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Justification of Reclamative Watershed Regimes of the Forest-steppe Zone of the Western Part of the Republic of Bashkortostan with Regard to Their Provision with Heat and Moisture

Ayrat Khafizov*, Aigul Khazipova, Damir Kutliyarov, Radik Mustafin, Liliya Kamaletdinova, Igor Nedoseko, Enric Galeev, Amir Kutliyarov and Ruslan Zubairov

Federal State Budgetary Educational Establishment of Higher Education
Bashkir State Agrarian University, Ufa, Russia
✉ Chafizov@mail.ru

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Abstract: The methods used for the research are based on modern techniques of watershed mapping represented by catenas and facies; of the numerical solution of two-dimensional catenas equation of moisture transfer in the unsaturated zone and in the zone of complete water saturation; of the crop productivity calculation, depending on the provision with heat and moisture; and on the classification of the watershed catenas by the natural and climatic indicators of their landscapes. The paper presents a model of the stable watershed functioning, which allows to determine environmentally safe reclamative regimes taking into account the provision of landscapes with heat and moisture. This paper also presents the results of predictive calculations and their verification with the data of field experiments.

There was made a detailed classification of watershed catenas and facies of the forest-steppe zone of the Western part of the Republic of Bashkortostan. The method of environmentally appropriate reclamative regimes was developed, and there was determined the dependence of water input on the hydrothermal index and humidity factor.

For the catenas of the forest-steppe zone reclamation of eluvial facies of watershed catenas is recommended, the optimal irrigation rate being 60 mm. It's recommended the drainage of superaqual facies with the optimal drainage rate up to q.75 m. As a result, the relative productivity of eluval facies by 1.5 times, that of the transit facies – by 1.29 times and of superaqual – in 3.2 times.

Key words: Reclamation regime, water regime, watershed, landscape zone, heat provision, natural and climatic indicators, physiographic zoning, irrigation rate.

Introduction

Currently the general situation in Russia and in many other countries is characterized by a rather tense ecological state. The lack of knowledge about the laws of interaction between natural and anthropogenic components, about the processes that are developing in the natural environment in the complex reclamation of watersheds, is one of the obstacles to the creation of environmentally sustainable and economically effective systems of watersheds functioning.

Such scientists as Aydarov, A.I. Golovanov, V.I. Smetanin and others raised the importance to carry out integrated reclamation which includes hydrotechnical,

*Corresponding Author

agrotechnical, chemical measures and measures of forest improvement in accordance with natural conditions of land-reclamation facilities. The integrated reclamation in their opinion should provide the creation of stable highly productive and environmently friendly landscapes (Aydarov, 2007). The papers of many scientists including A.I. Golovanov, A.G. Isachenko, S.D. Isaev, G.H. Ismayilova, L.V. Kireicheva, D.A. Manukyan, A.S. Ovchinnikov, V.I. Olgarenko, V. Shabanova and A.V. Shuravilin are dedicated to the study of the integrated development of watersheds, land reclamation and impacts of human activities on individual components of the natural environment.

The papers present the determination of quantitative criteria to estimate tree influence on the stability of the slopes (Khisamov et al., 2018; Mustafin et al., 2018). The authors developed and tested a methodology for calculating the stability of slides, taking into account erosion by applying the only mathematical model method which amplifies the effect of the root systems of trees. The results of the research allow to solve the problem of long-term integrated assessment of slopes (transit facies) with subsequent correction of ecological forestry and reclamation impacts. Having summarized the results of long-term researches, the papers present (Kutliyarov and Kutliyarov, 2010) the principles of forecasting the quality of water reservoirs and offers the technique of the forecast of chemical composition of water reservoirs of a concrete watershed. The effect of anthropogenic activity (technogenic activity, reclamation, etc.) on water flow is shown.

