USING GEOGRAPHICAL INFORMATION SYSTEMS FACILITIES IN ORDER TO MANAGE TORRENTIAL HYDROGRAPHIC BASINS

Cornel Cristian TEREŞNEU, Lecturer PhD. Eng., Transilvania University of Brasov, România, cteresneu@unitbv.ro

***Abstract**: Given the fact that natural phenomena, which used to be manifested according to relatively known laws, are exercising there influence more and more chaotically and unpredictably, increasingly affecting different strategic objectives (communication ways, reservoirs, touristic sites and even human habitats), the need to study torrential hydrographic basins using modern instruments is rising quickly. This is why we have purposed that in the current paper we shall expose the Geographical Information Systems facilities available to the user in order to adopt the best management of a torrential hydrographic basin.*

***Keywords:** torrential watershed, GIS, AutoCAD.*

1. Introduction

Chaotic development of weather phenomena of recent times need new methods of study, with direct involvement of the latest technology, in view of adopting the most accurate solutions to counteract their effects. Torrential rainfalls of last summer (2009) have adversely affected many areas in our country. Such a situation occurred in the locality Bran-Poarta, Braşov County, where, negative effects were obvious both at the level of Communal Road DC 51 Bran-Poarta (figure 1), and the level of other objectives such as: homes, parking area and annexes related to the ski slope Zănoaga etc. (fig. 2).

Starting from the negative implications of this, the problem of planning nd arrangement of the hydrographic basin Valea Porții in total area of 2135.05 ha has been studied. As particular problems were found in the section located immediately downstream of the forestry sector and, following the principle laid down by late Professor S. Munteanu according to which "the field is defending at mountain", the question of arrangement of the sector upstream the inhabitable area was raised. Consequently, the study will consider a torrential hydrographic basin of 1256 ha (fig. 3).


Fig. 1. Road degradation DC 51


Fig. 2. Households affected by floods

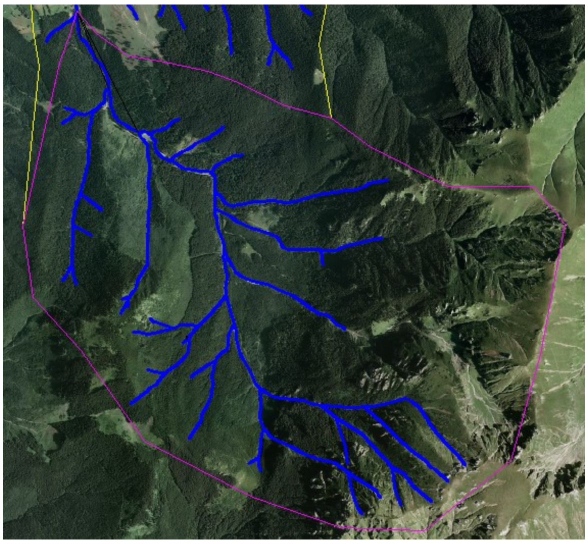

Fig. 3. Hydrographic basin examined

2. GIS facilities in planning torrential hydrographic basins

2.1. Using AutoCAD to determine the elements of basin and hydrographic network morphometry

A. Morphometrycal elements of watershed

a. ***The surface*** was calculated by utilization of function *Terrain – Terrain Model Explorer – Create Surface*, that creates automatically the *NamelayerSRF-BDR* layer and it specifies the value of surface in area *Extended Surface Statistics*. The founded value is F=12564950.667 m^2≈1256 hectares;

b. ***The perimeter*** results automatically in AutoCAD, the numbers of the both characteristics appearing together. In this case, P_b=14052.997≈14 km;

c. ***The mean length of watershed*** was computed with the known formula:

$$\overline{L}_b = \frac{P_b}{4} + \sqrt{\frac{P_b^2}{4} - F} = 1316.939 \approx 1.3 km \cdot \quad (1)$$

d. ***The shape of watershed*** was studied using the next coefficients:

- Gravelius coefficient: $Gr \cong 0{,}282 \cdot \frac{P_b}{\sqrt{F}} = 1.12$; (2)
- Ratio of circularity: $RC = 12{,}566 \cdot \frac{F}{P_b^2} = 0.80$; (3)

These results indicate that the studied watershed is slightly elongated.

