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Model of transformation of quantitative indicators of the maximum expenditures of drainage of waters of showers in the system of clough drainage areas of the small rivers

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The purpose. To assess intensity of erosion-hydrological situations according to basin principle as scientific basis of heightening anti-erosion protection of soils. **Methods.** Laboratory-field, mathematical-statistical, topometric, morphological. They studied ordinary eroded chernozems of agrolandscapes of the basin of river Aidar (the left-handed inflow of river Siverskyi Donets). **Results.** On the database of erosion-hydrological factors (drainage area, km^2; showers, mm; share on drainage area of cross woodland belts, %; ploughness of drainage areas, %; quotient of ecological integrity; content of humus on key points; %) mathematical-statistical model of expenditures of drainage from showers in the rivers is developed. To characterize changes of hydraulicity of the river on the path from river head to mouth they applied quotient of reduction of river beds and reduction of hydrographic network. In view of reduction of rainfalls, river beds and hydrographic network of basin of river Aidar they elaborated the model of transformation of a river flow on downslopes separately for right- and left-handed shores. By means of program complex MapInfo they digitized model of transformation of river flow on downslopes and the skeleton map of slope runoff. **Conclusions.** Application of state-of-the-art GIS-TECHNIQUES enables to gain vector characteristics of quantitative indicators of the maximum expenditures of drainage in basin of the small rivers, to map their transformation on downslopes in the form of TIN-surfaces and isolines and to make their quantitative assessment in 3-level system: river basin → system of clough drainage areas of hydroposts → downslopes. The most influential erosion-hydrolytical factors are: showers, ploughness up of terrains and area of drainage areas. Diminishing indexes are: content of humus, quotient of ecological stabilization and cross woodland belts.

Key words: *basin, drainage area, hydropost, downslopes, humus, drainage, expenditures, factors, quotient.*

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In the conditions of cyclic nature of storm precipitation manifestation in the course of general climatic changes, a reduction in the humus content of soils and, as a result, a decrease in their anti-erosion resistance, a decrease in environmental sustainability agricultural lands, the use of simplified agro-technical erosion measures, the risks of further erosive degradation of soils in the basins of small rivers have increased significantly.

The purpose of the work is to develop a model and a map of the transformation of the quantitative indicators of the maximum flow rates of the river. Aidar on the slopes of the beam watersheds. This will allow, using a spatial assessment of erosion-hydrological processes in the system: a small river basin → a beam catchment basin, to justify the ways of minimizing runoff, taking into account the natural potential of the watersheds of the r. Aidar.

Results of recent researches (justification of research direction)

For the last 20 years, the problem of minimizing erosion and maximizing the use of natural resources of soils in the agro-landscape aspect is solved in a comprehensive way and involves the formation of an ecological organization of the agricultural block and soil protection structure of crop rotation, the formation of ecosystem bands, the use of mineral fertilizers, biohumus, the study of the impact of soil erosion on the potential of climate [1, 2, 3].

For the territory of Ukraine, several schemes have been developed for calculating slope runoff and floodwaters. Most of the existing techniques are based on the analysis of artificial sprinkling [4], or on materials "Observations on small rivers and runoff stations" [5].

Almost all of the above recommendations and instructions are aimed at determining the ensured runoff and runoff values for the precipitation climate, which have changed significantly in recent decades. Therefore, in the methods of calculating flow for modern agrolandscapes, one must take into account their structure and the soil-conservation role of arable and natural forage areas [6].

In general, in the present time in Ukraine at the regional level and within the basin structures, the practical arrangement of small and medium-sized rivers is not targeted intentionally and the relevance of the research is that for the first time on the new technological basis the anti-erosion arrangement of small river basins is carried out at the system level.

Analysis of research materials shows that the program of solving soil and environmental problems should include:

- development of new methodical approaches to evaluation of manifestations and minimization of risks of erosion processes in the country lands;
- regional standards of the real speed of processes of erosion, which are established not by expert way, but experimentally, with application of estimation of erosion-hydrological situations by basin principle [7];
- ecological organization of the territory on the principle of minimum water losses and soil washing;
- ecological substantiation of soil protection structure of sown areas;
- development of nature-friendly technologies of harmonious functioning of soil formation indicators in modern agro-systems taking into account the factors of water erosion processes.

