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A NEW APPROACH TO PROMOTE RIVER DEVELOPMENT SOLUTIONS

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Abstract

River development is, most often, based on evaluations referring solely to technical and economic performance of the proposed solutions. To promote a certain investment, the well-known Benefit-Cost Analysis (BCA) is still widely used. This became an international practice, since there are so many publications that develop principles for the application of the aforementioned analysis. This paper proposes a new method to replace the BCA with a rational process of multi-criteria assessment, which takes into account the environmental impact of engineering solutions for watercourses development. The aforementioned method evaluates the physical environmental impacts of river basin development solutions, using a heuristic approach to assess a global impact of the river artificialization. The new method is attractive for specialists seeking more sustainable development solutions, for authorities in charge with the approval process, for investors, allowing better projects to be financed and for the public, since all phases for the assessment of the physical environmental impacts of river basin development solutions are transparent and do not require special engineering skills. The authors hope that the proposed method will encourage similar approaches, with positive effects on the sustainable development of society.

Keywords: decision criterion, environmental impact, river basin, watercourse development

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1. Introduction

Evolution of watercourse development is virtually identified with the evolution of mankind civilization. Principles of development have emerged from the experience collected over millennia, with permanent alterations and adjustments to the criteria and requirements (Abdulamit, 2000).

To validate different design solutions for any watercourse development, in addition to the loads affecting the structures other relevant aspects are taken into account, such as: lifetime, technologies used for construction, hydrological regime in the considered area, submersible or non-submersible character of solutions, cost of materials used, compatibility in relation to environmental factors (particularly flora and fauna) etc. Currently several general principles regarding the conception and planning of watercourses development are accepted, among which one can mention the following:

- solutions must be "plastic" (commonly referred to as "elastic"), capable to withstand large and uneven foundation deformations;
- solutions will be designed knowing that during operation, inevitably, some degradation (damage) could occur;
- solutions should not obstruct the water free flow mainly during floods; the same condition applies to ice or floating debris;
- solutions will be thoroughly embedded both upstream and downstream, to avoid potential damage initiated by erosion acting beneath the structure;
- solutions will mainly target environmental protection and biodiversity conservation etc.

To ensure the dynamic ecosystems restoration in areas affected by development solutions, planning

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documentation should provide opportunities for animal and plant colonization. Thus the foreseen solutions will ensure the highest degree of public acceptance of an investment.

2. General requirements on watercourses development

2.1. Legal and administrative requirements

It is assumed that all works and actions concerning watercourses development must comply with laws, regulations and technical norms. A special remark concerns the fact that all watercourses developments must conform to the provisions of River Basin Master (guiding) Schemes, representing the strategic planning tools in country's watersheds.

Any River Basin Master Scheme consists of two parts: The River Basin Development Plan (RBDP) and The River Basin Management Plan (RBMP).

2.2. Principles of fluvial geomorphology

Natural rivers and the adjacent floodplains are among the world's most complex and diverse ecosystems. Some of the most important natural functions of rivers and their wetlands are listed below (Diaconu, 1999):

- fish habitat function, which provides optimal conditions for reproduction;
- function of habitat for birds, mammals, amphibians, reptiles and a very diverse invertebrate fauna;
- function of water storage and sediments retention;
- function of self-purification of water by storage and recycling nutrients as well as organic and inorganic pollutants transformation;
- function of biodiversity;
- social and economic function: water supply source, transportation way, construction materials, tourism, recreation and education.

Geophysical and ecological evolution (especially of the aquatic habitats) in rivers depends almost entirely on the fluvial dynamics and morphology. Under natural conditions, rivers tend towards a relatively stable combination between characteristic variables such as:

- independent (control variables):
    - discharge;
    - solid discharge;
    - hydraulic gradient;
    - sediment characteristics (for riverbed and banks);
    - riparian vegetation.
- dependent (response variables or degrees of freedom):
    - riverbed width;
    - average depth;
    - maximum depth;
    - riverbed longitudinal slope;
    - flow rate;
    - spatial distribution of the major energy dissipation systems;
    - tortuosity of watercourse;
    - average diameter of sediment;
    - fines contents in granulometry of sediments;
    - wavelength of watercourse tortuosity.

On a watercourse in dynamic equilibrium, the dependent variables are continuously adjusting their values. After human interventions, the river tends to return to its natural state, if engineered solutions have been appropriately planned and realized.