There are also works of foreign scientists devoted to these actual problems of nowadays. In their papers, Hoekema and Sridhar (2011) prove that warming in the West of the United States is due to anthropogenic climate change. Their work answers the question of how the decline in runoff, the increase in temperature and rainfall have affected the distribution of water resources in the Snake Valley over the past 35 years (1971-2005). The identified impacts of climate change on water distribution should help to understand better how the forecasted climate change can affect water distribution across the territory. Trautz et al. (2017) proved in their works that the soil and vegetation within a watershed area are in a state of continuous dynamic interaction. The essence of this interaction is complex and remains insufficiently clear. Such variables as soil moisture, relative humidity, air temperature are analyzed.

Woodhouse and Pederson (2018) in their researches raise the problems of the effect of air temperature increase on the amount of precipitation and water resources runoff. To study quantitative and qualitative characteristics of the soils in different humidity conditions, scientists examined the amount of moisture and carbon in the soil and its water holding capacity. The works prove that the carbon increase of a water-soluble fraction leads to a significant increase in the level of soil moisture (Li et al., 2016).

Allein et al. note in their works that the lack of water supply is an environmental problem for agricultural areas, including temperate zones. The scientists propose to use an integrated platform of the assessment and modeling of territories, which links the multi-agent model with a geographic informational system. This is a system of interaction between water management and agricultural systems, which is used in irrigation of individual fields and affects the flow within the watershed boundaries (Allein et al., 2018).

A group of scientists from India and Canada prove in their work that water resources are currently under threat of severe depletion, especially as a result of population growth, urbanization, and climate change (Goyal et al., 2015). In their research, they suggest using a soil and water assessment tool (Soil and Water Assessment Tool or SWAT) to model the hydrological characteristics of a watershed. This is particularly relevant for estimating runoff from irrigation during dry periods and for land reclamation in general.

G.H. Merten, H.L. Welch and M.D. Toner in their works study the problem of washout of the rich soil layer and, in general, the process of erosion in a particular watershed. It is shown that in the years 2006-2008 the American USGS conducted a research to study the washout of suspended particles in the basins of the Iowa and the Yazoo rivers. The scientists have studied in details the effects of rain and floodwater on the soil erosion and have proved that a man can retard this negative process using good system decisions. However, this work does not analyze the question of how erosion processes affect the environmental sustainability of the territories.

In the works of German scientists M. Poltoradnev, J. Ingwersen and T. Stack, a great role in the process of analysis of the sustainability of territories is paid to the research of groundwater level. The quality and level of groundwater play a key role in crop yields. Qualitative monitoring of groundwater provides a stable irrigation management.

Of course, all these works have been thought through quite seriously, proved by laboratory and specific experimental studies and play an important role in the development and improvement of land reclamation. However, it should be noted that in these scientific works there is no method of substantiation of reclamation regimes, which should be based on the idea of integrated development of territories taking into account heat and moisture supply. Therefore, it is currently important to substantiate the parameters of environmentally safe reclamation regimes in the complex arrangement of watersheds, taking into account their heat and moisture supply.

Methods

The methods of definition of reclamation regimes applied are based on the idea of complex arrangement of territories proposed by V.V. Dokuchaev. According to these methods, carrying out water reclamation in large areas (watersheds) is considered as one of the main measures of complex arrangement. Justification of reclamation regimes is carried out taking into account the heat and moisture supply of the appropriate territories. The watersheds are schematized as catenas consisting of successive eluvial, transit, and superaquial facies (Glazovskaya, E.A.).

The proposed method is based on modern methods of comprehensive development of the watershed, including justification methods of water reclamation in the complex arrangement of large genetically homogeneous areas (watersheds) (Aidarov, 2007), on numerical solution of the two-dimensional equation of moisture transfer in the aeration zone and in the zone of complete saturation in the catenas (Golovanov A.I., Sukharev Yu. I.), on the calculation of crop productivity, depending on their provision with heat and moisture (Shabanov V.V., Olgarenko I. V.).

The analysis of the obtained parameters of reclamation was carried out on the basis of the developed catenas classification of watershed areas of the forest-steppe zone of the Western part of the Republic of Bashkortostan according to natural and climatic indicators of their landscapes (heat and moisture) (Hafiz). The classification establishes a system connection between the watershed catenas, which are geographically coincident with their physiographic areas and climatic indicators (heat and moisture supply) (Khafizov et al., 2013). The indicators of heat and moisture supply are hydrothermal coefficient (GT). Selyaninov) and moisture ratio (Ivanov N.N., Skeletal A.N. frame). The method allows to simulate different water regimes taking in account heat and moisture supply of each catena's facie of watershed, and to find environmentally safe reclamation regimes.

