, both directly by the transverse hydrotechnical works, and indirectly by covering the beds by all types of hydrotechnical works used (Bremer et al., 2021; Clinciu et al., 2008).

The article is addressing the scientific gap related to the estimation of the efficiency of hydrotechnical works, especially on forests.

There are recent studies (Arion et al., 2023) proposing the use of cost-benefit analysis based on real-cost methodology, so, for the purpose of this study, it was used the determination of the amount of alluvium retained due to retention and consolidation. Two significant indicators were used: direct retention and retention through consolidation, as proposed by scholars in Romania (Gaşpar et al., 1979; Clinciu, Gaşpar, 2005; Lupaşcu, 2009).

MATERIALS AND METHODS

On the following torrential valleys - on the right side, Fâncel, Sirod, Fătăciuniţa, and Pârâul Negru - which are situated on the direct slopes of the Gurghiu River and its tributaries-research on the efficacy of hydrotechnical works have been conducted. The areas under study are covered with projects to stabilize torrents, safeguard banks, and safeguard forest roads.

The Gurghiu hydrographic basin, which is a part of the Gurghiu Mountains' volcanic region, the Reghin Subcarpathians' hilly unit, and the Mureş Terraced Corridor, is situated in the Eastern portion of the Transylvanian Depression. In the hydrographic basin of the Mureş River, it is situated in the northeastern region of Mureş County. It is, also, part of the Eastern Carpathians, the North-Western part of the Gurghiu Mountains, part of the Gurghiu-Călimani-Harghita volcanic mountains and, the area with lower altitudes, is part of the Transylvanian Plateau.

The delimitation of the Gurghiu Basin and the sub-basins where torrent correction works were carried out was done with the ArcHydro9 application through a sequence of operations, the surface of the basin automatically resulting.

The surface of the hydrographic basin is 655 km^2 - 65,500 ha calculated as a result of the delimitation of the hydrographic basin by drawing the water balance on the Topographic maps 1:25,000, being included into the category of very large basins, so the effect of heavy precipitation and sudden melting of upstream snow is felt with a delay.

In the Orşova, Fâncel and Sirod sub-basins, in order to reduce the effects of torrential floods, since 1970, a large-scale development of the torrential hydrographic basins was started. This action mainly had in mind the protection of localities and public and forest roads by reducing the transport of alluvium and strengthening the torrential hydrographic basin.

The location of the hydrographic basins where works were carried out was done starting from the existing documentation and records at the Mureş Forestry Directorate (Figure 1).

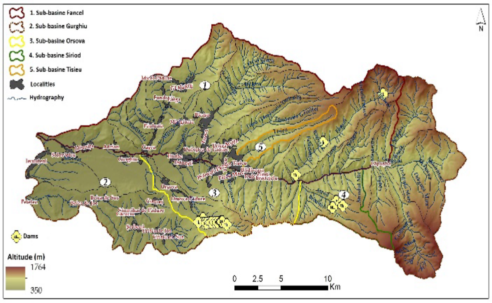

Figure 1. Location of hydrotechnical works on studied area

Estimation of Consolidated length, Consolidated Area and Volume of Alluvium

The consolidated length by covering the beds by the landings (Lat), the consolidated surface (Sat) and the volume of alluvium stored by the landings (Wat) are the studied indicators. They were quantified according to the methods proposed by scholars (Lupaşcu, 2009; Colişar, 2011), as follow:

- the SilvaClinoMaster hypsometer was used to measure the slope of the landing that had formed or was in the process of forming;
- Lat was measured using the 50 m tape;
- Sat was calculated as the product between the length of the landing and its width in the hydro-technical work location area;
- Wat was determined with the simplified formula proposed by Gaşpar (Gaşpar et al., 1979) for cases where the bed slopes and cross sections are constant:

$$\text{Wat} = 0.167 \cdot \text{Yat} \cdot \text{Lat} \cdot (2b + B) \qquad (1)$$

where:

- Yat - the blocked height of the transverse hydrotechnical work;
- b - the width of the riverbed thalweg in the area where the work is located;
- B - the width of the valley at the level of the landing formed or in the process of formation.

In order to verify the results obtained regarding the volume of the landing, the volume of alluvium estimated in the projects developed by Institute of Forestry Research and Management in Romania (I.C.A.S.) was compared with the volume of alluvium landed behind the hydrotechnical works.

