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EVOLUTION OF THE STATUS OF THE TRANSVERSAL HYDROTECHNICAL STRUCTURES USED IN THE TORRENTIAL HIDROGRAPHICAL NETWORK MANAGEMENT

SUMMARY

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CONTENT

1 INTRODUCTORY CONSIDERATIONS

Torrential watersheds, as units defined by distinct morphological, phytoedaphic and hydrological characteristics, following heavy rainfall or sudden melting of snow can generate torrential flows of great amplitude (Clinciu, 2000; Clinciu and Lazar, 1997), both from the peak flow perspective as well as its variation over time (Kuhn and Yair, 2004; Kasanin-Grubin and Bryan, 2007; Haidu et al., 2017).

In order to reduce the impact generated by torrential flows (Fig. 1.1, Fig. 1.2), soil protection is carried out in the watersheds through specific afforestation works (Clinciu and Gaspar, 2005; Munteanu, 1975; Snelder and Bryan, 1995) but also chosen by "the application on the entire surface of the torrential basins, both on the slopes and on the hydrographic network, of a set of organizational measures and biological, biotechnical and hydrotechnical works focussed on their hydrological and anti-erosion functions (Munteanu S.A., 1975).

Fig. 1.1. Torrential transport plug on the forest road following the blocking of an evacuation bridge

(Davidescu, 2018)

Fig. 1.2. House destroyed as a result of the torrential transport - Rucăr locality

(Mihalache, 2019)

Until the year 2007, in the forest fund of our country, almost 2200 km of torrential riverbeds were consolidated, being put into operation 2 700 longitudinal hydrotechnical works (mainly flood water drainage channels) and 15 930 transversal hydrotechnical works (traverses, thresholds, dams) (Adorjani, Davidescu and Gancz, 2008; Gancz C., 2012), all being strongly stressed in a varied way by the water flows. Ensuring the stability, resistance and functionality of the torrent-control structures is of great importance due to the particularities of torrential flows, characterized by: current heights of up to 2 meters, propagation speeds of 1 – 6 $m \cdot s^{-1}$, flow densities that can reach 2200 $kg \cdot m^{-3}$ and impact forces with values of tens of KN (Marchi et. al, 2019; Georg and Johannes, 2020; Nagl and Hübl, 2020; Nagl et al. 2021; Nagl et al. 2022).

The tests in laboratory conditions being impossible, , the monitoring of the hidrotechnical structures was conducted directly in the torrential watersheds where they are located, the technical-scientific progress recorded forcing the scientific research in the field to move from the global niche "behavior of the works" to the special niche "status of the structures". From this point of view, in the last two decades several contributions with elements of originality have been registered, both from a methodological point of view and under thematic relation (Clinciu et al., 2001-2006; Lupașcu, 2009; Tudose, 2011; Davidescu, 2013; Mihalache, 2020).

2 STATE OF ART

Because the theme of the thesis is derived from a thematic area with wide coverage in time, in addition to the most recent contributions that can be found synthesized in the present chapter, the authors of other contributions that played a role in the orientation of concerns from the classical, descriptivist study on the behavioral phenomenology of torrential river bed development structures to the current approach, based on the quantitative expression of the physical state of these works: Băloiu, 1980; Biali și Popovici, 2006; Ciornei, 2014; Ciortuz și Păcurar, 2004; Costin et al., 1975; Costandache și Nistor, 2006; Dîrja, 2000, 2006, 2007; Dîrja et al., 2002; Gaspar, 1975; Giurma, 1989, 1995; Hâncu, 1976; Ioniță, 2000; Mircea, 2002, 2008, 2014; Moțoc et al., 1975, 2005; Nedelcu, 2001; Păcurar, 2015; Pascu, 1974; Popovici, 1991; Pricop, 1999; Prișcu, 1974; Teju, 1971;Traci, 1985; Tuas, 2005; Untaru et al., 2008.

2.1. Research conducted before the introduction of the "status of works"

The response of transversal hydrotechnical works to extreme events that occur in torrential watersheds can only be characterized by some exceptional torrential flows, such those recorded in 1970, followed by those recorded in 1975, 1979, 1984, 1988, 1989, 1991 (Davidescu, 2013), as well as those recorded in the 21st century, in 2005 (Tudose, 2011) or 2018 (Mihalache, 2018), 2019.

2.1.1.The decade 1971 – 1980

Following the large-scale floods and flows affecting Romania in1970, when in the course of only a few days it rained as much as in a month, these events taking place after the prolonged drought period of 1969 (Marcean, 2002), about 1% of the torrent control structures executed up to that date were damaged or destroyed , the most affected being the structures located in the Ruşețu - Ialomița, Retevoieşti - Râul Doamnei, Aref - Argeş, Mălureni - Vâlsan and Secărele - Lotru perimeters.

The authors of the studies from 1970 also drew some conclusions regarding the hydrological studies and the determination of the pick flows, which contest some opinions expressed at the time according to which the maximum flood flows used in the calculation of the structures would have been excessively high~~.~~

2.1.2.The decade 1981 – 1990

After the re-examination of the calculation hypothesisand the introduction of different types of structures using various building materials, the need for a unique approach on the behavior of the works also appeared. As the evaluation method of the deficiencies that affected the parameters regarding the safety and functionality of the structures had not been concretized, in 1984 a first regulation (normative) was developed and introduced focussing on the monitoring of the behavior over time of the transversal hydrotechnical structures used in the torrential hydrographical network management (Gaspar, 1984).

Within this normative, the followed target was the vulnerability degree ofthe structures, the main quality parameters needed to be followed being (Gaspar, 1984):

- building safety: stability, resistance;
- structure deformation and the land in their area;
- structure durability;
- structure functionality;
- the degree of protection offered by the structures, the interaction between them, their influence on the environment and the effect of other constructions on torrent control structures.

Depending on the quality parameters taken into account, the normative presented the following classification scheme for deficiencies (damages):

(1) Deficiencies that affect the safety parameters: the deformation of the constructions and the foundation land, but also the durability of the structures;

(2) Deficiencies that affect the functionality: the degree of protection, the interaction between the constructions, their influence on the environment and the effect of other constructions on hydrotechnical torrent control structures.

2.1.3.The decade 1991 – 2000

At the beginning of this decade, Romania was again hit by a wave of floods. On July 28-29, 1991, "after a clear day without precipitation", torrential rains were recorded in the Carpathian area with flow waves about 7 meters high (Tazlău river, Bacău county), with flow values up to 95,6 $l \cdot m^{-2}$ (Lucănești hydrometric station), respectively 148,8 $l \cdot m^{-2}$ (Livezi hydrometric station) (Bălan, 2018), which led to a large number of damages recorded on the transversal hydrotechnical structures (Oprea et al., 1996), the behavioral events being mainly caused by exceeding the normed values of flows and levels, but also by some design and execution deficiencies (Lazar et al., 1994).

In this decade, through the research project 12 RA/1994 (Lazăr și Gaspar, 1994) for the first time, the intensity of some damages was introduced,, degradations being assessed as superficial (< 10 cm) and deep (> 10 cm). This project also took into account the "stability and resistance of the hydrotechnical structures used in the torrential network management" (Clinciu and Gaspar, 2006), the stability being examined according to the tendency of the different forces that would change the position of the structure compared to the initial one, the resistance being the object of the capacity transversal works not to be broken, fragmented, crushed, etc., during the entire (standardized) exploitation period (Clinciu and Gaspar, 2006) (Fig. 2.2).

As it is difficult to establish the concrete cause that leads to the destruction of the structures or to endangering some of their constructive elements, the first classification of damages was introduced in the 1994 research, which include the sum of factors that can influence the behavior of the works (Clinciu and Gaspar, 2006):

◦ “damages which take the works out of service", here being integrated the structures that, at the time of the field survey, could no longer fulfill any of the functions for which they were carried out; and

◦ “breakdowns which, although they caused damage to the structures, did not put them out of operation”.

Fig. 2.2. Overturning and breaking of the body of the structure after torrential flow of August 31, 1085

Șanturi Creek – Tărlung basin

(Mihalache, 2019)

2.2. Research for in-depth knowledge of behavioral events, the main premise of the introduction of the “structure status index”

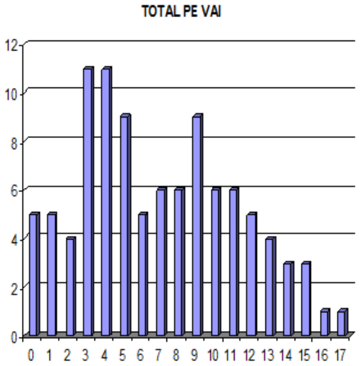
2.2.1. Research results on types, frequency, intensity and association of behavioral events

If until 2003 the research carried out on the transversal hydrotechnical works referred to the safety in operation and the durability of the structures, the damages and dysfunctionalities identified being described, centralized and subject to the conclusion, the subsequent research brought additions and adaptations of the old concepts. Completions related to deficiencies/damages that affect operational safety and the durability of structures consist of the introduction of unembedding and undermining (Clinciu et al., 2005). In the group of deficiencies/damages that affect the functionality of the works, the author considered: overflow area blockage, blockage of the energy absorber system, apron silting ± sediments ± vegetation, the uncontrolled installation of forest vegetation in the area upstream/downstream of the structures, incomplete sedimentation, exceeding the sediment deposit slope and burying some parts of the work, washing the bed downstream of the structure, frontal impact of the bank by the water current, erosions (± crumbling ± landslides) of the bank in the embedding areas..

The perspective on the torrential hydrotechnical structures inventory gained momentum with the study of the methodology applied in previous research in this branch (Gaspar, 1984; Gaspar et al., 1994), which was the base for the conception of the first torrential hydrotechnical structure inventory sheet, composed by 20 constituent parts of the work (Clinciu, 2011). Based of this new file, future studies laid their foundations (Lupașcu, 2009; Tudose, 2011), finally reaching the determination of a unique reference parameter, called the "structure condition index" (Davidescu et al ., 2012; Tudose et al., 2014).

In the framework of an extensive research topic (responsible: I. Clinciu), made up of 2 parts, damages and disfunctionalities were analyzed for the first time in terms of the relationships between them from a statistical point of view. The main new elements brought within this theme consisted of (Clinciu, 2010):

◦ For the first time in this field of research, the behavior of the transversal hydrotechnical works used in the torrential hidrographical network management was approached from a statistical perspective;
◦ A new concept was introduced and validated, the "behavioral events associated with parts of the work";
◦ A typological systematization of behavioral events was carried out, grouped into two categories (damages and disfunctionalities);
◦ For the first time, a ranking of behavioral events was carried out in relation to their frequency, for each individual class;
◦ A question gained an answer: the variation in the number of behavioral events recorded at a structure, does it follow any legality or not? (Fig. 2.5)



Normala:

$$f(x)=\frac{1}{s\sqrt{2\Pi}}\cdot e^{-\frac{x-\overline{x}}{2s^2}}$$

Charlier tip A:

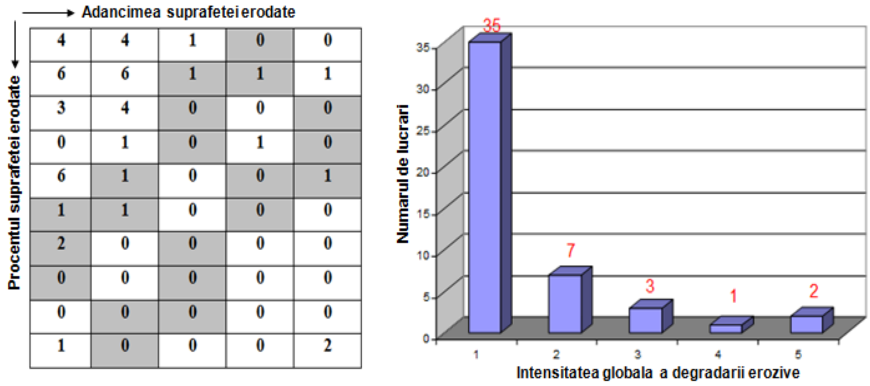
$$\varphi(u)=f(u)-\frac{\alpha}{6}\cdot f^{III}(u)+\frac{\varepsilon}{24}\cdot f^{IV}(u)$$

Beta:

$$f(x)=c\cdot(x-a)^{\alpha}\cdot(b-x)^{\gamma}$$

Fig. 2.5 Frequency distribution of the number of events recorded by a single structure (Clinciu, 2010)

- The most relevant outcome of the research, the establishment of legitimacy followed by the frequency and intensity of behavioral events (Fig. 2.6), may constitute a key aspect in a future program of monitoring works, which must be consistent with national management plans of flood risk.



4	4	1	0	0
6	6	1	1	1
3	4	0	0	0
0	1	0	1	0
6	1	0	0	1
1	1	0	0	0
2	0	0	0	0
0	0	0	0	0
0	0	0	0	0
1	0	0	0	2

Fig. 2.6. Exploratory research of one of the main behavioral events, erosive degradation of structures (Clinciu, 2010)

For all types of identified events, the classification was made into two groups:

I - events that affect the safety and durability of the structures;

II - events that affect the functionality of the works.

Based on the classification proposed in 1994, the scheme receivedsome additions and adaptations, where appropriate, as follows:

- in the category of deficiencies that affect operational safety and the durability of works, and which include (according to R. Gaspar): cracks, ruptures, ruptures, deformations, degradations, disaggregations, undermining and infiltrations, unembedding and suffusions were added;
- within the deficiencies that affect the functionality of the sturctures, the interaction of the works and the interaction between them and the environment, the typology considered in the research was: spillway blockage, dissipative teeth blockage, apron sillting with sediments/ floaters/ vegetation, unwanted vegetation in the upstream / downstream area or in the execution area and functionality zone of the structure, incomplete sedimentation, washing the blocked sediments, exceeding the projected slope and burying certain parts of the structure,river bed deepening in downstream structure area,the frontal hitting riverbed banks by thewaterflow current, erosions (±crumblings, ± slips) of banks in the areas of embankments.

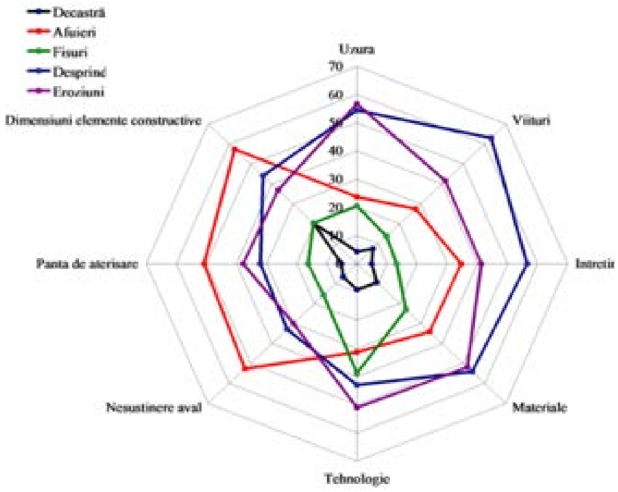


Fig. 2.8. Asocierea avariilor corpului lucrărilor și cauzele de apariție (Davidescu et al., 2012)

Following the new methodology proposed in 2003 (Clinciu, 2005), in the periods 2007-2009, studies were conducted regarding the behavior and effects of the transversal hydrotechnical structures in the upper Someşului Mic basin (Lupaşcu, 2009). Also based on this methodology, other studies were conducted in the upper basin of the Cârcinov river, in the hydrographic space of the Argeş river (Tudose and Clinciu, 2010; Tudose, 2011).

As part of the research carried out by the staff of the Torrent Correction department of the former ICAS, carried out between 2009 and 2011, a number of 3584 transversal hydrotechnical works were identified, among the most important conclusions reached by the authors is that the events behavioral appear associated with each other (Fig. 2.8) (Davidescu, 2013).

2.2.2.Results of statistical research on behavioral events

The statistical research undertaken in the upper Tărlung river basin (Clinciu, 2011) was focused on two distinct stages.In the first stage the frequency distribution of the total number of damages that were recorded on a single structure was compiled and studied (Fig. 2.10). The statistical tests took into account the main statistical indicators, and then an attempt was made to adjust according to three known theoretical distributions (normal distribution, Charlier-type A and Beta distribution).

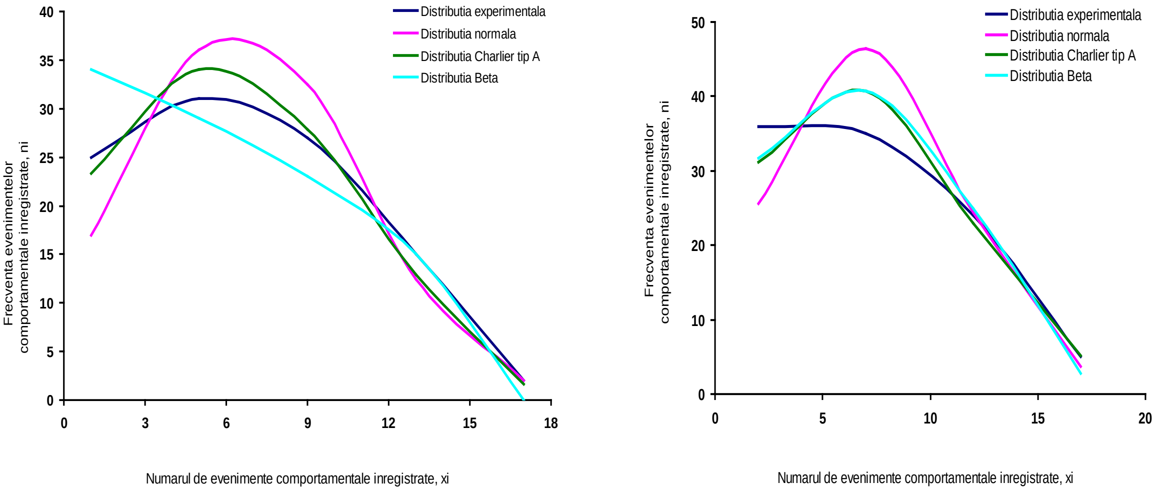
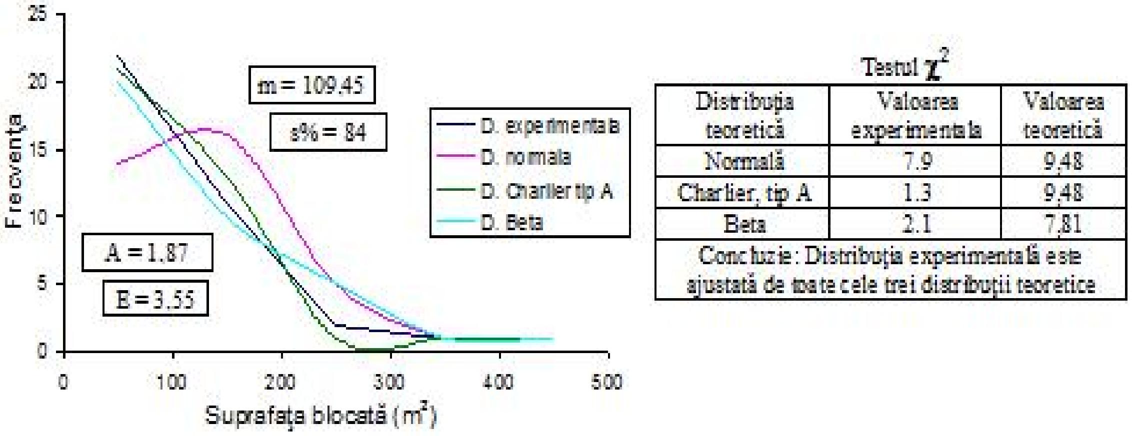


Fig. 2.10. The experimental distribution of the total number of damages recorded on a single structure and its adjustment according to three theoretical distributions (Clinciu et al., 2011)

From the perspective of blocking the free flow area of torrential flows, the influence of the uncontrolled installation of vegetation was also analyzed. The data obtained by the authors (Fig. 2.11) showed that the event of blocking the drainage corridor took place on a relatively small average area (about 110 m2), but the variability of the event from one transversal structure to another is particularly pronounced (s % = 84%).



Testul χ^2

Distribuţia teoretică	Valoarea experimentală	Valoarea teoretică
Normală	7.9	9.48
Charlier, tip A	1.3	9.48
Beta	2.1	7.81
Concluzie: Distribuţia experimentală este ajustată de toate cele trei distribuţii teoretice		

Fig.2.11. The polygon of experimental frequencies, the curves of theoretical frequencies, the values of the main statistical indicators and the values of the χ^2 test for the frequency distribution of the surface on which the uncontrolled installation of forest vegetation took place (Clinciu, 2011)

2.3. Research completed through the methodology of determining, interpreting and capitalizing on the "status index of works”

2.3.1. Introduction aspects

Although the progress made in relation to behavioral aspects is obvious, still until 2010 there was no question of quantifying how the behavioral events recorded in a certain period, taken together through all their consequences, are reflected in the physical condition of each structure and/or the system of works as a whole. It was only in 2012, based on research project PN 09460303 (Davidescu et al., 2009), that a new concept was crystallized, based on the quantification of the global effect of damages and dysfunctionalities through an equation that reproduces the physical state of the works. The idea of such an approach (Clinciu, 2011) was put into practice together with the staff of the Torrent Control department of the current Forestry Research and Development Institute "Marin Dracea".

2.3.2. Determination, interpretation and capitalization of the status index of the structure

Based on a large number of inventoried structures, it was possible to outline a methodology for determining the physical state of this works, which quantifies the intensity of all damages that occurred with a significant frequency in a given period. The proposed index is a tool which can be used in the permanent and systematic monitoring of transversal hydrotechnical structures, but also to follow the impact of various damages and dysfunctions on the physical state of the works.

The cumulative effect of the behavioral events affecting the transversal hydrotechnical structures is represented by the difference between the maximum value of the condition index (100 - very good condition) and the ratio (expressed as a percentage) between the damage index (YA) and the maximum value (Max YA) of this index for each category of works, identified for the 3854 hydrotechnical works taken into account (Eq. 2.1).

$$Y_S = 100 - \frac{Y_A \cdot 100}{Max\,(Y_A)} , \qquad \text{(Eq 2.1)}$$

In turn, the damage index is defined as the square root of the sum of the products between the damage severity (γi), their intensity rate (Ii) converted using the particular conversion factor (Fc) (Eq. 2.2).).

$$Y_A = \sqrt{\sum \gamma i \cdot Ii \cdot Fc} , \qquad \text{(Eq 2.2)}$$

where: γ_i represents the severity of the damage, I_i represents the intensity of the damage, F_c represents the unique conversion factor on the damage intensity, being calculated with the following relationship:

$$F_c = \frac{100}{Imax} \qquad \text{(Eq 2.3)}$$

where I_{max} is the maximum intensity, recorded by the respective damage (Davidescu et al., 2012).

Using this methodology, in the period 2011-2012, studies were undertaken that focused on the works in the Crișuri hydrographic basin (Davidescu, 2013), highlighting the impact of behavioral events on the status index (Fig. 2.12).