To justify reclamation regimes, a model of the stable functioning of the watershed catenas during water reclamation was developed (Figure 1).

Stable functioning means the functioning when the ecological condition of watersheds during water reclamation will be maintained at their natural state (before water reclamation).

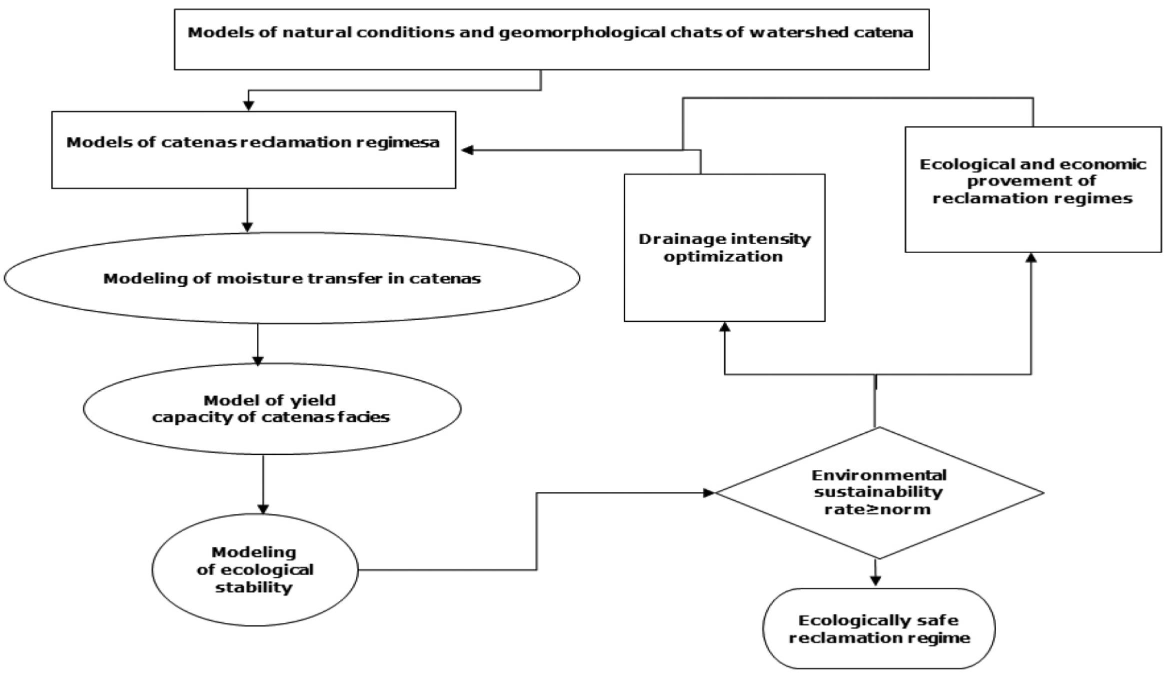

Figure 1: Model of stable functioning of catenas in water reclamation where η is a reclamation component of environmental sustainability of watersheds.

The ecological state of watersheds is estimated by the environmental sustainability rate when in the natural state K_n, which is determined according to recommendations (Aydaro, 2007), taking into account the areas of different lands at a watershed: forests, pastures, water bodies, gardens, meadows, arable lands and urban areas (Khafizov et al., 2009; Khafizov and Kamaletdinova, 2017). The relation of the coefficients of the environmental sustainability of reclamation catenas and unreclaimed (in natural state) K_{rc} is expressed in terms of the following formula (Aydaro, 2007):

$$K_{rc} = K_{\Pi} \cdot \eta, \qquad (1)$$

where η is a reclamation component of ecological sustainability of watersheds. When $\eta \geq 1$, water reclamation retains and even increases if necessary for the environmental sustainability of watersheds, which means the necessity to use water reclamation in the complex arrangement of watersheds. The reclamation component of sustainability η depends on the changes in the structure of water balance of watershed catenas due to water reclamation and is expressed in terms of the formula (Aydaro, 2007):

$$\eta = \frac{(c+g)_{\Pi}}{(c+g)_m} \cdot \frac{Y_r}{Y_n}, \qquad (2)$$

where Y_n, $(c+g)_n$ and Y_r, $(c+g)_m$, are respectively the yield of crops, surface runoff and moisture exchange between soil and groundwater in reclaimed and not reclaimed catenas.

