Ann. For. Res. 55(1): 125-143, 2012

ANNALS OF FOREST RESEARCH
www.e-afr.org

An evaluating methodology for hydrotechnical torrent-control structures condition

Ș.O. Davidescu, I. Clinciu, N.C. Tudose, C. Ungurean

Davidescu Ș.O., Clinciu I., Tudose N.C., Ungurean C., 2012. An evaluating methodology for hydrotechnical torrent-control structures condition. Ann. For. Res. 55(1): 125-143, 2012.

Abstract. Watershed management using torrent-control structures is an activity having more than 100 years history in Romania, So far, researches regarding works behaviour in service focused mainly on defining and assessing each damage type, without studying the interaction between them. Thus, damage classification criteria were substantiated taking into account nature and strength of the damages. This paper presents a methodology for assessing the condition of hydrotechnical structures by quantifying the cumulative effects of damages which occur with a significant frequency during their service. The model was created using a database, nationwide representative, with 3845 torrent-control structures. The identified damage types identified were weighted using multi-criteria analysis. Depending on the weight and strength off all damages occurred was calculated an indicator named "condition rate" (*Ys*). This new parameter may be used to track the impact of different features (structure age, components sizes, the position in the system, the construction materials, riverbed slope, geology of the area, etc.) on the condition of structures. By establishing the condition rate for all the structures within a collectivity (an entire watershed or catchment area, a single watercourse, a battery of works etc.), there may be made an analysis and a grading both at individual level and population-wide level, which lead to order the repairs or additions of new structures to existing hydrotechnical systems. Also, the model designed can be a part of a monitoring system regarding torrent-control structures, answering, thus, the requirements on this issue of the "National Strategy for Flood Risk Management" approved by the Romanian Government in 2010.
Keywords condition rate, damage index, torrent-control structures, dams, drain channels

Author. Şerban Octavian Davidescu (s_davidescu@icas.ro), Nicolae Constantin Tudose, Cezar Ungurean - Forest Research and Management Institute (I.C.A.S.) – Braşov Research Station: 13, Cloşca Street, Braşov, Ioan Clinciu – University Transilvania Braşov, 29, Eroilor Boulevard, Braşov, România.
Manuscript received January 25, 2012; revised February 03, 2012; accepted March 23, 2012; online first April 19, 2012.

Introduction

During the time through Romania were built more than 18000 torrent – control structures, most of them (about 16000) being transverse works (dams, sills and traverses – called further in the paper dams) leading up to reinforcing of more than 2100 km degraded river beds (Adorjani et al. 2008). Since the beginning of torrent – control practice were designed and built 39 different types and 56 variants of transverse hydrotechnical works (dams) and 5 different drain channel types (Lazar, Gaspar 1994). Dams and drain channels were placed on very different conditions (relief, geologic, climate), leading to different reactions of these structures occurring many damages in theres exploitation.

A synthesis of the hydrotechnical torrent-control structure behaviour, which consists in identifying, evaluating and ordering the damages, is a necessary tool for a permanent and systematic monitoring of these works. Due to the lack of experiments that use scale models, different kind of works used in watershed management all around the country have been tested directly in nature, in watersheds having different torrential levels, the validation process of these structures being possible only by monitoring their behaviour (Clinciu 2011).

Across Europe, part of the most recent concerns regarding monitoring activities of improved torrential watershed, were published by FAO as a result of scientific events organized by the working group for mountain watershed planning.

The volume Mountain Watershed Management, Lessons from the past – Lessons for the future (Proceedings of the Twenty-third Session, Davos, Switzerland, 2002), published by Swiss Agency for the Environment, Forests and Landscape (Bern, 2003), brings together papers that treat: (i) natural hazards zoning (Engler - Switzerland); (ii) lessons learned from past disasters (Pfister - Switzerland); (iii) risk management (Heinimann - Switzerland); (iv) mapping and description of a mountain watershed using geographical information systems (Parachini, Folving, Vogt et al. - Institute for Environment and Sustainability EC); (v) measures and programs regarding the mountain area and natural disaster management (G. Fiebiger, F. Rudolph, Miklos - Austria); (vi) IUFRO strategies for sustainable protection against flooding, with a special long-term action plan (Action Programme 2020), focused on the idea that monitoring of natural events in the mountain area is a defining part of risk management in the plains.

In Romania, researches regarding the behaviour of torrent-control structures and the damages occurred during their lifetime aimed at: the direct response to floods (Gaspar et al. 1972); the stability, strength and functionality of the torrent-control structures (Lazar, Gaspar et al. 1994); the behaviour of torrent-control structures used in Olanesti Watershed (Mircea et al 1992); in upper basin of Târlungului River (Clinciu et al., 2003, 2008 and 2010), in Argesel and Cerna watersheds (Nedelcu, Tuas 2008), in upper basin of Somes Mic River (Lupaşcu 2009), Criş River catchment area (Davidescu 2011) and in Cârcinov Watershed – Argeş River Basin (Tudose 2011); and a national overview based on a statistical coverage of all used types of structures (Davidescu et. al. 2011).

In order to substantiate a systematic and permanent monitoring program of torrent-control structures, in this paper, is established a quantitative expression according to actual condition of these works, based on the strength of behavioural events occurred during exploitation, the result being a "condition rate" characterizing the general behaviour of these works.

Materials and methods

The proposed methodology is based on an inventory of torrent-control structures which was part of the project PN 09460303 "Behaviour of Different Types of Hydrotechnical Torrent Control Structures Used in Romanian Watershed Management" financed by Romanian Ministry of Education, Research, Youth and Sports between 2008 - 2011.

The amount of inventoried structures was established as representative for a statistical assurance of 95%, keeping account of all types of structures and variants from all the river basins in Romania, using the following equation (Giurgiu 1972):

$$n = \frac{u^2 \cdot s_{\%}^2 \cdot N}{N \cdot \Delta_{\%}^2 + u^2 \cdot s_{\%}^2} \quad (1)$$

where: N represents the total amount of the population (18630); $s_{\%}$ the coefficient of variation (100%); $\Delta_{\%}$ the error limit admissible (5%); u the normal deviation corresponding to adopted probability (1.96).

Structures in the sample are spread in all major river basins of Romania (figure 1) and they were inventoried in two stages (2009 and 2010-2011) resulting two research areas: region I constituted by the following river basins: Someş, Criş, Olt, part of Siret (upstream Bistrița) and Prut and region II constituted by the river basins: Tisa, Mureş, Bega, Timiş, Caraş, Nera, Cerna, Jiu, Argeş, Ialomița, part of Siret (downstream Bistrita) and the direct slopes of the Danube.