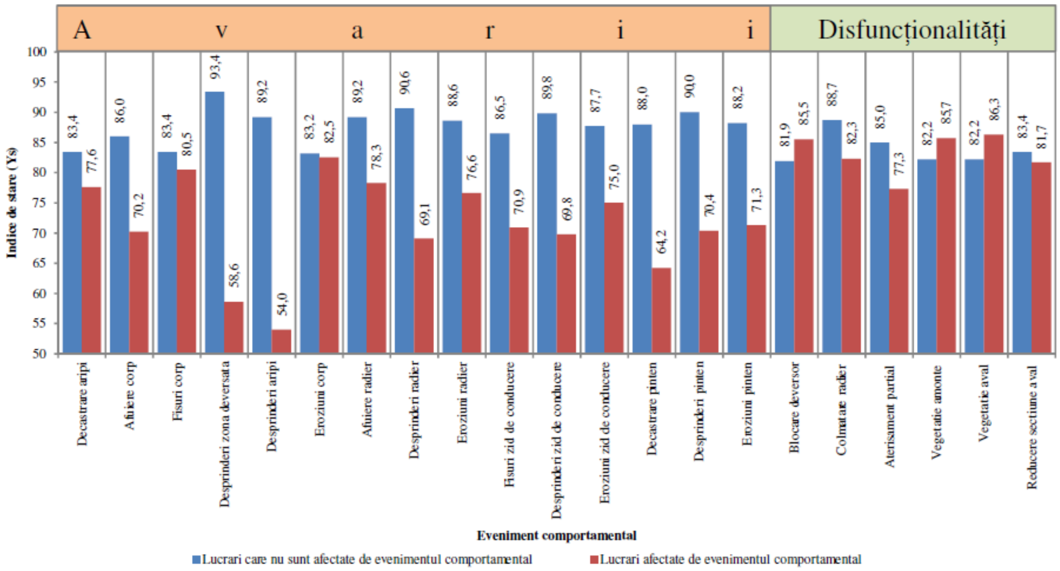


Fig. 2.12. Status index values (average) of structures, affected by different behavioral events (Davidescu, 2013)

In order for the condition index to reflect the state of the works as well as possible, the parameter used in the conversion factor has been changed to the relevant limit intensity (I_{lim}^{R}), which is the value of the damage that can take the structures out of service (or is in unavoidable danger), the impact of the damage with a value higher than this limit no longer being pronounced (Ec. 2.4).

$$F_c = \frac{100}{I_{lim}^{R}} \qquad \text{(Eq. 2. 4)}$$

Following the changes made, the condition index formula was improved, all damages that influence the physical condition of the structures being integrated. The established expression is of the form (Tudose et al., 2015):

$$Y_S = 100 - \frac{100 \cdot Y_S}{Y_A^{REF}} \qquad \text{(Eq. 2.5)}$$

where : Y_A^{REF} represents the theoretical, reference value of the damage index, which is determined for each category of transversal works (with or without apron).

Starting with the introduction of the condition index, a cumulative index of the impact of various damages occurred during the structure exploitation period (Davidescu et al., 2012; Tudose et al., 2014, 2015), research has gained momentum due different approach to the state of works, either at an individual level (Davidescu, 2013, Tudose et al, 2014; Mihalache, 2018), or at the level of a torrential watercourse,watershed (Davidescu 2013) or from the point of view of the evolution of the physical status of transversal hydrotechnical works (Mihalache, 2019).

2.3.3.Statistical - mathematical modeling of the average state index

Analyzing the meanings of all the coefficients separately and the coefficients with low significance being eliminated one by one, it was reached an equation that includes only 5 variables; these are: the age of the structures (in years); hydrographic order (O); the length of the hydrographic network (Km); the potential retention of land use (mm) and the average erosion index per basin ($m^3 \cdot year^{-1} \cdot ha^{-1}$). Through the determined equation, which answers very well for structures with condition index values greater than 50, the estimates give satisfactory results, the equation proving to be outdated for works in bad or very bad condition, case where are other factors with important influences. From the analyzes made on 48 watersheds, where the average status index per basin exceeded the limiting value of the equation (Fig. 2.13), it resulted that the morphometric elements of the basin, which also influence the hydrological parameters of the basin (flow discharge, sediment yield, etc.), have a significant effect on the state of hydrotechnical structures, torrential flows being the main element triggering behavioral events, along with other elements that favor degradation: unsatisfactory building materials, human interventions, incommensurate execution technologies, etc.

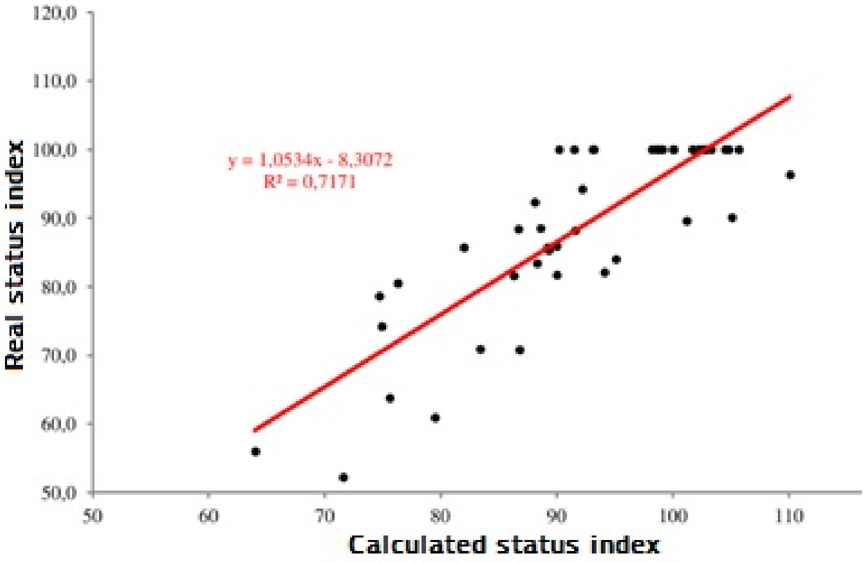


Fig. 2.13. The regression between the average condition index per basin calculated using the estimation made based on the hydrographic basin parameters and the real value of the average condition index per basin (Davidescu, 2013)

Having highlighted the link between the real condition index and the calculated condition index, where the correlation coefficient (0.84) is very significant, a condition index calculation relationship has been made, that can be used expeditiously to determine the condition index average on the basin (Eq. 2.6), different data being necessary, such as: the age of the works, the surface of the basin, the banks slope, the drainage density, the hydrographic order, the average potential retention on the basin and the average erosion index on the basin (Davidescu, 2013):

$$Y_s = 118{,}9714 - 0{,}4366 \cdot T - 9{,}6122 \cdot \ln S - 28{,}3670 \cdot Iv - 5{,}6762 \cdot \sqrt{Dr} + 9{,}5750 \cdot O.H.$$

$$+ 7{,}6870 \cdot \ln(Z) + 1{,}7822 \cdot q_v \qquad \text{(Eq. 2.6)}$$

where: T is the age of the structure;

S - watershed area;

Iv - the average value of the banks slope;

Dr - drainage density;

O.H. - hydrographic order;

Z - the average potential retention on the basin;

q_v - average erosion index on the basin.

2.3.4.Research on the same topic, from abroad

Studies on the torrent control structures behavior were also undertaken in research abroad (Alila et al., 2003; Boix-Faios et al., 2007; Castillo et al., 2007; Garcia Martinez și Lopez, 2005; Garcia et al., 2007, 2008; Garcia et al., 2011; Ki-Hwan Lee et al., 2022; Martin-Vide și Andreatta, 2009; Mazzorana et al., 2017; Remaître et. al., 2008; Sidle R.C., 2005; Zeng et al., 2009). For example, such a study was carried out in Italy, where after the inventory of 18 watersheds, 362 transversal hydrotechnical structures were identified, taking into account several variables that have an influence on the vulnerability of dams: the slope of the riverbed, age of the works, the geometry of the structure, the constructive type, the initial physical condition and the type of torrential event. Considering 6 component parts of the transversal hydrotechnical works (Fig. 2.14) and respectively 22 produced torrential events, the functionality of each post-event work was analyzed, dividing it into 4 categories: unaltered, slightly compromised, strongly compromised and without functionality (Dell'Agnese, 2013).

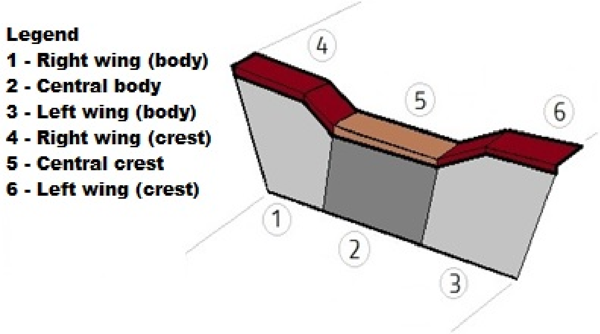


Fig. 2.14. The component parts of transversal hydrotechnical structure (after Dell'Agnese, 2013)

It has been proven that the physical condition of the works shows a regression over time, the structures older than 20 years having a higher damage index than those recently commissioned. It was also releaved that the damage index increases constantly with age (up to 40 years), after that it register a sudden increase until the age of 60 (Dell'Agnese, 2013). In addition, the structures that suffered damage prior to the analyzes proved to be more vulnerable to torrential events, the conclusions drawn after the recording of the torrential events referring to a decrease in the functionality of the transversal hydrotechnical works (Dell'Agnese, 2013).

3 RESEARCH AIM, OBJECTIVES AND STUDY AREA

3.1. Aim and objectives

As the title of the thesis shows, the research aims to develop the degree of knowledge on the evolution of the state of the transversal hydrotechnical structures used in the torrential hydrographical network to establish a new paradigm for their monitoring and maintenance.

To achieve the aforementioned goal, six specific research objectives were established and pursued:

- The main characteristics of the works studied;
- Type, frequency, intensity and association of behavioral events at the two inventories and in the period between them;
- Changes in the state of the structures in the period between inventories;
- The in-depth study of these changes in relation to the main influencing factors;
- The impact of a torrential event on the state of the structures (case study);
- Substantiation for using the gradient of the condition index in monitoring the condition of structures.

3.2. Study area location

To achieve the established objectives, 14 watershes and an improvement perimeter were chosen (Fig. 3.1), located in the Tisa, Someș, Crișuri, Banat, Jiu, Olt, Ialomița și Danube hydrographic areas. To mitigatetorrential phenomena, in those watersheds 285 transversal hydrotechnical works were built on 49 torrential streams in the hydrographic basins studied.

The torrential watersheds from which the data were collected show very varied conditions in terms of altitude, rainfall regime, temperatures and humidity, as well as in terms of pedology and vegetation. The confluence of the torrential streams is between 44 m (Jidoștița Valley, tributary of the Danube at Portile de Fier) and 875 m (Tesla creek- Tărlung hydrographic basin). The relief is represented by slopes with variable slopes, the drainage density being generally high, all of which contribute to the rapid concentration of the waters from the precipitation, which at high flow rates have implications on the amount of erosion and direct impact on the existing works systems.

Fig. 3.1. Location of the studied torrential watersheds

4 THE RESEARCH METHODOLOGY

Given the fact that this research aimed to continue and develop previously conducted research (Davidescu et al., 2012; Davidescu, 2013; Tudose et al., 2014), the method applied to achieve the first four objectives assumed, in essence, to go after the following steps:

- Establishing the volume of the study group (285 transversal hydrotechnical structures);
- Choosing the watersheds from which to extract and study the 285 transversal hydrotechnical works (according to the abht.ro database);
- The use of the abht.ro database (where the information stored has about 5,200 transversal hydrotechnical structures covering entire Romania) to extract the data related to the watersheds and the structures taken into the study, available at the time of the start of the present research;
- Surveying the land and making a new inventory of the structures, including the data obtained in the same abht.ro database;
- Exploitation of this database to know the evolution of behavioral events in the interval between the two inventories, to (re)determine the condition index at the second inventory and to determine the gradient of the condition index in the period between the two inventories of structures;
- Analysis and interpretation of the factors that influence the gradient of the status index (as an indicator that reflects, in quantitative terms, the evolution of the status of the structures).

- important resources of time and funding being necessary to re-inventory all the 5 198 transversal hydrotechnical works inventoried until 2020 throughout the country, out of a total of approximately 16 000 (Adorjani et al., 2008), a selective approach was undertaken, in order to capture the evolution, over time, of the state of the transversal hydrotechnical works, with a coverage probability of approximately 90%. The method provides for the collection of data from a limited number of structures (n), according to the following parameters (Giurgiu, 1972):

$$n = \frac{u^2 \cdot s_{\%}^2 \cdot \mathrm{N}}{N \cdot \Delta_{\%}^2 + u^2 \cdot s_{\%}^2} \qquad \text{(Eq. 4.1)}$$

where:

N is the number of units in the population;

$s_{\%}$- coefficient of variation specific of the phenomenom;

$\Delta_{\%}$- the allowed error limit (adopted by the researcher);

u – the normalized deviation corresponding to the coverage probability adopted (u = 1,96).

- The 285 re-inventoried hydrotechnical works, which are the subject of this thesis, generate a limit error of 10.5% (Tab. 4.1).

Tab. 4.1. The size of the survey according to the permissible error limit, under the damage ratio

Margin error		1%	3%	5%	7%	9%	10%	10,5 %	11%	12,5 %
Survey size	Number of structures	4506	2182	1074	610	387	318	290	266	208
	%	87	42	21	12	7	6	6	5	4

Depending on the same number of papers, but under the ratio of dysfunctionalities, the analyzes related to the size of the survey revealed that the number of structures generates a margin of error of 7,5 % (Tab. 4.2).

Tab. 4.2. The size of the survey according to the permissible error limit, under the dysfunctionalities ratio

Margin error		1 %	3 %	5 %	7 %	7,5 %	8 %	9 %	11 %	12,5 %
Survey size	Number of structures	4001	1408	613	332	292	258	206	140	109
	%	77	27	12	6	6	5	4	3	2

After determining the number of structures to be studied and choosing the related torrential watersheds, to determine and compare the parameters that reveal the safety in operation, as well as the functionality of the works, a second inventory of the works was made. It was carried out between 2016 and 2020, by the author of this thesis, the interval between the inventories being between 5 and 11 years. The data related to the damages and dysfunctionalities of the inventoried structures were stored in the same-mentioned database.

After creating our database, we resorted to redetermining the status index for each work. For this, the condition index equation (Eq. 4.2) was used (Davidescu et al., 2012; Davidescu, 2013; Tudose et al., 2014), an equation that takes into account the cumulative effect of damages, namely those recorded during the between the two inventories.

$$Y_S = 100 - \frac{100 \cdot Y_A}{Y_A^{REF}} \qquad \text{(Eq. 4.2)}$$

where:

Y_A is the damage index;

Y_A^{REF} - the maximum theoretical value of the damage index.

Calculation formulas from previous studies were used to calculate the intensity of different damages (Tudose et al., 2015).

The condition index gradient, the main subject in the development of this thesis, is given by the difference between the condition index Ys 2 (a parameter that reproduces the combined effect of the behavioral events that occurred in operation on structure up to the time of the second inventory) and Ys 1 (the value of the condition index obtained at the first inventory), the difference being related to the number of years between the inventories (Ec. 4.3).

$$Gs = \frac{Ys_{(2)} - Ys_{(1)}}{N} \qquad \text{(Eq. 4.3)}$$

where:

Gs is the gradient of the status index;

$Ys_{(2)}$ - the status index obtained at the second inventory;

$Ys_{(1)}$ - condition index obtained at the first inventory;

N – the number of years between the first and last inventory.
In the other hand, the gradient is a quantity that captures the annual average changes of the condition index (which takes values from 0 to 100); when the values of the gradient are negative,a degradation of the physical state of the structures occurred and when the values are positive we are dealing with an improvement of the state of the works. As the first situation is usually overwhelming (as in the present case), it means that the decrease of the gradient in the mathematical sense shows a depreciation of the state of the works, while the increase of the gradient in the mathematical sense shows an appreciation of the state of the structures.

*

Finally, we specify that the working method applied in the case of the last two research objectives will result from the text that present the results and discussions regarding these objectives (§ 5.10 § 5.11).

5 RESULTS AND DISCUSSIONS

5.1. The main characteristics of the studied transversal hydrotechnical structure

5.1.1.Types of hydrotechnical structures identified

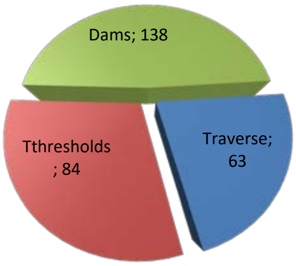


Fig. 5.1. Structures distribution common clasification

Among the 39 construction types designed in various variants (Lazăr și Gaspar, 1994), eight types were identified in the studied watersheds, starting from the trapezoidal dams with enlarged fruit to the newest construction types, the "undersized" dams on the Tigăi Valley (Tărlung hydrographic basin) (Tab. 5.1).

Tab. 5.1. Number of structures related to the type of works

Type of work	Year of conception	Type code	Number of structures
Trapezoidal dam with enlarged fruit	1949 - 1955	GR	158
Flared Foundation Dam	1962	GFE	78
Undersized dam	1968	GS	27
Precast dam on buttresses	1979	PC	6
Arch dam	1959	AR	5
Filtered dam	1968	FI	5
Precast dam without abutments	1979	P	4
Tubular dam	1979	T	2

Regarding the height of the elevation (Fig. 5.1), 138 are dams - structures with a height of more than 2 meters, of which 120 have apron, 84 are thresholds whose height is less than 2 meters, 58 thresholds with apron have been identified, the remaining 63 works are transverses, with the spillway at terrain level.

5.1.2.Building materials used

For the construction of the structures identified in the analyzed torrential watersheds, different building materials were used, like wood and dry stone, stone masonry, concrete and prefabricated elements of various materials (concrete, metal elements, used tires, etc.) (Tab. 5.3).

Tab 5.3. The number of structures concerning the construction material and construction solution

Construction material / Constructive solution	Material code	Structure body		Apron	Counter dam	Guarding wall	Terminal spur
		Spillway area	Wall wings				
Concrete	B	145	150	37	-	64	35
Stone masonry with cement mortar	M	126	129	148	2	116	124
Blocks, prefabricated concrete boxes	PB	4	4	-	-	-	-
Stone masonry with cement mortar + Concrete	B+M		1	-	-	-	-
Concrete buttresses and concrete beams (reinforced)	CBG	2	-	-	-	-	-
Precast concrete pipes	PT	2	-	-	-	1	-
Masonry buttresses and masonry slabs	CMPM	1	1	-	-	-	-
Concrete buttresses and metal beams	CBGM	1	-	-	-	-	-
Other materials	XX	1	-	-	-	-	-

5.1.3. Elevation height

In relation to this criterion, the transversal structures identified have an elevation (useful height) between 0 m (terrain level - traverse) and 10 m, the distribution by height categories from 0.5 to 0.5 m being represented in figure 5.2.

According to the usual classification, 63 traverses, 84 thresholds (with the elevation up to 2.0 m exclusively) and 138 dams (with the useful height equal to or greater than 2.0 m) were identified).

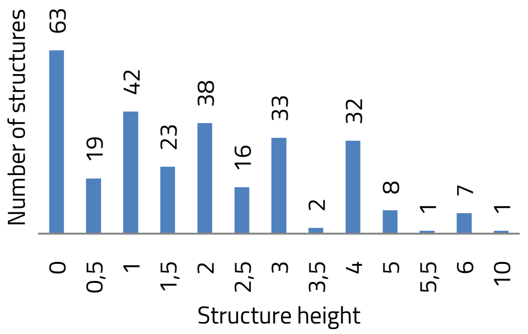


Fig. 5.2. Number of structures by height category

5.1.4. Opening at the top of the structure

Depending on the opening at the top of the structures, they were classified into categories, the size of the category being 10 meters; a distribution quite close to the normal distribution resulted. Most of the works have an upper opening between 10 and 30 meters (71 %) (Fig. 5.3).

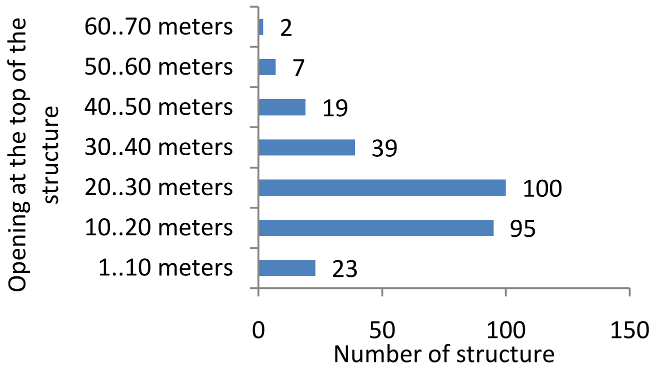


Fig. 5.3. Number of structures by opening at the top of the body

5.1.5. Spillway opening

In the present case, the opening of the spillway was divided into categories of 5 meters long, the number of works related to each category being the one shown in figure 5.4. The most common is the opening in the 5...10 meter category.

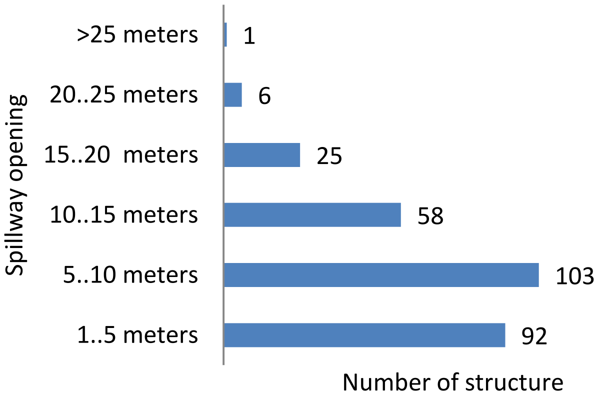


Fig. 5.4. Number of structures by the spillway opening

5.1.6. Spillway height

The height of the spillway is established according to the load in the spillway, the level of this load corresponding to the elevation to which the waters reach at the time of exceptional flows. This dimension, together with the spillway opening, defines the spillway section, i.e. the section through which the maximum forecast flow can be discharged. Most of the works studied have spillway heights between 0.5 and 1.5 m (Fig. 5.5).

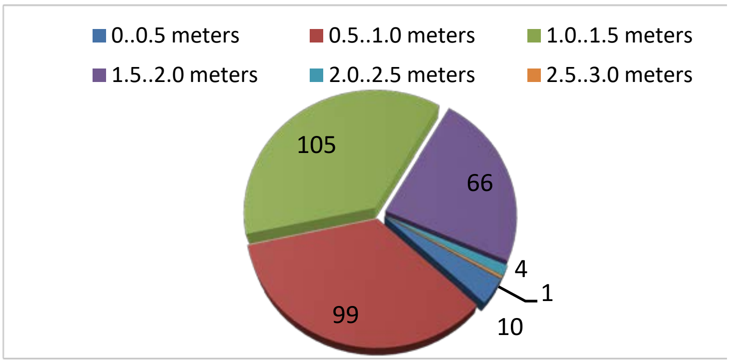


Fig. 5.5. Number of strcutures by the spillway height

5.1.7. Apron length

The dimensions of the apron are in accordance with the characteristics of torrential flows, especially with the flow that will be discharged through the spillway, the length of the apron being adopted in relation to the stroke length of the spillway blade. For the 185 apron identified at the transversal hydrotechnical structures taken into the study, a distribution was made by length categories, the obtained distribution being represented in figure 5.6.

