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WATER RESOURCES DEVELOPMENT: ECONOMIC AND LEGAL ASPECTS

Ecotone System of the Southeastern Coast of the Tsimlyansk Reservoir

T. V. Balyuk[a], A. V. Kutuzov[a], and O. G. Nazarenko[b]

[a] *Water Problems Institute, Russian Academy of Sciences, ul. Gubkina 3, GSP–1, Moscow, 119991 Russia*
[b] *Donskoi State Agrarian University, pos. Persianovskii, Oktyabr'skii raion, Rostov oblast, 346493 Russia*

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Abstract—The results of multidisciplinary environmental field studies aimed to elucidate the forms of influence of the Tsimlyansk Reservoir onto coastal ecosystems are presented. The ecotone analysis of the ecosystem structure of the reservoir coast is proposed as an approach to the analysis of the collected data. A brief characteristic of a version of a geographic information system based on field and remote-sensing data is given. A relationship is shown to exist between the reservoir level regime according to 10-year data and the transformation of vegetation cover on the coast against the background of minor changes in soils for the 50-year period of reservoir existence.

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INTRODUCTION

The problem of neohydromorphism and secondary salinization of soils has become more acute in the southern European Russia in the recent years because of present-day climate fluctuations and environmental transformations caused by water management. A large number of reservoirs with a total area of more than 4000 km^2 were constructed in southern Russia in the past 50 years. Water from these reservoirs permanently infiltrates into the subsoil water flow with the result that the nearby agricultural landscapes are being inundated and salinized [5]. The scientific literature that considers the environmental impact of the Tsimlyansk Reservoir is dominated by studies of shore transformation, whereas the forms of reservoir impact on the adjacent areas has not been adequately studied and assessed. This study is aimed to analyze the effect of the Tsimlyansk Reservoir on terrestrial ecosystems as components of the water–land ecotone.

The Tsimlyansk Reservoir was constructed in the middle part of the Don valley in Volgograd and Rostov provinces. Reservoir filling began on January 15, 1952, and the maximum operating level (MOL) was reached by early May 1953. Reservoir water covers the floodplain and terraces of the Don valley and the mouth reaches of its tributaries. When reservoir level rises, its backwater reaches up to the mouth of the Ilovlya River—a large left-hand tributary of the Don [1, 4, 9].

MATERIALS AND METHODS

The ecotone analysis of the water–land interface was used to study the mechanism of the reservoir influence onto the coast with allowance made for the distance from the water edge. Ecotone is a transitional zone between easily distinguishable areas and specific communities. Ecotones are commonly inhabited much denser than the communities that are in contact. The water–land ecotone system considers the dominating effect of water factor onto the environment and its differentiation depending on the transformation of coasts. Based on the concept of ecotone structure introduced by V.S. Zaletaev [11], four out of five structural blocks of the water–land ecotone were identified under natural conditions as a result of geomorphological, soil–geobotanical, floristic, and landscape–geographic studies on the southeastern coast of the Tsimlyansk Reservoir.

Fluctuation block is the central or amphibian block (the zone of direct contact between water and land) and features instant response to environmental changes and short-period (including daily) water level variations.

Dynamic block is a block on the land that features "fluctuation dynamics" of biocomplexes (low and medium floodplain subject to regular or periodic inundation).

Distant block is a block with delayed (distant) dynamics of biocomplexes and all natural processes (high floodplain belt); this dynamics is governed by variations in phreatic water level.

Marginal block is a block with delayed response determined by changes in biocomplexes under the effect of processes taking place in the biota of the floodplain and on the watershed.

Aquatic block is a block with a distant dynamics of aquatic biocomplexes, which is controlled by the interaction processes with the biocomplexes of the first block (input of matter from land into the water body and transport of pollutants by water); this block was not studied.