Solutions that are unable to be transformed during the process of dynamic rebalancing (because of their rigidity and artificiality) will calamitously and for a long term alter the riverbed morphology, distorting and threatening the ecological equilibrium of the river at much larger extents than the direct intervention (Diaconu, 1999).

2.3. Elements of environmental impact of watercourses development solutions

Riverbed "channelization", water courses diversion etc. represent anthropogenic actions with minimal natural correspondences that inhibit most of the evolution processes. When it comes of environmental factors related to watercourses it should be noted that a "channel" type development solution, accompanied by an increased width of the riverbed, can prevent the watercourse capacity to accommodate fish fauna.

Rivers and their corridors are forming complex ecosystems containing adjacent land, flora and fauna and watercourses. These ecosystems depend on the watercourses regime, well defined by factors such as discharge, sediment transport or water temperature etc. Any alteration of these factors compared to the normal natural values may trigger the equilibrium disturbance. That is why river engineered developments should aim at the in time and spatial preservation of the global dynamic balance of watercourses.

Building dikes and levees on long sectors of watercourses not only lead to a loss of biodiversity of the aquatic environment but also de-attenuate the peak discharges during floods.

The new European development concept, "more space for rivers" assumes the harmonization of social and economic requirements such as water supply or flood protection with environmental requirements. For this purpose, one should ensure the river continuity, as well as its connections with the adjacent floodplain by developing wetlands that could represent habitats for the conservation of aquatic flora and fauna, flood control and nutrient retention. The new developed ecosystems will provide optimum conditions for aquatic flora and fauna as well as recreation and tourism.

The intensity of the physical impact of river basin developments on the natural environment depends, to a substantial extent, on the type and nature of the engineered solutions and related activities. This environmental impact intensity may be categorized into four classes:

(1) very strong: riverbed correction and training, cutting-off river meanders, erection of dikes and levees, diversion of minor riverbed;

(2) strong: filling of wetlands, construction of riverbed protection transverse structures, bank protection developments etc.;

(3) average: maintenance works;

(4) weak.

Earthmoving works, embankments constraining riverbed, correction of (cutting-off) meanders lead to practically irreversible effects on the natural status of the watercourse.

3. Assessment of physical environmental impact of river basin developments

3.1. Impact of development solutions leading to "artificiality"

Several researchers (Diaconu, 1999; Wasson et al., 1995; Wasson et al., 1998) present a method for evaluating the physical environmental impact of river basin developments, perceived as a global effect of river "artificiality". The described method primarily serves to compare several alternative development solutions, based on an "artificiality index", named "global impact GI".

The above mentioned method is interesting since it allows the evaluation of the relative influence of various parameters of "artificiality", thus controlling the selection and improving the planned solutions. In principle, the method quantifies the "environmental costs" for four elements:

(1) characteristics of riverbed likely to be affected by hydraulic works;

(2) class of importance of the river (size of river and watershed, environmental quality, water quality, discharge value), defined as "river rank";

(3) the intensity of artificiality aggression by altering the river morphology;

(4) time.

The proposed index assesses the impact of river developments as a function of the combined effects of the length of the affected sector, the impact intensity and time, according to a relationship as expressed by Eq. (1):

$$GI_{si} = LITw^2 10^{-4} \qquad (1)$$

where: GI_{si} = global impact index of the *i* river development solution affecting a given river sector *s*; L = length of the analyzed river sector, expressed in multiples of w (Eq. 2); w = minimum width of the minor riverbed; $w^2\ 10^{-4}$ = area [ha] of each unit of developed river sector.

$$L = (l/w)\,AR \qquad (2)$$

where: l = length of the developed river sector; A = coefficient of river sector characteristics; R = river rank coefficient; I = overall coefficient of impact intensity for different "m" morphological alterations on the analyzed river sector:

$$I = \sum_m I_m \qquad (3)$$

where: T = total duration [yrs] of the cumulative impact of artificiality on the developed river sector.

The unit of the global impact index GI is a weighted area, thus allowing the summation of the values obtained for different developed sectors of the same watercourse. Also, comparison of ecological costs for different watercourses is possible. Global impact index (GI) allows the prioritization of river development plans, depending on the severity of impacts. It can also be helpful to adjust the plans towards the least harmful solutions for the environment.