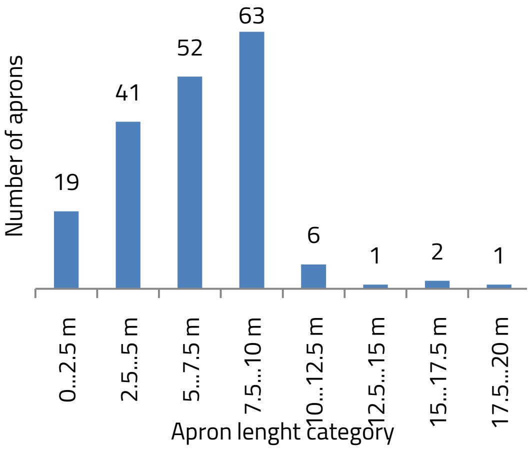


Fig. 5.6. The number of structures by apron lenght category

5.1.8. Apron width

The width of the apron is the distance reduced to the horizon between the guarding walls of the structure, this being established concerning the opening of the spillway at the top. In the works studied, the maximum measured width was 26 meters.

5.1.9. Energy dissipater type

For the hydrotechnical structures studied, we recorded 118 aprons without energy absorbed system, 65 with energy absorbed system and two works with a water mattress.

5.1.10. Age of structure

The oldest studied structures were put into operation starting in 1963 (Rebra Mare Perimeter - Someș- Crasna hydrographic basin) and the newest structures were identified in the Repedea hydrographic basin, where they were put into operation in 2009.

The number of transversal hydrotechnical works was staggered by age category, with an interval of 5 years, their distribution being as follows (Tab. 5.4):

Tab. 5.4. The number of structures by age category

Age category (age)	0...5	5...10	10...15	15...20	20...25	25...30	30...35	35...40	40...45	45...50
Number of structures	43	74	0	13	8	79	25	20	18	5

5.2. Behavioral events between inventories

5.2.1.Type and frequency of behavioral events at the first inventory

Out of the total number of inventoried structures, during the first inventory, damages were observed in 77.2% of them, the damage with the highest frequency being the apron detachments (42.7% of the aprons).

In the case of un embedding, the highest frequency was identified in the Beiului Valley torrential basin, where 7 works were affected by this damage (35%).

The undermining, damage that endangers the stability of the structure, by washing the sector immediately downstream of the work which can conduct to foundation exposing, affected 23.9% of the total number of works.

Cracks in the body structure were observed in 11.9% of the works, the maximum frequency of occurrence being reported in Jidoștița Valley.

Detachment from the spilled area was identified in 20.7% of the structures, the frequency of occurrence of the damage varying from 2% (Tigăi Valley) to 89%; the maximum frequency was identified at the Vârdaleș Valley structures.

In the non-spill area, the detachment affected 6.3% of the total number of inventoried structures (18 works), the maximum frequency of occurrence being in the Rebra Mare perimeter.

At the level of the apron, the frequency of occurrence of detachment also recorded a significant value; the breakdown affected 45 pieces (14.3%) of the total number of 185 (with apron).

Detachment of the counter dam, part of the work identified in only two cases on Valea Vârdaleș, were completely affected.

The apron undermining was identified in 79 transversal hydrotechnical structures(42.7%), most of them in the Tigăi torrential watershed.

Apron erosion was identified in 57 cases (30.8%), the highest frequency of occurrence being on Vârdaleș Valley, where 15 (83.3%) of the 18 pieces with apron were affected by this event.

And in the case of the guarding walls, various damages were recorded. Cracks were identified in 18 cases (9.9%) of the 181 guarding walls.

In the case of the terminal spur, the damages reported at the first inventory had low frequencies of occurrence; un embedding were measured on 6 terminal spurs (3.8%), detachments were observed in 7 cases (4.4%) and erosion affected 10 terminal spurs (6.3%).

Dysfunctionalities, behavioral events that contribute to a difficult functionality of the structure, were reported in most of the basins studied, the most frequent proving to be the apron silting; this affected 68.1% of the aprons.

5.2.2.Type and frequency of behavioral events at the second inventory

The analysis of the data from the second inventory reflected changes over time in the number of structures affected by various damages and dysfunctionalities (Tab 5.6). The changes were also observed in the intensity of the behavioral events, being reflected both by the variation of the status index and by the status index gradient values. The evolution of these events was favored by the lack of maintenance and repair operations, being caused by the torrential flows produced during the reported period.

This is how, at the second inventory, 276 transversal hydrotechnical structures were found to be affected by various behavioral events (97%), the maximum frequency of occurrence being observed at the erosion of the body of the structure, where the damage was recorded at 61, 8% of the pieces (176); at the opposite pole is the terminal spur cracks, recorded in only 1.3% of the structures (2 pieces). Among the dysfunctionalities, the uncontrolled installed vegetation in the upstream tributary was recorded in 232 works (81.4%).

The structures body, in direct contact with the torrential waters, recorded a significant number of damages: the un embedding affected 63 structures, the undermining was recorded in 95 cases, cracking was identified at 97 pieces, detachment in the area spilled affected 95 structures and the non-spilled detachments were identified at 45 works, erosion manifested at 176 structures.

Tab. 5.6. Data of affected structures by various damages and dysfunctionalities at the second inventory

Hydrographic basin / improvement perimeter	Specification							Damages																			Dysfunctionalities					
	Transversal hydrotechnical works	Structures affected by various damages		Structures with apron	Structures with energy absorber system	Structures with guarding walls	Structures with terminal spur	Body un embedding	Body undermining	Body cracks	Spilled area detachments	Wall wings detachments	Body erosions	Apron cracks	Apron detechments	Energy absorber system detachments	Counter dam detachments	Apron undermining	Apron erosions	Guarding walls cracks	Guarding walls detachments	Guarding walls erosions	Terminal spur un embedding	Terminal spur cracks	Terminal spur detachments	Terminal spur erosions	Spillway blockage	Apron silting	Incomplete sedimentation	Unwanted vegetations in the upstream sector	Unwanted vegetations in the downstream sector	Downstream reduction section
	No.	No.	%	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
Repedea Valley	29	29	100	24	8	24	19	3	19	8	14	4	15	1	18	8	-	14	13	7	5	11	1	-	1	1	6	12	4	29	29	8
Rebra Mare Perimeter	7	7	100	5	0	5	2	1	1	2	3	4	4	-	2	-	-	-	2	2	3	3	-	-	-	1	3	3	3	7	7	-
Crăiasa Valley	51	46	73	25	7	22	21	1	9	4	14	7	14	2	10	-	-	13	9	1	1	2	-	-	2	-	28	12	5	51	51	23
Beiului Valley	20	20	100	5	0	5	3	10	14	8	2	3	4	-	-	-	-	4	-	1	-	3	-	-	-	-	2	3	9	20	20	5
Sohodol Runcu Valley	17	17	94	11	0	10	8	2	6	4	7	-	9	-	5	-	-	2	5	-	4	-	2	-	3	2	4	6	8	17	17	-
Cetății Valley	11	11	100	9	1	9	4	7	-	5	8	6	9	1	1	1	-	1	3	2	1	3	-	-	-	-	8	8	1	10	3	2
Adânca de Jos Creek	12	12	92	9	7	9	9	5	5	5	3	2	7	1	2	4	-	1	5	-	2	2	3	-	2	1	7	8	3	12	12	6
Tesla Creek	13	13	100	1	1	1	1	2	12	3	3	1	12	-	-	1	-	1	1	1	1	-	-	-	-	-	9	1	1	4	3	12
Tigăile Valley	47	43	87	35	20	35	35	12	11	23	3	2	38	2	4	3	-	27	24	1	1	2	1	2	-	20	26	33	9	19	17	45
Zimbru Creek	17	17	100	12	6	12	12	4	5	5	4	1	14	-	2	3	-	8	9	1	-	5	1	-	2	7	12	11	-	10	8	17
Vidaș Creek	5	5	100	5	5	5	5	-	-	4	-	1	2	-	-	-	-	2	2	1	1	1	1	-	1	-	1	5	2	-	3	1
Dracului Valley	20	20	100	15	10	15	15	11	4	12	13	5	19	2	5	6	-	6	10	-	2	5	1	-	3	5	13	10	3	17	11	14
Vârdaleș Valley	19	19	100	18	2	18	16	2	6	5	18	8	18	-	16	-	2	10	15	8	11	12	1	-	3	2	7	10	5	19	19	13
Jidoștița Valley	17	17	100	11	0	11	9	3	3	9	3	1	11	2	6	-	-	2	5	5	4	-	1	-	2	-	8	8	1	17	16	8
Total / Average (%)	285	276	97	185	67	181	159	63	95	97	95	45	176	11	71	26	2	91	103	30	36	49	12	2	19	39	134	130	54	232	216	154

Fig. 5.9. Water course deviation due to apron silting

(Mihalache, 2019)

Among the behavioral events recorded at the apron, at the 185 structures with apron, cracks were found in 11 cases, detachments were identified in 71, 26 presented the ruptures of the energy absorber system and the erosions affected 91 aprons. The two counter dams were affected by the detachments, and erosions affected 103 structures.

Cracked guarding walls were found in 30 cases, the guarding walls of 36 structures recorded detachments and erosions were found in 49 cases.

The terminal spur, identified in 159 transversal hydrotechnical structures, was affected by un embedding in 12 cases, cracks were identified in 2 cases and detachment was recorded in 19 cases.

The transversal hydrotechnical structures dysfunctionalities from the second inventory were recorded at a significant number of works, the unwanted installation of vegetation upstream being the behavioral event that put a number of 232 works in difficulty.

5.2.3.Type and frequency of behavioral events between inventories

If among the 285 transversal works studied, at the time of the first inventory it was found that 65 did not inregistred any damage, after the second inventory the number of structures remaining unaffected was only 23; of these: 15 works are on the Crăiasa Valley, 6 are on the Tigăi Valley and one each on the Sohodol-Runcu Valley and the Adânca de Jos – Tărlung Stream.

In the period between the inventories, "disappearances" of some of the damages recorded at the first inventory were also observed, such as: body un embedding (for 2 structures), body undermining (8 cases) and the apron undemining (in 12 cases); this was possible due to the transport carried by the torrential flows, which covered the initially affected surfaces. Structures were also identified where the erosion "disappeared" (it was no longer reported): two cases at the body structure, 9 cases at the apron and one case each at the guarding walls and the terminal spur; the "disappearance" is due to the detachment that took place in the period between the inventories (Tab. 5.7).

It is worth noting that the behavioral events, in the period between the two inventories, were detected mainly at that structures that had already suffered certain damages.

The most frequent damage produced in the period between the inventories is erosion, identified in large numbers both in the case of the body structure, where another 108 pieces (38%) were affected and at the apron level, where another 55 pieces have were affected (30%).

5.2.4.The impact of the first inventory events and association among them in the period between invetories

The transversal hydrotechnical works that had body undermining (68 works), between the two inventories recorded new damages, of which: body erosion was observed in 19 cases, detachments appeared in the spilled area at 8 structures, 7 works were affected by cracks, 5 cases with new body un embedding, in 3 cases detachments appeared in the non-spilled area, the apron undermining was identified at 3 other structures, in two cases erosion occurred at the level of the guarding walls and in one case it has occurred the guarding wall rupture (Appendix 2).

Also, at the 79 transversal hydrotechnical structures with apron undermining during the first inventory, following the second inventory were observed: 34 cases with new apron erosions and in 15 cases were recorded apron detachments (Fig. 5.11).

The behavioral event with the most significant number of works affected in the second inventory is the erosion of the body structure, recorded in another 108 pieces.

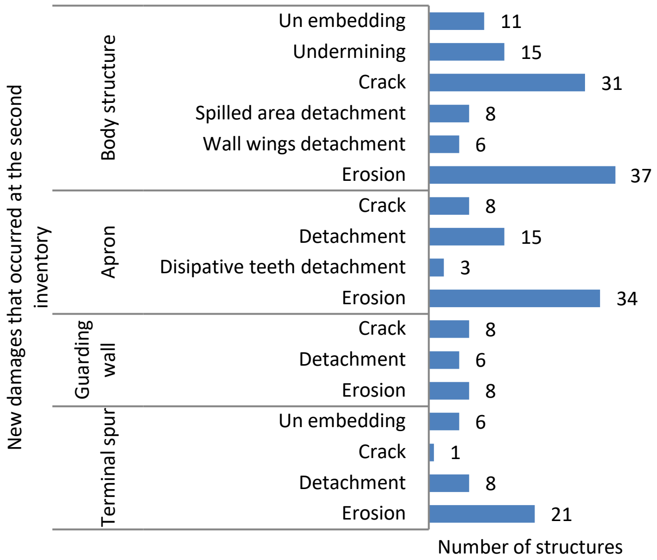


Fig. 5.11. Damages recorded at the first inventory fosr structures with new apron underming

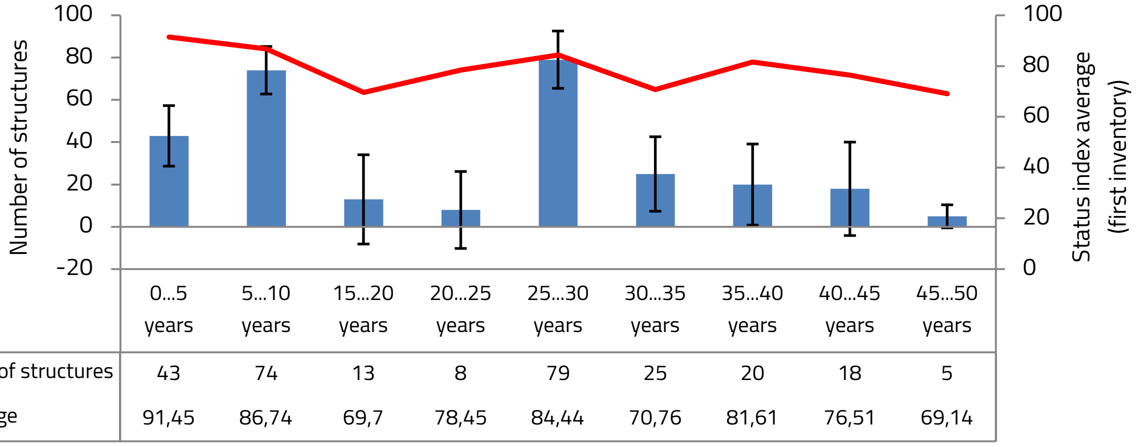
5.2.5.Intensity of behavioral events between inventories

Taking into account the average damage intensity, changes were observed between the two inventories, the biggest difference being recorded at the apron erosion, where following some detachments recorded at the apron, with maximum intensities from 0.8 to 1.0 (100% detachment in the case of 7 aprons), the average intensity of erosion decreased from 4.6 to 3.0. For the same reasons, the intensity of the cracks was reduced from 2.0 to 0.7, but with an average difference in the increase of the intensity of the cracks of 0.53.

5.3. Structures status in the period between inventories

5.3.1.Structure's status at the first inventory

From the perspective of the condition index, related to the age of the structures (Fig. 5.13), the most representative, numerically compared to the population average, turned out to be the 79 works in the 25-30 years category, whose condition index average is 84.44, with values between 100 and 35.39 (180 M 1 – Crăiasa Valley) and with a standard deviation from the category average of 13.53.



	0...5 years	5...10 years	15...20 years	20...25 years	25...30 years	30...35 years	35...40 years	40...45 years	45...50 years
▬ Number of structures	43	74	13	8	79	25	20	18	5
━ Ys average	91,45	86,74	69,7	78,45	84,44	70,76	81,61	76,51	69,14

Fig. 5.13. The number of structures and the average status index by age category, at the first inventory

The possible influence of used materials on the status index average was also investigated, with data showing that stone masonry performed better. The average condition index obtained for the 128 structures is 83.13, the deviation from the population average being 18.27 (Fig. 5.15); this category also includes filtered structures made of stone masonry, as well as pieces showing associations of masonry and other materials.

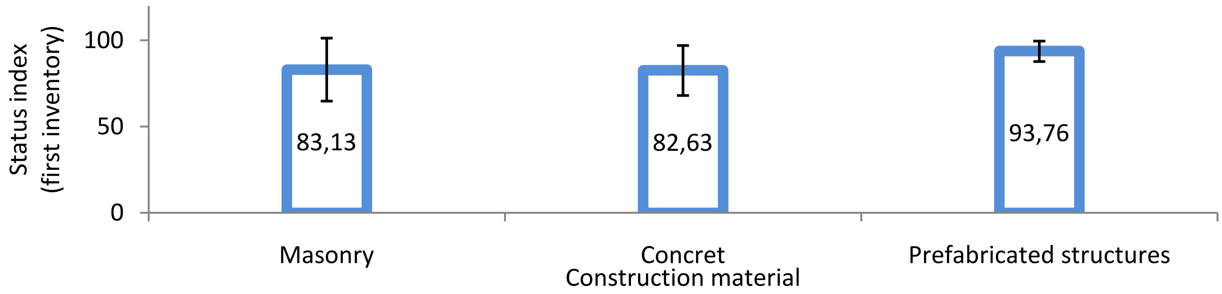


Fig. 5.15. The status index average by category of construction materials

For the qualitative characterization of the state of the transversal hydrotechnical structures located in different hydrographic basins, we used a classification previously proposed into 5 categories of the state of the works (Davidescu, 2013), as follows (Tab. 5.10) (Ys is the status index):

Category I - very bad condition (Ys ≤ 20);

Category II - bad condition (20 < Ys ≤ 40);

Category III - average condition (40 < Ys ≤ 60);

Category IV - good condition (60 < Ys ≤ 80);

Category V - very good condition (Ys > 80).

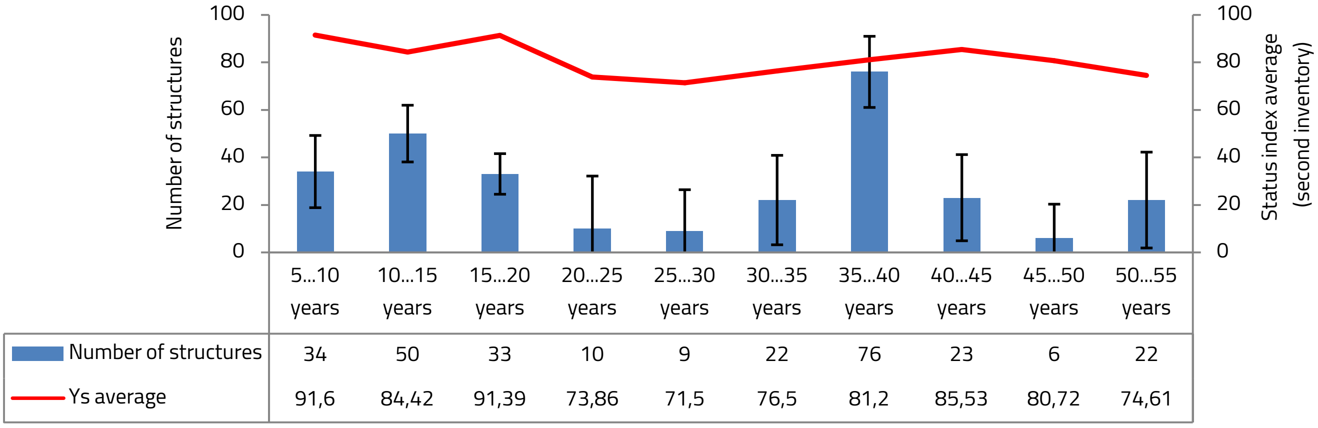
Tab. 5.10. The state of the transversal hydrotechnical structures by status category and hydrographical watershed, at the first inventory

Hydrographic torrential watershed / Improvement perimeter	Number of structures	Status index			Status category				
		Minimum	Maximum	Average	1	2	3	4	5
Repedea Valley	29	42,71	100,00	75,36	-	3	7	16	3
Rebra Mare Perimeter	7	34,24	100,00	68,57	-	1	3	2	1
Crăiasa Valley	51	35,49	100,00	93,1	-	1	3	7	40
Beiului Valley	20	27,72	100,00	75,46	1	-	5	10	4
Sohodol Runcu Valley	17	31,86	100,00	78,56	-	3	-	9	5
Cetății Valley	11	58,78	100,00	87,78	-	-	2	2	7
Adânca de Jos Creek	12	53,24	100,00	84,72	-	-	1	8	3
Tesla Creek	13	47,24	100,00	77,74	-	1	1	8	3
Tigăile Valley	47	43,78	100,00	89,4	-	1	2	21	23
Zimbru Creek	17	76,23	100,00	89,26	-	-	-	8	9
Vidaș Creek	5	84,30	94,29	90,27	-	-	-	2	3
Dracului Valley	20	68,03	100,00	88,48	-	-	1	12	7
Vârdaleș Valley	19	42,47	95,40	64,19	-	2	13	3	1

Hydrographic torrential watershed / Improvement perimeter	Number of structures	Status index			Status category				
		Minimum	Maximum	Average	1	2	3	4	5
Jidoștița Valley	17	23,46	97,61	74,67	1	1	5	8	2
Total / Weighted average	285	44,30	99,45	83,09	2	13	43	116	111

5.3.2.Structures status in the second inventory

At the second inventory, from the point of view of the age of the structures, the most affected turned out to be the structures from the category 25-30 years, with an status index average of 71.5, followed by the works aged 20-25 years, the status index average for those was equal to 73.86. The highest value of the status index (91.6) was obtained for the structures included in the first age category 5 – 10 years (Fig. 5.16).



	5...10 years	10...15 years	15...20 years	20...25 years	25...30 years	30...35 years	35...40 years	40...45 years	45...50 years	50...55 years
▬ Number of structures	34	50	33	10	9	22	76	23	6	22
▬ Ys average	91,6	84,42	91,39	73,86	71,5	76,5	81,2	85,53	80,72	74,61

Fig. 5.16. Number of structures and status index average, at the second inventory

Among the three major categories of construction materials, those that obtained the lowest value of the status index average were concrete structures (Ys2 = 72.69), followed by stone masonry works (76, 37) and prefabricated elements (80,58) (Fig. 5.18).