In addition to the descriptive notes about the structures, that include geographical location (longitude and latitude), identification elements and size of each structure and its components (body, apron, guarding walls and terminal spur for dams; apron, sidewalls and spur for drain channels), data collected refer to the nature (typology) and intensity of behavioural events (damages and dysfunctions). Therefore, operators measured and estimated 3845 structures; out of which 93% (i.e. 3584) are transverse hydrotechnical works (traverses, sills and dams further named dams) and about 7% (261) are

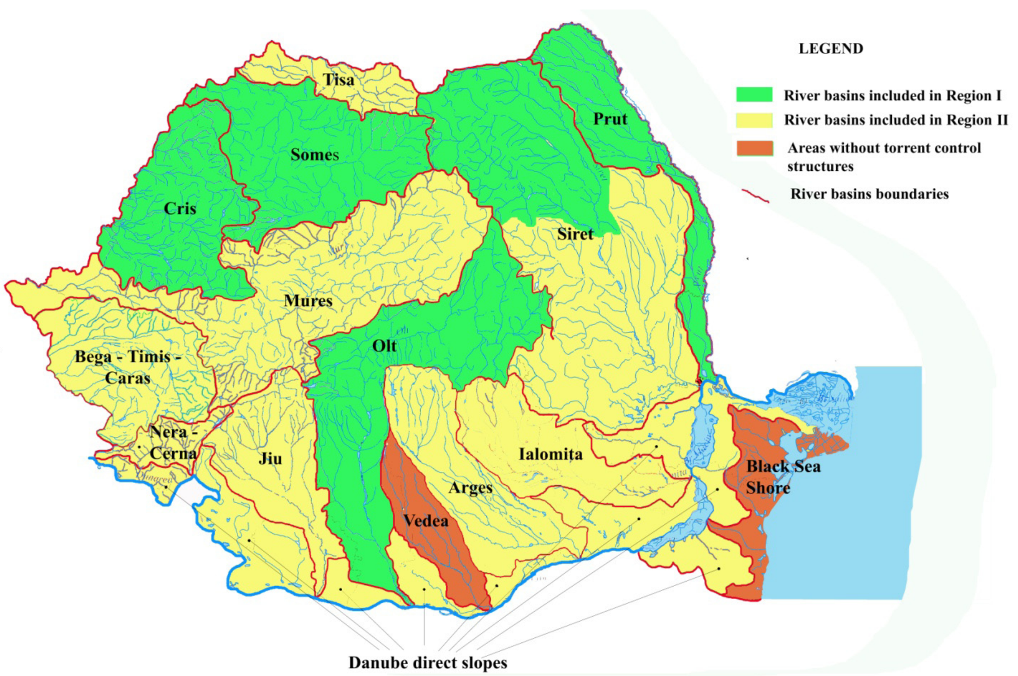

Figure 1 Major river basins of Romania

drain channels.

The identified damages were ordered by their nature and the part of the structure affected. Table 1 shows the damages that have been recorded (i.e. measured and/or evaluated) for each of the dams or drain channels under analysis and figure 2 shows a dam affected by multiple damages. The damages of the dam were augmented with possible breakings of the kinetics energy dissipation system (where applicable), concluding to identification of 23 damage types for dams and 16 for drain cannels. These behavioural events represent the subject and research material of this paper.

As mentioned above, this paper presents a method for the quantification of the effect of all damages occurred since the structures were built, the result being a parameter called "condition rate" (*Ys*). Some of the recorded damages were eliminated due to their rare frequency. Each of the remaining type of damage influences the condition rate by taking into account its strength and its importance in the general condition of the structure.

The novelty of this research lies in the application of a multi-criteria analysis approach in order to determine the weight each event's strength carries in determining a global indicator in relation to the physical condition of the work in a certain moment.

Determination of behavioural events that influence structure condition

The outline methodology is to establish a condition rate (*Ys*) for all the torrent-control structures which is substantiated considering only the events with a significant frequency of occurrence. Rare events, such as unembedding and cracks are omitted – following the definition of a "rare events" according to Poisson distribution, whose frequency is expressed as (Giurgiu 1972):

$$f(x) = \frac{\lambda^x}{x!} \cdot e^{-\lambda} \qquad (2)$$

where: λ is a constant, the arithmetic mean (the only parameter of the distribution), and x is the number of elements with characteristic data of the "n" statements, $x = 0, f_0 = e^{-\lambda}$ and for $x \neq 0, f(x+1) = f(x) \cdot \lambda / (x+1)$.

This statistical approach relies on the observation that out of 3584 dams, 2955 do not have any cracked components, and only 440 works have one component affected by cracks, 148 works have two components, 33 works have three components, 6 works have four and only 2 dams have five components affected by cracks.

The arithmetic mean for components of the dam cracked (m = 0.2592) is lower than the corrected variance (s^2_c = 0.3283), fact that allows us to call the compound Poisson distribu-

Table 1 Types of damages occurred during torrent control structures exploitation

Damage nature	Dam's components					Drain channel's components			
	Body							Spurs	
	Spilled area	Wall wings	Apron	Guarding walls	Terminal spur	Apron	Sidewalls	Central area	Wings
Unembedding	x				x			x	
Undermining	x		x					x	
Horizontal cracks	x	x		x	x		x	x	x
Vertical cracks	x	x		x	x		x	x	x
Cracked area			x			x			
Breaks	x	x	x	x	x	x	x	x	x
Abrasions	x		x	x	x	x	x	x	

tion, which takes the form (Giurgiu 1972):

$$f(x) = \left(\frac{\gamma}{\gamma+1}\right)^{\alpha} \cdot C_{\alpha}^{x} \cdot (-1)^{x} \cdot \left(\frac{1}{\gamma+1}\right)^{x} \qquad (3)$$

where $\gamma = m\ (s^2 - m^2)^{-1}$ and $\alpha = m^2\ (s^2 - m^2)^{-1}$
For x = 0 formula applied is: $f_0 = \gamma^{\alpha} / (\gamma+1)^{\alpha}$

By comparing the theoretical values resulted from the frequency equation to the absolute values (see Table 2) it is possible to observe a very good approximation between theoretical and experimental frequencies, exemplified in figure 3.

Using the Kolmogorov-Smirnov test (Lopes 2007) we checked whether the experimental distribution follows the Poisson law. Due to the fact that $1\text{-}k = 1.000 > D_{0.05\%} = 0.167$, the null hypothesis is not rejected, we can conclude that there are no significant differences between the two series.