It is also noteworthy that the Global impact index can be used to assess a watercourse rehabilitation project. Both river development and rehabilitation costs can be assessed in the very early stages of a project, even in the same decision-making process with a high degree of objectivity.

3.2. Global index method presentation

3.2.1. Developed sector characteristics

River sector characteristics are represented by a coefficient A, whose values (environmental costs) result from graph in Fig. 1, as a function of the length of the developed/affected zone relative to the total length of the sector.

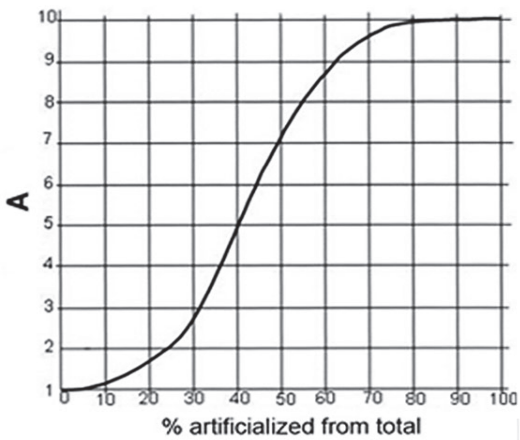

Fig. 1. Ecologic costs (A) due to artificiality status of river (adapted from Wasson et al., 1995)

3.2.2. River rank coefficient

The coefficient R, with values of ecological costs, results from the graph presented in Fig. 2, as a function of the river rank of the developed watercourse. One can observe the highest ecologic costs affect watercourses with extreme river ranks. For high river rank watercourses, engineered solutions could obviously lead to significant direct and derived effects, related to important ecologic costs.

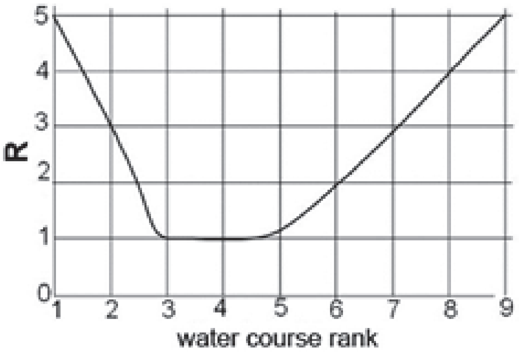

Fig. 2. Ecologic costs (R) due to rank of river (adapted from Wasson et al., 1998)

At the opposite end, lower river ranked watercourses, with small size watersheds or/and with a mediocre status of ecosystems are practically "demolished" from environmental point of view as a result of engineered solutions that induce the artificiality of riverbeds. Therefore, the ecologic costs are relatively high.

3.2.3. Impact intensity

Intensity of impact evaluates the discrepancy between the post-development river status and river morphology corresponding to the dynamic equilibrium status. The method uses a number of 8 factors, described by 8 specific morphological parameters allowing the system alteration quantification. The ecologic costs are assessed for every parameter "*m*" *(m=1...8)*, using the graphs presented in Figs. 3 and 4. From every graph, a coefficient of ecologic cost *Im* is computed, as a function of a specific alteration category.

I_5 represents the ecologic costs of physical structure (shelter for fauna) alteration, having values proposed by some technical reports (Diaconu, 1999).

3.2.4. Time (duration)

Assessment of the impact duration consists of three elements:

(1) persistence of physical alteration (depending on the reversibility of development solution);
(2) recurrence of engineered intervention leading to cumulative environmental impact;
(3) possible deterioration of long-term impacts, especially if morphodynamic equilibrium is disturbed.

Reversibility of a river development solution can be estimated based on the nature of the works and the specific energy associated to the river. Thus, a multiplication coefficient *T* is associated to a river development solution, representing the persistence of physical alterations or the duration of the cumulative environmental impact of the repetitive alterations [yrs].