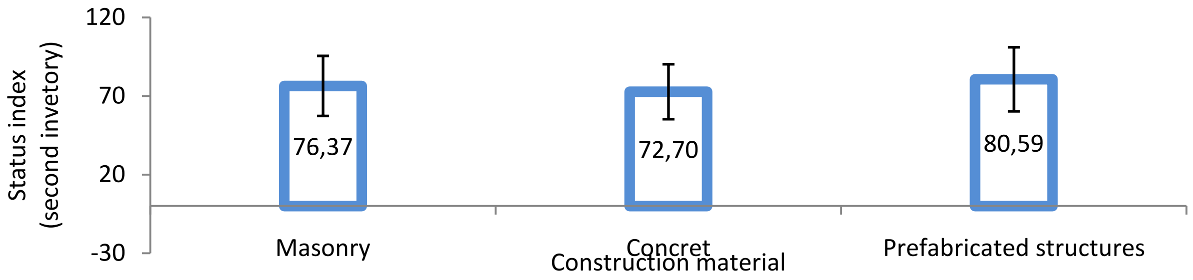


Fig. 5.18. The number of structures and the status index average by category of construction materials, at the second inventory

After the data processing and the breakdown of the results by torrential watersheds, the new values of the status index average per basin were obtained. From the perspective of damages and the variation (percentage) of the status index, the most affected hydrographic watershed turned out to be Repedea Valley, where after the torrential flows from 2012, many of the structures were seriously damaged, which also reflected on the status index category.

In relation to the number of parts affected by each damage, it was observed that their number increased, which led to variations in the status index average on behavioral events, the maximum difference between the indices being observed at the structures affected by ruptures of energy absorber teeth, where, despite the small number of affected works, the largest decrease in the condition index was observed (-13.96), from 82.77 to 68.81. This decrease is due to the impact of the association of behavioral events (of a maximum of 12), but especially the ruptures from the apron body, damage that affected all 6 structures with energy absorber teeth druptures.

5.3.3.Changes in the structure condition rate in the period between inventories

Although most of the structures were affected by several damages, pronounced variations of the status index could also be found at the works that suffered a small number of behavioral events (even a single one), but with high intensities.

The data shows that the structures on Adânca de Jos Valley recorded the largest decrease of 17.64 (20.8%), the decrease occurring from Ys1 = 84.72 to Ys2 = 67.08 and was due to behavioral events which led to decreases in the status index up to -63.28 (structure 60 B 0). Positive values of the difference between the variation of the condition index were also observed on this valley, the highest value being 18.99 units (structure 90 B 0 (Tab.5.13).

Tab. 5.13. Differences between the status index average in the analysed watersheds, following the two inventories

Hydrographic torrential watershed / Improvement perimeter	Number of structures	Ys 1	Ys 2	Difference		Variation amplitude Ys	
						Minimum	Maximum
Repedea Valley	29	75,36	58,89	-16,47	-21,9%	-52,23	1,04
Rebra Mare Perimeter	7	68,57	57,30	-11,27	-16,4%	-26,01	0,36
Crăiasa Valley	51	93,10	82,91	-10,19	-10,9%	-59,27	0
Beiului Valley	20	75,46	72,05	-3,41	-4,5%	-19,38	0,33
Sohodol Runcu Valley	17	78,56	76,05	-2,51	-3,2%	-14,42	0
Cetății Valley	11	87,78	80,75	-7,03	-8,0%	-22,99	5
Adânca de Jos Creek	12	84,72	67,08	-17,64	-20,8%	-63,28	18,99
Tesla Creek	13	77,74	65,82	-11,92	-15,3%	-71,64	8,22
Tigăile Valley	47	89,40	82,20	-7,20	-8,1%	-38,06	10,96
Zimbru Creek	17	89,26	80,83	-8,43	-9,4%	-39,64	5,38
Vidaș Creek	5	90,27	87,92	-2,35	-2,6%	-9,57	5,35
Dracului Valley	20	88,48	76,10	-12,38	-14,0%	-30,96	14,83
Vârdaleș Valley	19	64,19	59,75	-4,44	-6,9%	-21,52	6,45
Jidoștița Valley	17	74,67	75,35	0,68	0,9%	-8,59	11,37
Total / Average	285	83,09	74,51	-8,86	-10,1%	-	-

5.4. Condition rate evolution in relation to type, frequency, intensity and association of behavioral events

In order to respond to the 4th objective of the research, starting with the present subchapter and continuing with the next four (§5.5… §5.8), in the presentation and discussion of the results, in addition to the status index will be involved the status index gradient. Through this methodological paradigm, the transition is made from characterization of the current status index (at the time of the two inventories) to the knowledge of the evolution of the status of the structures in the period between the inventories (the average annual rate of change in the physical state of the works). It is worth noting that the values with a negative sign of the gradient show a "depreciation" of the state of the structures, the more important that the module of the gradient is higher. On the contrary, the values with a positive sign of the gradient show an "appreciation" of the structure status index.

5.4.1.The state of the structures induced by the doby structure damages

5.4.1.1. Body structure un embedding

Un embedding represents the behavioral event by which the connection between the wing of the transversal work and the bank where it has its support point is lost. The event is generally caused by bank phenomena (under washes, bank breaks, landslides, etc.) through which the bank in which the work is embedded is washed or dislodged.

Fig. 5.22. Structure 90 BCF 2.0 - Vinderel Creek

(Foto: Mihalache, 2017)

At the first inventory, 24 structures affected by un embedding were identified (8.4%), the distribution by hydrographic basins being as follows: one structure each in the Rebra Mare Perimeter and in the Crăiasa, Adânca de Jos and Zimbru valley, two structures each were identified in the Sohodol Runcu, Tesla, Valea Dracului, Vârdaleș and Jidoștița, 3 structures were observed in the Tigai basin and 7 works in Valea Beiului.

At the second inventory, the frequency of occurrence of damage had maximum values in the Tigaile basin, where 12 new case of un embedding were identified; another 11 structures were observed in Valea Dracului, 10 in Valea Beiului and 7 works in Valea Cetății.

For those 24 structures that presented this event at the first inventory, the average intensity of un embedding did not register large variations in the period between inventories. In 15 of these cases the damage intensity did not change, in two cases the intensity increased by 0.42 (for structure 170 B 1.0 - Beiului Valley) and 0.85 for 150 B 4.0 - Adânca de Jos Creek, and in another 5 cases reductions in intensity were observed, with values between -0.79 and -0.05.

5.4.1.2. Body structure undemining

The undermining represents the damage caused by the erosive action of the spillway blade in the immediate area downstream of the structure. It occurs especially at the works which are not equipped with another auxiliary construction in the downstream branch. This damage can take various shapes and sizes, the initial stage is gived by the superficial bed washing in the area of the discharge blade. The erosion can progress until the entire foundation is exposed, in which case the work is "floating" (Fig. 5.25), followed by by breaking and taken out of operation (Fig. 5.30), as well as endangering different objectives (Davidescu 2013).

Fig. 5.25. Structure 23 B 0 – Nanului Creek

(Mihalache, 2019)

The undermining average intensity at the first inventory was 0.17, with an average depth of 88 centimeters and an average damage proportion of 77%. The maximum intensity (1.8) was observed at structure 10 B 0 – Tesla Creek, which had a 1.8 meter deep spill over 100% of the spillway opening.

For those 68 structures detected with undermining since the first inventory, an increase in the average intensity of this event was found, from 0.70 to 0.81, in the calculation of these averages the 8 cases where the undermining "disappeared" in the period between inventories were also included. The average of the status index gradient is -0.74 units/year. If the 8 structures were to be abstracted, the average undermining intensity would be 0.72 at the first inventory and 0.92 at the second inventory, with an average gradient of -0.94 units/year.

At the second inventory, the average intensity for the 95 undermined structures was 0.82, with an average depth of 0.96 meters and an average damage proportion of 81.4%; the maximum intensity (of 2.5) was recorded at two works: 42 M 4.0 – Ravine 1 UP V – Sohodol Runcu Valley, respectively 23 B 0 – Nanului Creek. The status index for these structures registered a decrease, from Ys 1 = 75.5 to Ys 2 = 63.2, the status index gradient resulted to -1.74 units/year (Tab. 5.15).

Tab. 5.15. Data about the undermined structures

Specifications	Number of affected structures	Affected structures (%)	Damage intensity		Status index		Status index gradient Gs
			Inventory		Inventory		
			1	2	1	2	
Inventory 1	68	24	0,697	0,814	69,0	64,4	-0,74
Inventory 2 (total)	95	33	0,456	0,823	75,7	63,2	-1,74
Works with damage only to inventory 2	35	12	-	0,653	87,8	64,0	-3,11
Works where the damage "disappeared"	8	3	0,509	-	71,1	76,5	0,76

5.4.1.3. Body structure cracks

The cracks appear in the form of cleft in various parts of the structure, their appearance being caused by various factors such as: exceeding the permissible stretching effort, uneven settlement of the land, strong impacts on some small surfaces of the structure (logs transported from torrential flows), casting joints, etc. (Davidescu, 2013).

At the first inventory, 34 structures with cracks (12%) were identified, the most (8 pieces) in the Jidoștița basin. At the end of the second inventory, the cracking event affected 97 transversal hydrotechnical structures.

The concrete structures proved more vulnerable to cracks, both from the perspective of frequency of occurrence (66 pieces in total) and damage intensity, the last one doubling its value, from 0.120 (first inventory) to 0.242 (the second inventory) (Tab. 5.17). This ascertainment is also reinforced by the average gradient, which is -1.20 units/year for the concrete structures while masonry pieces value is -0.95 units/year.

Fig. 5.28. Vertical crack that generated the rupture of the spilled area of the structure 9 B 0 – Tigăi Valley

5.4.1.4. Detachment in the spilled area

Detachment (or rupture of some fragments of the structure) is the damage by which different parts of the body of the work or other component parts lose their connection with each other. The event may or may not be followed by displacement or overturning of the detached parts, an aspect that can lead either to a sudden degradation (Fig. 5.29) or to a progressive degradation of the physical condition. The event is generally caused by the evolution of cracks, the primary factor being the action of the waters and the dynamic stresses specific to torrential flows, frequently loaded with boulders, floaters, etc. (Davidescu, 2013).

During the first inventory, 59 structures with detachment in the spilled area were identified , most of them in the Vârdaleș Valley - 17 works. The average damage intensity for this 59 mentioned structures was 0.20 and increased to 0.26 at the end of the second inventory (Tab. 5.19).

Tab. 5.19. Data of structures with spilled area detachments

Specifications	Material	Number of structures	Detachment intensity		Status index Ys		State index gradient Gs
			Inventory		Inventory		
			First	Second	First	Second	
Inventory 1	Beton	19	0,03	0,33	82,96	72,88	-1,554
	Zidărie	40	0,06	0,23	83,23	76,43	-0,844
	Total	59	0,20	0,26	70,09	61,72	-1,073
Structures with damage only to inventory 2	Beton	19	0,00	0,20	81,21	63,68	-2,375
	Zidărie	16	0,00	0,08	89,06	74,69	-1,816
	Total	35	0,00	0,14	84,80	68,72	-2,119
Inventory 2 (total)	Beton	38	0,11	0,26	76,40	61,36	-1,964
	Zidărie	56	0,14	0,18	75,00	66,34	-1,122
	Total	94	0,13	0,22	75,57	64,33	-1,462

At the second inventory, it was found that 35 other structures were affected by this damage, most of them being identified in Repedea Valley - 9 cases. For these, the average damage intensity is 0.14, which, together with other associated behavioral events, led to a decrease in the status index from Ys1 = 84.8 to Ys2 = 68.7.

At the end of the second inventory, 94 structures were affected by detachment in the spilled area (Appendix 3), the average damage intensity being 0.22. The average status index is 64.33 and the status index gradient (Gs) is -1.46 units/year. The average gradient for those structures with detachment in the spilled area since the first inventory is -1.07 units/year and for those where the damage occurred in the period between the two inventories, the average gradient is -2.12 units/year.

5.4.1.5. Detachments in the non - spilled area

Detachment in the non-spill area (wall wings detachments) consists of the detachment of some portions of the wings body or the total detachment of the entire side portion, which may have various causes. The maximum severity occurs when one of the two lateral elements of the structure is completely detached, as a result of which the flow waters concentrate towards the non-discharged area. In this case, the flow waters are concentrated towards the non-discharged area, where, after the deepening of the water course thalweg, which can conduct to the washing the stored sediment stored behind the dam and underwashing of the foundation land, finally the structure being taken out of use (Davidescu, 2013). Such a case was observed at the structure 90 BCF 2.0 - Vinderel Creek, which, however, is not part of the present study (Fig. 5.22).

At the first inventory, the wall wing detachments was identified at 17 transversal hydrotechnical structures, most of those being observed in the Vârdaleș Valley.

Between the two inventories, another 28 pieces were affected by wall wings detachment. Among this structures, most of them were in Crăiasa Valley.

5.4.1.6. Body structure erosion

It is caused by the continuous (or intermittent) action of waters loaded with various materials, which lead to the washing and eroding of the materials from which the structures are built. It is mainly localized in the spilled area, which is in direct contact with the torrential waters, the erosion beeing more frequently at the masonry joints and the concrete layer on the surface of the construction.

Fig. 5.33. Structure 10 BF 5,0 – Tigăi Valley, affected by erosion at the body structure level

(Foto: Mihalache, 2019)

Y_S = 78,62 - year 2010

Apron: Detachment – 30%;

Detachment of dissipative teeth – 21/21;

Sedimentation height – 2m.

Y_S = 41,98 - year 2017

Body structure: Spilled area detachment – 70%;

Body structure erosion – 10 cm/ 30%

Apron: Undermining – 1,2 m/ 100%;

Apron detachment – 80%;

Righ guarding wall detachment – 100%;

Terminal spur: Cetral area detachment – 30%;

Sedimentation height – 0 m.

Fig. 5.29. Structure 17 B 2.0 – Repedea Valley, Tisa hydrographic basin (Mihalache, 2017)

At the first inventory, the number of structures affected by erosion was 70, most of them being in the Vârdaleș Valley.

After the second inventory, another 108 structures (38%) where identified with erosion (Appendix 3), most of them being located in the Tiga basin (38 works). The average intensity of damage was 3.1, which led to a decrease in the status index from 87.34 to 75.75 (inventory 2). The status index gradient for these structures, of -1.38 units/year, reflects the damages present since the first inventory but also the new damages that appeared in the meantime.

Between the two inventories, two cases of "disappearance" of the damage were detected, at structure 1 B 0 - Repedea Valley, respectively structure 20 B 4.0 - Beiului Valley (Tab. 5.21).

Tab. 5.21. Data of structures with body structure erosion

Specification	Structure affected		Damage intensity		Status index Ys		Status index gradient Gs
			Inventory		Inventory		
	Number	%	1	2	1	2	
First inventory	70	25	4,307	6,398	73,98	67,26	-0,98
Second inventory (total)	176	62	1,594	4,448	82,15	72,56	-1,21
Structures damaged between inventories	108	38	0,000	3,101	87,34	75,75	-1,38
Structures where the damage "disappeared"	2	1	10,500	0,000	76,7	59,3	-2,61

5.4.2.The state of the structures induced by the apron damages

5.4.2.1. Apron ruptures

Detachment (ruptures) of some fragments from the apron body is produced by the manifestation of other damages, the most frequent being cracks, which can evolve into erosion and, subsequently, detachment. The last one can affect different proportions of the apron, with variations in surface (Fig. 5.34) and in-depth.

At the first inventory, 45 aprons with extensive detachment between 2% and 100% were identified, the most affected cases (15) were found in Vârdaleș Valley.

Fig. 5.34. Total apron detachment at structure 3 B 4.0 - Repedea Valley

(Foto: Mihalache, 2017)

The number of structures where this damage occurred in the period between inventories totals 26 pieces, most of them on Crăiasa Valley(Appendix 1); the average damage intensity was 0.213 (with detachments from 1% to 90%), the average status index registered a decrease, from 88.50 (at the first inventory - aprons without detachments) to 72.38 (the second inventory, aprons detached in different proportions), the average status index gradient being -2.02 units/year (Tab. 5.22).

Tab. 5.22. Data of structures with apron detachments

Specifications	Number of cases	Damage intensity		Status index (Ys)		Status index gradient Gs
		Inventory		Inventory		
		1	2	1	2	
First inventory	45	0,422	0,545	62,89	55,56	-1,06
Second inventory (total)	71	0,268	0,423	72,26	61,72	-1,41
Structures damaged between inventories	26	0,000	0,213	88,50	72,38	-2,02

At the end of the second inventory, 71 aprons were identified with detachment, the damage intensity being between 0.01 and 1.0, with an average value of 0.423 (Tab. 5.22). The status index of these structures varied from 72.26 to 61.72, the average gradient being -1.41 units/year.

5.4.2.2. Apron undemining

The apron undermining consists of the deepening of the river bed level in the immediate downstream vicinity of the terminal spur (Fig. 5.35), ultimately leading to the divestment of the spur foundation; in this way, the spur, the apron and the guarding walls are put at risk (Davidescu, 2013).

During the first inventory, 79 undermined aprons were identified (Tab.5.23), at the end of the second inventory, for 12 of the 79 structures, the undermining was blurred due to the torrential flows sedimentation, the depth that was covered varying between 0,3 and 2.0 meters; and at the end of the second inventory, 91 structures were presented with the apron undermining (Appendix 3).

Fig. 5.35. Apron undermining

Structure 11 B 2,5 - Nanului Creek

Tab. 5.23. Data related to the structure affected by undemining

Specification	Number of affected structures	Damage intensity		Status index (Ys)		Status index gradient (Gs)
		Inventory		Inventory		
		1	2	1	2	
First inventory	79	0,813	0,808	83,29	73,27	-1,13
Seconde inventory (total)	91	0,597	0,811	84,60	74,48	-1,15
Structures damaged between inventories	24	0,000	0,415	87,67	74,93	-1,59
Structures with persistent damage since the first inventory	67	0,811	0,953	83,50	74,32	-0,99
Structures where the damage "disappeared"	12	0,829	0,000	82,1	67,4	-1,90

5.4.2.3. Apron abrasion

Erosion is the process by which successive layers of construction materials are washed away, often those in the area of concentration and impact of the spillway blade, the area near the structure is the most exposed to this type of damage.

Fig. 5.37. Apron erosion at 11 B 2,0 structure - Tigăi Valey (Foto: Mihalache, 2020)

From the total number of 185 aprons, during the first inventory, erosion was reported in 57 cases (31%).

For the 57 structures identified with apron erosion at the first inventory, the average damage intensity was 4.586 with a maximum intensity of 32 (40 cm depth on 80% of the surface).

At the end of the second inventory, another 55 structures were found with apron erosion, most of them in the Tigăi basin, where 24 of the 35 works (with apron) were affected by new erosions (Appendix 1).

5.4.3. The stats of the structures induced by the guarding wall damages

5.4.3.1. Guarding wall cracks

This type of damage consists by the presence of some cracks on the surface of the body of the guarding walls, and it can be due to various causes. The cracks can be surface cracks, as a result of the construction tour and deep cracks, due to shocks or internal stresses, these are the ones that endanger the hydrotechnical structure.

At the first inventory, 18 (10%) structures were identified whose leading walls had cracks, the average intensity is 0.36, with variations between 0.019 and 1.203, and the average condition index for those is 75.40, with values between 42.47 and 97.61.

At the end of the second inventory, the number of affected structures increased to 30, the average crack intensity being 0.35, with a minimum of 0.017 and a maximum of 1.203, and the condition index is 71.22.

5.4.3.2. Guarding wall ruptures

Detachment of guarding walls is represented by the different portions detached from the body of the wall, the most severe situation to which the event can lead is the total dislocation of the wall. In this case, the entire structure is placed in imminent danger from the loss of backfill behind the wall, the wings of the work itself being left without any support in the downstream area.

At the first inventory, 21 structures affected by this event were identified, most of them in Vârdaleș valley (7 works).

Between the two inventories, detachment in the guarding walls was observed at 16 transversal hydrotechnical works, the most cases being observed in the Repedea basin (5 cases) and Vârdaleș valley (11 cases).

For the 36 structures identified with guarding walls detachment at the end of the second inventory, the damage intensity increased from 0.11 to 0.23, the average condition index decreased from 70.42 to 59.48, and the status index gradient average obtained the value of -1.52 (Tab. 5.25).

Tab. 5.25. Data of the structure with guarding walls detachments

Specification	Construction material	Number of affected structures	Damage intensity		Status index Ys		Status index gradient Gs
			Inventory		Inventory		
			1	2	1	2	
Structures affected at the fisrt inventory	Masonry (M)	18	0,032	0,274	83,25	75,69	-0,769
	Concrete (B)	3	0,003	0,058	84,52	73,98	-1,547
	Total	21	0,190	0,243	61,26	55,47	-0,880
Structures affected at the second inventory	Masonry (M)	28	0,134	0,240	66,30	57,84	-1,189
	Concrete (B)	8	0,016	0,182	84,82	65,23	-2,694
	Total	36	0,108	0,227	70,415	59,48	-1,524
Structures affected only at the second inventory	Masonry (M)	10	0,000	0,178	80,44	65,84	-1,945
	Concrete (B)	6	0,000	0,213	88,49	65,77	-3,103
	Total	16	0,000	0,191	83,45	65,81	-2,379
Structures where the damage "disappeared"	Concrete (B)	1	0,100	0,000	86,85	76,60	-1,710

5.4.3.3. Guarding wall abrasion

From the total number of structures equipped with guarding walls (181 pieces), at the first inventory, 29 (16%) were identified with erosion on the guarding walls, most of them being in Vârdaleș Valley (Annex 1).

Between the two inventories, another 21 new cases were recorded with this event (Annex 3), the average intensity being 1.45 (in inventory 2). The status index average fell from 85.78 to 70.98, with an average gradient of -1.75.

At the end of the second inventory, the number of works with guarding walls affected by erosion was 49 (27%). For these, the average intensity was 1.91 and the status index registered a difference of approximately 10 units, from 77.67 to 67.00, with an average gradient of -1.37 (Tab. 5.26).

Tab. 5.26. Data of gruanding walls erosion

Specifications	Structure affected		Damage intensity		Status index Ys		Status index gradient Gs
	Number	%	Inventory		Inventory		
			1	2	1	2	
First inventory	29	16	2,20	2,18	70,58	63,14	-1,08
Second inventory (total)	49	27	1,24	1,91	77,67	67,00	-1,37
Structures damaged between inventories	21	12	0	1,45	85,78	70,98	-1,75
Structures where the damage "disappeared"	1	1	3	3,00	42,47	38,40	-0,68

5.4.4.The state of the structures induced by the terminal spur damages

5.4.4.1. Terminal spur un embedding

This type of damage results in the loss of connection between the terminal spur of the structure and the bank in which it is embedded. The loss of this connection can cause severe damage due to the instability of the hydrotechnical construction, the detachment of the terminal spur endangering the apron and the guarding walls, their main supporting element downstream.

During the first inventory, 6 structures were found with un embedding at the terminal spur, of which 2 cases were in the Sohodol Runcu Valley.

For the same 6 works, at the second inventory, the average damage intensity was reduced to 0.395.

Tab. 5.28. Data of un embedded terminat spur structures

Specifications	Structure affected		Damage intensity		Status index Ys		Status index gradient Gs
	Number	%	Inventory		Inventory		
			1	2	1	2	
First inventory	6	3	0,442	0,395	67,7	62,9	-0,85
Second inventory (total)	12	7	0,191	0,324	77,0	64,3	-1,64
Structures damaged between inventories	7	4	0,000	0,217	86,4	68,6	-2,10
Structures where the damage "disappeared"	1	1	0,360	0,000	87,0	86,1	-0,09

For the 12 works where terminal spur un embedding was observed only at the second inventory (Annex 3), the average damage intensity increased from 0.191 to 0.324, while the average value of the status index decreased from 77 (inventory 1) to 64.3 (inventory 2); with a gradient of -1.64 (Tab. 5.28).