Appling the same methodology for unembeddings, and considering the number of wings affected to 4 (two for the structure's body and two for the spur) the analysis shows a close resemblance between theoretical and experimental frequencies (see Figure 4); thus concluding that this type of event follows the Poisson distribution law as well. The conclu-

Figure 2 Multiple damages (wall wing and spilled area breaking, body abrasions, guarding wall breaking etc.) occurred during the exploitation of dam 90MF6.0 placed on the riverbed of Lungsor stream (Crişul Repede Watershed)

Table 2 Fitting of the experimental distribution regarding cracks occurrence with Poisson theoretical distribution

Dam's parts cracked		Frequency equation values		Theoretical frequencies
No. of components affected (x)	Structures affected (n)	Empirical	Theoretical	
0	2955	0.8245	0.7947	2848
1	440	0.1228	0.1627	583
2	148	0.0413	0.0338	121
3	33	0.0092	0.0070	25
4	6	0.0017	0.0015	5
5	2	0.0006	0.0003	1
Total	3584	-	-	3584

sion has been confirmed by the Kolmogorov-Smirnov test ($1\text{-}k = 1.000 > D_{0.05\%} = 0.200$).

The cracking of drain channel's components and the unembedding of channel's spur are even rarer than those that affect the dams, thus triggering the conclusion that cracks and unembeddings can be omitted from the process of establishing the structure condition rate both for dams and for drain channels.

Weight of different behavioural events on structure's general condition

After the rare events exclusion, there remain 11 behavioural events that affect the dams and 8 for drain channels shown in Table 3.

The two types of works (dam and drain channel) have to be analysed separately due to different ways they are facing loads resulted from floods. On another hand, dams are divided in two categories (with and without an apron), for the first category taking into account 11 behavioural events, only 4 events being considered for the second category. The influence of each damage type was analysed fixing its weight and strength.

The strength was established for each behavioural event depending on data collected. Breaks of structure components were evaluated using a single criterion (detached section of each component, counted as percent) this one defining the strength. For the rest of the damages strength was established using two criteria: the undermining depth (m) and the relative width (%) as seen in figure 5, respectively, the abrasion depth (cm) and ratio of the

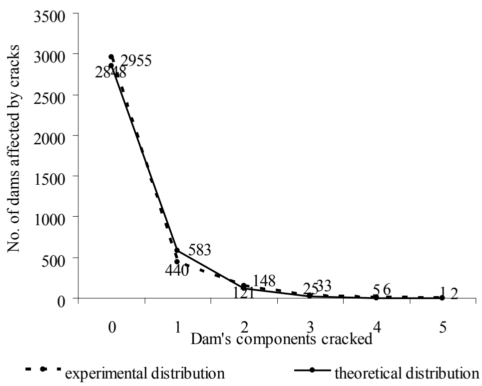

Figure 3 Distribution of number of dams depending on the number of parts cracked during exploitation

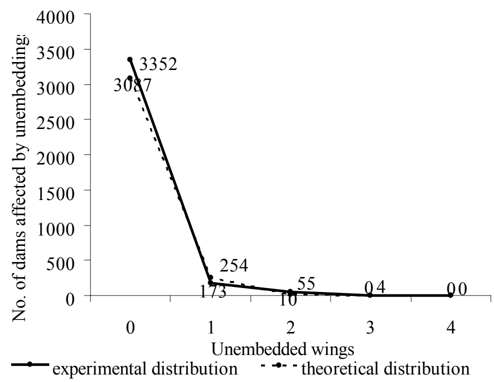

Figure 4 Theoretical (Poisson) and experimental frequencies for structures affected by unembeddings

Table 3 Types of damages occurred during torrent control structures exploitation

Damage nature	Dam's components					Drain channel's components			
	Body							Spur	
	Spilled area	Wall wings	Apron	Guarding walls	Terminal spur	Apron	Sidewalls	Central area	Wings
Undermining	x		x					x	
Breaks	x	x	x	x	x	x	x	x	x
Abrasions	x		x	x	x	x	x	x	

component surface affected (%). For these last types of damage, a parameter called "event intensity rate" has been defined, for establishing the strength, by multiplying values of both criteria.

To estimate the weight of each damage type (γ_i) a quadratic table was created for each type of structure studied (tables 4-6). The table was used to cross-compare one by one damages: the rows and columns in the table represent damage types, and each cell of the table field represents a comparison between two events. When an event in a row is compared to an event in a column, the cell value is as follows: 1 – if the first one is more important (in terms of structure condition) than the second; 0.5 – if both events have even importance and 0 – if the first event is less important than the second one.

The weight of each behavioural event in structure condition rate was set by adding points on each table line establishing a rank depending on the score resulted. If two or more events have the same amount of points the rank and level are the same, being admitted an equal value, even decimal. The equation that defines the weight of the event is given below (Bobancu 2010):

$$\gamma_i = \frac{(p + m + 0{,}5 + \Delta_p)}{-\Delta'_p + \frac{N}{2}} \tag{4}$$

where: γ_i is event weigh; p – score of the event; m – amount of outranked events; Δ_p - difference between event "i" score and of the less ranked event score; Δ'_p - difference between the event score and score of the best ranked event; N - amount of events considered.

Establishing a unique event intensity rate scale

Since each event has a different strength scale, depending on assessed elements, a conversion was made for of all the event intensity rates to a unique scale depending on the maximum value of each one (see Table 7). The intensity rates of the maximum drain channel event (for breakings, undermining and abrasion) were adopted same as the events which affect the dams.

The adopted scale has values between 0 and 100, normalization being performed using a

Figure 5 Apron undermining affecting 10% of the apron, having a depth of 3.0 m and an intensity rate of 0.3 of the structure 30B0.5 located on Bremenea Valley (the direct slopes of Danube)

Table 4 Dams with apron behavioural events weighting, using multi – criteria analysis

Criterion (behavioural event)	Body undermining	Spill area breaking	Wall wing breaking	Body abrasion	Apron breaking	Apron abrasion	Apron undermining	Spur breaking	Spur abrasion	Guarding wall breaking	Guarding wall abrasion	Computing elements		
												Score	Rank	Weight (γ_i)
Body undermining	0.5	0.5	0.0	1.0	0.5	1.0	1.0	0.5	1.0	1.0	1.0	8.0	3.5	2.88
Spill area breaking	0.5	0.5	0.0	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	8.5	2.0	3.47
Wall wing breaking	1.0	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	10.5	1.0	5.64
Body abrasion	0.0	0.0	0.0	0.5	0.0	0.5	0.0	0.0	1.0	0.5	1.0	3.5	8.0	0.72
Apron breaking	0.5	0.5	0.0	1.0	0.5	1.0	1.0	0.5	1.0	1.0	1.0	8.0	3.5	2.88
Apron abrasion	0.0	0.0	0.0	0.5	0.0	0.5	0.0	0.0	1.0	0.5	1.0	3.5	8.0	0.72
Apron undermining	0.0	0.0	0.0	1.0	0.0	1.0	0.5	0.5	1.0	1.0	1.0	6.0	6.0	1.70
Spur breaking	0.0	0.0	0.0	1.0	0.0	1.0	0.5	0.5	1.0	1.0	1.0	7.0	5.0	2.22
Spur abrasion	0.5	0.0	0.0	1.0	0.5	1.0	0.0	0.0	0.5	0.0	1.0	1.5	10.0	0.28
Guarding wall breaking	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.5	1.0	3.5	8.0	0.72
Guarding wall abrasion	0.0	0.0	0.0	0.5	0.0	0.5	0.0	0.0	0.0	0.0	0.5	0.5	11.0	0.06