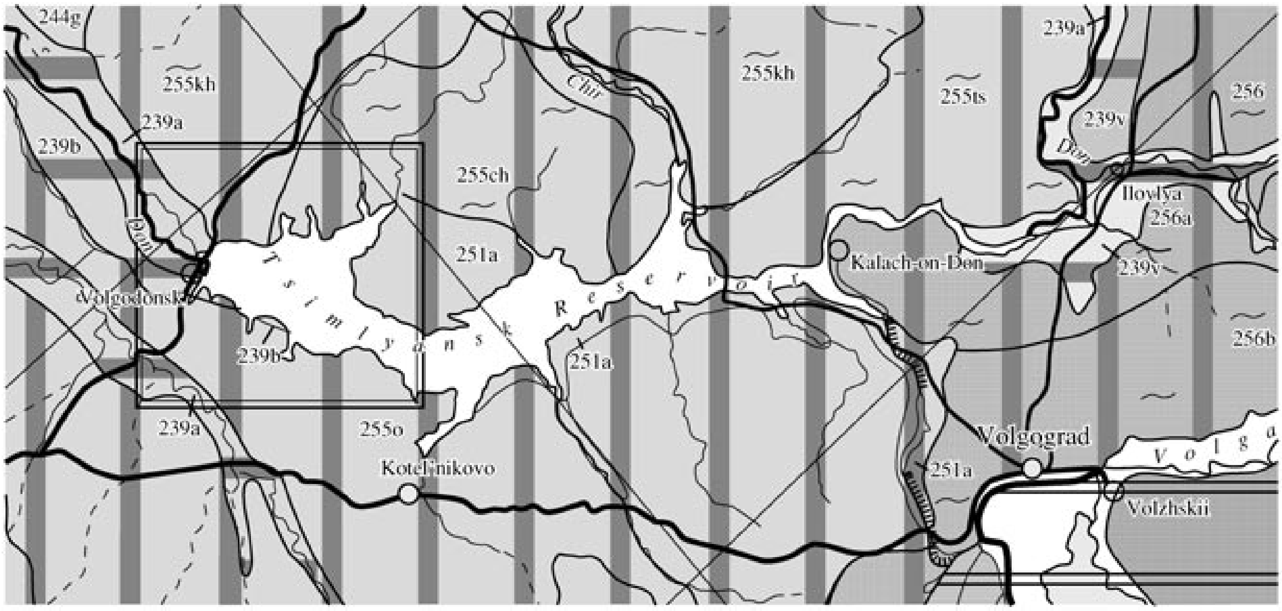

Fig. 1. Fragment of landscape map [6]. The square is the study area. Figures on the map are landscapes: (239a, 251a) floodplain and low terraces; (239b) above-floodplain terraces of large rivers; (255o) flat and slightly undulating plains with wide gullies; (255ch) plains, mostly flat, with deep gullies; (255kh) slightly undulating plains with gullies in near-valley parts. Soils: (239(a,b), 251a, 255kh) dark chestnut, alkaline; (255o) chestnut, alkaline; (255ch) dark chestnut.

Field studies were carried out to obtain field data on vegetation, soils, relief, geographic coordinates, and data reference features on images and maps. The studies included data collection on seven key areas that reflect the landscape diversity of coasts in the southwestern part of the Tsimlyansk Reservoir. The geographic information system (GIS) for this territory was developed with the use of remote sensing materials and long-term hydrological data for the identification of ecotone blocks in the territory under study [6] (Fig. 1).

The zone of hydrogenic influence of the reservoir is understood to be the territory of coasts that is subject to a direct or indirect influence of the reservoir. The direct influence includes all processes and phenomena associated with wave activity of water masses and periodic inundation or dewatering of the coastal zone due to reservoir drawdown. The indirect impacts include the processes and phenomena associated with land underflooding, backwater effects in aquifers, and changes in microclimatic characteristics and the character of land use.

The study was focused on the effect of reservoir on typical landscapes of coasts. The main landscapes are represented by plains: flat–wavy, slightly sloped, with gullies and ravines, with kettle–potyazhinnyi microrelief, with agricultural lands, and with areas of cereal and wormwood–cereal steppes (Fig. 1). Another group of landscapes is represented by floodplains and above-floodplain, flat and crest–kettle terraces with channels, arms, small forest areas, meadows, and agricultural areas.

The main method used in the field studies was the method of topo–ecological profiling, which allows all data of field observations in a key area to be converted into a single system. The Tsimlyansk profiles (TsP) were routed from the water edge transversely to the relief with the use of level lines up to either main vegetation or tillage. A transect was laid along this line to record changes in the relief and vegetation. Geobotanical sites with full description, soil section, or drilling down to subsoil water were established in each vegetation contour. The description point was fixed with the use of a GPS-navigator. Photographing of the panorama and typical landscape elements, as well as soil sections and samples was carried out simultaneously. Appropriate samples were taken for determining the salt characteristics of soils and subsoil waters. The zero point of profile elevation was assigned at the position of water level in the reservoir on the day of profile location with a correction made for the distance from the dam. All observational sites are reflected on the geographic grid in the form of points connected by route segments. This data system was superimposed on remote sensing materials (Fig. 2) and considered in landscape environment with the use of landscape and topographic maps fixed in the geographic grid. A version of GIS for this area was created in the ArcView 3.2 software package.