e. ***The minimum, maximum and mean altitude.*** Minimum (H_{min}) and maximum (H_{max}) altitude haven’t important signification regarding hydrology. Their identification is very easy, either consulting of database for the elaborated project or using *Inquiry – Surface Elevation* fuction. On the situation of studied watershed, the next values were computed:

$$H_{\min} = 914.50m;\ H_{\max} = 2260.80m;\ H_{med} = \frac{H_{\min} + H_{\max}}{2} = 1587.65m;$$

(4)

$$H_{med} = \frac{\sum_{n}^{n+1} F_{i,i+1} \times \frac{H_i + H_{i+1}}{2}}{F} = 1255.30m$$

(5)

f. ***The height of watershed***. In accordance to each situation, either maximum height or mean height of the watershed can be computed (Clinciu and Lazăr, 1999). The values of studied watershed are as follows:

$R_{\max} = H_{\max} - H_{\min} = 1346.30m$; (6)

$R_{med} = H_{med} - H_{\min} = 673.15m$; (7)

$R_{med} = H_{med} - H_{\min} = 340.80m$; (8)

g. ***The slope of watershed*** can result using AutoCAD in two ways:

- by achievement of network with vertical and horizontal lines using *Array* function, overlapping with digital model of land. In the knots of network, the values of slopes result resorting to *Label Slope (Terrain – Surface Utilities)* function. With this values, the mean slope of the watershed can be calculated ($I_{med} = 40.82\%$);
- by recourse to *Create Surface (Terrain – Terrain Model Explorer)* function, in the area *Extended Surface Statistics* the mean value of slope results too ($I_{med} = 41.65\%$).

h. ***The length of mountainsides from watershed.*** Usually, the length of a mountainside can be computed with AutoCAD in a few ways:

- in the case of 2D system, the length of a mountainside results using a polyline (with actively perpendicular mode in *OSNAP*), to draw the line of the highest slope beetwen one point from thalweg to the chosen point from topographical line of the analyzed mountainside;
- in the case of TIN model, *Slope Arrows... (Terrain – Surface Display►)* function is used to indicate the general orientation of trickling from watershed. By their analyze, the line of the length for each mountainside can be discovered.

The mean length of mountinsides from watershed was calculated with the next expression:

$\overline{L}_v = 5.5 \frac{F}{L_r} = 280m$. (9)

In this case, to determine the length of the hydrographic network an *AutoLisp* sequence has been developed which automated this calculation. This sequence relied on calling the function *Inquiry – Continuous Distance* and *'cal*. To automate this process of measuring the hydrographic network and, at the same time, to label each bed segment with a value corresponding to its length, when creating the basic hydrographic basin the order corresponding to each segment must be taken into account. Thus, for development and proper functioning of *AutoLisp* sequence the following actions will be made: indicating how hydrographic network runs (upstream to downstream, so from 1st order segments towards higher order ones), calling function *Inquiry – Continuous Distance, OSNAP Midpoint* mode for labeling bed segment in the middle with values corresponding to the hydrographic order and its length, specifying the next bed segment, at each network node making an interrogation of the order of segments that intersect and labeling the following segment as follows: if the order of intersected segments is identical, the next segment will have the order higher by one unit; if the intersected segments order is different, the highest order will be kept (fig. 4).

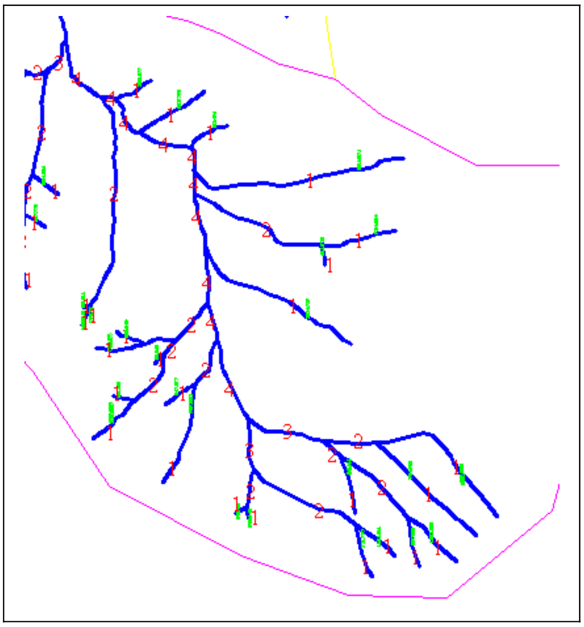

Fig. 4. Automated labeling of hydrographic network

B. Morphometrycal elements of the hydrographyc network

a. ***The hydrographyc rank***. In concordance with Strahler system, the torrential watershed contains sectors with I, II, III and IV ranks.