Table 5 Dams without apron behavioural events weighting, using multi – criteria analysis

Criterion (behavioural event)	Body undermining	Spill area breaking	Wall wing breaking	Body abrasion	Computing elements		
					Score	Rank	Weight (γ_i)
Body undermining	0.5	0.5	0.0	1.0	2.0	2.5	1.43
Spill area breaking	0.5	0.5	0.0	1.0	2.0	2.5	1.43
Wall wing breaking	1.0	1.0	0.5	1.0	3.5	1.0	5.00
Body abrasion	0.0	0.0	0.0	0.5	0.5	4.0	0.20

Table 6 Drain channels behavioural events weighting, using multi – criteria analysis

Criterion (behavioural event)	Apron breaking	Apron abrasion	Sidewall breaking	Sidewall abrasion	Undermining	Spur wing breaking	Spur central area breaking	Spur abrasion	Computing elements		
									Score	Rank	Weight (γ_i)
Apron breaking	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	7.5	1.0	5.50
Apron abrasion	0.0	0.5	0.0	0.5	1.0	1.0	0.5	1.0	4.5	3.5	2.00
Sidewall breaking	0.0	1.0	0.5	1.0	1.0	1.0	1.0	1.0	6.5	2.0	3.80
Sidewall abrasion	0.0	0.5	0.0	0.5	1.0	1.0	0.0	1.0	4.0	5.0	1.47
Undermining	0.0	0.0	0.0	0.0	0.5	1.0	0.5	1.0	3.0	6.0	0.94
Spur wings breaking	0.0	0.0	0.0	0.0	0.0	0.5	0.0	1.0	1.5	7.0	0.40
Spur central breaking	0.0	0.5	0.0	1.0	0.5	1.0	0.5	1.0	4.5	3.5	2.00
Spur abrasion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	8.0	0.09

Table 7 Converting intensity rates to a unique scale

Structure type	Behavioural event type	Affected structure component	Maximum intensity rate (I_{max})	Converting factor (F_c)
Dams	Undermining	Structure body	5.0	20.00
		Apron	4.0	25.00
	Breaking	Body wall wings	1.0	100.00
		Body spilled area	1.0	100.00
		Apron	1.0	100.00
		Terminal spur	1.0	100.00
		Guarding walls	1.0	100.00
	Abrasion	Structure body	1.0	100.00
		Apron	0.5	200.00
		Terminal spur	0.5	200.00
		Guarding walls	0.7	142.86
Drain channels	Undermining	Spurs	4.0	25.00
	Breaking	Apron	1.0	100.00
		Sidewalls	1.0	100.00
		Spurs	1.0	100.00
	Abrasion	Apron	0.5	200.00
		Sidewalls	0.7	142.86
		Spurs	0.5	200.00

conversion factor (F_c), as a result of dividing 100 (maximum value on the unique intensity rate scale) to the maximum value of each event intensity rate ($I_{max,\,i}$):

$$F_c = \frac{100}{I_{\max,i}} \tag{5}$$

Damage index and condition rate

The cumulative effect of behavioural events that affect hydrotechnical works is represented by the square root of the sum of the products between damages weight (γ_i), their intensity rates (I_i) converted using the particular converting factor ($F_{c\,i}$)., resulting an equation that define a so called damage index (Y_A):

$$Y_A = \sqrt{\sum \gamma_i \cdot I_i \cdot F_{ci}} \tag{6}$$

The damage index was determined for all the works (3845), regardless of their type (dams with apron, dams without apron or drain channels), finally yielding in distinct values of this parameter. The maximum values calculated for each structure type were: 38.5 for dams with apron; 25.6 for dams without apron and 36.2 for drain channels.

In order to make comparative analysis between different structures and to gain the results representative for a hydrotechnical system as a whole, due to different damages that occur in the exploitation of different kinds of structure, it was necessary to harmonize the damage indexes resulted from the analysis. To emphasize the condition of the structure a new parameter was defined whose value decreases as the damage degree increases. Those issues were considered and by taking account of maximum value of the damage index for each structure type $Max(Y_A)$, a scale from 0 to 100 to define structures health and the particular value for structures damage index (Y_A), the condition rate for each work (Y_S)was calculated using the following equation:

$$Y_S = 100 - \frac{Y_A \cdot 100}{Max(Y_A)} \tag{7}$$

Condition rate frequencies distribution

The entire statistical population studied was stratified so its variability could be analyzed using different criteria: structures age, typology, materials used to build them, height (for dams) etc. Along with collecting data concerning structures, the damages occurred and their strength, field operators praised works general condition using a five levels scale (1 - meaning a totally damaged structure to 5 - a very good structure with no important damages occurred). Therefore structures stratification according to condition rate was made on five classes (levels) accordingly to those used in visual assessment, as shown in the Table 8.

Dam's distribution depending on their condi tion follows Meyer equation (Figure 6), which expresses theoretical frequencies as:

$$f_x = k \cdot e^{-\alpha \cdot x} \quad (8)$$

where: e is the natural logarithm, k and α - Meyer equation parameters, which depend on the experimental distribution specifications, namely structures condition rate.

The Kolmogorov-Smirnov test was used to check the null hypothesis, and the differences between theoretical and experimental frequencies have been found to be insignificant. As $1\text{-}k = 1.000 > D_{0.05\%} = 0.200$, the null hypothesis is not rejected, so the two data series did not differ significantly.

Regarding the drain channels, even if data amount is much smaller, their distribution according to structure condition follows the Meyer equation too (Figure 7), the indicator $D_{0.05\%}$ (0.200) being less than $1\text{-}k$ =1.000.