The data treatment procedure included drawing of profiles, which were provided with extended legends reflecting the state of all components under study. In the case of vegetation, these data included the name of vegetation community, total projective cover, the number of species, and the productivity. The data for soils

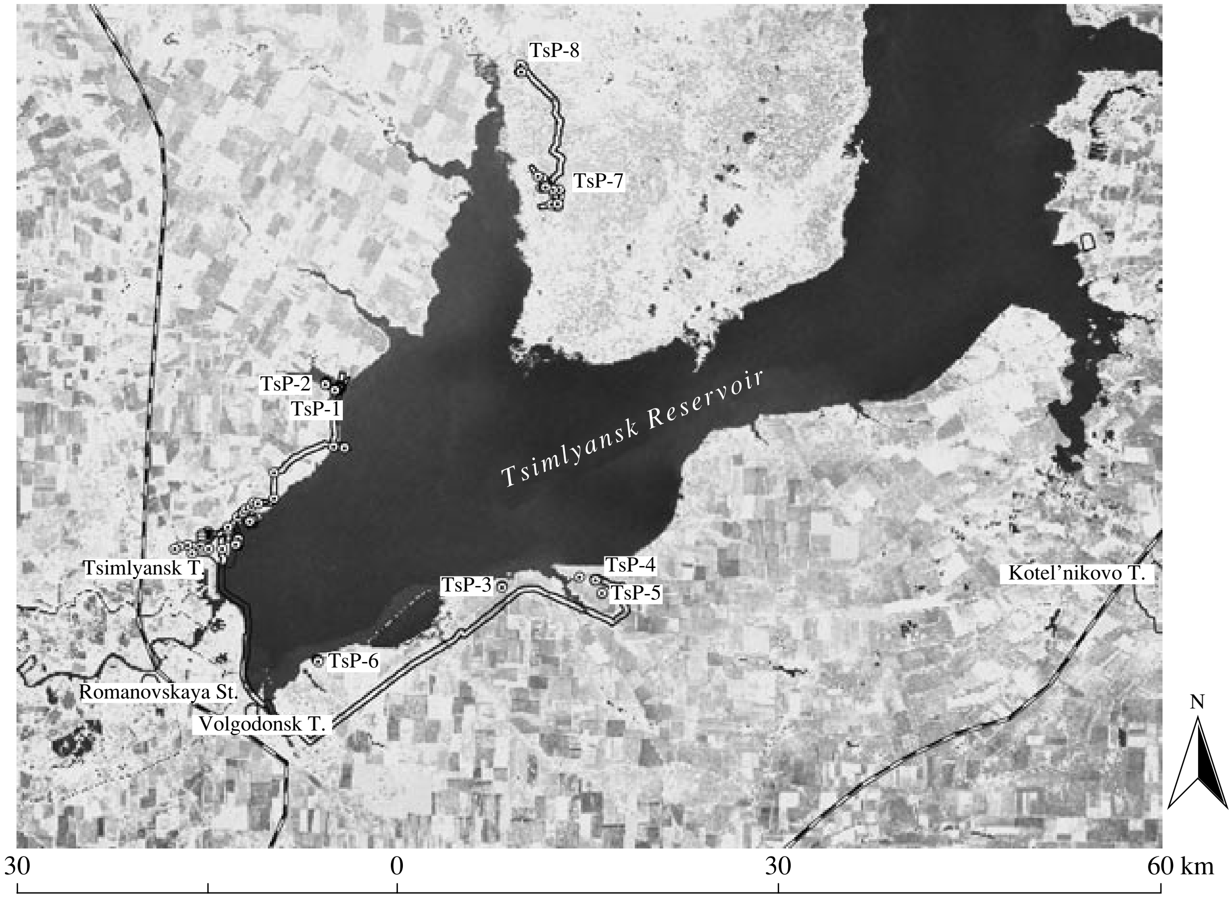

Fig. 2. Layout of profile points and the work area in Landsat 2000 space photograph.

included soil name, weighted mean of salt content in the 0–1-m horizon, chemism, maximum salt content in the soil profile and the horizon where it was recorded, oxidation–reduction potential of the soil (ORP). The data for subsoil water included the depth of occurrence, salinity, and chemism. Such extended legends allow the coastal area to be considered as a single system of interacting water body and the adjacent land, i.e., ecotone water–land system (Fig. 3).