Estimation of Direct retention (RD)

The direct retention (RD) is represented by the transverse works, dams and thresholds, constituted by the volume of the landing formed or in the process of formation.

Estimation of Retention through Consolidation (RC)

The action of correcting the torrents through the landscaping works stops the erosion of the banks and riverbeds during the operation of the works. Retention through consolidation constitutes the volume of alluvium fixed by these works and can be expressed by the following parameters (Lupașcu, 2009):
- retention by consolidation, originating from formed landings, evaluated separately for dams and clogged thresholds;
- retention by consolidating the beds by the works themselves, considered separately for each work.

Reinforcement by capping the banks was calculated considering the length covered by the flood drainage channels, which supports the defence of the banks against lateral erosion and other mass transport phenomena.

Retention by consolidation was analysed and calculated on torrential valleys and on each work separately, using the following calculation formula:

$$\mathrm{RC} = \mathrm{N} \cdot \mathrm{Waa} \quad (2)$$

where:
- N - the number of years of the period of operation of the works;
- Waa - the volume of alluvium, which in the assumption of the non-application of the works would have been transported from the bed sectors covered with the landings of the works.

Waa was determined according to the Gaspar-Apostol method (Gaspar et al., 1995), which forecasts the approximate amount that could have been transported from the torrential network.

$$\mathrm{Waa} = 0.0175 \cdot (0.5 \cdot H) \cdot (0.125 \cdot F) \cdot \left(\frac{\mathrm{Lv}}{\mathrm{La}} \cdot 0.15\right) \cdot \mathrm{f} \cdot \sum \left(\mathrm{L} \cdot \mathrm{qa} \cdot \mathrm{c} \cdot \left(\frac{\mathrm{ia}}{\mathrm{is}}\right) \cdot 0.5\right) \quad (3)$$

where:
- H (mm) - average annual rainfall;
- F(ha) - basin surface;
- Lv (m) - the length of the slopes;
- La (m) - the length of the main bed;
- Ia - the average slope of the main bed;
- Iv - the average inclination of the slopes;
- F - coefficient established according to the textural class of the substrate;
- L (km) - the length of each bed sector;
- qa (mc/year/ha) - specific standard erosion;
- c (mc/year/ha) - the average erodibility coefficient on the sector of length L;
- ia - the real average slope of the considered bed secto;r
- is - the average slope of the considered bed sector.

It must be specified that some of the elements introduced in the calculations were measured or assessed during the field survey phase, others were taken from the forestry plans, while others were taken from the situation plans at the scale 1:5,000 and 1:10,000, and others being taken with the help of the GIS application.

The precipitation retention potential was determined by land use category and subsequently the period of operation of the hydrotechnical works executed was established.

Estimation of the economic effects produced by reducing the transport of alluvium

Torrential alluvium causes damage to various objectives and lands inside and outside the basins, such as clogging of forest roads, agricultural and forestry lands, civil, industrial and household buildings.

The volume of flood alluvium transported from the basins is determinable as (25-75)% of alluvium causes damage (Grudnicki & Ciornei, 1997). The assessment of these damages is done by determining both the costs of reflate, removal of alluvium, and the costs of repairing the damage. The estimation of the partial economic effects of the development works is calculated by adding up the values of direct retention and retention through consolidation, and only the expenses that would have been occasioned by the excavation, transport and storage of alluvium are considered torrential (Lupașcu, 2009; Ciornei, 2000). It is considered that the extraction of coarse alluvium is carried out mechanized and manual, the transport would have been done over 5 km, with unit costs updated from the 1984 Design Standard.

RESULTS AND DISCUSSIONS

Direct retention

In the Fâncel and Sirod hydrographic subbasins, all the levees and dams executed fulfilled their role of retaining the alluvium, at the date of the inventory of the works, the retention capacities of the works were exhausted (Figure 2).

Figure 2. Direct retention, Fâncel and Sirod sub-basins

The surface, length and volume of the landings formed in the Fâncel, Sirod and Orșova hydrographic subbasins

Based on the measurements and calculations carried out, the landings that are formed behind the transverse works on the torrential streams in the basin under study extend over a length of 424 m, having a total area of 6,770.11 m^2 and forming a volume of alluvium of 6,774.55 m^3 (Table 1).