5.4.4.2. Terminal spur detachment

Fig. 5.38. Detachment recorded at the terminal spur

Structure 2 B 3,0 –Nanului Creek

(Foto: Mihalache, 2019)

The detachment from the body of the terminal spur is the consequence of the wear of the structure over time, of the uneven settlement of the land, either naturally, or as a result of the action of undermining or as a result of the evolution of cracks and erosions, finally reaching the detachment of fragments of different sizes and shapes.

Following the first inventory, 7 structures (4%) were found with the terminal spur affected by detachment (Tab. 5.30). The maximum value of the status index for these works was 84.3 (structure 30 PB 6.0 – Vidaș Creek), and the minimum value was 23.46 (structure 30 M 1.0 – Jidoștița Valley).

Most of the cases where the damage occurred between inventories were found in Dracului Valley, where 3 of the 15 structures with a terminal spur recorded this damage.

Tab. 5.30. Date privind lucrările afectate de desprindere în pintenul terminal

Specification	Number of affected structures	Average damage intensity		Damage intensity		Status index Ys		Status index gradient Gs
		Inventory		Minimum	Maximum	Inventory		
		1	2			1	2	
First inventory	7	0,379	0,381	0,08	1	57,4	54,1	-0,57
Second inventory (total)	19	0,139	0,235	0,08	1	73,3	60,7	-1,61
Structures damaged between inventories	12	0	0,15	0,01	0,43	82,5	64,6	-2,21

5.4.4.3. Terminal spur abrasion

The event consists of the successive washing of the constitutive layers of the body of the spur, either on the water flow path or on larger surfaces, under the action of the transport of material in suspension, to which are added the temperature variations that lead to repeated freeze-thaw phenomena (Fig. 5.39), with consequences regarding the premature erosion of some surfaces of the terminal spur.

At the first inventory, 10 terminal spurs (6%) were affected by erosion, most of them being on Zimbru Creek (3 structures). For cases where damage occurred between inventories (30 cases), the average intensity is 3.15, and the status index averages are 89.4 (at the first inventory) and 78.9 (at the second inventory). The gradient of the status index for these structures is -1.06 (Tab. 5.32).

Tab. 5.32. Data of the structures affected by terminal spur erosion

Specification	Affected structures	Average damage intensity		Damage intensity		Status index Ys		Status index gradient Gs
		Inventory		Minimum	Maximum	Inventory		
		1	2			1	2	
First inventory	10	3,230	3,200	0,30	8	79,51	75,73	-0,52
Second inventory (total)	40	0,801	3,169	0,30	8	86,89	77,13	-0,92
Structures damaged between inventories	30	0	3,148	0,15	36	89,30	78,93	-1,06

At the end of the second inventory, erosion of the terminal spur was identified in 40 cases (25%), with the average intensity increasing from 0.81 (first inventory) to 3.17 (second inventory), with an status index gradient average of -0.92 units/year.

5.4.5.The state of the structure induced by dysfunctionalities

5.4.5.1. Spillway blockage

Of the total of 285 structures taken in the study, a large part had, to a greater or lesser extent, the spillway blocked with various materials. At the first inventory, 136 spillways (48%) were found with different blockage intensities, the average dysfunctional intensity being 19%; however, it decreased during the time between the two inventories to 8%.

In the period between inventories, another 48 structures (17%) "faced" the blocking event.

The number of structures affected at the end of the second inventory is 134 (47%), the average spillway blockage intensity for them being 12% (first inventory) and 11% (second inventory); the status index gradient average is -1.08 (Tab. 5.34).

Tab. 5.34. Data of the structures with the spillway blocked

Specification	Number of affected structures	Dysfunctionality intensity (%)		Status index Ys		Status index gradient Gs
		Inventory 1	Inventory 2	Inventory 1	Inventory 2	
First inventory	136	19	9	83,76	75,59	-1,10
Second inventory (total)	134	12	11	85,42	76,00	-1,08
Structures damaged between inventories	48	0	5	86,70	76,79	-1,28

5.4.5.2. Apron silting

The apron, as the main annex of the transversal hydrotechnical structure, located in downstream of the spillway area, with the role of protecting (the zone) it from undermining and reducing the kinetic energy of torrential flows. Apron is required by various forces during torrential events, after which the coarse materials and floats remain often blocked or sedimented on the apron when the flow loses its intensity (Fig. 5.40).

Fig. 5.40. Apron silting

Structure 11 B 2,0 –Tesla Creek

During the first inventory, 126 cases (68%) were identified with apron silting (Tab 5.36).

Tab. 5.36. Data of silted aprons

Specifications	Structure affected		Dysfunctionality intensity		Status index Ys		Status index gradient Gs
	Number	%	Inventory		Inventory		
			1	2	1	2	
First inventory	126	68	0,228	0,220	84,3	75,4	-1,07
Second inventory (total)	130	70	0,203	0,226	86,3	78,0	-0,99
Structures affected only at the second inventory	27	15	0,000	0,061	87,1	78,4	-1,08
Structures where the dysfunctionality "disappeared"	23	12	0,103	0,000	75,9	64,1	-1,54

The average intensity of silted aprons for those 23 structures where the dysfunction "disappeared" (the rived deposits on the surface of the apron were washed or removed) was 0.103, and the average status index reduced from 75.9 (first inventory) to 64.1 (second inventory), the status index gradient average being -1.54 units/year.

5.4.5.3. Incomplete sedimentation

The height of the transversal blocked sediments is the length measured from the base of the elevation to the level at which the sediments were deposited. Failure to achieve the maximum height of the blocked sediments in the expected time is rated as a dysfunction because the existence of the sediments is absolutely necessary to support the upstream structure.

At the first inventory, from the 222 structures capable to sediments blockage, 216 landings were fully formed; the average intensity of the event decreased from 0.924 to 0.904 (second inventory), the status index gradient is -1.04.

In the period between the inventories, 9 structures (3%) which at the first inventory had a blocked sediments with an intensity of 0.948 lost their landing as a result of the detachment recorded on the body structure, the average intensity of the detachment being 20,1%.

At the end of the second inventory, 207 structures were found with landing formed or in the process of formation, the landing intensity increasing slightly from 0.923 (inventory 1) to 0.943 (inventory 2), which denotes that part of the structures blocked new sediments in the period between inventories.

5.4.5.4. Vegetation installed uncontrolled

This dysfunction does not directly participate in the occurrence of damages, but, in an indirect form, it can lead to disruptions of the integrity and operation of the structures. It can lead to changes in the water course, downstream or upstream of the structure, which conduct in the diversion of the torrential flow route (Ungurean et al., 2021).

With vegetation installed uncontrolled in the upstream, at the first inventory, 80 cases (28%) were detected. In the absence of maintenance, the average event intensity of 2.15 (inventory 1) increased slightly to 2.51 (inventory 2).

At the end of the second inventory, for 232 cases identified with uncontrolled vegetation installed upstream of the structure, the average intensity was 1.81 (inventory 2).

In the downstream sector of the structures, at the first inventory, uncontrolled vegetation was identified, at a number of 64 works (22%), the average intensity is 2.25. In the case of the second inventory, the frequency increased to 216 cases (76%), with an average intensity of 1.53

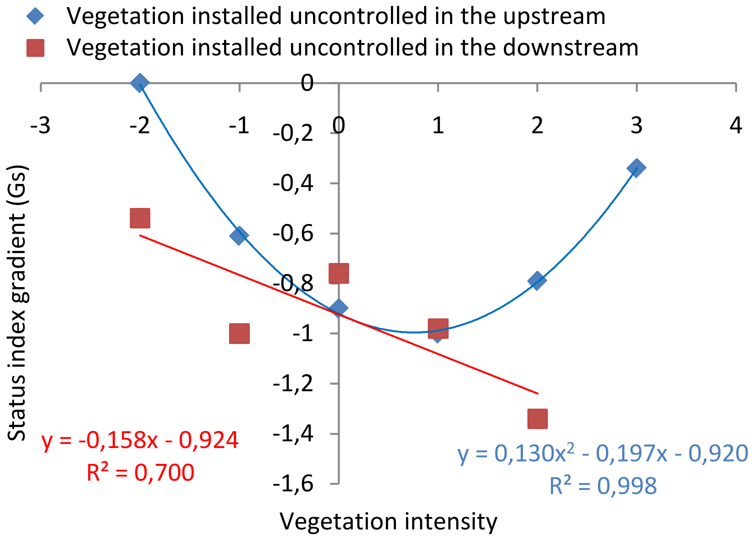


Fig. 5.41. The variation of the status index gradient in relation to the vegetation installed uncontrolled upstream/ downstream of the transversal hydrotechnical structures

5.4.5.5. Downstream section reduction

The downstream blockage is mainly caused by blocking the materials transported by torrential flows, on the one hand by reducing the flow speed, and on the other hand, by encountering various obstacles that lead to the blocking and creating deposits in areas with a higher roughness coefficient.

At the first inventory, 84 cases (29%) of reduction in the downstream section were identified, with an average intensity of 29%; the last one experienced a 2% reduction between the two inventories.

At the second inventory, reductions of the downstream section were recorded in another 87 cases (31%), the average intensity being 37% and the maximum 95%. For those 87 cases, the average of the status index gradient was -0.78 units/year. At the end of the second inventory, the structures that presented reductions in the downstream section were 154, the average intensity being 35% and the average of the status index gradient records -1.04 units/year.

5.5. The state evolution in relation to some characteristics of the emplacement

5.5.1. The state in relation to the geographical location

The physical status of the transversal hydrotechnical works in the analyzed basins and perimeter reflects the varied conditions that are due (and) to their geographical positioning in different areas of the country such as: the size of the basin, the geological conditions, the rainfall regime, the bed width, etc., altogether leading to variations in the status index gradient. To highlight the impact of the influencing factors, we resorted to determining the status index and the gradient for each torrential hydrographic basin (Tab. 5.38).

Although generalizations cannot be made at the level of a large watershed, it can be observed that the most severe deteriorations in status were observed at the Tisa basin hydrotechnical structures, where the average difference in the status index values is -16.5 units, with an average gradient of -2.35 units/year.

The highest values of the coefficient of variation were obtained for the structures located in the Someș hydrographic basin, where due to the small number of structures but also the pronounced amplitudes of the status index, values of 40.7% were obtained for the status index related to the first inventory and 48.8% for the second inventory.

In the case of the status index gradient, the highest value of the coefficient of variation (54.8%) was obtained for the structures localized in the Olt hydrographic basin, this being due to a large number of structures, as well as the large amplitude of the status index gradient, which evolves between -14.32 units/year (structure 1 B 0 – Tesla Creek) and 2.37 units/year (90 B 0 – Adânca de Jos) (Tab. 5.38).

Tab. 5.38. The variability of the status index and status index gradient, across large hydrographical basins

Hydrographic basin	Number of structures	Status index (Ys)			Status index gradient Gs	Gradient amplitude		Variation coefficient (%)		
		Inventory		Difference		Minimum	Maximum	Ys		Gs
								Inventory		
		1	2					1	2	
Tisa	29	75,36	58,89	-16,46	-2,35	-7,46	0,15	21,5	27,6	43,1
Someș	7	68,57	57,30	-11,27	-1,41	-3,25	0,05	40,7	48,8	39,5
Crișuri	51	93,10	82,91	-10,19	-1,27	-7,41	0,00	19,3	21,6	45,4
Banat	20	75,46	72,05	-3,41	-0,57	-3,22	0,05	25,6	26,8	27,4
Jiu	28	82,18	77,90	-4,28	-0,58	-2,89	0,50	21,5	22,7	29,8
Olt	114	87,43	77,71	-9,72	-1,14	-14,32	2,37	17,2	19,4	54,8
Ialomița	19	64,19	59,75	-4,44	-0,74	-3,58	1,07	17,8	19,1	30,6
Dunăre	17	74,67	75,35	0,68	0,11	-1,43	1,89	24,2	23,9	35,1
Total / Average	285	83,1	74,5	-8,6	-1,1	-	-	23,5	26,2	38,2

5.5.2.The state in relation to the riverbed opening at the top of the structure

The opening of the torrential valley, along with other factors, dictates the length at the top of the transversal hydrotechnical structure.

In the case of the works located in the lower sector of the managed torrential valley, the traverses record an average gradient value of -1.76 units/year, followed by thresholds (-1.21) and dams (-0.71 units/year). In the middle sector, proved vulnerable thresholds (-1.50 units/year), subsequent traverses (-1.44 units/year) and the dams (-0.94 units/year). In the case of the structures located in the upper third of the managed torrential valley, approximately the same average values of the gradient were recorded: traverses (-1.01 units/year), -1.00 at thresholds and -0.97 for dams (Tab. 5.41).

Tab. 5.40. The status index gradient in relation with the structure type and its opening at the top

Top opening interval (m)	Traverses in the sector:			Threshold in the sector:			Dam in the sector:		
	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
0 - 10	-0,73	-1,61	-1,35	-1,59	-3,22	-2,48	-	-2,88	-
10 - 20	-2,34	-1,36	-0,34	-1,27	-0,84	-1,08	-	-0,80	-0,53
20 - 30	-1,15	-0,68	-2,82	-1,25	-1,32	-1,38	-0,33	-0,43	-0,96
30 - 40	-	-3,81	-	-	-0,75	-0,77	-0,72	-1,18	-0,68
40 - 50	-	-	-	-0,05	-2,39	0,95	-1,10	-1,99	-0,90
50 - 60; >60	-	-	-	-	-	-0,13	-2,14	-1,27	-0,38
Average	-1,76	-1,44	-1,01	-1,21	-1,50	-1,00	-0,71	-0,94	-0,97
	-1,34			-1,23			-0,79		

Note: The delimitation of the three sectors was done according to the numerical criterion, that is, by dividing the total number of structures in the managed sector by three. Therefore, the number of structures from one sector to another is equal within the same valley.

5.6. The state index evolution in relation to some structure dimensional characteristics

5.6.1.The state in relation to the structure height

The gradient of the status index gradient proved to be in correlation with the height of the structures,

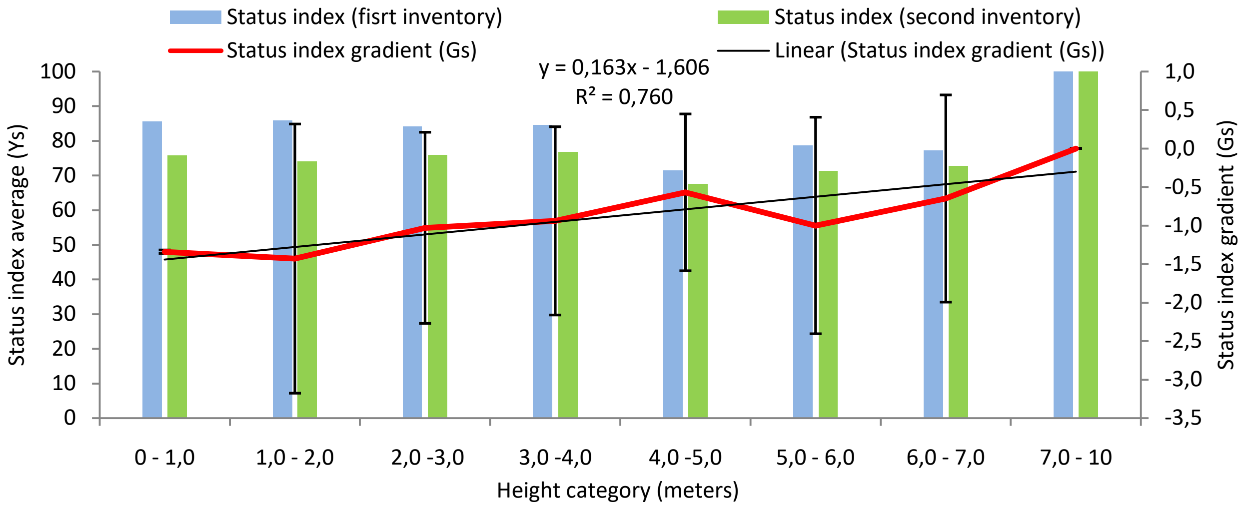


Fig. 5.42. Status index gradient in relation to the structures height category

leading to conclusive variations even if a certain legitimacy could not be established, the coefficient of determination being 0.760 (Fig. 5.42). The average gradient was -1.34 for structures with heights between 0 – 1.0 meters and -1.31 for those with heights between 1.0 – 2.0 meters. The most affected were the thresholds of 0.1 – 0.5 meters, for which the gradient recorded the value of -2.1 units/year.

5.6.2. The state in relation to the spillway opening

The influence of spillway opening on the status index gradient was further studied, with a strong link observed in a certain category.

The most representative category proved to be for the structures whose spillways have an opening between 5 and 10 meters, the coefficient of determination for those being 0.959 (Fig. 5.43).

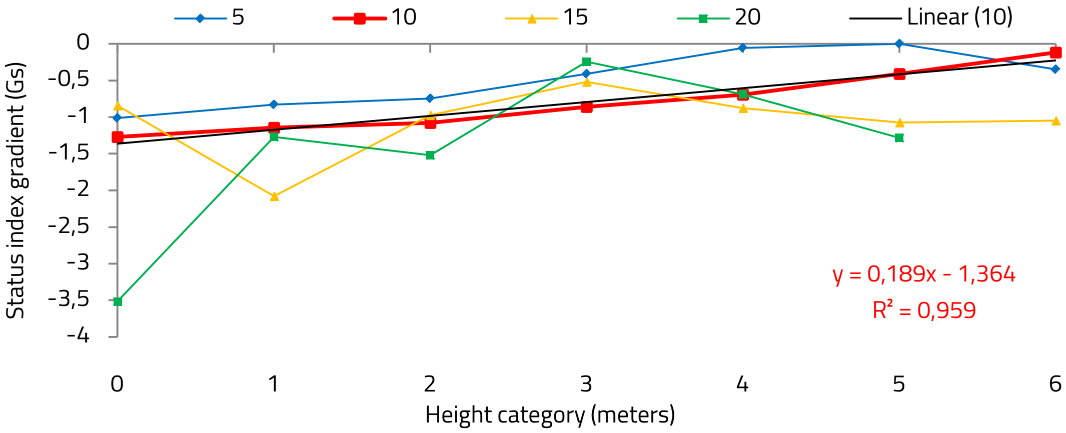


Fig. 5.43. Status index gradient in relation to spillway opening

5.6.3.The state in relation to spillway height and structure height

Based on the centralized data in the following table, it was found that the structures with a height of up to a maximum of 2 meters show the greatest variations in the status index gradient, more affected being thresholds up to 1.0 meters high (- 1.43 units/ year), followed by traverses (-1.33 units/ year), dams with 5.0 meters high (-1.06 units/ year) and 2.0 meters high (-1.03 units/ year).

Tab. 5.41. The status index gradient concerning the height of the spillway and the structure height

Spillway height (m)	Number of structure	Structure height category (m)								Total / Average
		0	1	2	3	4	5	6	10	
0,01...0,5	10	-	-1,47	-1,88	0	-	-1,42	-	-	-1,40
0,51...1,0	99	-1,45	-1,51	-0,65	-0,66	-1,12	0	-0,41	-	-1,06
1,01...1,5	105	-1,41	-0,93	-0,64	-1,11	-0,33	-0,40	-1,14	-	-1,02
1,51...2,0	11	-0,59	-2,06	-1,68	-1,29	-0,28	-2,90	-0,27	-	-1,27
>2	60	-	-1,33	-1,38	0	-	-0,60	-	0,00	-0,66
Average / Total	285	-1,33	-1,43	-1,03	-0,95	-0,57	-1,05	-0,65	0,00	-1,10

5.7. The state evolution in relation to other characteristics

5.7.1.The state in relation to structure age

Depending on the structure age, a pronounced variability of the gradient was found in accordance with the number of analyzed works. Thus, more pronounced variations of the gradient were found at the newest structures (age category 5-10 years), even though it were put into operation most recently (Tab. 5.42). But, the most significant decreases in the status index gradient were found in the case of structures in the 10 - 15 years age category, where the 50 cases examined presented an average gradient of -2.13. The structure with the most severe damage is the 10 B 0 localized on Tesla Creek.

Tab. 5.42. The status index gradient concerning the structure's age

Age category	Number of structure	Status index		Status index gradient Gs	Gradient amplitude		Standard deviation of the gradient
		Ys 1	Ys 2		Minimum	Maximum	
5 - 10	34	91,60	85,14	-0,84	-7,13	1,89	1,515
10 - 15	50	84,42	69,73	-2,13	-14,32	1,64	2,522
15 - 20	33	91,39	83,78	-0,76	-3,81	1,10	0,826
20 - 25	10	73,86	67,82	-1,01	-3,58	0,00	1,259
25 - 30	9	71,50	62,14	-1,22	-2,93	0,15	1,022
30 - 35	22	76,50	72,45	-0,62	-3,22	0,05	0,828
35 - 40	76	81,20	72,53	-0,98	-7,91	2,37	1,539
40 - 45	23	85,53	80,07	-0,67	-2,52	0,39	0,849
45 - 50	6	80,72	77,28	-0,44	-1,43	0,50	0,662
50 - 55	22	74,61	68,19	-0,84	-7,46	1,58	1,935

5.7.2. The state in relation to construction materiales

It could be observed that, along the age, the nature of building materials can influence the variation of the status index gradient, each building material having a certain behavior over time (Ki-Hwan Lee et al., 2022).The data in table 5.43 show that stone masonry with cement mortar structures performed better during the service period, having a gradient of -0.87 units/year, lower than that of concrete structures (-1, 28 units/year). In other words, local materials (building stone) are more resistant to weathering than other materials, this conclusion also results from other previous studies (Davidescu, 2013; Mihalache, 2020).

Tab. 5.43. The gradient in relation to the sontruction material

Construction material		Number of structures	Status index		Status index gradient	Gradient amplitude		Gradient standard deviation
Cod	Name		Inventory		Gs	Minimum	Maximum	
			1	2				
B	Concrete	144	83,62	73,57	-1,28	-14,32	1,93	2,37
M	Stone masonry with cement mortar	124	83,58	76,77	-0,87	-7,46	1,37	1,58

Construction material		Number of structures	Status index		Status index gradient Gs	Gradient amplitude		Gradient standard deviation
Cod	Name		Inventory			Minimum	Maximum	
			1	2				
PB	Blocks, prefabricated concrete boxes	4	90,64	87,70	-0,27	-0,87	0,56	0,48
BCF	Concrete buttresses and concrete beams (reinforced)(filtered dam)	3	61,49	60,07	-0,20	-0,76	0,49	0,15
BF	Concrete (filtered dam)	3	68,96	53,07	-2,27	-3,67	1,99	0,01
MB	Stone masonry with cement mortar + Concrete	3	65,02	60,83	-0,70	-1,41	0,71	0
BT	PREMO tubes filled with local materials	2	100	96,00	-0,50	-1,00	0,71	0
MF	Stone masonry with cement mortar (filtered dam)	1	81,58	73,00	-1,43	-1,43		-
XX	Other materials (used tires)	1	43,78	43,70	-0,01	-0,01		-

5.8. The evolution of the structure state according to their initial state

The evolution, in a given period, of the status of the transversal hydrotechnical structures used in torrential riverbeds management it largely depends on the initial state of the works. Indeed, the intensity of damage and dysfunctionalities varies over time, structures with a "good" condition at the first inventory experiencing greater decreases in the status index, compared to structures that, after numerous damage recorded over time, reach a certain status " of balance" (Tab 5.44), an aspect that was also observed in a previous study (Mihalache, 2018) (Fig. 5.44).