Vegetation most readily responds to environmental changes under the effect of water factor and reflects its typical seasonal state. Definite types of elementary natural–territorial complexes formed in coastal areas with similar abiotic conditions. These complexes can be reliably identified by vegetation communities in terms of their response to changes in the aquatic environment. A model ground was studied in the center of each vegetation contour. This ground was chosen to represent the entire landscape diversity of the territory (Fig. 3): relief elements (beach, natural levee, edge of the above-floodplain terrace, above-floodplain terrace, upland); vegetation of forest, meadow, and grass-meadow communities (Salix alba; Eleocharis palustris, Alisma plantago–aquatica, Bidens tripartia, Butomus umbellatus; Calamagrostis epigeios, Poa angustifolia, Cichorium intybus, Coronilla varia, Dichostylis micheliana, Galium verum, Genista tichtoria, Melandrium album, Phleum pratense, Plantago lanceolata; Festuca beckeri, Poa angustifolia, Ajuga genevensis, Centaurea jacea, Cichorium intybus, Galium verum; Festuca beckeri, Achillea micrantha, Allium inaequale, Ambrosia artemissiifolia, Centaurium erythraea, Cichorium intybus; Festuca valesiaca, Agropyron desertorum, Galium verum); sandy soils (light gray, low-humus, gley, dark gray with signs of changes in ORP). The character of overmoistening was also recorded (in this case, inundation, and soil–ground).

RESULTS AND DISCUSSION

As can be seen from Fig. 4, the decade-maximum level of 36.01 m (hereafter, the absolute elevations in the Baltic System are given) was recorded in the Tsimlyansk Reservoir in May 1994, and the minimum level of 32.5 m was recorded in March 1997 and January 1998. The curve of water level in the reservoir from 1994 to 2003 was used to determine the major blocks of the ecotone system: fluctuation, dynamic, distant, and marginal. The fluctuation block contains the land area

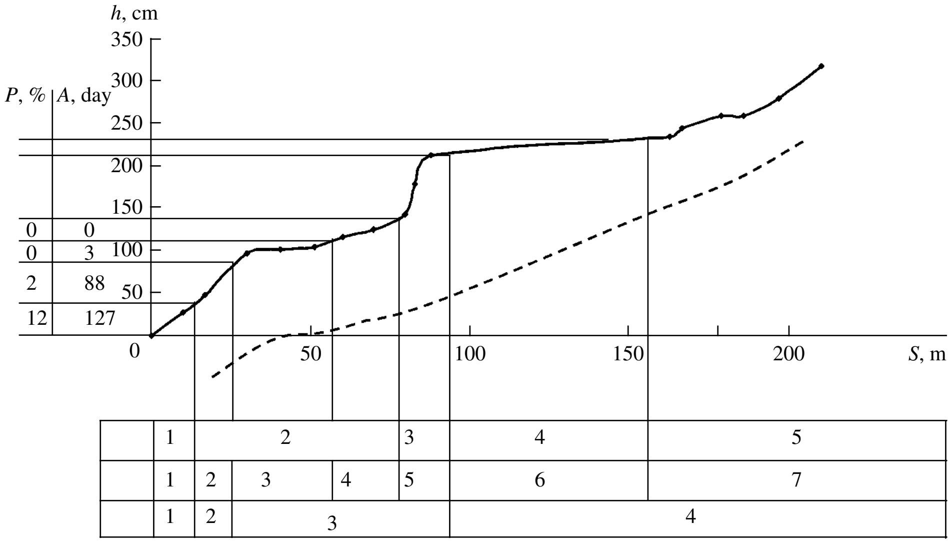

Fig. 3. Profile on the boundary of "Tsimlyanskie Peski" Natural Park from subsoil water level in the bay. (I) Relief elements: (1) beach, (2) natural levee, (3) edge of above-floodplain terrace, (4) above-floodplain terrace, (5) upland. (II) Vegetation: (1) White-willow floodplain forest, (2) spike rush community, (3) bluegrass–small reed meadow with miscellaneous herbs, (4) bluegrass–fescue community with miscellaneous herbs, (5) herb–fescue, (6) fescue–wheatgrass with Russian bedstraw, (7) combination of herb–bluegrass and fescue–wheatgrass communities. (III) Sandy soils: (1, 5) light gray low-humus; (2, 3) glayey; (4) dark gray with signs of changes in ORP. *P*, %, is level occurrence; *A*, day, duration of inundation.