In connection with the above, the condition when $\eta \geq 1$ is accepted as the criterion of catenas sustainability. When observing this condition, environmentally safe reclamation mode, increasing crop yields and maintaining environmental sustainability of the watershed are justified.

Justification of reclamation regimes taking into account parameters of heat and moisture supply is made on the example of catenas of 15 river watersheds of the forest-steppe zone of the Western part of the Republic of Bashkortostan. Herewith, natural conditions in the block “Models of natural conditions of watersheds and geomorphological catenas schemes of watersheds” are formed on the basis of the data of long-term climate observations (over 40 years), soil, geological and hydrogeological conditions of the considered catenas. Based on these data the connection between the watershed catenas (physiographic areas) and heat and moisture supply (climatic parameters) of their landscapes will be formed.

Geomorphological schemes of watershed catenas in the same block depict the surface topography of watershed by catenas, consisting of paired facies with different high-altitude relative position: hills (eluvial facies), slope (transit facies) and the lowlands (superaqual facies). The number of catenas in the watershed corresponds to the number of physical and geographical areas located in the water basin area. Parameters of catenas geomorphological schemes are determined on the basis of geomorphological analysis of the watersheds of the Western part of the Republic of Bashkortostan (Khafizov et al., 2013a).

“Models of reclamation regimes in catenas” are characterized by a set of parameters affecting the gauges of water balance in water reclamation. Antecedent soil water, irrigation and drainage norms are accepted as the parameters of the model to be studied.

Modelling of moisture transfer processes in catenas is performed by computer program of numerical solution of the two-dimensional equation of moisture transfer in the unsaturated zone and in the zone of complete moisture saturation (Khafizov et al., 2013b). From 1973 to 2013 using natural conditions, geomorphological schemes and catenas reclamation regimes as initial models, the computer program was calculating the gauges of water balance, soil washability, moisture exchange between the root layer of the soil and its underlying layers of conjugated catenas facies under the natural regime and under water reclamation.

The block of the “model of productivity facies catenas” was based on the model taking into account the change in crop yield when there is a deviation of productive stored soil moisture from its optimal indicator. The productivity of agricultural land in watersheds is expressed through the yield of these crops.

Modelling of environmental sustainability is carried out using the formula (2). According to this formula, the problem of determining environmental reclamation regimes (compliance $\eta \geq 1$) can be solved by reducing the surface runoff and moisture exchange in reclaimed land $(c+g)_m$. For this purpose, the following environmental techniques are used in the model:

- Optimization of drainage intensity, reducing surface runoff and moisture exchange in superaqual (reduced) facies. We have established the dependence of the facies yield on the intensity of drainage of reduced facies. The obtained dependences are used in the block “Optimization of drainage intensity” referred to the model of the stable functioning, and allow to determine environmentally safe drainage standards.

- Optimization of irrigation regime, reducing moisture exchange (soil washability) and surface runoff in eluvial (elevated) facies. They are reduced by the decrease in the value of the antecedent soil water, but it also reduces the yield. By reducing gradually the value of the antecedent soil water, according to the model of stable functioning, environmentally safe irrigation standards are established.

The correctness of the parameters of reclamation regimes obtained by the calculation is verified by comparing them with the corresponding experimental data. Two parameters have been compared: the calculated and natural geomorphological scheme of the Vorobyevka spring in Ufimskiy physiographic region of Birsky district of Pribelskaya province of the Western forest-steppe zone of the Republic of Bashkortostan. And the calculated and experimental values of the groundwater level at the experimental region "Podymalovo" of Dmitriyevskiy inter-farm irrigation system in the Ufimskiy region, situated in Chishminskiy physiographic area of Chermasanskiy district of Pribelskaya province of the forest-steppe zone of the Western part of the Republic of Bashkortostan.