b. ***The length of riverbed.*** This parameter can result in AutoCAD using *Inquiry – Continuous Distance* function. The function achieves a labeler of the measured element with corresponding distance also, for case.

$$L_{ar} = \frac{L_a}{\cos\alpha} = 8134.82m = 8.13km \qquad (10)$$

c. ***The mean slope of the main riverbed***. In the classical mode this parameter results such as a fraction between the level difference of extreme points and horizontal length of the riverbed: $I_a = \frac{H_{am} - H_{av}}{L_a} = 0.23 \rightarrow I_a = 23\% \rightarrow I_a = 13^0 8'$. The values H_{am}=2247.45m and H_{av}=914.50m were computed using *Inquiry – Surface Elevation* function.

2.2. Estimation of the maximum flow capacity of high-water

In situations of torrential watersheds from Romania, the forecast of the maximum flow capacity of high-water is accomplished by indirect methods. That are methods based on the rain which is the source of high-water and the elements of watershed that can influence the formation and propagation process of high-water (Clinciu and Lazăr, 1999).

Even there are many methods to compute the maximum flow capacity of high-water, in this paper we used only two of them:

a. ***The rational method***, that utilizes the follow expression (Munteanu et al, 1979):

$$Q_{max1\%} = 0,167 \cdot c \cdot i_{1\%} \cdot F \qquad (11)$$

where:

c is the mean coefficient of trickling in the watershed;

$i_{1\%}(mm/\min)$ - the mean intensity of rain used in estimation with 1% probability, having an equal duration with the concentration time of trickling in the watershed;

F(hectare) – the area of watershed.

First, the concentration time of trickling was calculated. The *Hidrology (Hidrology - Runoff► - Time of Concentration (Tc)...)* module was utilized for this, finding in this way $T_c = 31\min$. The mean intensity of rain required in estimation was computed further on, using the concentration time of trickling ($I = 1.62 mm/\min$). Therefore, considering the precipitation generated by rain used in estimation and the hydrological category of land, the retention coefficient resulted (c_z). After that, the infiltration coefficient (c_I) was found depending on mean intensity of rain used in estimation and the soil texture. Using the c_z and c_I values, the trickling coefficient for the watershed resulted (c=0.24). In this way $Q_{\max 1\%} = 81.58 m^3/s$ was computed.

b. **The method of hourly rain** is base on the follow formula:

$$Q_{\max 1\%} = \frac{0.28 \cdot F \cdot c \cdot H_{60}}{(F+1)^n}, \tag{12}$$

where:

F(km^2) is the area of torrential watershed;

c – mean coefficient of trickling, that is established for geographical regions from Romania (c=0.70);

H_{60}(mm) – maximum hourly precipitation, in cases of climatic zones from Romania, at 1% probability (H_{60}=115mm);

n – exponent smaller than one, having districts in Romania (n=0.48).

As result, $Q_{\max 1\%} = 81.00 m^3/s$.

2.3. Forecast of silt transport

To develop solutions for torrential hydrographic basin planning is necessary both the forecast of annual average silt transport and the prediction of silt transport from a single downpour.

A. Transportation of silt in a downpour

For indicative assessment of this transportation, the design normative recommends applying a relationship obtained by simplifying Herheulitze formula:

$$W_{al}^{p\%} = 50 \cdot b \cdot F \cdot (P - Z - I), \tag{13}$$

where:

$W_{al}^{p\%}$ is the volume of silt transported during rain with probability p%;

b – dimensionless coefficient that takes values according to the general slope of the main riverbed and the percentage occupied by excessively degraded lands from the total area of the basin;

P(mm) – height of the layer of precipitations caused by rain with probability p%;

Z(mm) – height of the layer of precipitation retained by vegetation and micro depressions;

I(mm) – height of the layer of precipitation infiltrated into the soil, at duration of calculation rain;

F(km^2) – basin area.

A version of the above relation was applied which is based on the average flowing coefficient per basin. Thus, for reference probability p=1%, the silt transport generated by downpour will be:

$$W_{al}^{1\%} = 50 \cdot b \cdot c \cdot F \cdot H_{1\%}, \quad (14)$$

where:

$H_{1\%}(mm)$ is the height of the total calculation rain;

c – average flowing coefficient per basin;

To determine the coefficient b, as excessively degraded lands have been considered on the hydrographic network and has been taken into account the total length of the network and the width of riverbeds as per orders.