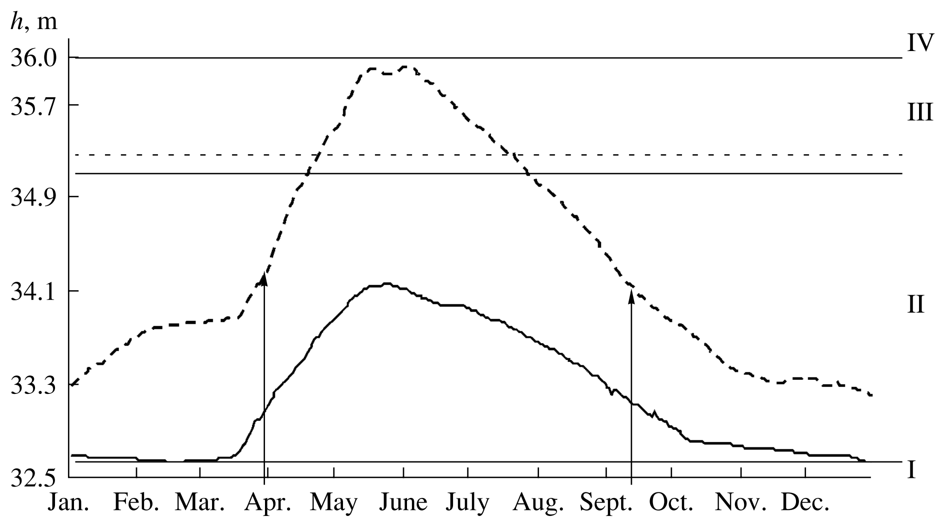

Fig. 4. Plot of variations in the reservoir level (full line) in low-water 1997 and (dashed line) high-water 1994. Arrows are limits of vegetation period. Full horizontal lines are boundaries of blocks of the water–land ecotone: (I) aqual, (II) fluctuation, (III) dynamic, (IV) distant; dashed line is groundwater level in the season of studies.

between elevations of 32.6 and 34.2 m, which is inundated every year.

The dynamic block is the land area that is inundated with variable frequency; it is located between the elevations of 34.2 and 36.01 m. The distant block contains the area on the reservoir coast that is never inundated by its water but is affected through the rise of subsoil water level. The maximum level of water stand that is attained once in several decades is sometimes marked by a bench in the relief and a brush belt. The distant block begins from the maximum elevation that has been inundated for at least one time (36.01 m) and ends at the elevation of 39 m. The upper boundary of this block is drawn conventionally based on the opinion regarding the depth of subsoil water occurrence at which it does not take part in the soil-forming process. Areas of strong, median, and weak inundation were identified here depending on the position of subsoil water level,