Results

Geomorphological schemes of the Vorobyevka spring showed the similarity of the constructed and actual profiles.

Verification of the groundwater levels showed that the results average difference between experimental and calculated values of groundwater level in the area "Podymalovo" made up 11% by superaqual and 12% by eluval.

The analysis showed that the calculations give a sufficient convergence of the experimental and calculated values of groundwater level (GWL), and allow to use the developed model to forecast calculations of water regime when the justification of the reclamation regimes is reasoned in the conditions of forest-steppe zone of the Western part of the Republic of Bashkortostan.

Calculations of parameters of reclamation regimes on watershed facies and their analysis are performed according to the classification of watersheds upon natural and climatic indicators (heat and moisture supply) (Khafizov, 2010) (Table 1).

There were made the calculations of the projected water regimes of watershed catenas facies of the forest-steppe zone of the Western part of the Republic of Bashkortostan, depending on their supply with heat and moisture for the period from 1973 to 2013 (Table 2).

Discussion

Based on the calculation results mentioned above, we could study the dynamics of the changes in gauges of the water balance before and after the reclamation actions were taken. There was also revealed the dependence of land reclamation and water regimes of catenas facies on their supply with heat and moisture. Aquatic measures change the water regime of watershed facies by doing one of the following:

- The soil water absorption of superaqual facies decreases together with the increase in the hydraulic coefficient. As for transit facies, the same indicator increases together with the humidity factor.
- Transit facies evapotranspiration decreases together with the increase in the hydraulic coefficient, but increases together with the increase in the humidity factor.
- Soil washability of transit and eluvial facies increases especially when the hydraulic coefficient is 1.15-1.30 and the humidity factor is 0.6-0.7. The exudational nutrition regime of superaqual facies changes to the water nutrition regime.
- Eluval facies show maximal land productivity which makes up 0.76 of relative productivity (Figure 2).

The results of the research coincide with the results obtained by other authors (Ovchinnikov A.S., Poddubsky A.A., Shuravilina A.V., Surikova N.In.), in particular with the studies conducted for the Moscow region.

Based on the analysis of water balance and relative cropping capacity, it is recommended to irrigate all the catenas of the forest-steppe zone to increase watershed productivity. Superaqual facies need drainage, for which a systematic drainage installation is required. As environmentally sound antecedent soil water for the forest-steppe zone watersheds, 0.72 UFWC is recommended, and for the optimal humidity UFWC should be 0.83.

Conclusions

1. There was developed a detailed classification of catenas facies of 15 rivers of the forest-steppe zone of the Western part of the Republic of Bashkortostan according to heat and moisture supply, allowing to analyze the effect of heat and water supply on the reclamation and water regimes of watersheds.

Table 1: Classification of watershed facies catenas of the forest-steppe zone of the Western part of the Republic of Bashkortostan according to the physiographic zoning and natural and climatic indicators