Passing from reference probability (p=1%) to the probability of verification (p=0.5%) was determined by correction coefficient $K_{0.5\%}$ established within the maximum high flood flow.

Therefore, the amount of silts that could be triggered in a downpour whose exceedance probability p=0.5% will be:

$$W_{al}^{0.5\%} = K_{0.5\%} \cdot W_{al}^{1\%} = 3435.8 m^3 / year. \quad (15)$$

B. Annual average silt transport

In practical applications of torrents planning in Romania, for the annual average transport of silt was accredited the method proposed by R. Gaşpar and A. Apostol (Clinciu & Lazăr, 1999), method that has been designed for the specific of torrential basins of our country. It is based on the relation:

$$W_a = W_{av} + W_{aa}, \quad (16)$$

where:

$W_{av}(m^3 / an)$ is the average annual volume of silt resulted from slopes' erosion;

$W_{aa}(m^3 / an)$ - average annual volume of silt resulted from riverbed erosion.

a. <u>Transport from slopes</u>

The aforementioned authors recommend the following relation:

$$W_{av} = a \cdot b \cdot \sqrt{I_v} \cdot \sum(F_i \cdot q_{li}), \quad (17)$$

Where:

a is a dimensionless coefficient, with values ranged from 0.7 to 2.2 depending on the average length of basin slopes;

b – dimensionless coefficient, of decreasing silt amount carried from slopes, if slopes consist of a sequence of terraces or the lower side is slightly sloped; in such conditions local alluvial sedimentation and consolidation is possible. For this coefficient are adopted values between 0.5-1.0;

I_v - average slope of the basin sides;

q_{li} - specific index of erosion in surface $(m^3 / an \cdot ha)$ of a particular category of land in the basin;

F_i surface (ha) of the land category concerned.

For determining the specific surface erosion index, GIS project has been used for the entire basin Valea Porții, making a new thematic map with categories and subcategories of land in the basin (fig. 5), this way the areas occupied by it could easily be determined. Two categories have been identified (forest and grasslands). 4 subcategories were demarcated in the forest category (1-B_2, 2-B_2, 3-C_1, 5-B_3).

Given that a=2.17, b=0.93, $\sum(F_i \cdot q_{li}) = 6948.7$, results that $W_{av} = 3127 m^3 / an$.

b. <u>Network transportation</u>

In assessing the average annual volume of silt from riverbed erosion, indicative results are obtained by applying the relation:

$$W_{aa} = b \cdot \sum \left(L_i \cdot q_{li} \cdot \sqrt{\frac{i_a}{i}} \right), \quad (18)$$

where:

b is a dimensionless coefficient for reduction of silt volume driven from riverbeds as a result of storage of a part of this silt volume over time; values ranged between 0.5-1.0 are adopted;

L_i – the length in km of sectors in the hydrographic network, mainly, in unconsolidated alluvial deposits that can be easily eroded (excluding portions of erosion resistant riverbeds);

q_{li} - depth erosion specific index $(m^3 / an \cdot km)$ on riverbed sector of length L_i;

i_a – the average bed slope on length sector L_i;

i – the “standard” value of slopes of a certain width, considered to determine values of erosion indices q_{li}.

Considering at a first stage that the whole hydrographic network provides silt, value $W_{aa}^{100\%} = 7364.6 m^3 / an$ /year will be determined. The result thus obtained has been corrected by a subunit coefficient of silt influx (c_a), coefficient which approximated the basin network participation in generating annual average silt transport. For this coefficient is recommended the relation $c_a = \frac{F_{E3} + F_{E4}}{F}$ (19), where F (ha) represents the basin surface, and F_{E3} and F_{E4} represent areas occupied in the basin by erosion lands of 3 and 4 degree.