It is found that the largest volume of alluvium stored behind the works is in the Orșova valley with 5301.98 m^3, the reasons being the greater number of works, the works are much larger and the torrential valley has a much wider opening large in relation to the other two sub-basins. The Fâncel subbasin has the lowest values for the elements considered, because of the number of fewer works, although the works in this basin have exhausted their retention capacity to the maximum.

Table 1. The area, the length and the volume sediments behind dams of the Orșova, Fâncel and Sirod sub-basins

No	Torrential valley/Transversal work	Length (Lat) (m)	Area (Sat) (m^2)	Volume (Wat) (m^3)
1	Orșova dam 1	25.0	480.00	881.76
2	Orșova dam 2	31.0	654.1	1,009.51
3	Orșova dam 3	17.0	266.9	202.70
4	Orșova dam 4	25.0	417.5	508.93
5	Orșova dam 5	23.0	478.4	304.21
6	Orșova dam 6	23.5	472.35	486.64
7	Orșova dam 7	17.0	277.1	182.60
8	Orșova dam 8	16.8.0	231.84	432.06
9	Orșova dam 9	18.0	304.2	292.18
10	Orșova dam 10	23.0	333.5	232.69
11	Orșova dam 11	24.0	439.2	427.739
12	Orșova dam 12	23.2	392.08	340.95
	Total Orșova	266.5	4,747.17	5,301.98
13	Fâncel dam 1 Pr. Porcul de Jos borna 22	18.9	217.35	138.88
14	Fâncel dam 2 Pr. Tarcea de Sus borna 80	26.3	433.95	494.11
15	Fâncel traversă 3 Pr. Buneasa	11.8	171.1	39.45
	TOTAL Fâncel	57.0	822.4	672.44
16	S.1 prag Pr. Borna 51/VIII	13.6	108.8	66.77
17	S.1 dam Pr. Borna 52/VIII	23.4	210.6	200.08
18	S.1 dam Pr. Borna 54/VIII	25.1	238.45	251.50
19	S.1 prag Pr. Borna 104/VIII	18.3	270.84	124.69
20	S.1 prag Pr. Borna 106/VIII	20.1	371.85	157.09
	Total Sirod	100.5	1,200.54	800.14

(source: own calculations)

Length, area and volume of landings on transverse works

The three previously mentioned indicators and their frequency were analysed separately for each work, according to Figures 3 and 5.

Analysing the length of the landings formed or in the process of formation behind the transversal works, it can be seen in Figure 3 that the longest length is recorded in the Orșova sub-basin at dam 2 (Lat = 31 m), followed by the dam on Pr. Tarcea de Sus, and the shorter length is recorded at the threshold of Pr. Buneasa (Lat = 11.8 m) in the Fâncel sub-basin.

Looking at the frequency of works by Lat classes (Figure 4) most landings, in number of 9, have a length between 20 and 25 m, 6 landings have a length between 15-20 m, only 2 landings have a length between 25 and 30 m.

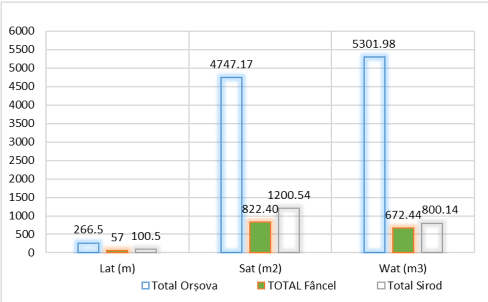

Figure 3. The length, the area and the volume of sediments behind dams

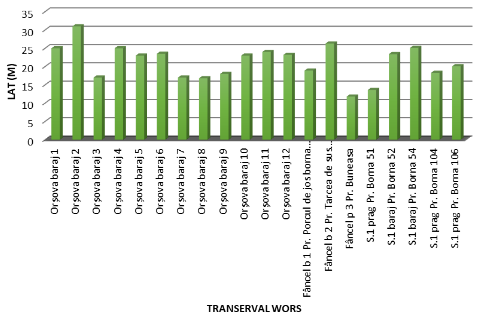

Figure 4. The length of the transversal works sediments behind dams

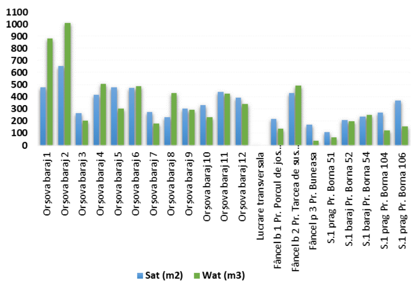

Figure 5. Distribution of area and volume of sediments behind dams on transverse works

The area of landings (Sat) was determined as a product between Lat and the width of the landing formed in the hydrotechnical work location area. Sat may vary depending on the width of the valleys.