Objects and methods of research

The purpose of the research is to assess the intensity of erosion and hydrological situations based on the basin principle as a scientific basis for increasing the anti-erosion protection of soils.

The object of the study is the eroded chernozems of the usual agro-landscapes of the Aidar Basin within the framework of the four systems of the gutter catchments confined to the biologists Bilolutsk, Kuryachivka, Starobilsk, Bakhmutivka (Fig. 1).

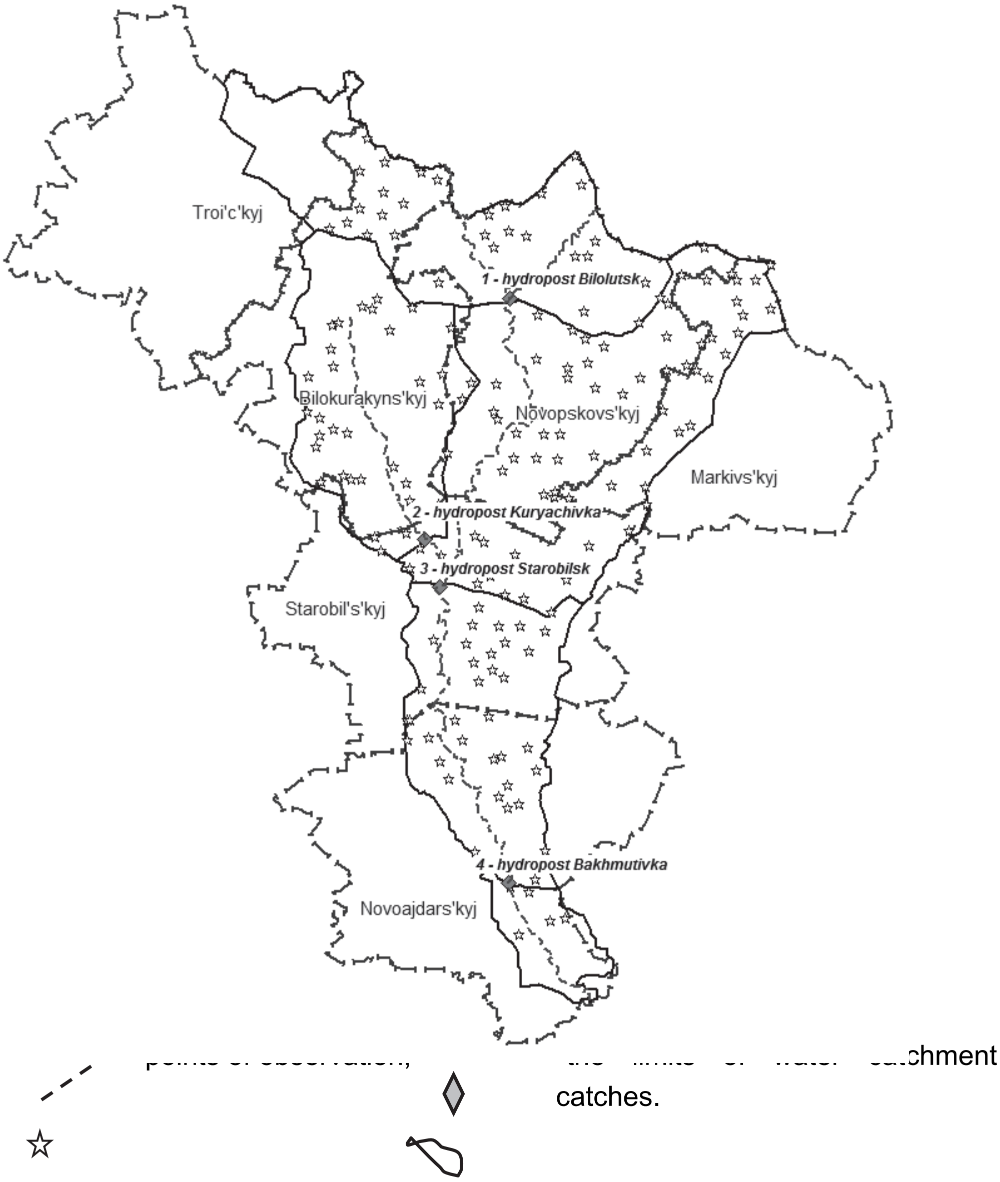


Figure 1. Object of research (Aidar river basin within the Lugansk region)