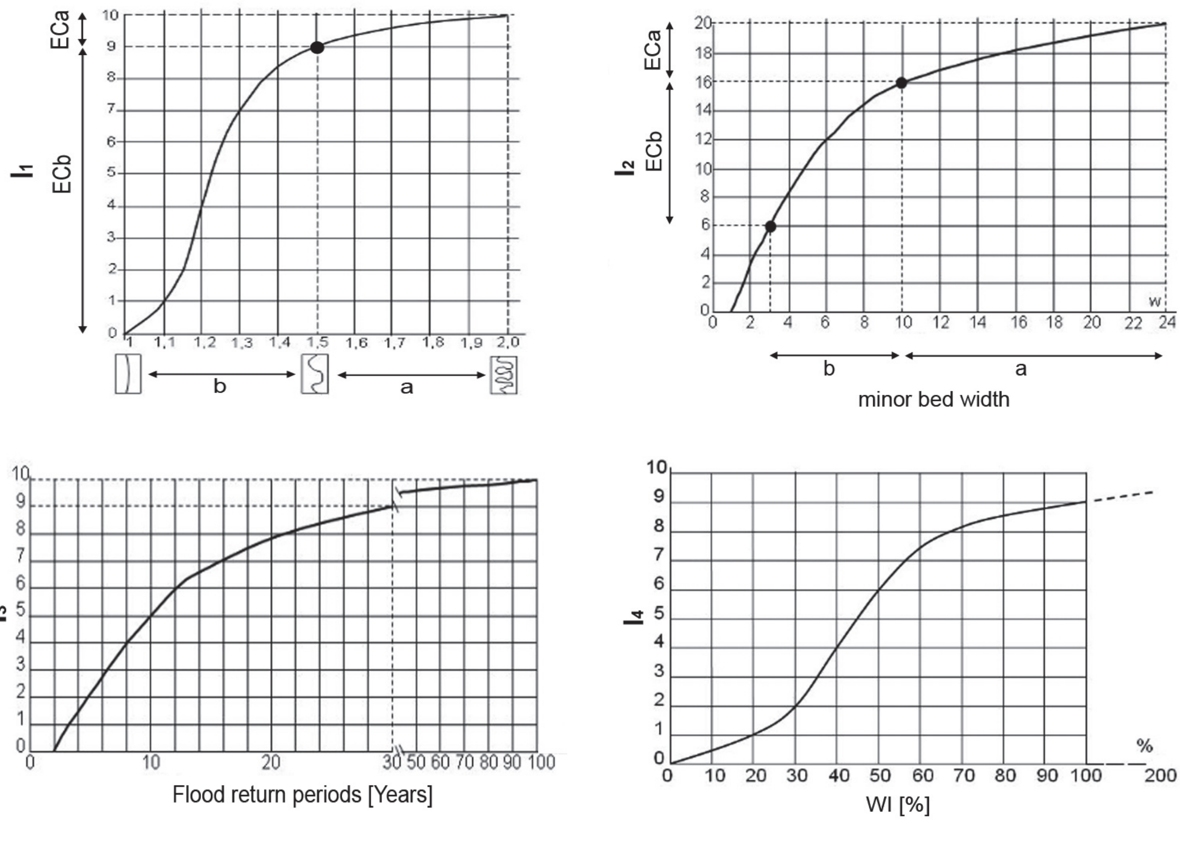

Fig. 3. I1…I4 – intensity of impact of a development solution upon the ecological status of river. EC = economic costs; WI = riverbed width increase at minimum discharge; a, b = zones with different alteration extents due to development solutions (adapted from Diaconu, 1999)