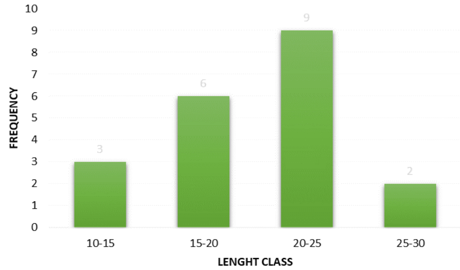

Figure 6. The frequency of transversal works on length classes

The landed surface of the transverse works is larger on the Orșova valley, because the valley is wider than the other two valleys. Also, it is observed that only dams 1 and 2 in the Orșova sub-basin have a large volume of stored alluvium, namely 1009 m^3 and 881 m^3, respectively, due to the total blocked height. Although the length of the landings on Orșova is longer, it can be seen that the surface and the volume landed is not that big, the reason being: some dams are filtering and others have not yet reached their maximum retention capacity.

Regarding the distribution of the terms Lat, Sat, Wat by classes of height of transverse works, for the variables Lat and Sat, the distributions of the values are similar. The best representation for the length and surface of the landing is the class 2.0-2.5 m, followed by in order of classes 4.0-4.5 m and 3.0-3.5 m. In the case of the variable Wat, the class with the highest value is 4.0-4.5, followed by classes 3.0-3, 5 m and 2.0-2.5 m (Figure 7).

The fact that in the category of low height works further demonstrates the impact of the height of the works, up to 2.5 m, Sat predominates over Wat, while at heights greater than 2.5 m, Wat predominates over Sat. Not only the height of the work, but also the elements that define the morphology of the subbasins leave their mark on these terms. The volume of alluvium retained is directly proportional to the height of the works and the width of the valleys and inversely proportional to the landing length.

The retention of alluvium from the landings led to a storage of amounts of alluvium that caused problems for the transport facilities in hydrographic basin Gurghiu, stabilized the banks of the beds in the area where the works are located and reduced their slope.

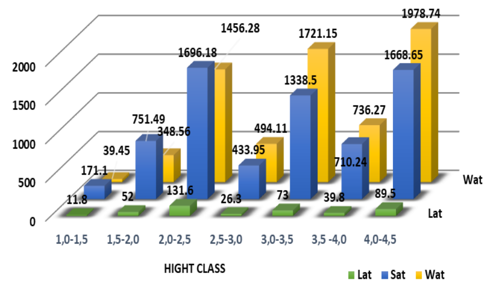

Figure 7. The length, the area and the volume distribution on works height classes

Retention through Consolidation

Analysing the retention values obtained through consolidation, it is observed that the highest value appears at the dam on Pr. Tarcea de Sus with a percentage of 27.52%, followed by the B2 dam on the Orșova River with 15.26%, followed by the dams from Orșova and then Fâncel.

Through the execution of the works on the three basins studied, the following retention values were achieved: direct retention in landings is 6,774.5 m^3, retention through consolidation has a volume of alluvium of 18,185.8 m^3 (Table 2), and the total amount of alluvium retained in the valleys of hydrographic basin Gurghiu is 24,960.3 m^3.

Consolidation retention for works that have fully formed landings has a weight of 62.5% of the total value of consolidation retention due to landings. One cause would be an overly optimistic forecast of the transport of alluvium within these sub-basins, a characteristic that will have to be considered in the choice of future technical solutions for the arrangement of the torrential hydrographic network, and a knowledge of the evolution of the effects of the works would be needed.

A reason that leads to the consumption of the alluvium retention capacity by the transversal works would be the intensive exploitation of the trees in the top of the streams and the setting up of the installations to remove and close the woody material.

It can be said that the greater the volume of alluvium retained directly by the transversal works, the greater the volume of alluvium consolidated on the torrential streams, an aspect for this situation would be the number of hydrotechnical works built.