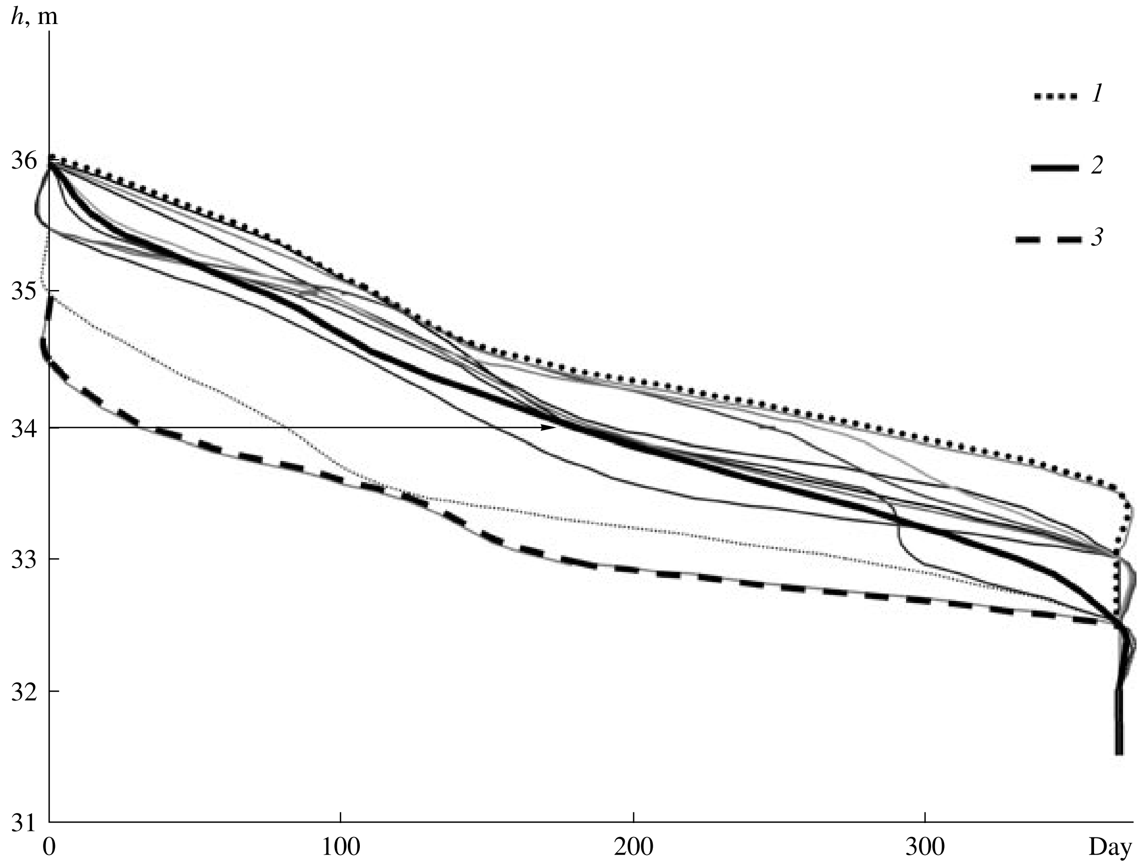

Fig. 5. Duration of the period of flood inundation of the main elevation marks for 1994–2003. (*1*) maximal, (*2*) median, and (*3*) minimal values. Arrow is for 50% occurrence level of food waters.

which lie at depths of 0–0.5, 0.5–1.5, and 1.5–3 m, respectively, and the very weak impact at subsoil water level lying at depths from 3 to 5 m. The marginal block of the ecotone system begins in this place above 39 m, where the species composition of zonal vegetation is disturbed by species–migrants from previous blocks with azonal vegetation. This approach to the analysis of the structure of coasts enables the assessment of the hydrological interaction between the water body and the surrounding land.

Data of Roshydromet were used to carry out statistical treatment of the results regarding the daily variations in the reservoir level for 10 years and determine the *duration* and *occurrence* of the inundation level for different elevations (Fig. 5). These characteristics of the dynamics of reservoir level regime were evaluated by using standard hydrological formulas [7].

The occurrence is understood as the number of cases when water level has reached the given elevation within the entire observational period (in our case, 10 years)

$$P = (n - 0.3)/(D + 0.4)100\%,$$

where P is the occurrence of the level, %; n is the number in the ranked series; D is the number of observational dates.

The duration is evaluated as the time of reservoir water standing at the given elevation within the year (averaged over the observational period) (Fig. 5).

$$A = m/N,$$

where A is duration, day; m is the number of days of water standing at the given elevation (over the observational period); N is the length of the observational period, year. The latter formula was applied to data of the summary table.

As can be seen from Fig. 5, the level of 32.50 m is the minimum mark to which the reservoir level has ever dropped. The area below it is inundated permanently. This level is the upper boundary of the aquatic block of the ecotone, which is reflected in the plot by a linear segment of the total curve within the same elevation range.

Variations in the reservoir level have the strongest effect on the coastal vegetation in the vegetation season (April–October). In this period, the reservoir level varies within the range of 32.5–36.0 m (according to 10-year data).