Table 8 Structures classification according their condition rate

Structure condition	Visual assessment	Condition rate value (Y_s)
Very bad	1	0 – 20
Bad	2	20 – 40
Average	3	40 – 60
Good	4	60 – 80
Very good	5	80 – 100

Comparison between works general condition visually assessed and their condition rate

Confirming that the experimental distribution of structure's condition rate may be adjusted by a law of a theoretical distribution we conclude that the experiments were carried out correctly and the newly-defined parameter "condition rate" can be used in further statistical analy-

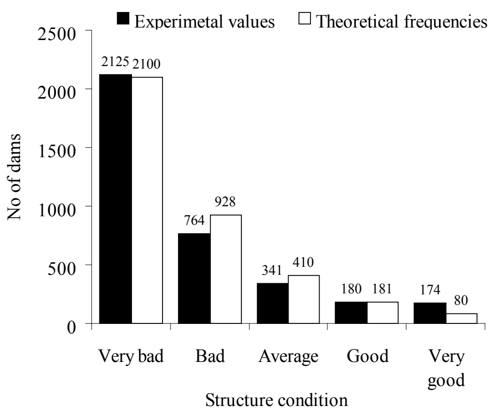

Figure 6 Dams condition rate experimental distribution adjusted by Meyer equation

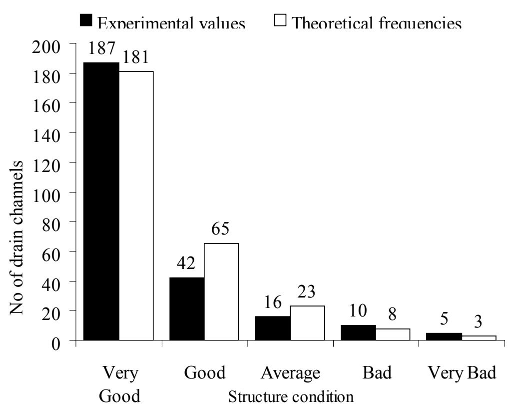

Figure 7 Drain channels condition rate experimental distribution adjusted by Meyer equation

ses. As mentioned above, along the field work, operators estimated all works condition using a five-level assessment scale. In order to test the accuracy of structures condition rate calculated according to presented methodology a comparative analysis was performed between visually examination of the structures and their condition rate. Firstly there were compared the structures amount to the paired levels of both scales (as presented in table 8), the results being shown in figure 8.

Secondly a correlation was made between the visually assigned condition category and condition rate value for each of the 3584 structures, obtaining a linear regression whose correlation coefficient, 0.8274 (see Figure 9), proves a very significant relation for a series with 3582 freedom degrees.

Regarding the drain channels, both correlation types (between the amounts of structures in paired categories and piece by piece comparison) are tight, having correlation coefficient values that prove it (0.9757, respectively 0.8299 for series with 3 and 259 freedom degrees).

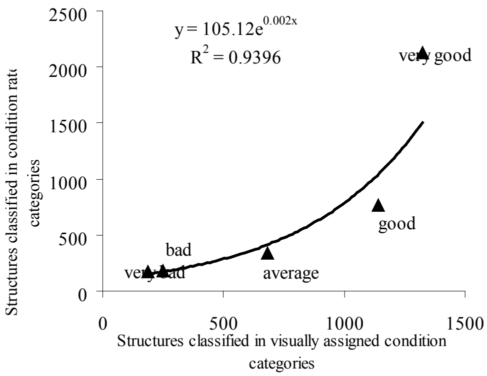

Figure 8 Correlation between the structures amount in categories established by visual assessment and calculated condition rate

Dam age influence over its condition rate

The age influence over the condition rate was spotted considering 5 year categories and the average value of the condition rates for all the structures within a category limits. Due to the relative little number of structures older than 50 years, a special category was created (50-106 years old) having an average age of 78. A logarithmical inverse regression (see Figure 10) was found, which shows that as structures get older, their condition rate decreases.

A simple variance analysis between age categories was carried out, in order to explain the experimental line discontinuity and to capture time periods when low quality structures were built (see Table 9).

By applying the Fisher test, it can be concluded that significant differences occur among

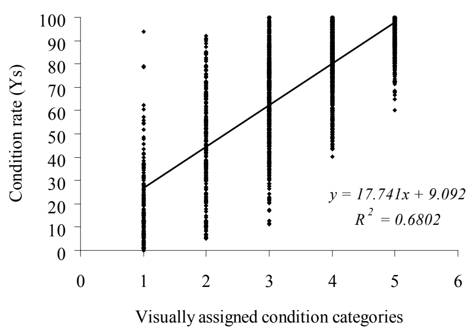

Figure 9 Relation between the condition rate and the visually assigned condition categories

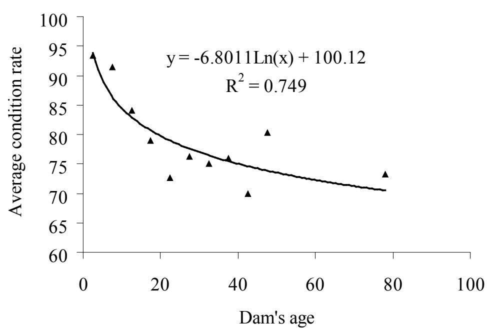

Figure 10 Relation between dam age and their condition rate

age categories considering the average condition rate. A detailed analysis was carried out as a part of this research concerning the variance between age categories (Table 10).

The error regarding the differences between age categories (s_d) was determined using the residual variance, according to the following equation (Giurgiu 1972):

$$s_d = \sqrt{s_e^2 \cdot \left(\frac{1}{n_i} + \frac{1}{n_j} \right)} \tag{9}$$

n_i and n_j being the number of observations for analyzed categories.

Maximum values of the differences between two condition rates of age categories, according to the transgression probability, were determined using following relations (Giurgiu 1972):

$$DL_{5\%} = 1.96 \times s_d \tag{10}$$

$$DL_{1\%} = 2.58 \times s_d \tag{11}$$

$$DL_{0.1\%} = 3.29 \times s_d \tag{12}$$

Drain channel age influence over its condition

Even where the regression line gradient is low

Table 9 Influence structure age in the condition rate, highlighted by simply variance analysis

Age categories		Structures within age category limits	Average condition rate	Variance source	Freedom degrees	Variances	F
No.	Category limits (age)						
1	0-5	193	93.4	Between variables	10	$s_t^2 = 15294.0$	27
2	5-10	309	91.5				
3	10-15	196	84.1				
4	15-20	249	79.0				
5	20-25	554	72.6	Residual variance	3573	$s_e^2 = 558.4$	-
6	25-30	535	76.3				
7	30-35	617	75.0				
8	35-40	316	75.9				
9	40-45	203	70.0	Entire variance	3583	$s^2 = 599.5$	$F_{0,05} = 1.83$ $F_{0,01} = 2.32$
10	45-50	194	80.3				
11	>50	218	73.3				

Table 10 Variation significances between age category average condition rates

Age categories	Average condition rate	Structures within age category limits	Age categories										
			1	2	3	10	4	6	8	7	11	5	9
			Differences between average values of the condition rate										
1	93.4	193	-	1.9	9.3***	13.1***	14.4***	17.1***	17.5***	18.4***	20.1***	20.8***	23.4***
2	91.5	309	-	-	7.4***	11.2***	12.5***	15.2***	15.6***	16.5***	18.2***	18.9***	21.5***
3	84.1	196	-	-	-	3.8	5.1*	7.8***	8.2***	9.1***	10.8***	11.5***	14.1***
10	80.3	194	-	-	-	-	1.3	4.0*	4.4*	5.3*	7.0**	7.7***	10.3***
4	79.0	249	-	-	-	-	-	2.7	3.1*	4.0*	5.7***	6.4***	9.0***
6	76.3	535	-	-	-	-	-	-	0.4	1.3	3.0	3.7**	6.3***
8	75.9	316	-	-	-	-	-	-	-	0.9	2.6	3.3*	5.9**
7	75.0	617	-	-	-	-	-	-	-	-	1.7	2.4	5.0**
11	73.3	218	-	-	-	-	-	-	-	-	-	0.7	3.3*
5	72.6	554	-	-	-	-	-	-	-	-	-	-	2.6
9	70.0	203	-	-	-	-	-	-	-	-	-	-	-

Note: * - significant difference at $p < 0.05$, ** - significant difference at $p < 0.01$, *** - significant difference at $p < 0.001$.