Subject of research - erosion-hydrological situation according to the basin principle at different hierarchical levels of the river basin (basin of the river → beam catchment): runoff costs and its transformation into slopes.

The method of conducting research.

The methodological basis of the research is the spatio-temporal analysis of the factors of influence on the erosion and hydrological processes on the basis of the basin concept in the system: the basin of the small river → the beam catchment, its mathematical modeling, digitization of the obtained models by means of GIS technologies in the form of TIN-surfaces.

The climatic characteristic contains information on the annual course of precipitation for three characteristic water years (wetland, medium, shallow water) and the amount of precipitation per year. Observations of the hydropost Kuryachivka, Bilolutsk, Starobilsk, Bakhmutivka.

The relief and hydrological parameters are characterized by slope, length and exposure of the slope, as well as by the dismemberment of the riverside and lagoon-bilge water catchment network of the Aidar Basin (mapping data of topographic maps M: 1: 10000, Google Maps, Wikimapia.org, processed in Mapinfo).

Data on rainfall losses from runoff for modern agricultural activities are characterized by the maximum losses of river runoff and forecasting indicators on the model of runoff [8] taking into account the natural and man-made data of the river catchment.

The ecological organization is estimated by the ratio of arable land, onion, forest in different natural climatic, soil and anthropogenic conditions of the river basin.

Results and discussion

For the construction of a mathematical and statistical model of runoff costs from storm rainfall in rivers, a database of erosion-hydrological factors of the basin [9] with rainfall differentiation (mm) by hydropost: a full year, average, low year of the year and corresponding to these periods, maximum runoff costs, m^3/s (Table 1).

Table 1. *Erosion and hydrological factors of the flow cost model from storm rainfall in the rivers*

Hidropost	Flow losses (Q_{max}), m^3/s	Maximum rainfall (X), mm	The catchment area (F), km^2	Humus content (F_{hum}), %	Plowing (Fn), %	Coefficient of environmental sustainability (F_{kes})	Transverse forest bands (F_{ls}), %
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
full water year							
Bilolutsk	38,3	72,9	2250	5,11	69,4	0,022	0,46
	38,3	72,9	2250	4,59	69,4	0,026	0,08
	38,3	72,9	2250	3,75	69,4	0,027	0,60
Kuryachivka	18,4	78,7	820	5,04	62,7	0,014	5,65
	18,4	78,7	820	4,58	62,7	0,025	0,12
	18,4	78,7	820	3,56	62,7	0,030	0,20
	18,4	78,7	820	2,53	62,7	0,029	1,33
Starobilsk	60,6	63,7	6370	4,38	71,1	0,023	0,07
	60,6	63,7	6370	3,72	71,1	0,028	0,08
Bakhmutivka	47,9	93,5	7160	4,39	72,6	0,036	0,36
	47,9	93,5	7160	3,5	72,6	0,032	0,09
	47,9	93,5	7160	2,65	72,6	0,028	0,68
medium precipitations							
Bilolutsk	18,9	69,6	2250	5,11	69,4	0,022	0,46
	18,9	69,6	2250	4,59	69,4	0,026	0,08
	18,9	69,6	2250	3,75	69,4	0,027	0,60
Kuryachivka	8,4	76,5	820	5,04	62,7	0,014	5,65
	8,4	76,5	820	4,58	62,7	0,025	0,12
	8,4	76,5	820	3,56	62,7	0,030	0,20
	8,4	76,5	820	2,53	62,7	0,029	1,33
Starobilsk	33,2	60,0	6370	4,38	71,1	0,023	0,07
	33,2	60,0	6370	3,72	71,1	0,028	0,08
Bakhmutivka	28,8	89,2	7160	4,39	72,6	0,036	0,36
	28,8	89,2	7160	3,5	72,6	0,032	0,09
	28,8	89,2	7160	2,65	72,6	0,028	0,68
shallow water year							
Bilolutsk	7,5	64,6	2250	5,11	69,4	0,022	0,46
	7,5	64,6	2250	4,59	69,4	0,026	0,08
	7,5	64,6	2250	3,75	69,4	0,027	0,60
Kuryachivka	2,6	68,2	820	5,04	62,7	0,014	5,65
	2,6	68,2	820	4,58	62,7	0,025	0,12
	2,6	68,2	820	3,56	62,7	0,030	0,20