So, $W_{aa} = c_a \cdot W_{aa}^{100\%} = 5523.4 m^3 / an$. (20)

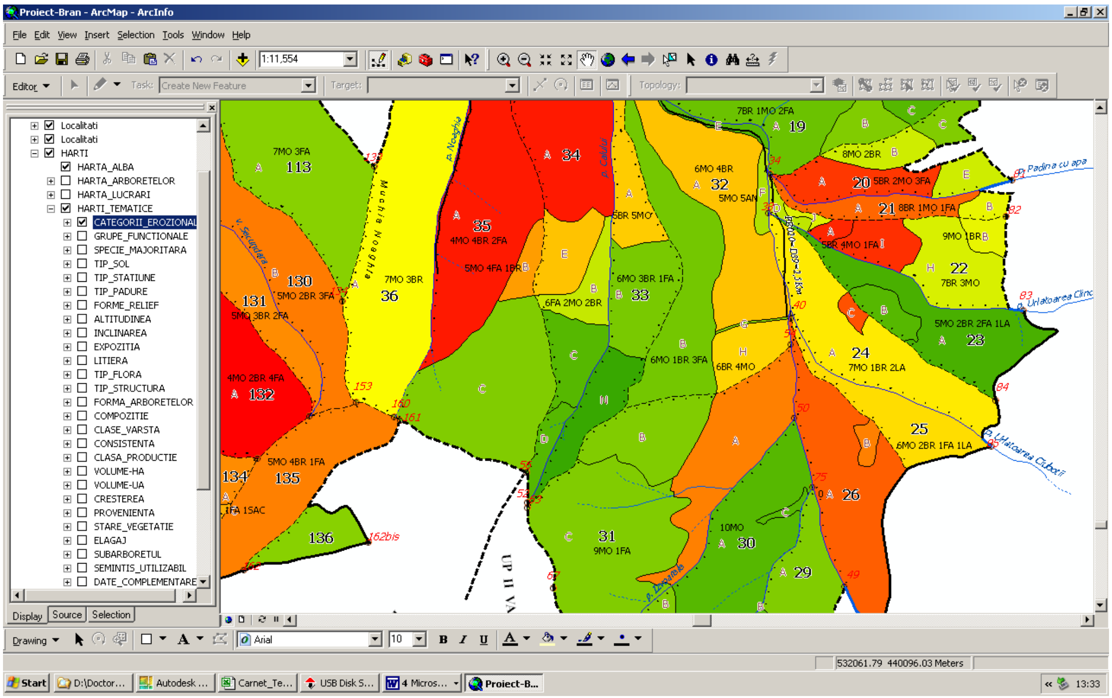

Fig. 5. Thematic map with basin erosion categories

C. Alluvial volume in channel fill

The design of retention capacity in the basin requires direct knowledge of the volume of silt that can be stored as channel fill. This volume comes both from the annual average transport of silt and from transportation of silt in a downpour.

a. <u>Channel fill volume derived from annual average transportation</u>

For indicative estimation of silt volume that could form channel fills, R. Gaşpar & A. Apostol recommend riverbed slopes of at least 3% and elevation height of dams up to 6 m, and application of the formula:

$$W_a^{ater} = A \cdot W_{av} + B \cdot W_{aa} = 4556.2 m^3 / an; \quad (21)$$

Where:

$W_{av}(m^3/an)$ represents the annual average volume of silt from erosion of sides;

$W_{aa}(m^3/an)$ - annual average volume of silt from erosion of riverbeds;

A and B – coefficients depending on the diameter of silt from erosion of slopes and river beds, respectively.

b. *Volume in channel fill from transport during downfall*

In case of downpours providing p=0.5%, the silt volume that can form channel fills can be assessed with a relation of the type:

$$W_{0.5\%}^{ater} = \frac{W_a^{ater}}{W_a} \cdot W_{al}^{0.5\%} = 1794.3 m^3. \quad (22)$$

2.4. Adopting technical solutions

Regarding adopting technical solutions were considered only aspects that can be GIS simulated.

A. Planing period or new works

It adopted N = 5 years.

B. Volume of silt able to form channel fills

Is determined with the relation: $W_{ater}^{5ani} = 5 \cdot W_a^{ater} + W_{0.5\%}^{ater} = 24575 m^3$. (23)

C. Probable slope of silt settlement in channel fill

It is adopted in accordance with legislative recommendations, mainly taking into account the granulometric composition of deposits driven in high floods. It also takes into account that in this case, works will be located on the hydrographic network of IVth order, where deposits are predominantly composed of coarse gravels ± boulders of 1-7 cm. Therefore the probable settlement slope of silt in channel fill will be 3%.

D. Retention capacity of a single dam. Number, height and location of dams

- By using the extension *Civil Design* of *AutoCAD* has been made the longitudinal profile of the main riverbed downstream (fig. 6).
- Based on topographic measurements made on the first 2 km of the main riverbed and using HEC-RAS software, an average transversal profile was made.
- The retention capacity of a single dam was studied according to its useful height considered in the range 5.0-3.0.