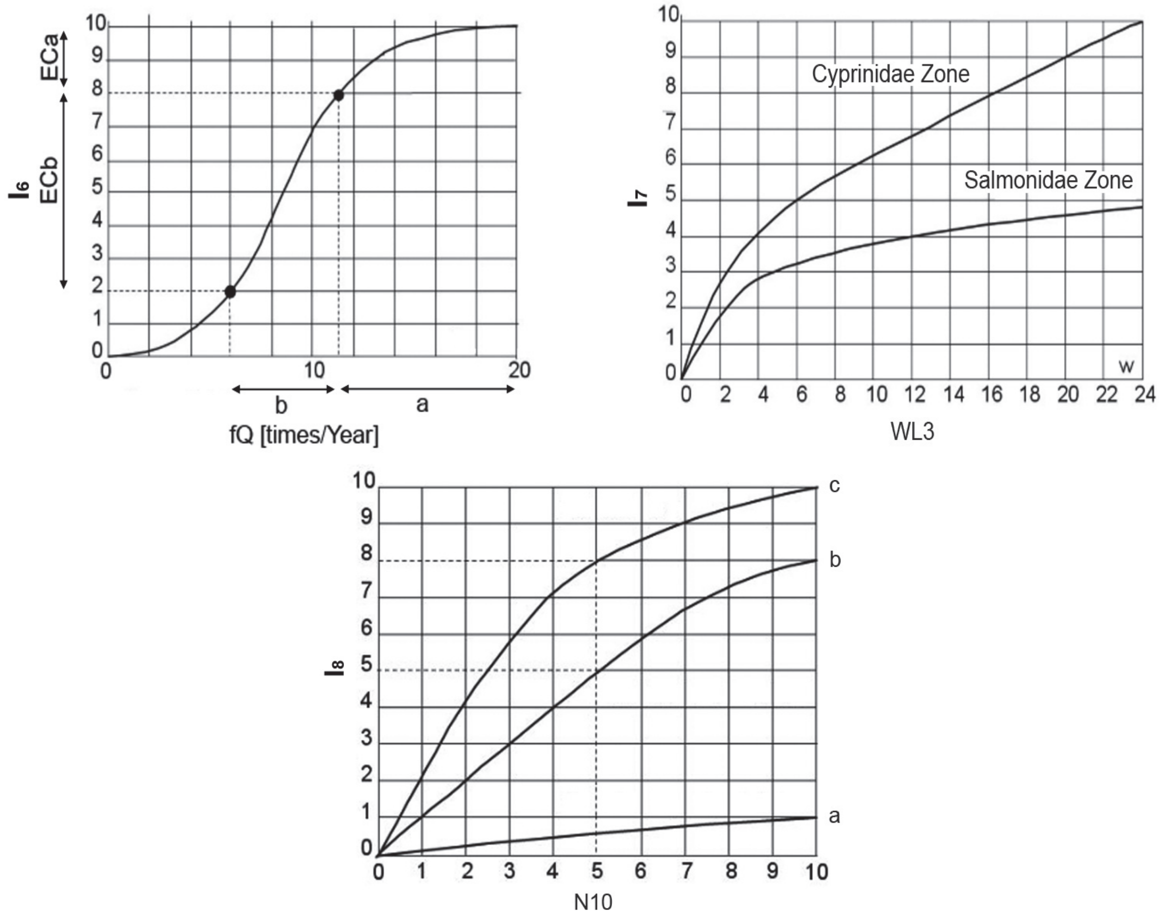

Fig. 4. I6…I8 intensity of impact of a development solution upon the ecological status of river. fQ = occurrence of discharge to mobilize riverbed material; WL3 = loss of flooded zones at Q3%; N10 = obstructions no. along 10 km of developed sector; a, b = zones with different alteration extents due to development solutions
(adapted from Diaconu, 1999)

4. A new method for the selection of watercourse development solutions

4.1. Principles of multi-criteria decision method

The new proposed method appears to assist professionals in making proper selections between several river development alternatives, based on a series of relevant criteria. The literature proposes a large number of heuristic multi-criteria decision methods, widely used worldwide.

The proposed method is a simplification derived from ELECTRE multi-criteria decision analysis method, bringing the assessed alternatives to a common conventional unit defined as "score" (Boldur-Lăţescu et al., 1982). Basically it consists of the summation of scores corresponding to a number of analyzed alternatives based on different criteria, weighted by each criterion importance. At the end of the assessment, the alternative having the highest score is to be considered the optimal (Ionescu, 1986, 2001, 2007).

4.1.1. Choice of criteria

The criteria may be different depending on the situation or the type of environment and its dominant features (natural, anthropogenic, polluted or unpolluted, rural or urban etc.) and the type of river development project and consequently the dominant types of impact (pollution, land use, deforestation etc.). Usually the criteria correspond to the categories of environmental elements detailed and weighted depending on the given circumstances. One can cite as examples of criteria: the general economy, the local economy, ecosystems protection, social situation etc.

Additional local specific criteria can be considered, such as land occupation, dislocation of population, interference with the natural resources, landscape alteration, disturbance (even provisional) for population etc. Typically, the analysis process is limited to maximum 5...8 criteria, plus the imaginary "zero criterion", the least important compared to all the others, usually automatically discarded to avoid the eventual removal of a chosen important criterion.