(Figure 11) – considering 260 freedom degrees and a 1% transgression probability ($R_{0.01\%}$ = 0.181) – the correlation coefficient has a value of 0.2177, which suggests a distinct significant relation between channel age and its condition rate.

The low gradient of regression line is explained by the good condition of drain channels 50 – 60 years old, in that situation being reported 13 drain channels built using cement

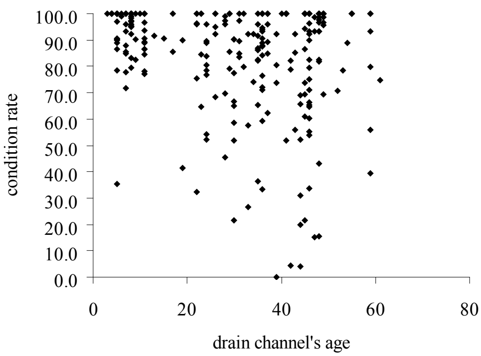

Figure 11 Relation between drain channel's age and its condition rate

mortar masonry, part of them being repaired during 1975 – 2005 (Figure 12).

Next, the condition rate decrease due to some channel characteristics (length, depth, apron width and age) was checked using Pareto chart (see Figure 13). This diagram type allows separating the influence of independent factors over a dependent one (condition rate).

The results obtained show that age has the greatest influence on a channel condition rate, followed by its width, channel depth and channel length. The last three factors are below a 5% transgression probability.

Common influence of the most important two factors (age and apron width) is revealed using a regression plan (see Figure 14), concluding that young channels having a small width are in a very good shape, the condition rate being between 80 and 100.

The equation (13) that defines the condition rate (Y_s) according to apron width (l) and channel age (T) corresponding to the regression plan shown above, has a 95% level confidence each coefficient being inside confident limits

Figure 12 Drain channel 10KM137 on Plaic Stream (Tisa Watershed) built on 1965 and repaired on 2005

$$Y_S = 96.1316 - 1.4919 \times l - 0.2653 \times T \qquad (13)$$

Dam height influence over its condition rate

To check the height influence on dam condition rate it was studied the correlation dependence between these parameters for each structure, setting 16 height categories from the dam's database. Category limits were established for each 0.5 m until 7.0 m height, with dams exceeding 7.0 m height being included in a special category (7.0 – 12.0 m).

Due to the low value for the regression gradient, fact simultaneously sustained by a decreased regression coefficient (0.2678), the conclusion is that between those parameters there is not an obvious influence; dam's height does not affect directly the condition of the structure.

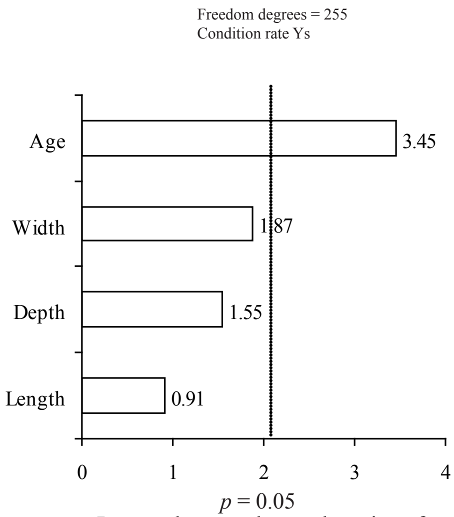

Figure 13 Pareto chart used to rank various factors influence over drain channel's condition rate

Building material and dam type influence on its condition

To emphasize the influence of the construction material on dam condition, there were defined 12 dam categories taking into account the building material and the constructive solution adopted for the most important materials (concrete and cement mortar masonry). For each category a complex histogram was created that highlights ratio of each category of dams on each condition rate category set out in table 8 (Figure 15), the values on the top of the chart showing the average condition rate for each

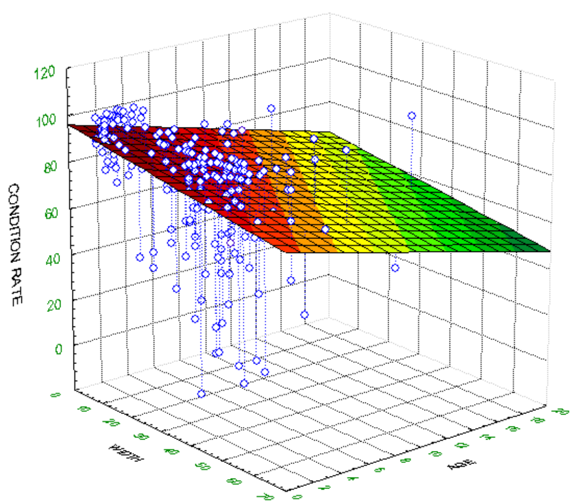

Figure 14 Condition rate variation due to age and width highlighted using a regression plan

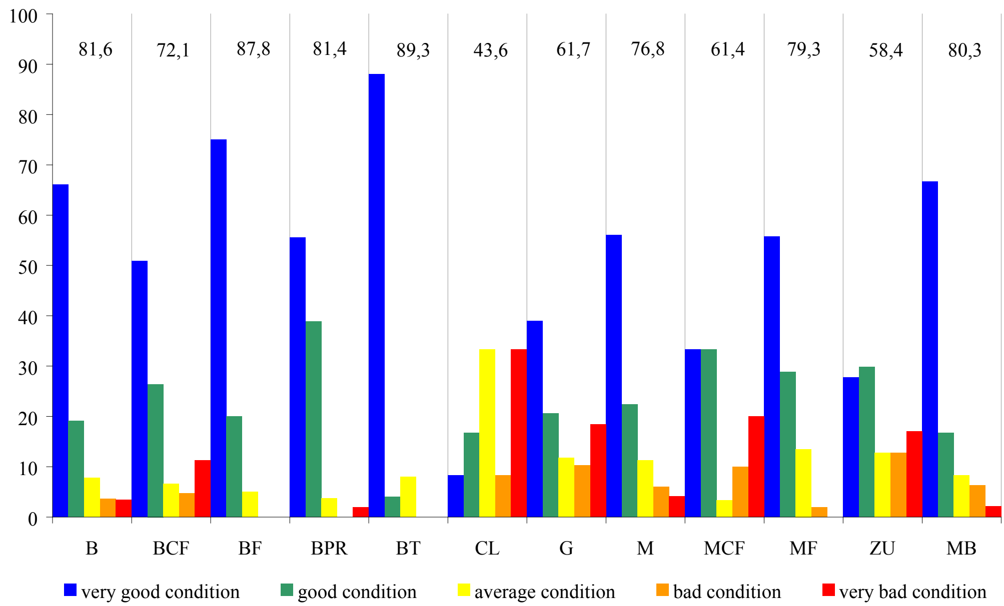

Figure 15 Frequency histogram of dams according to structure and condition categories

work category.