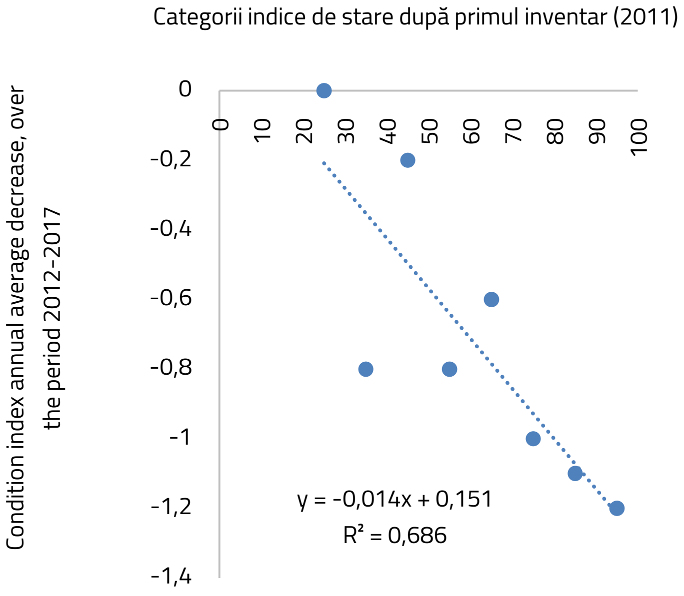


Fig. 5.44. The influence of the initial state of the structures on the status index (Mihalache, 2018)

According to the data, it was observed that the structures from 90-100 category (otherwise also the most numerous) recorded the lowest values of the gradient, the value of -1.30 units/year attesting to the fact that the structures with a very good physical condition at the first inventory have been identified with the most damages and dysfunctionalities (at the second inventory), the gradient taking values between -14.32 and 0.48 units/year. The initial state of the structures therefore proved to have an impact on the gradient.

5.9. Results of the statistical analysis on the status index gradient

5.9.1. Level of statistical significance of influencing factors

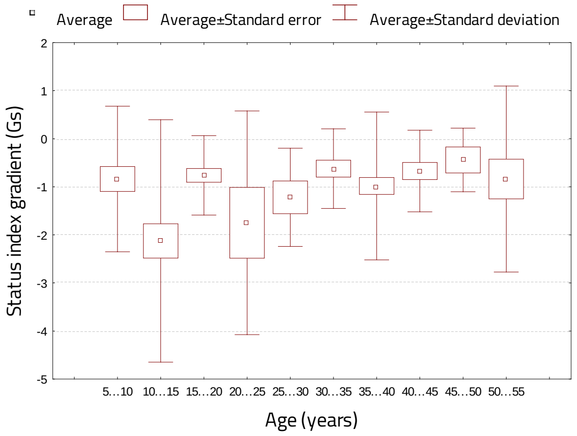


Fig. 5.47 Gradient variation in relation to the age of the structure

From the perspective of the gradient, the state of the transversal hydrotechnical structures is dependent on the factors acting at the individual level. To highlight the statistical influence of these factors, with the help of the Statistica 7 program, the ANOVA test was applied for the variables whose data showed homogeneity (Levene's test) and the Kruskal-Wallis test for the data sets that did not meet the homogeneity condition. Statistical tests applied to the influence of these factors proved this dependence, but only partially.

Thus, at the level of the entire population of re-inventoried structures, among the influential factors related to the structure itself and it location, significant influences on the status index gradient were identified for the: age of the work (p^1 = 0,003; Fig. 5.47), spillway opening (p = 0.042), hydrographic area (p = 0.0001; Fig. 5.49) and the annual precipitation average (p = 0.0002; Fig. 5.50).

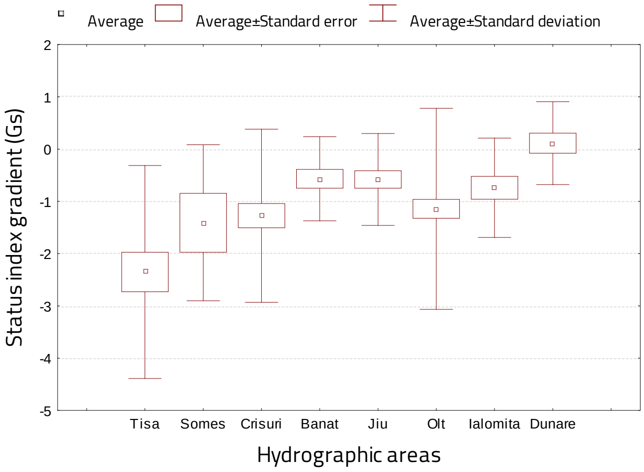


Fig. 5.49. Gradient variation concerning the hydrographic areas

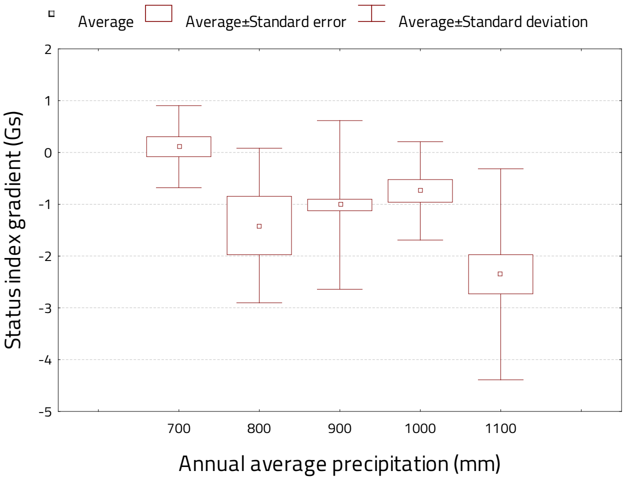


Fig. 5.50. Gradient variation concerning annual precipitation average

Regarding the influence of construction materials, among the 9 types, significant differences were found only between the first two categories: concrete and stone masonry with cement mortar.

The age of the structures proved to have a significant influence on the variation of the status index gradient (p = 0.003), these variations being observed concerning all age categories (Fig. 5.47) (Annex 5a).

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[1] p – probability of rejecting the null hypothesis

And under the location of the transversal hydrotechnical structures by large hydrographic basin, a clear differentiation resulted in the status index gradient, with pronounced variations (Fig. 5.49) (Annex 5b). These can be due, among others, both by the characteristics of the torrential basins and by the bumpy relief of each large hydrographic basin, the steep slopes of the Tisa or Olt hydrographic basin inducing gradient amplitudes from -7.46 to 0.15 units/year, respectively from -14.32 to 2.37 units/year.

The amount of precipitation was found to have a significant impact on the status index gradient variation ($p < 0.001$), even though the variations are pronounced in relation to each category. Thus, as can be seen from figure 5.50, the structures with the most significant values of the status index gradient are located in areas where the average precipitation is quantitatively more significant, at 1100 mm/year (in the Tisa basin) (Annex 5c).

Among the behavioral events that influence (statistically proved) the gradient of the status index, we mention: un embedding of the body structure ($p < 0.01$), undermining of body structure ($p < 0.01$, Fig. 5.52), detachment in the spilled area ($p < 0.01$, Fig. 5.53 a), wall wings detachment ($p = 0.02$), apron detachment ($p = 0.001$), apron erosion ($p = 0.03$), guarding walls detachment ($p = 0.001$) and terminal spur undermining ($p = 0.001$).

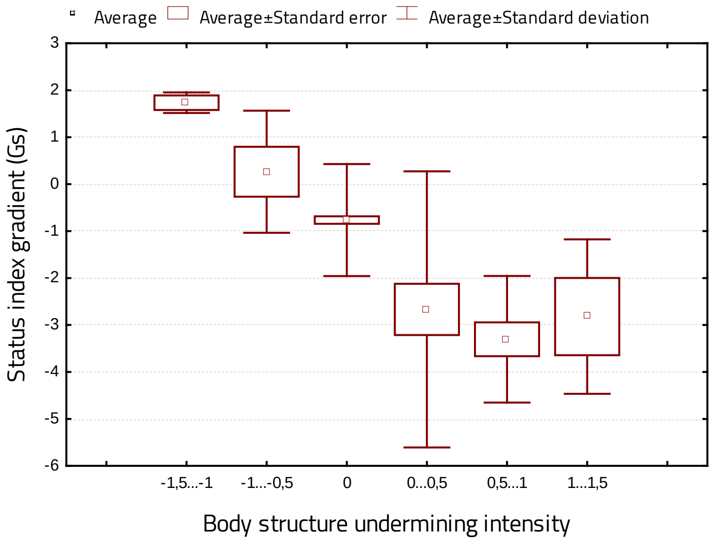


Fig. 5.52. Gradient variation concrning body structure undemining intensity

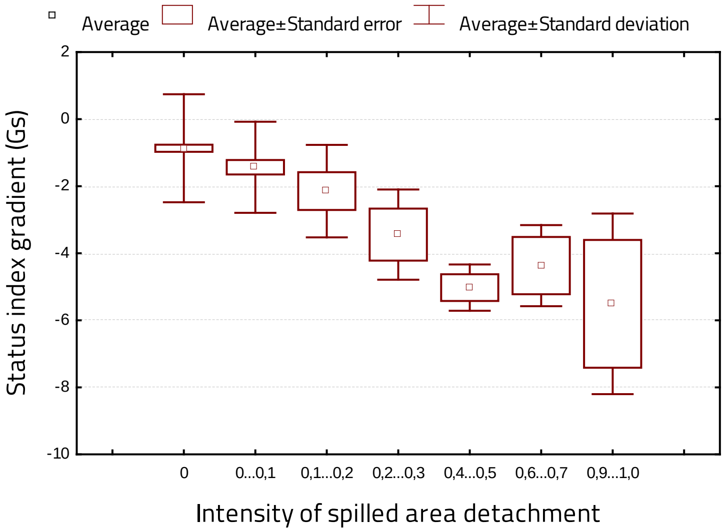
From the perspective of the body structure, with the reduction of the intensity of the damage, positive values are recorded for the gradient, respectively, negative values are recorded with the increase of the intensity of the damage (Fig. 5.52), significant differences being observed between different categories of undermining (Tab. 5.46).

Tab. 5.46. The significance of the differences between the body structures undermining category

Undermining intensity category	-1,5...-1,0	-1,0...-0,5	0...0,5	0,5...1,0	1,0...1,5
-1,5...-1,0	-	0,448	0,014 *	0,007 **	0,03 *
-1,0...-0,5	-	-	0,008 **	0,003 **	0,048 *
0...0,5	-	-	-	0,411	0,904
0,5...1,0	-	-	-	-	0,719
1,0...1,5	-	-	-	-	-

Note: * – Significant; ** – Significantly distinct

And for the detachment from the spilled area, an otherwise expected result was found, in which the intensity of the damage has a major impact on the physical condition of the structures. As can be seen from figure 5.52 a, if detachments are greater than 60%, the damage brings large variations on the status index gradient. In other words, the greater the detachment intensity, the more the transversal hydrotechnical structure loses its functional role and implicitly will be exposed to fewer associated damages (Fig. 5.53b).



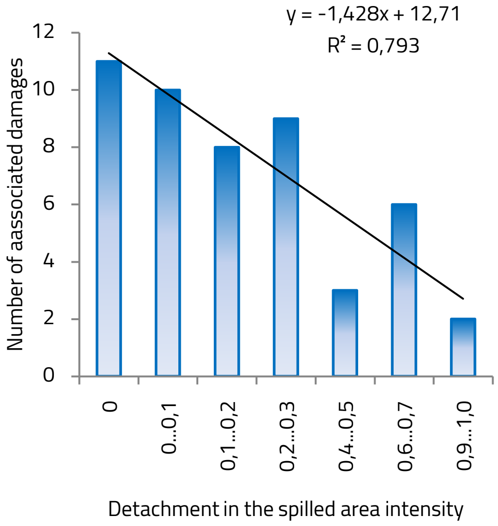


Fig. 5.53 a- Status index gradient variation concerning spilled area detachment

Fig. 5.53 b- The maximum number of associated damages concerning the intensity of detachment in the spilled area

5.9.2. Frequency distribution of the status index gradient

In order to better understand the variability of the status index gradient and to represent the frequency distribution of this index, among other things and because certain statistical indicators and certain statistical methods of data processing asume the prior proof of the normality of the frequency distributions, the data were framed and tracked according to various criteria.

After checking the experimental distribution in relation to two theoretical distributions (normal and Meyer distribution), it was proven that the frequency of the gradient is distributed differently depending on both the size of the classes and the chosen criteria according to data stratification.

The gradient being the result of the variation of the staus index, in the period between the inventories, a question was asked: which distribution follows the differences between the status indices? In this sense, the frequency distribution was represented and was compared with the theoretical one (Gauss), the result being a distribution close to the normal one (Fig. 5.57).

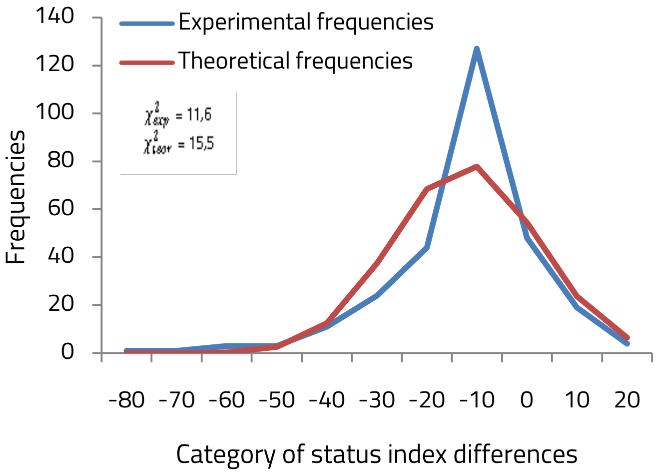
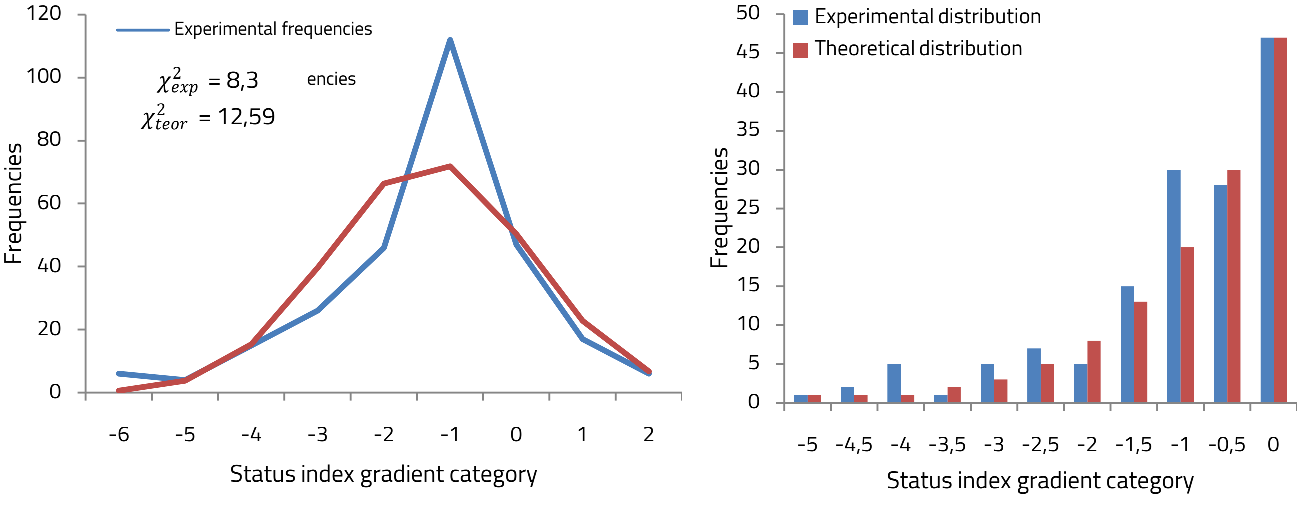


Fig. 5.57. Frequency distribution of the status indicies difference

In the case of the total number of structures taken into the study (285), for categories of 1.0 of the gradient, the frequency distribution turned out to be close to the normal distribution, if the positive values of the gradient are also taken into account (Fig. 5.58 a), the χ^2 test confirming this aspect (Annex 6b). In fact, on categories of 0.5 of the gradient, the frequency distribution was found to follow Meyer's law, the experimental distribution approaching the theoretical one (Fig. 5.58 b), the t-test confirming that the frequencies of the experimental data are significant for the analyzed population.



a

b

Fig. 5.58. Frequency distribution of the status index gradient for total number of structures

Depending on the usual typology of the structure, for all three categories of works (traverses, thresholds and dams) it was possible to observe the closeness between the experimental distribution of the gradient (by class categories of 1.0) and the normal distribution, only in the situation in which both negative and positive gradient values are taken into account (Fig. 5.59) (Annex 6c).

In the case of the presence or absence of the apron, the frequency distribution of the gradient approached a normal one, in both cases, confirmed by the χ^2 test (Annex 6d).

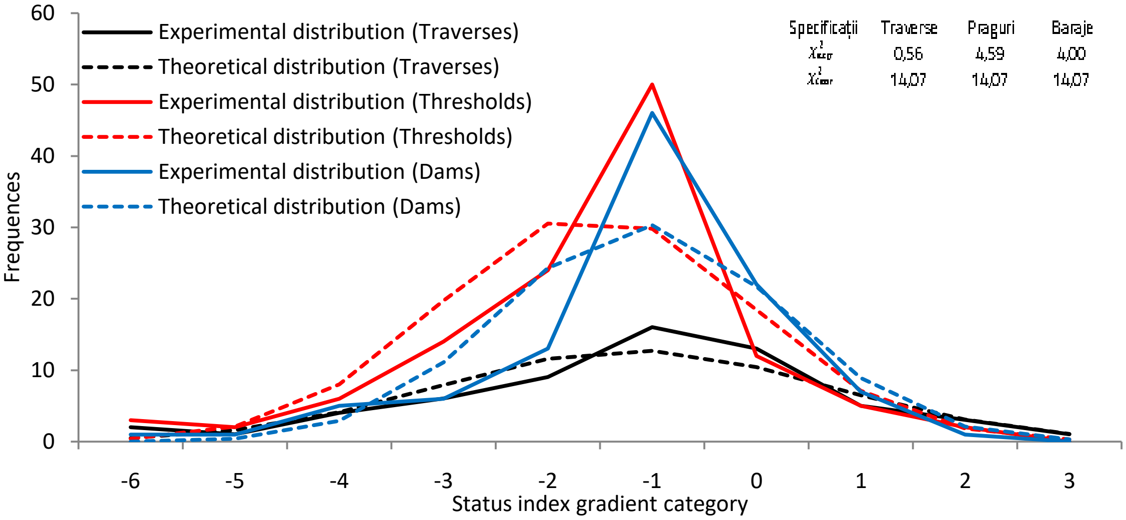


Fig. 5.59. Frequency distribution of the gradient in accordance to theoretical distribution, for usual typology of structure

5.9.3.Principal Component Analysis (PCA)

By replacing the large number of initial variables with only two variables (latent, nonmanifest), this method of multidimensional analysis successively extracts the variability that is common to all parameters, indicating the percentage of the total variance attributable to each component (Petrițan, 2008).

In the present research, principal component analysis was limited to only those factors that were found to have a significant influence on the status index gradient (Fig. 5.64). In this case, following the introduction of the 12 variables, a coverage of 35% of the total variance on the first two axes was reached (Annex 7). On the first axis, correlations are highlighted between: apron undemining, body structure undermining and the opening of the spillway, to which is also added the correlation between the apron detachment and average annual amount of precipitation.

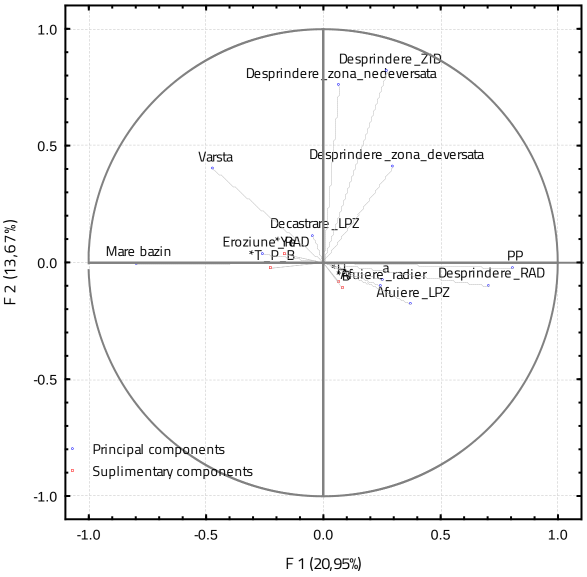


Fig. 5.64. Graphic representation of principal component analysis on Gs, for statistically significant components

5.10. Impact of a torrential event reflected in the statu index gradient (Case study)

To achieve this objective of the research, the period 26.06.2018–30.06.2018 was taken into account, in which the rain gauge station and the rain gauges installed in the Tigai basin (Fig. 5.65) (equipment financed by the CLISWELN project[2]), ecorded a quantity of precipitation of 205 mm, with a maximum intensity of 1.1 mm/min (29.06.2020 hours 00:10 - 00:20).

As this amount of precipitation sums up about a quarter of the precipitation that falls annually in the area of the Săcele Reservoir - 820 mm (CarpatClim-eu.org), we chose to study the influence of the flows generated by these rains on the state of the transversal hydrotechnical structures. For this purpose, we choose to use the hydrological model MikeHYDRO (www.mikepoweredbydhi.com).

The calibration of the model for the entire Tărlung basin was carried out on a daily level, over a period of 10 years (2000 – 2010) (Fig. 5.69), with a limit error of the flow rates of approximately 2%, obtaining a determination coefficient of $R^2 = 0.580$. However, as in this study we are interested about the maximum discharge generated during the torrential flows, calibration was then carried out by running at the daily level of the year 2005, which was chosen for the sequence of torrential events that took place in the summer season. Following the calibration for the year 2005 (with the flows provided by INHGA), the resulting coefficient of determination was only $R^2 = 0{,}21$, the resulting values being induced especially by the most sensitive parameters (snow melting, underground supply). But although the model has this

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[2] Climate Services for the Water – Energy – Land – Food Nexus

disadvantage of sensitive parameters (Johandideh et al, 2020), the extreme summer season flows resulting from the calibration were achieved in most cases, with the extreme peak of the hydrograph being overestimated by only 2% (Fig. 5.70). After the calibration procedure, the model was also validated, the maximum flows simulated for the year 2009 being overestimated by approximately 37% (Fig. 5.71). The year 2009 was chosen because it presents similar conditions, in terms of precipitation, with the year of interest - 2018.