4.1.2. Ranking and choice of criteria weights

The decision maker (analyst) compares the criteria Ci (i = 1,2, ... m) in pairs (trying to ignore the rest of the criteria) giving 2 points to the more important criterion, based on his own subjective (biased) judgment, for the specific assessed case. The 2 points mark is filled in the corresponding cell of the matrix table. Obviously, 0 points mark is filled in the cell symmetrical to the main diagonal. In case of indecision, 1 point is awarded to both criteria, the marks being filled in cells placed at the intersection of lines and columns corresponding to each criterion, symmetrical to the main diagonal.

To moderate the subjectivity, inherent to such a process of assessment, the criteria matrix can be independently developed by a large number of persons involved in the decision analysis. The results of each decision maker are presented in a matrix of the form shown in Fig. 5. Every C_i criterion will have a t_i score, while the "zero criterion", C_6 will have a null score, t_6=0. The total score of the considered criteria will be (Eq. 4):

$$T = \sum_i t_i = m^2 - m \tag{4}$$

The weight of a criterion will be (Eq. 5):

$$p_i = t_i / T\ ;\ \sum_i p_i = 1 \tag{5}$$

In the above presented example, $p_1=p_2=7/30=0.233$; $p_3=4/30=0.133$; $p_4=3/30=0.1$; $p_5=9/30=0.3$.

	C_1	C_2	C_3	C_4	C_5	C_6
C_1		0	1	0	2	0
C_2	2		0	0	1	0
C_3	1	2		1	2	0
C_4	2	2	1		2	0
C_5	0	1	0	0		0
C_6	2	2	2	2	2	
TOTAL SCORE:	**7**	**7**	**4**	**3**	**9**	**0**

Fig. 5. Example of matrix to assist the decision making process. $C_1...C_6$ = weighted criteria used in assessments (adapted from Ionescu, 2001)

4.1.3. Selection of alternatives

Using the same judgment as that previously presented for the criteria decision matrix, one can select a number "n" of different alternative development solutions (or different operation conditions) V_j, (j=1,2,...n), significantly different in terms of environmental impact. In case of decisions on the suitability of a given development solution, one of the alternatives will be "the zero alternative" i.e. doing nothing or non-implementation of the project. For practical reasons, it is recommended that n≤6.

4.1.4. Grading alternative development solutions based on selected criteria

Grading the "n" alternative solutions based on "m-1" criteria (we drop the zero criterion) is successively performed in 2 phases: primary scores and normalized scores.

I. Primary scores

For a certain criterion C_i, for each alternative solution V_j primary scores $N^*_{i,j}$ are given, using one of the following procedures:

I.a. If alternative solutions can be characterized by a quantifiable sum $M_{i,j}$ directly proportional to the development benefits (e.g. energy production, additional discharge to supplement the minimum natural one, expected fish production, new created jobs etc.), the primary scores can be expressed as (Eq. 6):

$$N^*_{i,j} = \frac{M_{i,j}}{\sum_{j=1}^{n} M_{i,j}} \tag{6}$$

I.b. If alternative solutions can be characterized by a quantifiable sum $M_{i,j}$, inversely proportional to the development benefits on the environment (e.g. maximum discharge as a result of flood routing, occupied land, damaged households etc.), the primary scores can be expressed as (Eq. 7):

$$N^*_{i,j} = \frac{\frac{1}{M_{i,j}}}{\sum_{j=1}^{n} \frac{1}{M_{i,j}}} \tag{7}$$

I.c. If alternative solutions cannot be characterized by a quantifiable sum, the primary scores are estimated using one of the following procedures:

I.c.1. Using 0...10 varying scores. If alternative solutions are considered to bring benefits on the environment, the corresponding scores will be in the range 6...10. If benefits are not associated to the alternative solution, the scores will vary in the range 0...4. The neutral solutions with regard to environmental benefits will get the score 5.

I.c.2. If a criterion C_i matches with an element or group of elements of the environmental impact assessment matrix, the primary score can be the sum of the columns values.

I.c.3. If considered appropriate, the scores can be determined using the procedure described at 4.1.2 paragraph, using V_j development alternatives instead of C_i criteria. In this case, $N^*_{i,j}$ primary scores will correspond to the p_i weights of the criteria.

II. Normalized scores

Since the importance of the criteria is reflected by their weight p_i, the sum of all scores given to every alternative development solution for any criterion C_i should be the same. Otherwise, the score values can alter the weights and importance of the criteria, thus affecting the discrimination of alternatives.