River watersheds	*Natural and climatic indicators*		*Physiographic regions according to facies of river watersheds*		
	*HC**	*HF**	*Eluvial*	*Transit*	*Superaqual*
Bystryy Tanyp	1.00-1.15	0.5-0.6	Burayevskiy		-
	1.15-1.30	0.5-0.6 0.6-0.7	Burayevskiy		
Baza	1.00-1.15	0.5-0.6	Bazinskiy. Prichermasanskiy		
Bir	1.00-1.15	0.5-0.6 0.6-0.7	Izyakskiy		
	1.15-1.30	0.5-0.6 0.6-0.7	Burayevskiy	Izyakskiy	
Usa	1.00-1.15	0.6-0.7	Ufimskiy.Izyakskiy	Ufimskiy.	
	1.15-1.30		Ufimskiy., Izyakskiy		
Syun	0.85-1.00	0.5-0.6	Prichermasanskiy		
	1.00-1.15		Bazinskiy. Syunskiy		
Chermasan	0.85-1.00	0.5-0.6	Chishminskiy. Udryakskiy.	Prichermasanskiy	
	1.00-1.15		Prichermasanskiy.	-	
Karmasan	0.85-1.00	0.5-0.6		Chishminskiy	
	1.00-1.15		Chishminskiy		
Usen	0.85-1.00	0.5-0.6	Kandrykulskiy. Usenskiy		
	1.00-1.15		-Kandrykulskiy.	Usenskiy	
	1.15-1.30	0.6-0.7	Aksakovskiy		
Urshak	1.00-1.15	0.5-0.6	Urshakskiy.Karmaskalinskiy	Urshakskiy.	
	0.85-1.00		-	Urshakskiy.	Urshakskiy.
Sim	1.15-1.30	0.6-0.7	Simskiy		
Inzer	1.15-1.30	0.6-0.7	Simskiy		
Nugush	1.00-1.15	0.5-0.6	Nizhnenugushskiy	-	
		0.6-0.7	Nizhnenugushskiy	-	
	0.85-1.00	0.5-0.6	-	Nizhnenugushskiy	
Zilim	1.00-1.15	0.6-0.7	Simskiy,Priziganskiy		
Dema	0.85-1.00	0.5-0.6	Chishminskiy. Udryakskiy		
		0.6-0.7	-	. Tyaterskiy	
		0.7-0.8	Pridemskiy	-	-
	1.00-1.15	0.6-0.7	Aksakovskiy		
		0.7-0.8	Pridemskiy		
Ik	0.85-1.00, 1.00-1.15	0.5-0.6	Usenskiy		
	1.15-1.30	0.6-0.7	Aksakovskiy		

**Remarks:* HC – Hydraulic coefficient, determined by G.T. Selyaninov. HF – Humidity factor, determined by N.N. Ivanov and A.N. Kostyakov.

Table 2: Gauges of the water balance of the watershed catenas facies divided into groups