In low-water years, hydrophilous vegetation starts growing in the area that has become free of water. This vegetation can fix, if the following years will be also

Characteristic of the dynamical block of water–land ecotone

TsP	Soils	Well no.	Depth to subsoil water table, cm	*h*	Character of overmoistening	Elements of relief in the composition of block
1	Thick meadow-chestnut carbonate gleyey medium loamy soil on loess-like loamy soil	1	120	35.95	Inundation	Reservoir beach
2	Dark chestnut medium-thickness medium-washed, medium-loamy soil on loess-like loamy soil	1 2	70 70	35.77 36.20	Soil–ground and inundation	The same
4	Chestnut medium-thickness, medium loamy soil on loess-like loamy soil	1	140	35.82	Inundation	Beach
5	Chestnut, not completely developed, carbonate, gleyey, medium-loamy soil on yellow-brown loamy soil underlain by green clay	1	150	35.98	″	The same
6	Chestnut, residual-meadow, carbonate, thick, medium-loamy soil on yellow-brown clay or chestnut, residual-meadow, carbonate, deposited, medium-loamy soil on yellow-brown clay	1 2 3	80 130 130	35.42 36.02 36.20	″	Beach, natural levee changing into floodplain terrace
7	Sandy, dark gray soils with signs of changes in ORP	1 2 3	90 110 90	35.56 35.84 36.35	″	Sand beach with signs of grazing, natural levee, terrace slope
8	Sandy, light-gray, low-humus soils or low-humus, glayey soils	1 2	110 100	35.58 36.28	Inundation and soil–ground	Beach, natural levee

low-water, or can be replaced by aquatic vegetation if water level will be high. In terms of elevation, this range consists of two parts of the water–land ecotone which correspond to the fluctuation and dynamic blocks, respectively. The fluctuation block (32.5–34.2 m) is inundated by floodwater every year for a long period (more than 250 day/year); the dynamic block (34.2–36.0 m) is inundated not every year with the mean duration of 75 day/year.

The effect of the reservoir onto the nearby territory extends beyond the dynamic block through subsoil water because of a rise in its level in its discharge sites on the reservoir coast [2, 3]. Subsoil water flow can slow down and even reverse, inundating the adjacent areas. The distant block starts from here (from 36.0 m elevation) and extends up to the boundary of influence of subsoil water determined by the depth of 3 m. At this depth subsoil water is still available for most plants because of the capillary rise of water. The elevations of this boundary can significantly differ in different landscapes. Depending on soil lithology in the given block (sandy or clay), the height of capillary rise varies, as also does the boundary of the distant block of the ecotone.

The marginal block begins outside the boundary of subsoil water availability. The vegetation dynamics in this block is affected by the dynamics in the previous blocks of the ecotone via invading species. The vegetation of this block becomes typical (zonal) with the distance from the reservoir. Therefore, its upper boundary should be diffuse. The fluctuation block is not presented in the examined profiles, because it was inundated in the season of observations (Fig. 5).

The dynamic block, in accordance with its name, is quite diverse for different landscapes in which the Tsimlyansk profiles were routed (table). The length of the block (Fig. 6) varies from 1 (TsP 3) to 150 m (TsP 2, 6, 7) depending on the steepness of slopes. Steep shore slopes were recorded in flat landscapes. Lands in this block are virtually not used for agriculture. The most stable characteristics of the block are the relief elements in which it occurs; the main among them is the reservoir beach; a natural levee that passes into a floodplain terrace is typical of landscapes of the floodplain and low terraces in this block.

Soils in this profile are diverse, though, irrespective of the ecotone block, they are relatively homogeneous along the profile and hence are only slightly transformed under the effect of the reservoir. The depth of subsoil water varies from 70 to 150 cm from the land surface. The vegetation is quite diverse, though the communities are mostly of hydrophilous type, because the reservoir level regime ensures the overmoistening of an inundation character. Mint (Mentha arvensis) is the most universal species in open areas. The vegetation diversity in this block is affected by many factors: the