Table 2. Distribution of the sediments volume of the Orșova, Fâncel and Sirod sub-basins

No	Works on torrential valleys	The year of execution/no. of years	Waa (m^3/ year)	Total Waa (m^3)
1	Orșova dam 1	1970/48	19.2	921.6
2	Orșova dam 2	1970/48	57.8	2,774.4
3	Orșova dam 3	1970/48	10.3	494.4
4	Orșova dam 4	1970/48	36.9	1,771.2
5	Orșova dam 5	1970/48	11.5	552
6	Orșova dam 6	1970/48	15.7	753.6
7	Orșova dam 7	1970/48	8.1	388.8
8	Orșova dam 8	1970/48	10.6	508.8
9	Orșova dam 9	1970/48	9.3	446.4
10	Orșova dam 10	1970/48	11.2	537.6
11	Orșova dam 11	1970/48	17.9	859.2
12	Orșova dam 12	1970/48	14.1	676.8
13	Fâncel b 1 Pr. Porcul de jos Borna 22	2008/10	84.2	842.0
14	Fâncel b 2 Pr. Tarcea de sus Borna 80	2008/10	500.4	5,004.0
15	Fâncel p 3 Pr. Buneasa	2008/10	93.5	935.0
16	S.1 prag Pr. Borna 51	2009/10	6.0	60.0
17	S.1 dam Pr. Borna 52	2009/10	11.0	110.0
18	S.1 dam Pr. Borna 54	2009/10	35.0	350.0
19	S.1 prag Pr. Borna 104	2009/10	6.0	60.0
20	S.1 prag Pr. Borna 106	2009/10	14.0	140.0
	Total			18,185.8

(source: own calculations based on preliminary studies to substantiate the need for hydrological works in the small hydrographic Fâncel watershed)

The economic effects produced by reducing the transport of alluvium

The value of direct retention is 6,774.55 m^3 and retention through consolidation is 18,185.8 m^3, and the total amount of alluvium retained in the valleys of hidrographic basin Gurghiu is 24,960.3 m^3.

The unit cost of manual extraction of coarse alluvium is estimated at 80 lei/m^3 and the cost of mechanized extraction of coarse alluvium is estimated at 69 lei/m^3 updated. Having in mind the geography of the area, it can be estimated that 50% could mechanized extracted and 50% manually, which implies an average cost of 75 lei/m^3. The costs were established by consulting the local economic operators that provide such services, considering that, by the Emergency Ordinance no. 85/2018 for the repeal of some legal provisions in the field of investments financed from public funds, dated 13/09/2018, thus repealing the cost standards for investment objectives financed from previously existing public funds, the beneficiaries returning the obligation to update and approve on his own responsibility the updated value of the works from the intervention works (Table 3).

Table 3. Estimative costs of sediments excavation

No	Indicator	Measurement unit	RC	RD
1	Volume	m^3	18,185.8	6,774.55
2	Unitary cost	lei/m3	74,5	74.5
3	Estimated value	thousand lei	1,354.84	504.70
5	Estimated Total	lei/m3	1,859.55	

The analyse shows that the expenses that would have been necessary for the excavation of torrential alluvium would have been approximately 1,859.55 thousand lei.

CONCLUSIONS

The results are in the line with the recommendations formulated by The World Bank Group (Darghouth et al., 2008). These recommendations highlight the relevance of using of economic and financial analysis when an investment on watershed is planned. Also, its emphases the "cost of inaction", by estimating the externalities at their real-value costs (Bhaduri et al., 2016).
The retention of alluvium in the landings led to the storage of quantities of alluvium which caused problems for the transport facilities in hydrographic basin Gurghiu, stabilized the banks of the beds in the area where the works are located and reduced their slope.
A weight of 62.5% of the total consolidation retention due to landings is assigned to consolidation retention for works with fully formed landings.
The following retention values were reached through the execution of the works on the three basins under study: direct retention in landings is 6774.5 m^3, retention through consolidation has a volume of alluvium of 18,185.8 m^3, and total alluvium retention in the valleys of hydrographic basin Gurghiu is 24,960.3 m^3. The higher the volume of alluvium obtained by RD from the transverse hydrotechnical works, the higher the volume of RC.
The watershed management works help to lessen how destructive torrential events are as well as the risk of flooding on nearby communities and socioeconomic goals.
The limit of the study includes the insufficient similar studies to allow an in-depth comparison of the result, so the need for further studies is obvious.

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