HC	*Regime*	*HC 0.85-1.00*						*HC 1.00-1.15*						*HC 1.15-1.30*						*Average*					
		Gauges of water balance, mm						*Gauges of water balance, mm*						*Gauges of water balance, mm*						*Gauges of water balance, mm*					
		IN	*SW*	*ETr*	*GO*	*AGWD*	*CC*	*IN*	*SW*	*ETr*	*GO*	*AGWD*	*CC*	*IN*	*SW*	*ETr*	*GO*	*AGWD*	*CC*	*IN*	*SW*	*ETr*	*GO*	*AGWD*	*CC*
Eluvial facies																									
0.5-0.6	Natural	-	31	345	17	5.4	0.50	-	52	322	47	7.8	0.40	-	56	330	75	8.4	0.70	-	46	332	46	7.2	0.53
	Reclamation	61	70	384	60	3.1	0.78	81	108	371	59	4.7	0.75	48	121	339	102	4.2	0.77	63	100	364	73	3.9	0.77
0.6-0.7	Natural	-	-	-	-	-	-	-	97	308	77	11.1	0.40	-	75	331	76	9.2	0.50	-	86	320	77	10.2	0.45
	Reclamation	-	-	-	-	-	-	30	213	361	67	7.5	0.73	38	252	376	78	10.8	0.78	34	232	369	73	9.1	0.75
0.7-0.8	Natural	-	24	338	2	1.9	0.51	-	24	338	2	1.9	0.51	-	-	-	-	-	-	-	24	338	2	1.9	0.51
	Reclamation	83	28	351	3	1.4	0.7	83	28	351	3	1.4	0.80	-	-	-	-	-	-	83	28	351	3	1.4	0.75
Average	Natural	-	27	342	10	3.6	0.5	-	57	323	42	6.9	0.44	-	65	330	75	8.8	0.60	-	55	330	42	6.5	0.49
	Reclamation	72	49	368	31	2.2	0.74	65	116	361	43	4.5	0.76	43	186	357	90	7.5	0.77	60	117	361	50	4.8	0.76
Transit facies																									
0.5-0.6	Natural	-	50	311	88	7.0	0.40	-	66	306	106	8.5	0.40	-	52	309	110	9.3	0.60	-	56	308	101	8.3	0.46
	Reclamation	52	65	320	210	6.6	0.69	55	77	304	206	3.8	0.67	-	100	262	141	2.5	0.67	54	81	295	186	4.3	0.68
0.6-0.7	Natural	-	45	311	50	4.1	0.70	-	70	312	81	11.9	0.50	-	103	303	115	11.2	0.50	-	73	309	82	9.1	0.56
	Reclamation	-	50	306	55	1.7	0.73	-	75	332	99	4.6	0.72	-	201	308	145	4.6	0.69	-	109	315	100	3.7	0.71
0.7-0.8	Natural	-	-	-	-	-	-	-	8	316	56	3.7	0.61	-	-	-	-	-	-	-	8	316	56	3.7	0.61
	Reclamation	-	-	-	-	-	-	-	11	354	58	1.6	0.70	-	-	-	-	-	-	-	11	354	58	1.7	0.70
Average.	Natural	-	47	311	69	5.6	0.55	-	48	312	81	8.0	0.51	-	78	306	112	10.3	0.55	-	58	311	80	7.0	0.54
	Reclamation	52	57	313	133	4.2	0.71	55	54	330	121	3.4	0.62	-	150	285	143	3.5	0.68	54	87	321	115	3.2	0.70
Superaqual facies																									
0.5-0.6	Natural	-	-247	456	13	0.6	0.30	-	-223	406	23	0.5	0.30	-	-240	378	24	0.3	0.20	-	-237	413	20	0.5	0.26
	Reclamation	0	37	428	2.5	1.7	0.64	0	44	390	0.4	3.04	0.63	0	49	370	0	2.9	0.60	0	43	396	0.96	2.5	0.62
0.6-0.7	Natural	-	-173	311	16	0.2	0.09	-	-131	375	15	0.4	0.30	-	-270	392	18	0.3	0.20	-	-191	359	16	0.3	0.19
	Reclamation	0	95	316	7.7	1.3	0.57	0	73	372	0.1	2.4	0.64	0	82	389	0.1	2.04	0.63	0	83	359	2.6	1.9	0.61
0.7-0.8	Natural	-	-	-	-	-	-	-	-294	356	34	0.25	0.11	-	-	-	-	-	-	-	-294	356	34	0.3	0.11
	Reclamation	-	-	-	-	-	-	0	95	341	0.94	1.4	0.62	-	-	-	-	-	-	0	95	341	0.94	1.4	0.62
Average	Natural	-	-210	384	15	0.4	0.19	-	-216	379	24	0.4	0.24	-	-255	385	21	0.3	0.20	-	-227	376	23	0.3	0.19
	Reclamation	0	66	372	5.1	1.5	0.61	0	71	368	0.5	2.3	0.63	0	65	379	0.05	2.5	0.62	0	67	365	1.5	1.9	0.62

Remarks: HC – Hydraulic coefficient, IN – Irrigation norm, SW – Soil washability, ETr – Evaportanspiration, GO – Groundwater outflow of decrease facies, CC – Cropping capacity, AGWD – Average long-term groundwater depth.

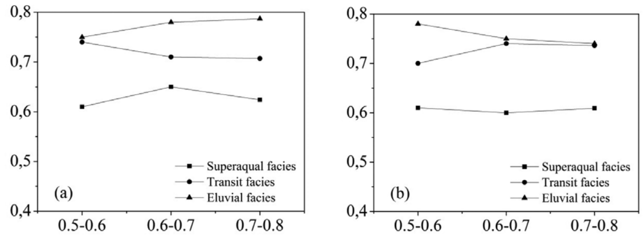

Figure 2: Dependencies of land productivity on heat and moisture supply after the water reclamation (a – by the HC, b – by the humidity factor).

2. There was developed a methodology of justification of environmentally safe reclamation regimes of watersheds by modelling the functioning of watershed facies catenas, allowing to determine the best options for the antecedent water, safe environmental irrigation and soil washability norms at possibly maximal cropping capacity.

Water reclamation leads to the increase by 1.5 times in the relative eluvial facies productivity, by 1.29 times in transit facies and by 3.2 times in superaqual facies productivity.

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