Therefore, the scores for a criterion have to be normalized. Thus, the summation of scores for any "n" alternative will lead to the same value (e.g. 1). For this purpose, one can define the normalized score $N^*_{i,j}$ (Eq. 8):

$$N_{i.j} = \frac{N^*_{i.j}}{\sum_{j=1}^{n} N^*_{i,j}} \tag{8}$$

It is obvious that $\sum_{j=1}^{n} N_{i,j} = 1$. Excepting the cases presented at I.c.1, I.c.2, primary scores will match the normalized ones.

4.1.5. Calculation of scores

After grading all the scores associated to selected criteria for the alternative development solutions, the evaluation process as follows:

- computation of the weighted scores (Eq. 9):

$$\left(N_{i,j}\right)_p = N_{i,j} p_i \quad (9)$$

- summation of the weighted scores for each alternative development solution V_j, for all C_i criteria.

As a result, the overall score for an alternative is (Eq. 10):

$$N_j = \sum_{i=1}^{m-1} N_{i,j} p_i \quad (10)$$

This score is a relative characteristics of alternative development solutions.

- to highlight even more the differences, it is useful to calculate the relative overall score for each considered alternative (Eq. 11):

$$\left(N_j\right)_R = \frac{N_j}{\sum_{j=1}^{n} N_j} \quad (11)$$

The calculation spreadsheet can be organized according to the pattern presented in Table 1.

4.1.6. Decision making

On a regular basis, the alternative development solution having the highest total score is preferred.

Given the many issues within the process assessment, score differences between the alternatives lower than 10% (i.e. less than 0.1 difference between the overall relative scores) should not be considered as crucial. In such situations, either additional studies or evaluations are required, or new criteria are considered, or the main decision maker is to select the preferred solution from the group of 10% margin, based on its own criteria.

To decrease the bias in the score assessment, it is recommended to increase the number of people involved in the judgments concerning the environmental effects of alternative development solutions. This will considerably increase the evaluation effort and time.

4.1.7. Choice of decision criteria

For river basin development solutions one can consider among the following criteria and sub-criteria:

(a) economic:

- investment costs and maintenance expenses for 5...20 years;
- related costs: reduction in revenues from tourism, fishing, sport, recreation;
- side effects costs: erosions, collapsed river banks (affecting households, land, crops etc.);

(b) social:

- aesthetics, landscape;
- recreation, tourism, sports;
- quality of riparian water;
- riparian flood protection;
- riparian population features: restrictions, traffic, stress etc.

(c) ecological:

- global impact index GI of a river development solution, taking into account the characteristics of the riverbed sector, river importance or “rank”, artificiality aggression of the engineered solution upon the river, time (duration).
- influence of technical solutions for the river development;
- deterioration of the existing ecosystems (protection, conservation, transformation, destruction etc.).

(d) conformity with restrictions:

- compliance with the provisions of The River Basin Development Plan (RBDP) and The River Basin Management Plan (RBMP).
- respect water storage areas during floods;
- protected areas restrictions;
- protection of public services (water supply, sewerage, waste deposits etc.);
- restrictions of developments affecting public or national utility activities.

4.2. Case study

The new proposed method is a rather lengthy process and it will be appropriately presented in a subsequent paper. For our case study one have proposed the development of a river sector, considering the following alternative solutions:

Solution 1: de-meandering solution by means of a concrete trapezoidal stream section, with massive side walls and a concrete slab at the bottom of the channel. Unfortunately, the channelized solution is not imaginary, being adopted in some flood protection developments even in recent years. The total cost of the development solution (including maintenance costs for a period of 5 years) was estimated at I_1.

Solution 2: preserves the natural tendencies of the stream, using only minor recalibration works and stabilization of river cross section with gabions and Macaferri mattresses, combined with gesynthetics and vegetative protection. It was estimated that the investment has a value equal to 1.32 I_1.

Solution 3: is the "zero option", i.e. doing nothing and letting the natural processes to develop freely with possible negative effects upon the flow conditions within the river sector. It was estimated that minor but permanent maintenance works to stabilize river banks and river bed, as well as to protect the existing human infrastructure may lead to investment cots surpassing the solution 1 costs.

Fig. 6 briefly illustrates solutions 1, 2 for the analyzed river sector.