The defined dams categories were: continuous concrete dams (B), buttresses concrete dams (BCF), filtering concrete dams (BF), continuous cement mortar masonry dams (M), buttresses cement mortar masonry dams (MCF), filtering cement mortar masonry dams (MF), prefab materials made dams (BPR); PREMO pipes made dams (BT); wood, made dams (CL), gabions dams (G), dry masonry dams (ZU), mixed masonry dams (MB).

Building material and drain channel type influence over its condition

Similar to the analysis described above, there have been established 7 drain channel categories: concrete channel (KB), reinforced concrete channel (KBA), cement mortar masonry channel (KM), concrete and prefab materials channel (KBPR), prefab material channel (KP), dry masonry channel (KZU); resulting the frequencies shown in the following table.

For concrete channels, over 80% were found to be in a very good condition, the fraction being in a bad or very bad condition being insignificant. However, the general image on the mortar walled channels is different, non-damaged structures representing only 66%, and the fraction being in a bad or very bad condition representing 9% (Table 11).

Discussions

Concerns regarding the monitoring of natural events and the importance of torrent – control structures to mitigate river bed erosion and to prevent downstream alluvial deposits were main subjects of recent researches carried out by Hancock and Willgoose (2004), FAO (2004 and 2005) Conesa-Garcia et al (2007, 2008 and 2009), Martin – Vide and Areatta (2009), Garcia et al. (2011). Those papers reached conclusions that help understanding behaviour and benefits of torrent – control structures.

Table 11 Structure frequencies (%) according to their building material and condition rate category

Condition category	Drain channel type					
	Concrete channel	Concrete and prefab materials channel	Cement mortar masonry channel	Dry masonry channel	Reinforced concrete channel	Prefab material channel
very good	81.7	-	66.2	-	100.0	-
good	13.8	50.0	17.9	-	-	-
average	1.8	50.0	6.9	100.0	-	100.0
bad	0.9	-	6.2	-	-	-
very bad	1.8	-	2.8	-	-	-

The study of 106 torrent-control structures located on Tarlung Watershed, upstream Sacele reservoir (Clinciu et al. 2010; Clinciu 2011) led to the substantiation of a complex research methodology regarding the behaviour of these structures. An important part of the methodology is the completion of the classification system of failures and dysfunctions (Gaspar 1984, Lazar & Gaspar 1994), and its statistical foundation opened new horizons in the research of behavioural events occurred during exploitation of torrent-control structures.

In the upper watershed of Somes Mic River (Lupascu 2009) research regarding almost 300 torrent – control structures led to a detailed analysis of all behavioural events occurring in their service. The applied methodology improves the one crystallized during research undertaken in Târlung catchment; first defining scales for assessing following events: breakings, apron undermining, body undermining, suffusion, spillway obstruction, clearing of the siltation, non-accomplishment of the siltation. As the authors know an approach that determines the cumulative effect of damages occurred during the torrent-control structure exploitation was not defined yet by any other research and thus, this approach constitutes a novelty in the field.

First of all, the events types were ranked, and for each one of those that have a significant frequency, was established its weight that combined with its strength lead to the condition rate, a parameter that synthesize all the behavioural events occurred. Using a conformity test (Kolmogorov- Smirnov) it was proved that results gained by using outlined methodology respect a natural distribution law (Meyer) so they can be used further on studies regarding torrent-control structures.

To approve the condition rates obtained, they were compared with the condition visual assessment made while structures were inventoried and evaluated from behavioural point of view. By studying the regressions between visual and calculated condition assessment using two methods (paired categories and piece by piece comparison) for dams and drain channels, we concluded that the condition rate reveal the real status for over 90% of the studied structures, the resulted correlation factors having significant values related to the freedom degrees of each analyzed series.

Despite these tight correlations there have been some structures that were visually assessed as having a very bad condition, but the condition rate was high due to the fact that this methodology do not counted all the events that occurs during a structure life time (unembedding and cracking, being excluded cause there rare frequency). Unembedding does not always trigger other events, but the structure could be damaged by right. In the same time due to the approach using the condition rate model tends to reduce the influence of peak values of the various damages strength, but responds very well in situations where more behavioural events affect a same structure simultaneously. Furthermore, comparing the visual established condition category with the recorded damages and their strength, few erroneous assessments were reported, which explains the possible underestimation of some structure condition.

In terms of dams age the analysis emphasizes that those made between 1986 to 1990 (5th age category) have a lower condition than those from near categories, being a lot more damaged (see Figure 9), due to economical policies regarding torrent-control structures. The smallest condition rate (70.0) is recorded for structures done during 1966-1970 (9th age category) that passed over their normal life time. Older ones (built during 1961-1966) have a condition comparable with those of 15 years old due, on one hand, to their elaborate execution, and on the other one, to repairs made since there were built.

Figure 11 shows that drain channels having a condition rate less than 20 (very bad condition) were built during 1961-1976, structures being at the limit of their service period or exceeded it. The examination of drain channels older than 60 years data base revealed that are 13 pieces made using cement mortar masonry, part of them being repaired since 1975 to 2005.

There are young structures (less than 10 years old) from both categories (dams and drain channels) having a bad condition or worse because they faced successively many floods (2005, 2006 etc.) and torrent-control systems were caught empty, and so, vulnerable to shocks.

Dams built using PREMO pipes are in a very good condition, reflected by the highest value for the condition rate ($Y_s = 89.3$). Small condition rates (43.6) are reported for wood structures, three quarters having an average condition or less. Those structures life time is expected for 15 years and the average age of these structures is 21 years.

Gabions or dry masonry's dams were built prevalent for an immediate river bed stabilization followed by afforestation of it and shores. Generally torrent activities are a lot diminished, even extinguished, structures, beside their degradation, fulfilled their role, actual condition being satisfactory and they don't need to be rehabilitated anymore.

The overwhelming majority of dams are made using cement mortar masonry and concrete (91%). Cement mortar masonry structures condition is lower then concrete ones, in both cases filtering dams being better then continuous, which are better then buttresses dams.