Calculation of channel fill volume is based on the below relation:

$$W_{at} = \frac{Y_M^2}{6(i_a - i_{at})}\left(3b + 2 \cdot \overline{m} \cdot Y_M\right) = 432 m^3, \quad (24)$$

Where:

YM (m) is the useful height of transversal works;

b(m) – average width of the riverbed in the area where channel fill is formed;

m – slope coefficient (average) of the two riverbed sides;

ia – average slope of riverbed thalweg, where channel fill is formed;

iat – slope "for calculation" or design slope (average slope probable of silt settlement in channel fill).

E. Number of dams

It has been determined with the relation: $N = \frac{W_{ater}^{5ani}}{W_{at}} = 35$. (25)

F. Dams' height

Was adopted Y_M=4.5m

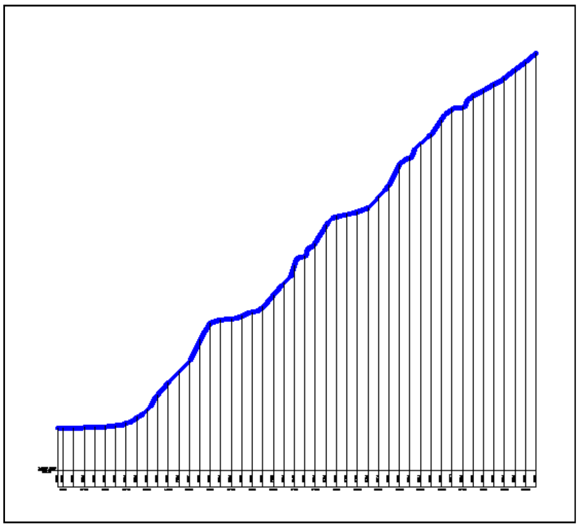

Fig. 6. Transversal profile of the riverbed

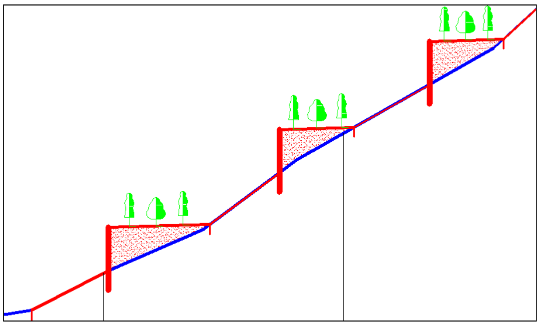

Fig. 7. Automatic location of dams

In order to adopt technical solutions, it has been made an *AutoLisp* sequence involving the following aspects preliminary to execution: selects polyline designating the longitudinal riverbed profile, indicating the riverbed width (which is assumed to be constant), Stereographic 1970 projection coordinates of the first point of dam location, dam height, depth of its foundation, length of invert, volume of silt able to form channel fill (W_{ater}^{5ani}), design slope. This sequence will make: draw of the first dam at indicated point and its invert, stimulates complete filling with silts at design slope value, determination of filling surface by interrogation with function *Inquiry-Area* of the area bordered by dam wall, line of longitudinal profile and design slope, calling function '*cal* to determine the channel fill volume of the first dam (will take into account the riverbed width), continues drawing and calculation of channel fill volume until covering the previously indicated value. In this case, resulted a number of only 33 transversal works (dams), the difference from the previous value (N=35) being given by the fact that the longitudinal profile is not constant as slope (fig. 7).

3. Conclusions

Because of damages occurred to a large number of objectives of Bran-Poarta, Braşov County, after downpours in the summer of 2009, the question of stopping torrents formed in this area was put. Immediate defense method of the objective downstream was used, taking into account that: funds assigned to torrent planning actions are limited, torrential hydrographic basins planning is a difficult and time action that cannot be carried out in phases.

This paper has highlighted the possibilities that *AutoCAD* provide to the user in view of easy determination of basin morphometric parameters, the maximum liquid volume of high-flood, transportation of silt, as well as possibilities of *AutoLisp* programming that can lead to an optimal location of torrents correction works in the studies basin. It is noted the possibility to locate these works downstream the main riverbed after specifying the geographical position of the first dam and, based on objective calculation of the volume of silt retained by each dam, setting the correct number of necessary dams, as well.

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