For the given example, one have presented only the comparison of solutions 1 and 2, i.e. river development solutions and not the "zero" option. Table 2 shows the criteria values and scores and the final scores for the above mentioned solutions.

Comments:

- the assessment process indicates solution 2 seems to be the most advantageous;
- despite significantly higher investment costs of solution 2 (over 32% higher than for solution 1), the modern and sustainable materials and technologies, as well as natural ecosystems preservation were decisive in allocating higher scores for this solution;
- a simple B/C analysis (BCA) would have led to the promotion of solution 1, with the lower investment cost.

5. Conclusions

The use of Benefit-Cost Analysis (BCA) has become an international practice for promoting river development solutions. The method is mainly used to compare different river development solutions, based on an “artificiality index”, or “global impact GI”. The authors of the paper propose a new method to replace the rigid BCA with a rational process of multi-criteria assessment, which takes into account the environmental impact of engineering solutions for river development.

Table 1. Calculation of scores for alternative river development solutions (adapted from Ionescu, 2007)

C_i	p_i	V_1			V_j			V_n	
		$N_{i,1}$	$N_{i,1}\cdot p_i$	...	$N_{i,j}$	$N_{i,j}\cdot p_i$	...	$N_{i,n}$	$N_{i,n}\cdot p_i$
C_1	p_1			...			...		
C_2	p_2								
...	...								
C_{m-1}	p_{m-1}			...			...		
TOTAL	-	-	N_1	...	-	N_j	...	-	N_n

Table 2. Calculation of scores for alternative river development solutions 1 vs 2

Criterion	*Criterion weight P*	*Sub-criterion*	*Sub-criterion weight p*	*Solution 1*		*Solution 2*	
				Normalized score N	*Weighted normalized scores Np1*	*Normalized score N*	*Weighted normalized scores Np2*
Economic C1	0.415	investments - C1.1	0.2075	0.569	0.118	0.431	0.089
		secondary effects - C1.2	0.2075	0	0	0	0
Social C2	0.170	aesthetics - C2.1	0.0570	0.182	0.010	0.818	0.047
		population regime - C2.2	0.1130	0.333	0.038	0.667	0.075
Ecological C3	0.415	C3.1	0.1369	0.287	0.039	0.713	0.098
		C3.2	0.2075	0.055	0.011	0.945	0.196
		C3.3	0.0705	0.110	0.008	0.890	0.063
TOTAL	**1**		**1**		**0.225**		**0.568**

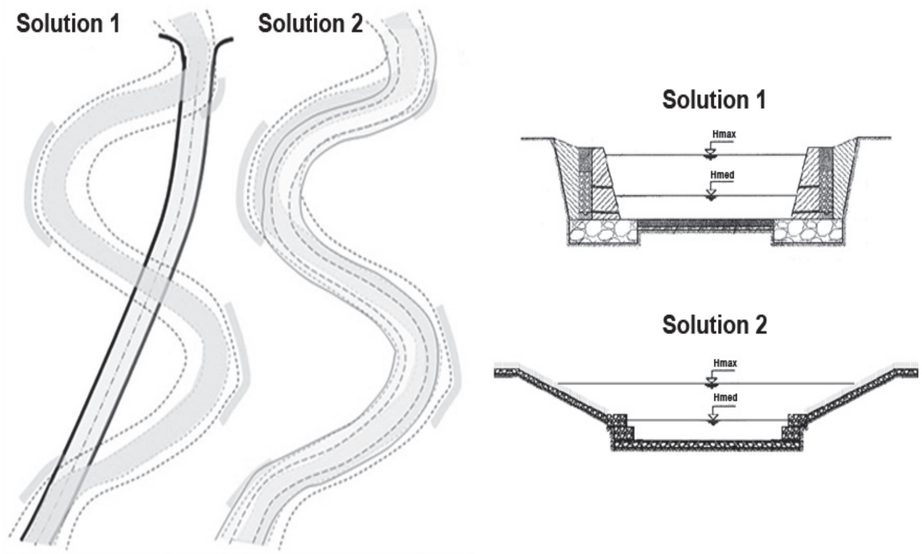

Fig. 6. Typical development solutions 1 vs. 2 for a given river sector

Even if solutions identified as optimal by the proposed method do not match with the best ones according to the BC criterion, they are actuality the most valuable in terms of environmental impact and its sustainable development.

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