Following the simulation of the torrential events that took place between 26.06.2018 and 30.06.2018, the following flow rates and maximum speeds were generated at the exit of the spillways of the structures (Tab. 5.48):

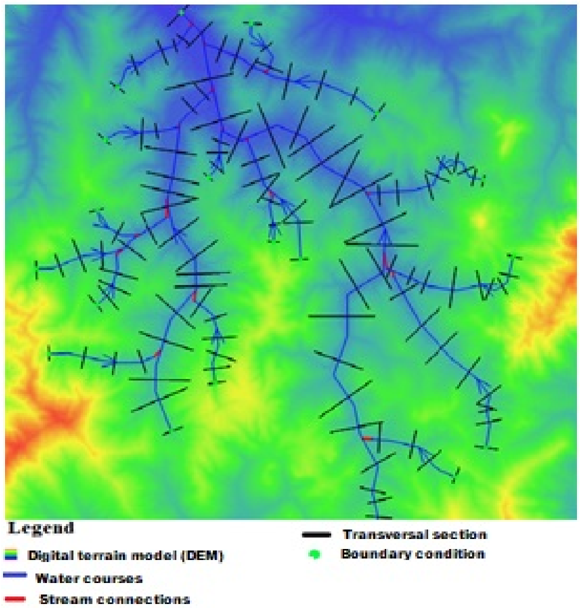


Fig. 5.67. Creating the Mike Hydro model for the upper basin of the Tărlung river basin– Upstream of the Săcele Reservoir

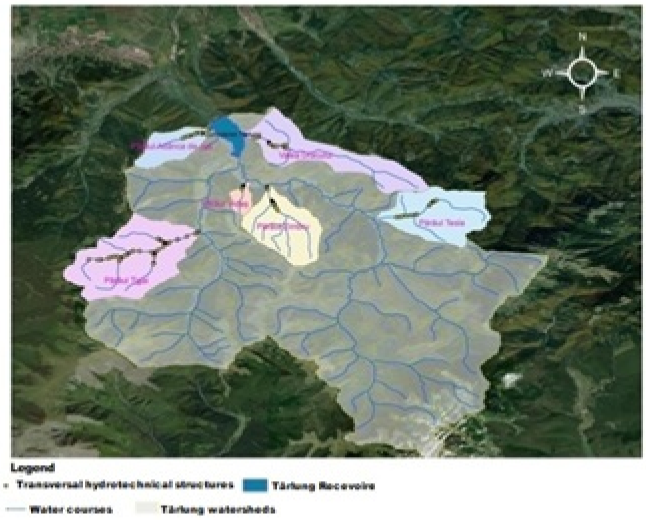


Fig. 5.72. The basins and transversal hydrotechnical structures studied, in Tărlung river basin– Upstream of the Săcele Reservoir

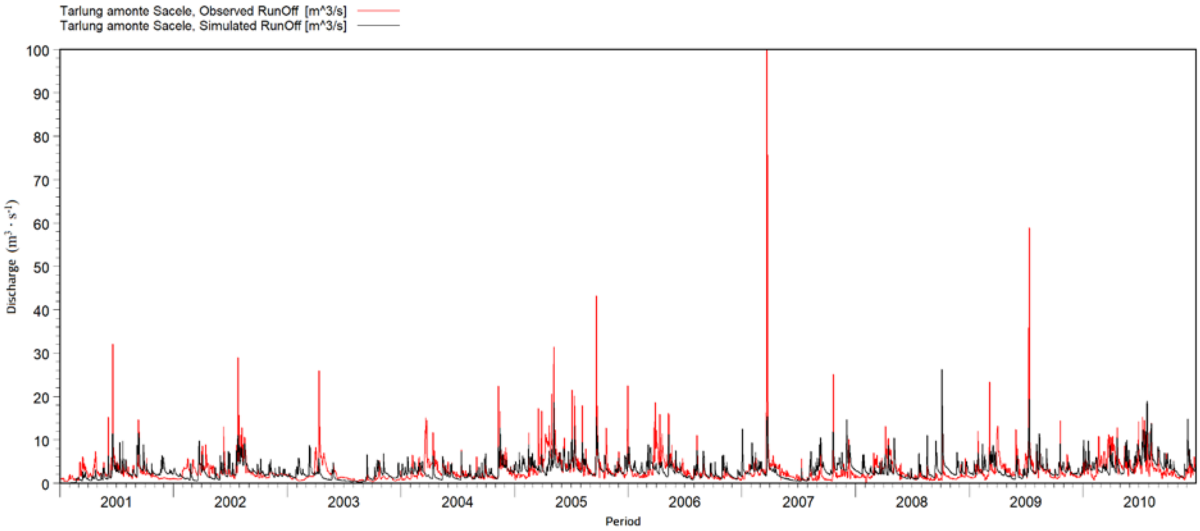


Fig. 5.69. Simulated flows following calibration of the Mike Hydro model, over a 10-year period

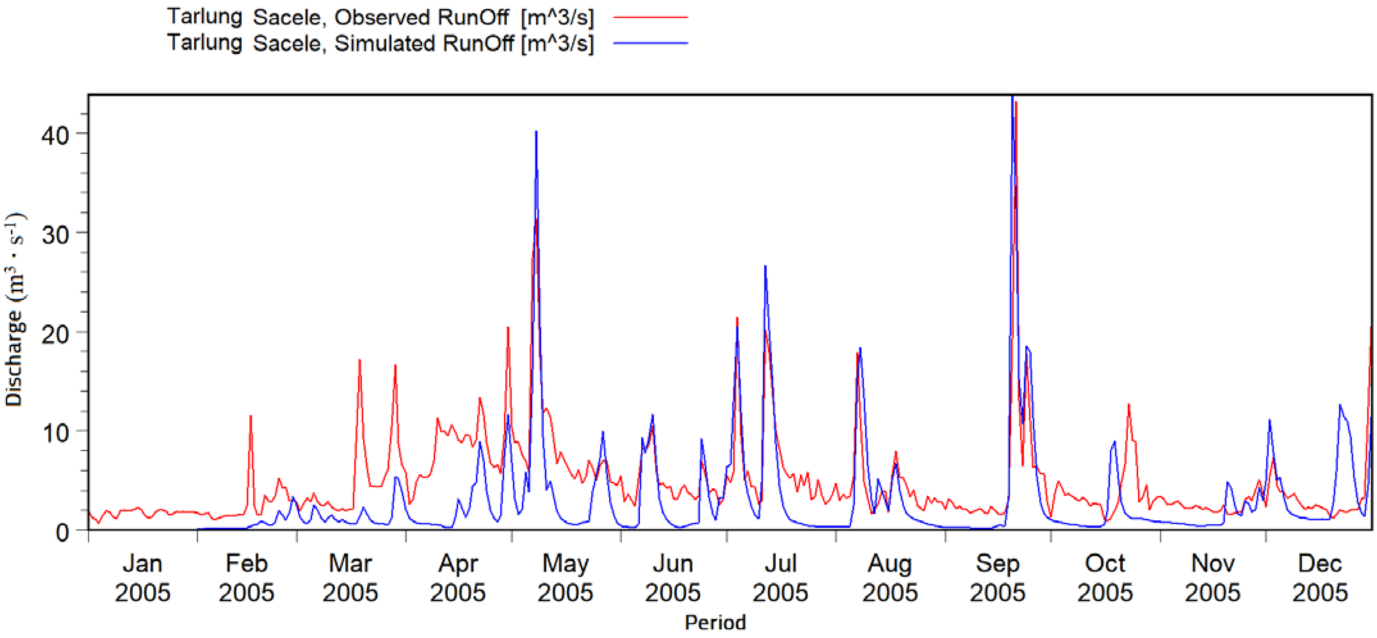


Fig. 5.70. Simulated discharge following the calibration of Mike Hydro model for the year 2005

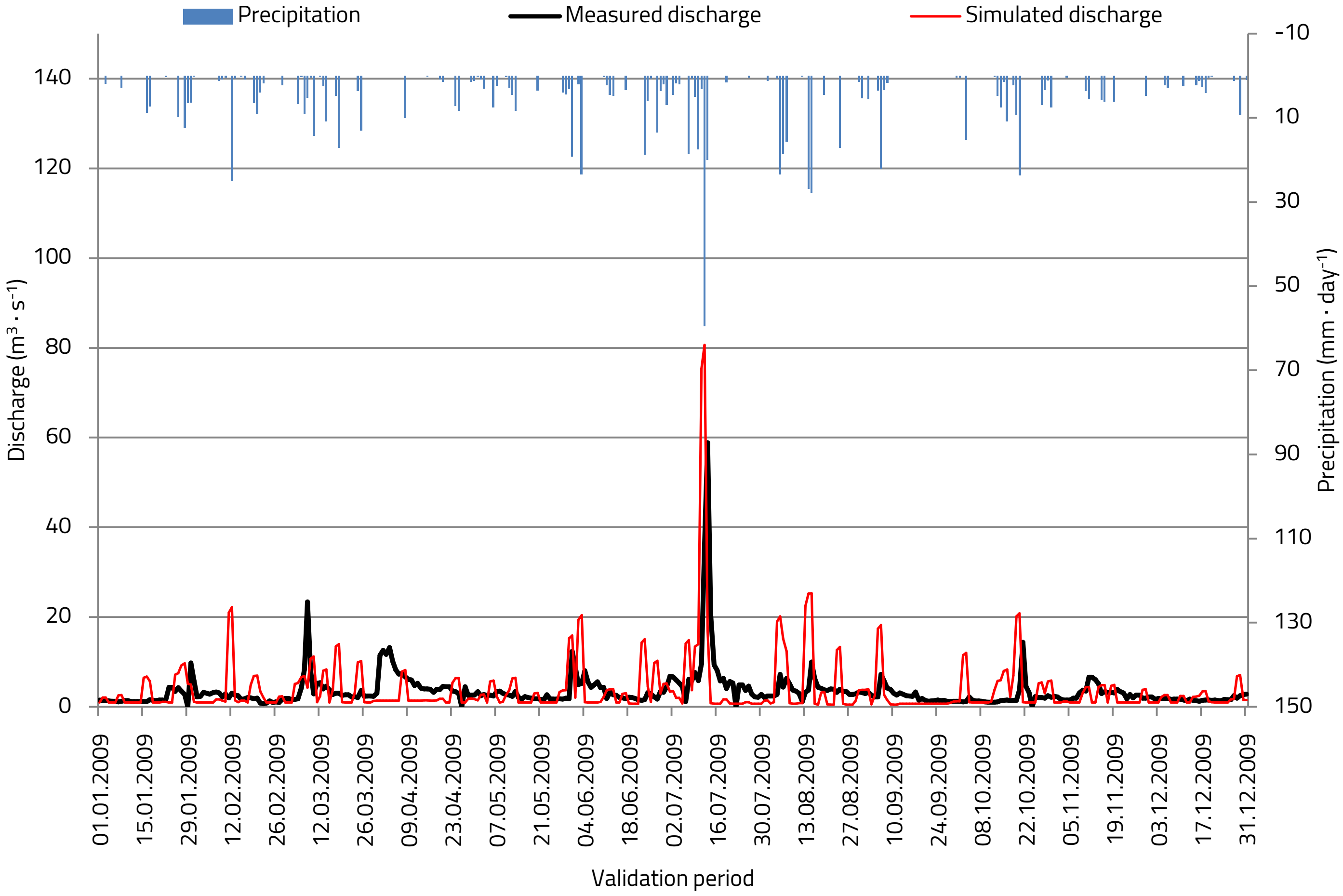


Fig. 5.71. Simulated discharges following validation of the Mike Hydro model

Tab. 5.48. Specifications relating to the discharges and velocities, generated during the torrential flow

Torrential basin	Water course	Maximum discharge		Flow velocity ($m \cdot s^{-1}$)	Registration time (Data/ hour)
		Transversal hydrotechnical structure	Discharge ($m^3 \cdot s^{-1}$)		
Adânca de Jos Valley	Main course	10 M 1	4,35	2,82	30.06.2018 / 00:08
Tigăi Valley	Main course	1 B 0	46,32	3,74	30.06.2018 / 00:07
	Left Creek	1B 0	4,09	2,26	30.06.2018 / 00:04
	Nanului	11 B 0.5	1,63	1,28	30.06.2018 / 00:05
	Ferencz	1 B 0	1,44	1,84	30.06.2018 / 00:08
Vidaș Creek	Main course	20 B 2	2,12	1,64	30.06.2018 / 00:06
Zimbru Creek	Main course	10 B 0	14,61	2,62	30.06.2018 / 00:14
	Farfuriei Creek	10 B 0	1,87	1,01	30.06.2018 / 00:04
Tesla Creek	Main course	1 B 0	10,7	3,38	30.06.2018 / 00:25
Dracului Valley	Main course	10 M 3	16,15	2,94	30.06.2018 / 00:17
	Amiază Creek	20 B 2,5	2,17	1,75	30.06.2018 / 00:06

The statistical evidence supports that the newly appeared damages, which obtained strong correlations and which proved significant to the status index gradient were: body structure un embedding ($p < 0.001$), body structure undermining ($p < 0.001$), detachment in the spilled area ($p = 0.01$), wall wings detachment ($p < 0.001$) and body structure erosion ($p = 0.02$). In addition, the conclusion drawn regarding the vulnerability of the traverses, stated earlier, was also demonstrated in the present case.

For the un embedding of the body structure, the velocity proved to be an influential factor, the impact on the production and development of the damage following a linear condition in relation to the velocity increase, the clearest influence being at current speeds of more than 3 $m \cdot s^{-1}$.

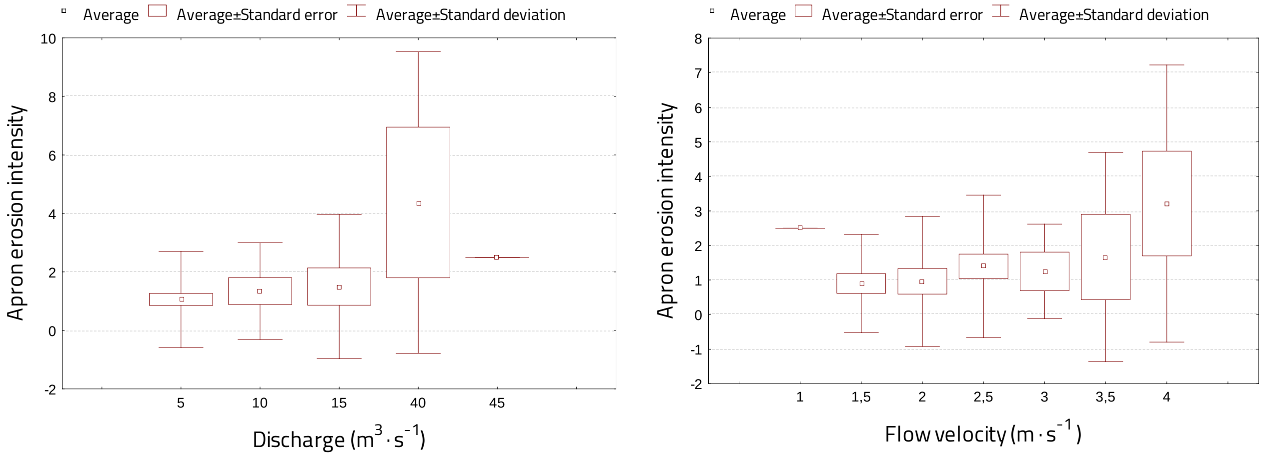
And from the point of view of the intensity of the body structure undermining, a concordance was observed in relation to the discharge, but also to the flow velocity.

Erosion of the body structure, damage significantly influenced by both the discharges generated by the torrential flows and the current velocity, turns out to be more frequent at flows of up to 15 $m^3 \cdot s^{-1}$ and at flows of 35 – 40 $m^3 \cdot s^{-1}$. The speeds at which the highest erosion intensity amplitudes were observed were 2,5 – 3 $m \cdot s^{-1}$.

And from the perspective of apron detachment, the ascertainments are similar, the biggest variations in the damage intensity are observed at flows of up to 15 $m^3 \cdot s^{-1}$, the velocity categories related to these flows being from 1 la 4 $m \cdot s^{-1}$.

Apron erosion follows a linearity condition in relation to the amplitude of the damage intensity and the flow discharge or flow velocity. Thus, as can be seen from figure 5.78 a, from the point of view of discharges, large variations in erosion intensity was obtained at 40 $m^3 \cdot s^{-1}$. The apron erosion increases in intensity as the current velocity values increase through the spillway and implicitly on the apron.

And from the point of view of the apron undermining, large amplitudes were observed in relation to all velocity categories, the most significant being at speeds of 1,5 – 2 $m \cdot s^{-1}$ and 3 – 3,5 $m \cdot s^{-1}$.



a b

Fig. 5.78. The influence of discharges and flow velocity to apron erosions

Another important aspect was observed at the spillway blockage. As expected, at high flows and velocities (extreme in the present case), the materials that initially blocked the spillway can later be washed away. This episode was observed at the 1 B 0 Tigăi structure, where the torrential flow generated a discharge of 46,3 $m^{3} \cdot s^{-1}$ and a flow velocity through the spillway of 3,74 $m \cdot s^{-1}$ washed away the coarse materials that were blocking the spillway by 90%!

In the case of the apron silting, a very relevant aspect resulted. Although the discharges generated by the torrential flow recorded values of up to 50 $m^{3} \cdot s^{-1}$, at low flows were observed silting intensities from -0.2 to +0.2, at high flows the velocity was the influencing factor.

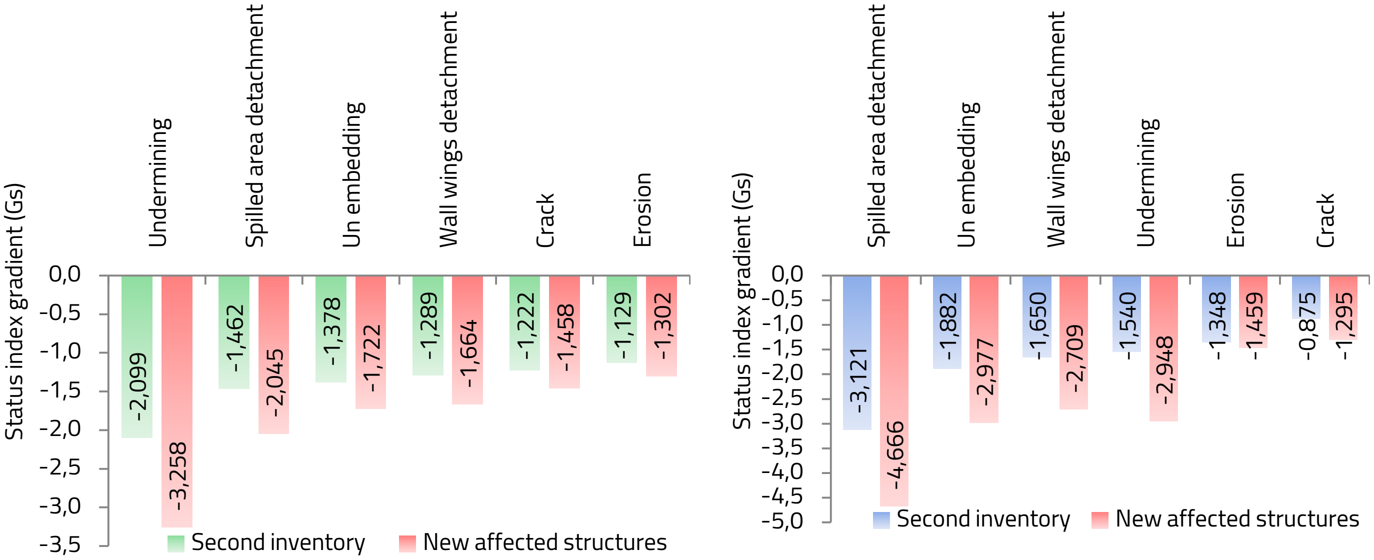
Although neither the flow rate or the current velocity doesn't proved their significance on the gradient variation, nevertheless it could be found that these two parameters play, indirectly, an important role in the evolution of the state of the structures. Thus, for flows of up to 15 $m^{3} \cdot s^{-1}$ the gradient registers large amplitudes, these being mostly due to the number of damages affecting the structures, from 1 to 13 associated damages. Regarding the flow velocity, the biggest variations occurred at values of 2 – 2.5 m · s-1, where the amplitude of the gradient resulted due to up to 11 associated damages, respectively 13 associated damage.

5.11. Status index gradient, a tool for prioritizing interventions to rehabilitate the state of the structures

Starting from the fact that the status index gradient reflects the annual variation of the physical condition of the structures (in units/year), it was considered necessary and useful to rank the studied damages according to the measure of their reflection in the gradient, in the analysis being taken only six of the most representative damage to the body structure and not all the events described in the thesis.

After grouping the structures according to the presence/absence of the apron, for the structures that present this annexed part, it was established that, at the first inventory, detachment in the spilled area and erosion induced the lowest average values for gradient, of -1.103 units/year, respectively -0.897 units/year. For structures without apron, the greatest impact on the gradient was found to be taken by erosion (-1.226 units/year) and detachment in the spilled area (-1.015 units/year).

From the point of view of structures affected at the end of the second inventory and the newly affected ones by various behavioral events (Fig. 5.84), the most severe impact to the apron structures was found to be given by the undermining. Detachment in the spilled area also induced a significant impact, the gradient values being -1.462 units/year for the structures that registered damage at the end of the second inventory.



a – apron structures b – structures without apron

Fig 5.84. Hierarchy of studied damage at the second inventory and at the newly affected parts according to the status index gradient, based on the obtained data

To make the potential use of the status index gradient easier to adopt the investment prioritization decision, a graphic representation based on the pooling of data from both inventories was further used, which highlighted the rank of damages according to the impact of each on the weighted average of the gradient (Fig. 5.85).