	2,6	68,2	820	2,53	62,7	0,029	1,33
Starobilsk	13,6	49,1	6370	4,38	71,1	0,023	0,07
	13,6	49,1	6370	3,72	71,1	0,028	0,08
Bakhmutivka	14,9	65,5	7160	4,39	72,6	0,036	0,36
	14,9	65,5	7160	3,5	72,6	0,032	0,09
	14,9	65,5	7160	2,65	72,6	0,028	0,68

Charts of the equations of factors, the order of their influence in the construction of models is shown in Figure 2.

The model is expressed by the empirical formula:

$$Q_{max} = A \cdot F^{0,6248} \cdot X^{1,4659} \cdot F_{ls}^{-0,0738} \cdot F_n^{0,9243} \cdot F_{KES}^{-0,2876} \cdot F_{hum}^{-0,6419}, \qquad (1)$$

де: $A = 4,4 \cdot 10^{-6}$

F – catchment area, km^2; X – storm rainfall, mm;

F_{ls} – forest strips are transverse, %; F_n – plowing, %;

F_{KES} – coefficient of environmental sustainability;

F_{hum} – humus content, %

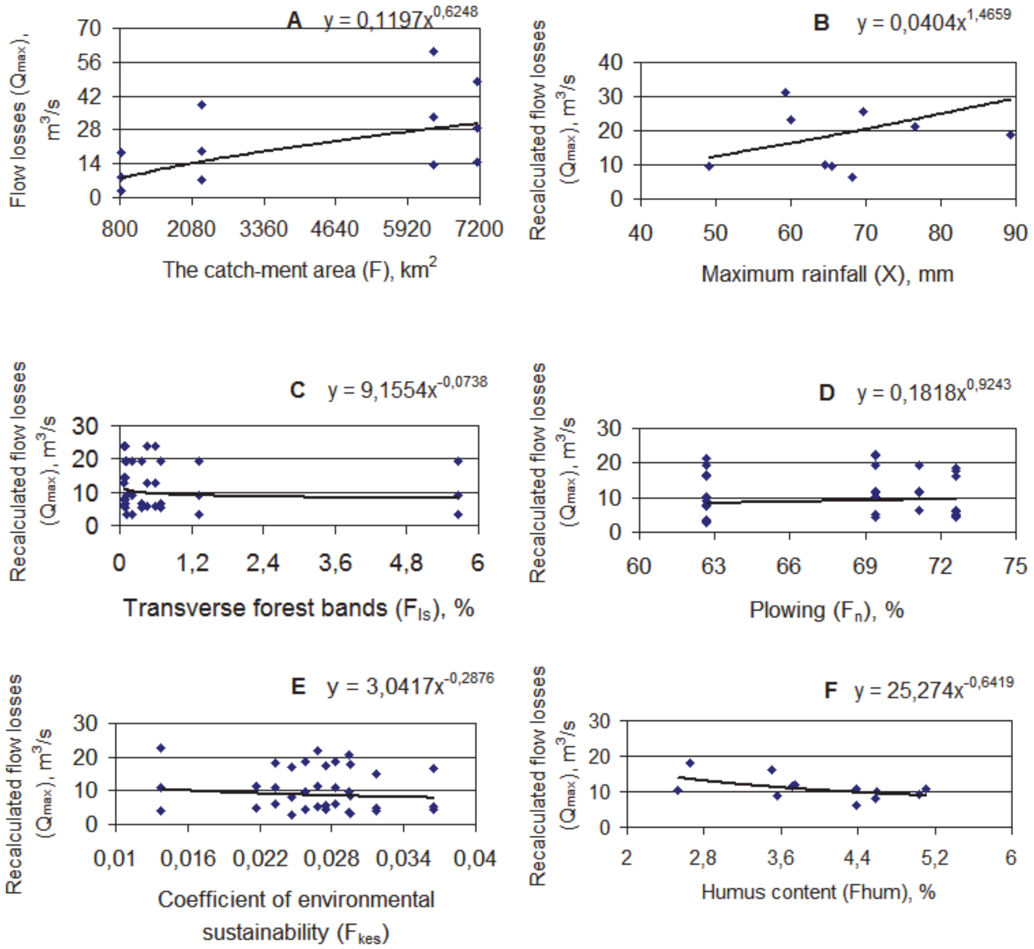


Figure 2. Dependence of flow costs (Q_{max}) on erosion-hydrological factors

Characteristics of the cost of runoff from storm rainfall in the rivers is given in Table 3.

Table 3. *Characteristics of the model of runoff costs from storm rainfall in the rivers.*

Erosion-hydrological indicators	Equation model	Leading factors, their impact on the model,%	Characteristics of the model	
			E, %	R
Catchment area, km^2	$y = 0{,}1197\ F^{0{,}6248}$	15,55	2,35	0,8474
Storm rainfall, mm	$y = 0{,}0404\ X^{1{,}4659}$	36,48		
Forest strips are transverse, %;	$y = 9{,}1554\ F_{лс}^{-0{,}0738}$	1,84		
Plowing, %;	$y = 0{,}1818\ F_{п}^{0{,}9243}$	23,00		
Coefficient of environmental sustainability	$y = 3{,}0417\ F_{KEC}^{-0{,}2876}$	7,16		
Humus content, %	$y = 25{,}274\ F_{гум}^{-0{,}6419}$	15,97		

The most influential erosion-hydrological factors are storm rainfall, growing area and catchment area (36,5, 23,0 and 15.6% of the impact on the model in the direction of increasing flow costs); this indicator reduces the humus content, the ecological stabilization factor and transverse forest bands (respectively 16, 7,2 and 1,8% of the impact). The coefficients of the multiplication correlation (R) of 0,85 and the relative error of the model (E) indicate a high reliability of the calculations received.