Conclusions

Structure condition established using the model proposed and proved as valid by this paper may be extended to a whole torrent-control system or to a battery of dams and channels. Condition rate determined for a single structure or for a group leads to a classification according to their damage degree. Thus those parameters may be used, on one hand, as indicators of catchment's structures status and, on the other hand, according to these rates, it may be established an order of repairs or additions to existing torrent-control systems with new structures.

A ranking system of repairs / additions can use framing structure categories proposed, based on the condition rate: first stage includes works having very bad condition, $Y_s \leq 20$ (code red); in the second stage works having bad condition, $20 < Y_s \leq 40$ (code orange); in the third stage works having average condition, $40 < Y_s \leq 60$ (code yellow) etc. This is not a strictly prioritization method, it can be changed, frames being established by those interested in, depending on their own criteria (available funds; available manpower, particular machinery available etc.); being a very malleable method.

Last but not least by applying the proposed model integrated into a geographic database, it is possible to create a torrent control structures monitoring system, answering to the European requirements on this issue.

Acknowledgements

Data used on this paper were recorded as part of the project "Behaviour of Different Types of Hydrotechnical Torrent Control Structures Used in Romanian Watershed Management" integrated in the program GEDEFOR (Sustainable Management of Forest Ecosystems in the Context of Global Environmental Change) funded by the Romanian Ministry of Education, Research, Youth and Sports, and we like to thanks to all the people involved in it.

References

Bobancu Ş., 2010. Creativitate şi inventică [Creativity and invention], Editura Universităţii Transilvania. Braşov, 162 p.

Clinciu I., 2011. Cercetări privind lucrările de amenajare a reţelei hidrografice torenţiale din bazinul superior al Târlungului (amonte de acumularea Săcele). [Researches regarding the torrential hydrografical management structures in upper Târlung Watershed (upstream Săcele water storage dam]. Editura Universităţii Transilvania din Braşov, 400 p.

Clinciu I., Petriţan I.C., Niţă M.D., 2010. Monitoring of the hydrotechnical torrent – control structures: a statistical approach. Environmental Engineering and Management Journal 9(12): 1699-1707.

Conesa-Garcia C., Lopez-Bermudez., Garcia-Lorenzo R., 2007. Bed stability variations after check dam construction in torrential channels (South-Est Spain). Earth Surface Processes and Landforms 32(14): 2165-2184.

Conesa-García C., García-Lorenzo R., 2008. Effectiveness of check-dams in the control of general transitory bed scouring in semiarid catchment areas (South-East Spain). Water and Environment Journal 23(1): 1-14.

Davidescu Ş.O., 2011. Comportarea în exploatare a lucrărilor hidrotehnice utilizate în amenajarea albiilor bazinelor hidrografice torenţiale, predominant forestiere, din spaţiul hidrografic Crişuri. [In service behaviour of hydrotechnical torrent-control structures used in predominantly forested watersheds from Criş hydrographic area]. PhD report. University Transilvania Braşov, 67 p.

Davidescu Ş.O. et al., 2011. Comportarea în exploatare a diverselor tipuri de lucrări hidrotehnice utilizate în amenajarea bazinelor hidrografice torenţiale din România [In service behaviour of various types of torrent-control structures used for watershed management. Final Report I.C.A.S. 165 p.

FAO, 2004. Twenty–fourth session of the Working Party on the Management of Mountain Watersheds, Final report, European Forestry Commission-FAO, Rome, Italy.

FAO, 2005. Preparing for the next generation of watershed management programmes and projects. Europe, Proc. European Regional Workshop on Watershed Management, Megève, France.

Garcia J.L., Garcia F., Ciulianu A., 2011. The works in the torrential correction and their effect after a century. Proceedings of the Biennial International Symposium "Forest and Sustainable Development". Transilvania University Publishing House pp. 415-420.

Gaspar R., Apostol Al., Costin A., 1972. Comportarea lucrărilor hidrotehnice de corectare a torenţilor în timpul viiturilor din anul 1970 [The behaviour of torrent-control structures during floods from 1970]. Revista Pădurilor 1: 23-30.

Gaspar R., 1984. Norme tehnice pentru urmărirea comportării în timp a lucrărilor de construcţii folosite în amenajarea torenţilor [Technical rules for monitoring the behavior of constructions used in torrents management. I.C.A.S., Forestry Minister. 48 p.

Giurgiu V., 1972. Metode ale statisticii matematice aplicate în silvicultură [Statistical methods applied in forestry]. Editura Ceres, Bucharest, 565 p.

Giurgiu V., 2008. Cu privire la gestionarea durabilă a pădurilor din bazinele hidrografice torenţiale [Regarding the sustainable management of forests in the torrential watershed]. Silvologie VI, Editura Academiei Române. Bucureşti, pp. 353-371.

Hancock R.G., Willgoose R.G., 2004. An experimental and computer simulation study of erosion on a mine tailings dam wall. Earth Surface Processes and Landforms 29(4): 457-475.

Lazăr N., Gaspar R. et al., 1994. Cercetări privind stabilitatea, rezistenţa şi funcţionalitatea lucrărilor hidrotehnice de amenajare a torenţilor [Research regarding stability, durability and functionality of torrent – control hydrotechnical works]. Final report I.C.A.S. Bucharest, 120 p.

Lupaşcu F., 2009. Cercetări privind comportarea şi efectele lucrărilor de amenajare a reţelei hidrografice torenţiale din bazinul superior al Someşului Mic [Research regarding the behaviour and effects of torrent control structures from upper Somesul Mic catchment]. PhD thesis, University Transilvania Braşov, 64 p.

Lopes R.H.C., Reid I., Hobson P.R., 2007. The two-dimensional Kolmogorov-Smirnov test. XI International Workshop on Advanced Computing and Analysis Techniques in Physics Research (April 23–27, 2007), Amsterdam.

Martin-Vide J.P., Andreatta A., 2009. Channel degradation and slope adjustment in steep streams controlled through bed sills. Earth Surface Processes and Landforms 34(1): 38-47.

Mircea S., Vasilescu C., Mircea A., 1992. Observaţii asupra modului de comportare a lucrărilor hidrotehnice transversale executate pe formaţiunile torenţiale din b.h. Olăneşti [Comments on the behaviour of hydrotechnical transverse works made on torrential formations from Olăneşti catchment]. Buletin Ştiinţific, Seria E, (34) U.S.A. Bucharest.

Tudose N.C., 2011. Cercetări privind fundamentarea amenajării torenţilor din bazinul superior al râului Cârcinov (B.H. Argeş) [Research regarding the scientific base for torrent control in the upper Cârcinov catchment (Argeş Watershed)]. PhD thesis, University Transilvania Braşov, 271 p.