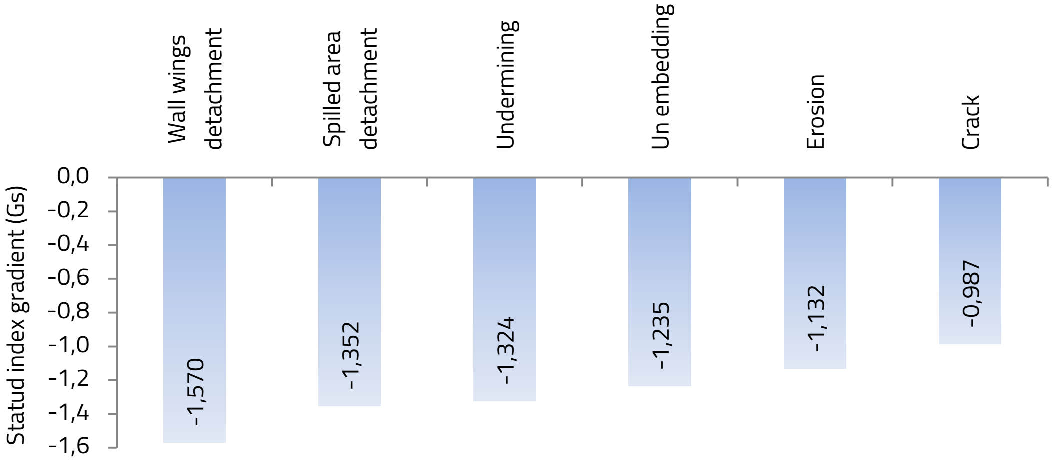


Fig. 5.85. Hierarchy of the studied damages according to the weighted average value of the status index

A more convenient alternative could be to organize and run the rehabilitation on large hydrographic basins, in an order that will also be dictated by an average value of the status index gradient. According to the calculations shown in Annex 8, the order of intervention on large hydrographic basins, in the case of the 285 structures taken into the study, should be the following: Tisa, Someș, Crișuri, Ialomița, Banat, Olt, Jiu and Danube.

Finally, we believe that an even more appropriate alternative could be to act at the level of the 45 torrential watersheds studied, but by ranking them on large hydrographic basins according to the highest value of the product among the number of structures to be rehabilitated and the average gradient corresponding to these works. From here, we can conclude that, for the studied cases, a number of 3 basins would be classified in the first intervention emergency: Crăiasa Valley (-61.18), Repedea Valley (-49.14) and Tesla Creek (- 30.94); for the second emergency it would be classified: Vârdaleș Valley (-8.67), Beiului Valley (-8.19), Mărului Creek(-6.1), Ravine 1 Up V (-5.10), possibly also Jidostița Valley(-1.04).

6 SYNTHESIS OF THE OBTAINED RESULTS AND CONCLUSIONS ON RESEARCH OBJECTIVES

6.1. The main features of the structures

In the 49 torrential hydrographic basins located in different areas of Romania, in 8 large basins or hydrographic areas, at different altitudes and different location conditions, 285 transversal hydrotechnical structures were identified, classified into eight types. Of the total number of structures, 63 are traverses, 84 are thresholds and 138 are dams. Of these, 185 (65%) have apron in the downstream area, 181 have guarding walls (63%) and 159 have terminal spurs. The main construction materials used in the construction of the structures were concrete (51%) and stone masonry with cement mortar (44%), and the age of the works is between 8 and 54 years.

6.2. Type, frequency, intensity and association between comportamental events

After the first inventory of the structures, about 77.2% of these were affected by at least one damage, the part of the work with the most registered damage denote to be the apron, followed in order by the body structure, the guarding walls and the terminal spur.

The absence of structures maintenance in the interval between inventories led to an increase in the number of affected works, in certain cases it led to variations in the intensity of damage and dysfunctionalities, so, at the end of the second inventory, almost 97% of works were affected. Compared to the first inventory, a transposition was also observed, in the sense that the damage association conduct to a severe state depreciation to the body structure, thus becoming the most affected part of the work, followed in order by the apron, guarding walls and the terminal spur.

Among the new damages that appeared in the period between inventories, the most common was erosion, its frequency of occurrence also dictating the order of the most affected parts of the work: the structure body, the apron, the terminal spur and the guarding walls.

6.3. Changes in the structure's status

Most of the structures that were downgraded in the status index categories (47%) were those that at the first inventory presented a very good condition (80 < Ys < 100) and that at the second inventory fell into category IV (60 < Ys < 80) . Deterioration of the physical status of these structures was up to 38% compared to the initial state and the gradient values, from a mathematical point of view, had values up to 5 times lower than the average value of the gradient for all analyzed structures.

6.4. The evolution of the structure state in relation to main influencing factors

6.4.1. Status index gradient induced by location characteristics

Geographical area. According to the resulting data, from a mathematical point of view, the transversal hydrotechnical works on the Repedea Valley (B.H. Tisa) have an average gradient of 148% lower than the general average and the structures that are located in the Tesla Valley (B.H. Olt) have gradient values of 116% smaller.

Opening at the top of the structure. In the case of thresholds and dams, the most pronounced deterioration in condition was observed for openings of up to 10 meters.

If the ***position of the structure in the system*** is also taken into account, high vulnerability was shown by the traverses located in the lower third of the managed torrential sector, followed by the thresholds in the middle sector, while the dams with a high risk of serious damage were found in the upper third of the managed valley.

6.4.2. Status index gradient induced by structure characteristics

Structure height. Structures above 0.5 meters (but not exceeding 2.0 meters) have lower gradients than the average values of the most affected structures. The gradients for the works with heights between 2.0 and 3.0 meters have lower values compared to the most affected height category or compared to the global average.

Spillway dimensions. The most significant deteriorations of the status suffered that structures whose spillway has a height of up to 0.5 meters, followed by those where the spillways have a height between 1.5 - 2.0 meters.

Age of structure. The most pronounced impact on the deterioration of the physical condition was recorded for the structure between 10 and 15 years old, which were subjected by torrential flows in a relatively short time after they were put into operation, when these structures had incomplete sedimentation.

Construction materials. Although masonry with cement mortar structures has about the same number of damages as concrete work, the module of the status index gradient for concrete work is about 31% higher than the masonry work. The rate of depreciation is, therefore, higher for concrete.

6.4.3. Status index gradient induced by behavioral events

6.4.3.1. Status index gradient induced by body structure damages

The most frequent behavioral event observed at the level of the body structures is erosion, which together with other damages left the gradient with the minimum value, 12 times lower than the average of the entire population.

The maximum impact of un embedding is correlated with 11 other associated damages, with the gradient value nearly 13 times lower than the overall average.

The impact of the undermining, as singular damage, leads to gradient values 2.5 times lower than the average, and in association with other events leads to values up to 13 times lower.

Cracking appeared mainly at structures where the apron undermining where present, the body structure undermining, the un embedding, the detachment in the spilled area (4%) and the body structure erosion (4%), damages that in different associations led to values of gradient more than 5 times lower than the general average.

Spilled area detachment was not identified as singular damage, but manifested itself with 1 – 10 other damages, inducing values up to 7 times lower than the average value of the gradient.

Wall wings detachment was recorded more frequently at masonry structures, but the average damage intensity was higher at the concrete work, where the average gradient was also lower.

The body structure erosion was mainly manifested at the dams; however, under the gradient ratio, the traverses proved more vulnerable.

6.4.3.2. Status index gradient induced by apron damages

Apron, the main annex part of the transversal hydrotechnical structure, identified in 185 cases (of which: 3% traverses, 32% thresholds and 65% dams), recorded various damages, the order of the first two being: dissipative teeth detachment and erosion.

Apron detachment was more frequent at the dams, the detachment being more frequent in the masonry aprons, but the maximum intensity and the lower gradient were found in the case of concrete aprons. As single damage, the apron detachment conducted the gradient values 1.4 times lower than the average; in association with other 1 – 12 damages, the detachment led to values of the gradient more than 5 times lower.

Apron undermining, although identified with higher frequencies at dams, however, the status index gradient was found to be lower in the case of the threshold. In association with up to 11 other damages, the gradient recorded values more than 5 times lower.

The apron erosion, also favored by its undermining, was more pronounced at dams and more frequent in the case of masonry with cement mortar, but the intensity of the damage was slightly higher for the concrete aprons, whose gradient resulted in 10% smaller.

6.4.3.3. Status index gradient induced by guarding walls damages

Guarding walls damage often occurred due to behavioral events occurring at other component parts of the structures.

Cracks were favored by a series of old damages and occurred predominantly in masonry guarding walls.

Guarding walls detachments were identified mostly at dams, and in most cases occurred at masonry walls, where the damage intensity was higher.

Erosion, although occurred with higher frequencies in the masonry guarding walls, however, the intensity was greater in concrete walls, structures that also recorded lower gradients.

6.4.3.4. Status index gradient induced by spur damages

Spur un embedding was frequently at dams, the status index gradient for those being lower than in the case of thresholds.

The dams spurs were more frequently affected by the detachment. The gradient of these structures recorded lower values than the gradient of the thresholds.

The erosion of the terminal spur, which often appeared as a result of the apron undermining, was mainly manifested at the dams, their gradient being lower than the gradient of the thresholds.

6.4.3.5. Status index gradient induced by disfunctionalities

These behavioral events generally occurred in association with each other, but also with 2 to 5 other associated damages. The spillway blockage occurred in association with 1 - 12 other damages, being identified mainly at dams (72%). The apron silting occurred in association with 3-5 other damages, with higher frequency at dams. Incomplete sedimentation was found in about a quarter of the structures capable to capture sediments, of which more than half are dams. Unwanted installed vegetation (upstream and downstream) often took place at apron structures, most of which were dams. The reduction of the downstream section prevailed at the apron structures, with a higher frequency at the dams, but the lowest values of the gradient were recorded at the thresholds.

6.5. Simulation of the torrential event on the Tigăi Valley

From the perspective of the damages generated by the torrential event (discharge and velocityes) recorded following the simulation of the rainfall event captured in the Tigăi Valley in the Tărlung basin, those that directly influence the status index gradient proved to be: the body structure un embedding, body structure undermining, detachment in the spilled area and wall wings area, as well as the body structure erosion.

Un embedding proved to be more frequent in the sectors where the bed river slopes induced an increase in speed, while the body structure undermining experienced a large amplitude of intensity in parallel with the reduction of flow and speed. The body erosion recorded large amplitudes at low discharges, while the apron detachment was more frequent at a lower flow rates. The apron erosion followed a condition of linearity in relation to the discharge, but especially with the velocity.

Among the dysfunctionalities, the spillway blockage reduction was positively influenced at very high flows and velocities, and apron silting was found to be deeply influenced by the characteristics of the flood, especially by the water velocity.

6.6. Status index gradient: foundation and arguments for its uses as an indicator of the evolution of the state of transversal hydrotechnical structure and as a tool for prioritizing rehabilitation interventios

The evidence obtained from the statistical analysis of the status index gradient (§ 5.9), together with the result of the ranking of behavioral events concerning the weighted average values of the gradient(§ 5.11), constitute foundations and arguments for this indicator to be used in future scientific research, summarizing the following:

1. Statistical evidence. Although the transversal hydrotechnical structures are damaged over time due to torrential events, to which local factors also contribute, however, only certain damages have a significant influence in a statistical sense regarding the deterioration of the physical condition of the structures, including changes in the status index gradient.

2. Hierarchy of the main damages. After the global weighted average gradient calculation, the following ranking resulted: wall wings detachment : Gs = -1.570; detachment in the spilled area: Gs = -1.352; undermining: Gs = -1.324; un embedding: Gs = -1.235; erosion: Gs = -1.132; cracks: Gs = -0.987. Where the funds allocated for the maintenance of the torrential structures are limited, it is justified (theoretically speaking) that interventions to these works should be carried out in stages in the order of the gradient averages, namely: first to the structures affected by detachment, then to those affected by undermining and so on. From a practical point of view, however, it could be more convenient to rank the developed torrential valleys by large watersheds, with the highest value of the product between the number of structures to be rehabilitated and the average gradient corresponding to them. In such an alternative, the following order must be taken into account: the first intervention must be Crăiasa Valley from the Crișuri watershed, Repedea Valley from the Tisa watershed and Tesla Creek from BH Olt.

7 FINAL CONCLUSIONS. PRACTICAL RECOMMENDATION AND ORIGINAL CONTRIBUTIONS

7.1. Final conclusions

(1) The torrential hydrographic basins in which the 285 transversal hydrotechnical structures are located cover the entire range of situations encountered in the management of torrential riverbeds in Romania. The respective works are themselves, representative both in terms of technical, constructive and typological characteristics, as well as in terms of exposure to a diversity of behavioral events during the operation period.

(2) Monitoring the physical condition of these structures, as a basic requirement of the maintenance activity, involves the inventory and re-inventory of the works and the determination, finally, of two indicators:

- the status index, which helps to quantify the physical condition of the works at a certain moment (the moment of each inventory), and

- the status index gradient, which can be used to quantify the evolution of the condition of the works over a period of time (in the period between two inventories).

While the evolution trend (depreciation or appreciation of the state) is indicated by the algebraic sign of the gradient (the minus sign signifying depreciation and the plus sign signifying appreciation), the average annual rate of state changes is expressed by the module value of the gradient.

(3) For the overwhelming majority of the works, the status index gradient registered the negative sign, which means that, in the period between the inventories, the condition of the structures depreciated.

The annual average rate of depreciation, expressed in units/year, falls within a range from 0 to -14.33, the variability is determined not only by the nature, frequency, intensity or association of behavioral events, but also by the characteristics of the structures and the characteristics their location.

The highest rate of depreciation was identified for 75 structures, which were downgraded from the status categories in which they were initially classified. Most of these are works that, at first inventory, were in very good condition.

(4) Following the in-depth study of the relationship between the state of the structures and the main influencing factors, it turned out that the works on Repedea Valley (BH Tisa) and those onTesla Creek (BH Olt) present gradients up to 1.5 times lower than the overall average of all studied structures. It was also found that the annual rate of depreciation is more advanced in the case of works of low height (1.0...2.0 meters), with spillways of 10 - 15, which were surprised by flows in a relatively short time after they were put into operation, often with incomplete sedimentation.

In addition, from the point of view of the position that the transversal work occupies within the suite of structures on the same valley, the data obtained highlighted an interesting aspect, which, however, cannot be generalized. The question needs to be answered: why is the highest advanced average annual degradation rate found in the case of the traverses on the lower sector, in the case of thresholds on the middle sector, and in the case of dams on the upper sector?

(5) The variance analysis applied to the status index gradient highlighted the significant influence of the following factors:

- the annual average amount of precipitation, from the category of emplacement characteristics;

- construction material and age from the category of structure characteristics;

- the body un embedding and body undermining, detachment from the spilled area, from the apron and from the guarding walls, as well as the apron detachment, from the category of behavioral events (damages) produced during the period of operation.

(6) The evolution of the physical status of the transversal hydrotechnical works, illustrated by the gradient frequency, has been shown to closely follow some theoretical laws. Thus, following attempts to adjust the experimental distributions according to two theoretical distributions (normal and Meyer) it turned out that the gradient frequency is distributed differently depending on the class interval size, but also on the criterion chosen for data stratification. For the studied cases, it was found that by increasing the class interval, the experimental gradient frequency distributions approach a normal distribution. This result, expected by the way (due to a large number of influencing factors), is also consistent with the result obtained following the application of the principal component analysis, where, in the case of the 12 variables with proven statistical significance, the coverage percentage of the total variance is 35%.

(7) Following the hydrological and hydraulic modeling of the 2018 torrential event on the Tigăi Valley, followed by the analysis of how the torrential flow and velocity affected the variation of the status index gradient, a significant influence in the case of the following events resulted:

- from the category of body structure damage: un embedding, undermining, detachment (from the spilled and wall wings) and erosion;

- from the category of dysfunctionalities: spillway blockage and apron silting.

(8) Following the determination of a weighted average gradient induced by six of the identified damages, it resulted that the annual average rate of depreciation of the physical condition, attributed to these events, decreases in the following order: wall sings (Gs = - 1,570); detachment in the spilled area (Gs = -1.324); undermining (Gs = -1.324); un embedding (Gs = -1.235); erosion (Gs = -1.132); cracks (-0.987).

(9) The practical meanings presented by the status index gradient, including the supposable evolution of the structure's condition, constitute an important argument for this niche to continue, to focus attention and concerns in the research activity.

7.2. Practical recommendations

(1) The status index gradient should be integrated, along with the status index, in the new methodology proposed in 2015 for the monitoring of the structures used in the management of the torrential hydrographic network.

(2) In order to obtain the most representative data on the variability of the gradient, it is recommended to continue the re-inventory action of the structures already included in the abht.ro database. Also, is recommended to continue the inventory of the other structures currently existing in the managed torrential watersheds located in the forestry heritage of the country.

(3) Starting from the fact that the phenomenology associated with the torrential structure status is strongly influenced by the genetic factor of torrential flows, it is necessary to increase the number of torrential basins (already) hydrotechnically managed to be equipped with modern, pluviometric and hydrometric equipment, having as a model the infrastructure existing today in Băii Valley and Tigăile Valley, in the mountainous area of Brașov.

7.3. Original contributions

◦ Introduction in research of a new parameter to estimate the annual variation of the physical status of the transversal hydrotechnical structures used in the torrential riverbeds management, called the status index gradient;

◦ The in-depth research of the variability of the physical state of these structures in relation to the evolution of behavioral events, with the emplacement characteristics and with the structure characteristics;

◦ Researching the structure's status evolution according to their position in the managed river sector, delimited in accordance to an equal number of works in the sector;

◦ The hierarchy, for the first time, of the behavioral events with their impact on the physical status evolution;

◦ The use, for the first time, of the Mike Hydro model for simulating the impact, generated by a torrential event, on the status index evolution.

8 DISSEMINATION RESULTS AND FUTURE EXTENSIONS

8.1. Results dissemination

Published results in ISI indexed journals

◦ **Mihalache A.L.;** Marin M., Davidescu Ș.O.; Ungurean C., Adorjani A., Tudose N.C., Davidescu A.A., Clinciu I., 2020: *Physical status of torrent control structures in Romania*, Envinmental Engineering and Management Journal, 19 (5)., pp. 861 – 872.

◦ Marin, M., Clinciu I., Tudose N.C., Ungurean C., Adorjani A., **Mihalache A.L.**, Davidescu A.A., Davidescu Ș.O., Dincă L., Cacovean H., 2020: Assesing the vulnerability of water resources in the context of climate changes in a small forested watershed using SWAT: A review. Environmental Research, vol. 184, 109330, https://doi.org/10.1016/j.envres.2020.109330.

◦ Tudose, N.C.; Marin, M.; Cheval, S.; Ungurean, C.; Davidescu, S.O.; Tudose, O.N.; **Mihalache, A.L.**; Davidescu, A.A., 2021: SWAT Model Adaptability to a Small Mountainous Forested Watershed in Central Romania. *Forests*, *12*, 860. https://doi.org/10.3390/f12070860.

Published results in BDI indexed journals

◦ **Mihalache A.L.**, Clinciu I., Davidescu Ș.O., Tudose N.C., Marin M., Ungurean C., Davidescu A.A., Tudose O., 2021: Gradientul indicelui de stare al lucrărilor hidrotehnice transversale utilizate în amenajarea albiilor torențiale, Revista Pădurilor, 4, pp. 15 – 30.

◦ **Mihalache A.L.**, Clinciu I., Davidescu Ș.O., Tudose N.C., Ungurean C., Marin M., Davidescu A.A., Tudose O., 2021: Gradientul indicelui de stare al lucrărilor hidrotehnice transversale utilizate în amenajara albiilor torențiale, indus de unele avarii ale lucrării propriu – zise, Revista de Silvicultură și Cinegetică, 49, pp. 5 – 18.

- Ungurean C., **Mihalache A.L.**, Davidescu Ș, Tudose N.C., Davidescu A., Tudose O., Marin M., 2021: Evaluarea prin modelare hidraulică a impactului vegetației lemnoase ripariene asupra dinamicii inundațiilor, Revista de Silvicultură și Cinegetică, 48, pp. 58 – 65.
- Marin M., Clinciu I., Tudose N.C., Cheval S., Ungurean C., Davidescu Ș.O., Adorjani A., M**ihalache A.L.**, Davidescu A.A., Tudose O.N., 2020: Simularea impactului schimbărilor climatice și al modificării folosinței terenului asupra proceselor hidrologice din bazinul hidrografic Tărlungul Superior, Revista Pădurilor, 135 (3), pp. 1-26.

Book in the Accredited publishing house

- Davidescu Ș.O., Clinciu I., Tudose C.N., Niță M.D., Adorjani A., Gancz C., Ungurean C., Oprea V., Păcurar V., Petrițan I.C., Davidescu A.A., **Mihalache A.L.**, Crivăț M., Marin M., 2020: Estimarea torențialității bazinelor hidrografice mici și monitorizarea lucrărilor de amenajare a albiilor torențiale, pe baza indicilor de risc și de stare. Seria II: Lucrări de cercetare. Editura Silvică, 210p.

Contribution to create of a meteorological internationally centralized data base

- Tudose N.C., Ungurean C., Marin M, **Mihalache A.L.**,Davidescu Ș., 2019: Meteorological research datasets collected from the Tarlung river basin using research infrastructure installed within the CLISWELN project. În 4TU.Centre for Research Data – Science Engineering Design, http://doi.org/10.4121/uuid.8cdfd0c6-1976-417c-bc20-7397f6382e7f.

Communications to Symposiums and International Conferences

- **Mihalache A.L.**, 2018: Physical status of torrent control structures in Romania, International Conference "Forest Science for a Suitable Forestry and Human Wellbeing", 18-21 septembrie, București.
- Crivăț M., Ungurean C., Davidescu Ș.O., Adorjani A., Tudose N.C., Davidescu A.A., Babătă (Marin) M., **Mihalache A.L.**, 2018: Assessment of logging trails erosion coupled with timber harvesting. International Conference "Forest Science for a Suitable Forestry and Human Wellbeing", 18-21 septembrie, București.
- **Mihalache A.L.**, Marin M., Davidescu Ș., Ungurean C., Tudose N.C., Davidescu A.A., Tudose O., Clinciu I., 2020: Assessment of the physical status of the torrent control structures in Romania. 9th International Symposium Forest and Sustainable Development. 16 – 17 Octombrie, Brașov.
- Marin M., Clinciu I., Tudose N.C., Ungurean C., Davidescu Ș.O., **Mihalache A.L.**, Tudose O.N., 2020: The impact of forest and climate change on seasonal dynamics of hydrological processes in Upper Tarlung watershed. 9th International Symposium Forest and Sustainable Development. 16 – 17 Octombrie, Brașov.
- Tudose N.C., Ungurean C., Marin M., Davidescu Ș.O., **Mihalache A.L.**, 2020: Assessing the hydrological impact of land and forest management change under climate projections in the Tarlung river basin (upstream Sacele Recevoir). 9th International Symposium Forest and Sustainable Development. 16 – 17 Octombrie, Brașov.
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8.2. Future extensions

(1) Possibilities and ways to integrate the status index gradient into the previously proposed methodology (2015) with reference for the monitoring of the structures used in the torrential riverbeds management, so that besides the psyhical status at a certain moment (expressed by the status index) to take into account the annual average rate of the probable evolution of the state of the structures (expressed by the gradient of the status index).

(2) Clarify the relationship between the evolution of the physical status of the structures and the position whit it occupies within the managed riverbed sector on one and the same valley (lower/ middle/ upper sector).

(3) Determinate by hydrological and hydraulic simulations of the influence of the alluvium storage and the influence of the storage slope on the evolution of the physical status of the transversal hydrotechnical structures.

(4) The study between the correlational links indicator of the evolution of the physical status of hydrotechnical structures on the torrential hydrographic network (the status gradient) and some indicators of the terrain of the valley side, including here some hydrological parameters (the potential retention, the erosion index), as well as some characterizing parameters of the forest structure (the afforestation degree, age, the crown density of the stand, site class, etc).

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