Model of river flow transformation on slopes.

Determination of the controlling capacity in such large agro-landscapes as a river basin does not allow to predict the possible manifestation of water-erosion processes in a specific section of the agro-landscape. The stream in the locking structure of the river system is many times reduced on the way from the watershed of the river system to the mouth.

As a result, the stock flow, calculated on a certain area of the river basin, is significantly lower than actual, due to:

- uneven precipitation at the catchment;
- different control of the components of natural and man-made landscapes;
- reduction of runoff formed on the slopes in temporary watercourses on the way from the upper links of the hydrographic network (beam rates, filtration in the tales of ravines and beams) to the river bed;
- river flow control (involves water consumption during the peak of the flood to replenish the groundwater level, humidifying the floodplain, filling the reservoirs, various kinds of water intakes for industrial and agricultural needs).

The model of river flow transformation on slopes contains four blocks of submodels [1], (Fig. 3).

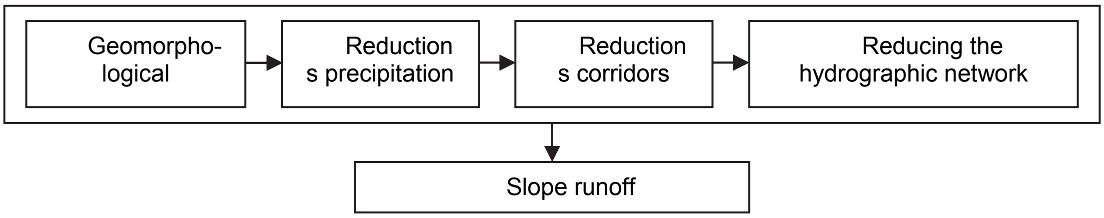


Figure 3. Structure of the river flow transformation model

To characterize the changes in the water content of the rivers on the way from the leakage of the river to the mouth, united by the concepts of channel regulation, the coefficient of reduction of the channels and the reduction of the hydrographic network is applied. For this purpose, for a long period in the basin of the Aydar River, 4 river water springs have identified flood rates for runoff costs.

One of the main channels of runoff loss is moisture absorption on the slope and on the way of traffic along its hydrographic network to the river bed. The reduction coefficient in the hydrographic network ($K_{r.c}$, $K_{r.g.n.}$,) is defined as the value of the excess of the potential runoff layer (Q_l) of the slope above the drain in the upper section of the river (the most approaching to the leak) Q_u:

$$K_{r.c(r.g.n)} = \frac{Q_l}{Q_u}, \qquad (2)$$

where: Q_l and Q_u - maximum runoff costs (m^3/s) in the upper and lower hydrous solutions, respectively.

The primary data of the determination of the potential runoff (Q_{sg}), the calculation of the coefficient of reduction corridors of the hydrographic network ($K_{r.p}$,$K_{r.g.n}$) are given in Table 4.

Table 4. Ratio reduction coefficient and hydrographic network

Hidropost	Cost of drain in sections, m^3/s		Length of river (L), km	Dissociation coefficient catchment area (R)		Reduction coefficient ($K_{r.p}$,$K_{r.g.n}$)
	Q_l	Q_u		right bank	left bank	
Bilolutsk	16,0	16,0	36,53	0,96	0,54	1,00
Starobilsk	29,1	16,0	115,99	1,00	0,64	1,82
Bakhmutivka	31,7	16,0	191,82	1,24	0,51	1,98
Kuryachivka	31,7	29,1	75,83	0,98	0,93	1,09

In general, the equation of the transformation of drain on the slopes has the form:

$$Q_{sg} = Q_l \cdot K_{r.p} \cdot K_{r.c} \cdot K_{r.g.n}, \qquad (3)$$

where: Q_{sg} - maximum costs of a slope of a certain supply, m^3/s;

Q_l - maximum runoff costs in the closing structure of the river, m^3/s;

$K_{r.p}$, $K_{r.c}$, $K_{r.n}$ - coefficients of reduction of precipitation, channels and hydrographic network. For the convenience of working with coefficients, an analysis of the pair relationships of the reduction coefficients with the main geomorphologic features of the basins (length of the river, dismemberment of the catchment) was carried out. The results of the analysis are shown in Fig. 4, 5.

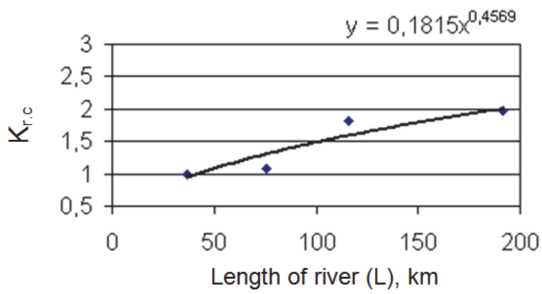


Figure 4. *Reduction of runoff ($K_{r.c}$) depending on the length of the river (L)*

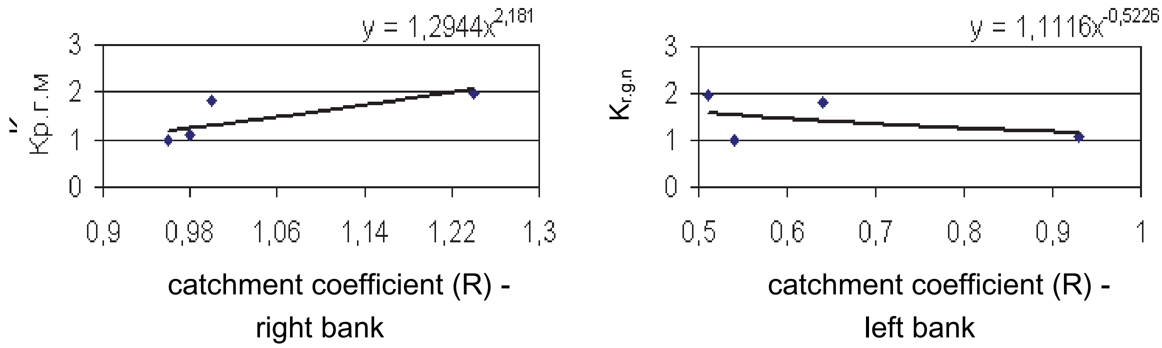


Figure 5. *Reduction of the runoff of the hydrographic network ($K_{r.g.n}$), depending on the dismemberment of the catchment (R): A - right bank, B - left bank*

The curves of the coupling are described by the equations for the reduction coefficients:

precipitation: $K_{r.p} = 3,86 \cdot F^{-0,13}$ (4)

corridors: $K_{r.c} = 0,1815 \cdot L^{0,4569}$ (5)

hydrographic network:

- right bank $K_{r.g.n} = 1,2944 \cdot R^{2,181}$ (6)
- left bank $K_{r.g.n} = 1,1116 \cdot R^{-0,5226}$ (7)

де: *F* – area of the catchment for which the calculation was made, km^2;

L - the length of the channel for the locking structure from the source, km;

R - dismemberment of the hydrographic network (lagoon-beam), km/km^2.

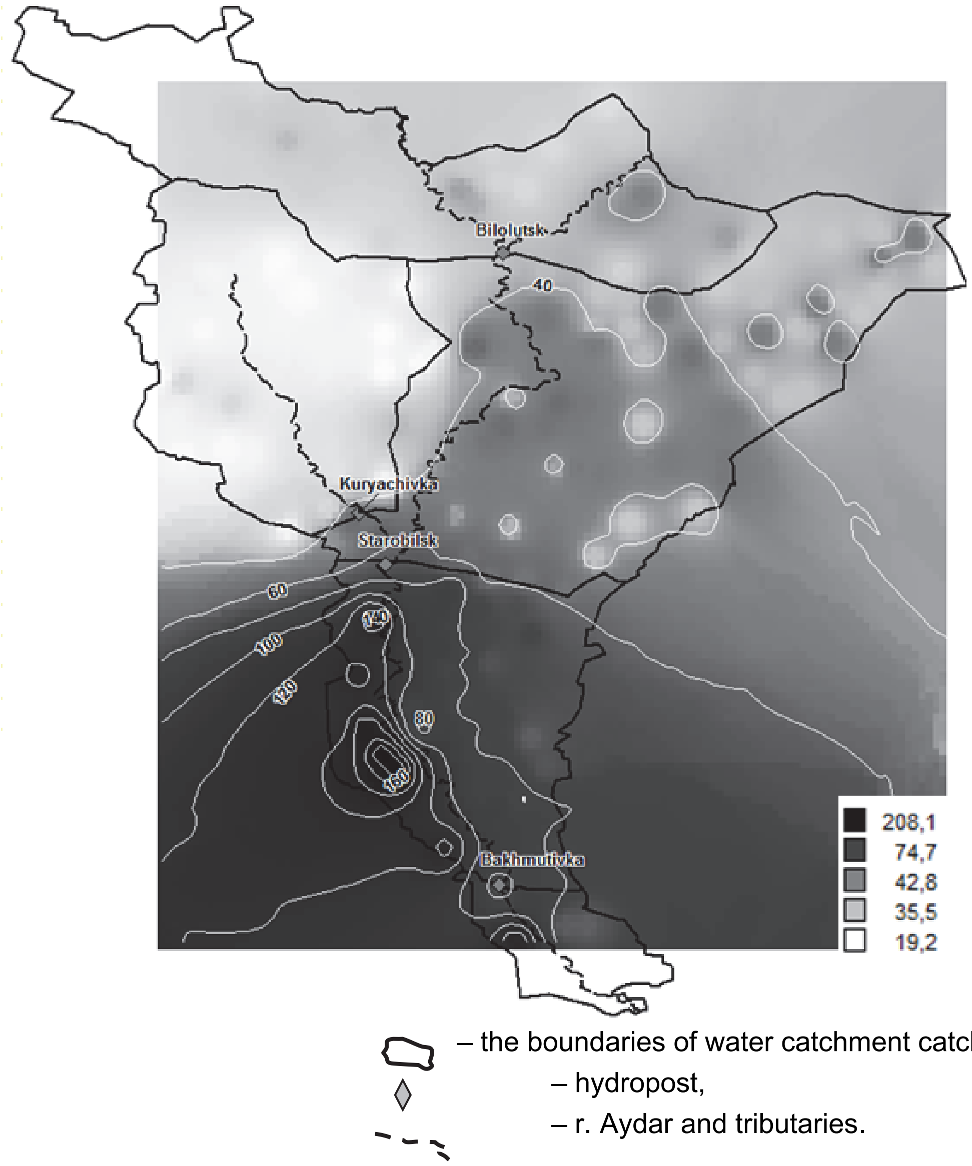
Substituting equation 4, 5, 7 into 3, we obtain a model for determining the waste run of the slope (for the conditions of the basin of Aydar River - separately for the right and left bank) in the form:

- right bank: $Q_{sg\ r.b} = Q \cdot 0,91 \cdot F^{-0,13} \cdot L^{0,4569} \cdot R^{2,181}$, (8)
- left bank: $Q_{sg\ l.b} = Q \cdot 0,78 \cdot F^{-0,13} \cdot L^{0,4569} \cdot R^{-0,5226}$, (9),

where: Q - estimated flow costs of 10% of security in the closure of the pool.

Obtained by the formulas (8, 9), the indicators of slope runoff digitized by means of the Mapinfo programmer on the Mercator projection (WGS 84), the UTM zone 37 of the northern hemisphere, form the TIN surface of the IDW with interpolation with the adjustment (the size of the link is 0.1-0 , 5, degree 1-3, search radius 50-70 km) and the method of equal intervals (5-8). The TIN surfaces of the MapBasic add-on for the 3-D simulation of the isoline_cont_line.MBX are constructed by isolating the polylines with a step of 10 m^3/s in Mapinfo, constructing the surface of the shaft drain, isolation - a schematic diagram of the slope drain is obtained (Fig. 6).

According to the characteristics of Qmax, anomalous manifestation of the cost of drainage increases from 19-35 and 35-42 (water catchment of the hydropost Kuryachivka and Belolutsk) to 42-74 and 74-160 m^3/s (respectively, the catchment of hydropost Starobilsk and Bakhmutivka). This determines the necessity to develop differentiated systems of soil protection measures for minimization of erosion and hydrological processes.



– the boundaries of water catchment catchments,
– hydropost,
– r. Aydar and tributaries.

Figure 6. *Mapping of the transformed sloping runoff in the Aidar river basin, m^3/c*

Conclusions

1. According to the results of the research, a mathematical-statistical model of the flow of runoff from storm rainfall in the rivers is constructed. The most influential erosion and hydrological factors are storm rainfall, land plots and catchment area (36.5, 23.0 and 15.6% impact on the model in the direction of increasing flow costs); this indicator reduces the humus content, the ecological stabilization factor and transverse forest bands (respectively 16, 7.2 and 1.8% of the impact.
2. For the basin of the Aidar River, a model of river flow transformation on the slopes has been developed, which takes into account the reduction of precipitation, the reduction of channels, hydro graphic network separately for the right and left bank.
3. Application of modern GIS technologies allows obtaining vector characteristics of quantitative indicators of maximum runoff costs in the basin of small rivers, reflecting

their transformation on slopes in the form of TIN surfaces and isolines, and give a quantitative assessment in the 3-level system: river basin → beam system water catchment hydro stations → slopes.

4. The resulting models of discharge costs from rainfall and their transformation onto the slopes can give more accurate long-term forecasts for the development of erosion on slope catchments, optimize the costs of designing, implementing and operating measures for soil protection from erosion.

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