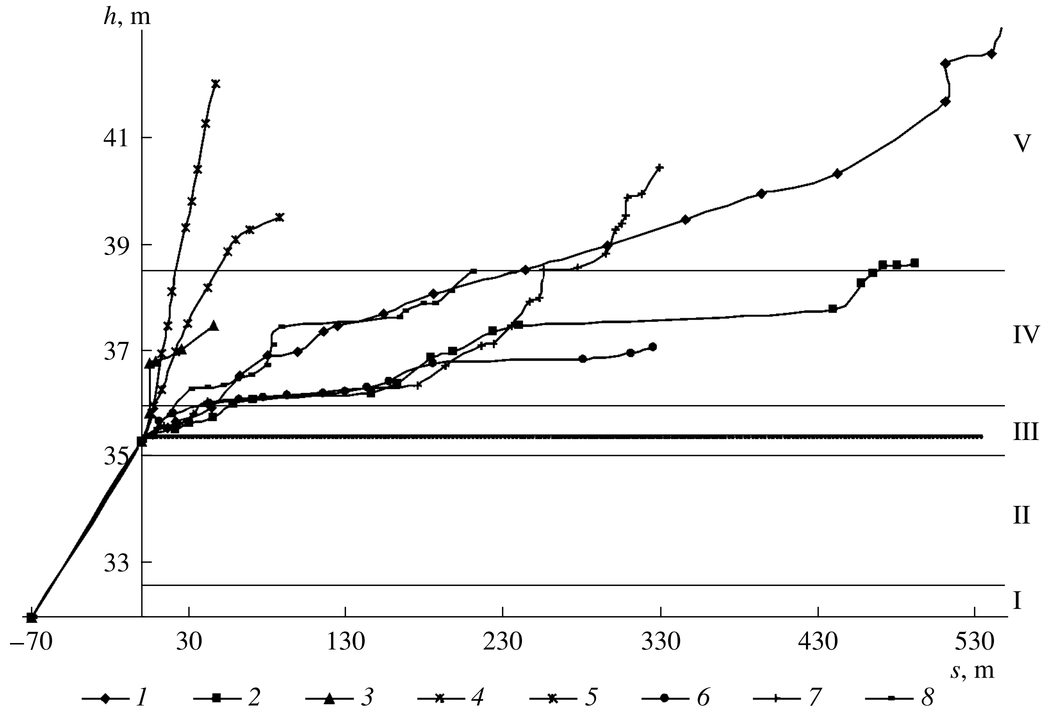

Fig. 6. Layout of contours (TsP 1–8, curves *1–8*, respectively) in the block of water–land ecotone. Horizontal full lines are boundaries of blocks. (I) Aqual, (II) fluctuation, (III) dynamical, (IV) distant, (V) marginal. The horizontal dash line is groundwater level in the season of study.

character and degree of soil salinization, the position with respect to the main bed of the reservoir (the absence of wave activity in bays), and the steepness of slopes. Thus, various forest communities can be met here: amorpha–ash-tree forest in bays (TsP 1); willow–poplar floodplain forest on the shores of bays (TsP 7); white-willow floodplain forest in oxbows (TsP 8) and various meadows.

The distant block is represented mostly by above-floodplain terraces or steep slopes of the reservoir shore in flat or slightly undulating plains with wide ravines; in the near-valley areas, they have ravines, erosion troughs, and kettle-type microrelief, agricultural lands, areas of cereal and wormwood–cereal steppes (TsP 3–5). This block was met on the floodplain terrace only in floodplain landscapes with low terraces (TsP 7). Such decline in its position can be attributed to the character of soils. Sandy soils retain less soil moisture and, notwithstanding the high level of subsoil water (1–2 m), fail to provide the capillary rise of moisture to the same height as clay soils. The length of the block (Fig. 6) varies from 10 (TsP 4, 5) to 450 m (TsP 2, 6), depending on the steepness of the slope and the type of landscape. The gentlest coastal slopes occur in floodplain landscapes. The lands of this block are virtually not used for agriculture. However, they can be used for pastures and haymaking, considering the degree of soil salinization. This block of the ecotone system has experienced different degree of transformation in different landscape conditions. Some features of gley and former presence of meadows persist in floodplain and terrace landscapes. In landscapes of upland plains, vegetation is transformed, whereas soils only slightly reflect the neohydromorphic processes. Subsoil waters in the distant block are relatively close to the land surface (within 3 m); therefore, the vegetation here has some signs of additional moistening.

The marginal block lies on uplands in flat and slightly undulating plains with wide gullies, ravines in near-valley parts, and zones of cereal and wormwood–cereal steppes (TsP 3–5). The marginal block in floodplain and low, flat and crest-kettle terraces with channels, branches, rare small oak and alder forests, meadow massifs, and agricultural areas is extremely remote. The length of this block is large; in some profiles, it was recorded at a distance of up to 200 m (TsP 1). As a rule, this block contains plough lands. The marginal block was found only on upland landscapes where subsoil water lies at greater depth (more than 3–5 m). The natural complexes are represented here by zonal types.

CONCLUSIONS

The results of studies showed that the character and degree of the transforming impact of the Tsimlyansk Reservoir on its coast is determined primarily by the relief, lithology, and the appropriate vegetation background.

Two zones of influence of the reservoir on the main shore formed within the past 50 years. These zones correspond to two blocks of the water–land ecotone—dynamical and distant—which are subject to inundation by spring floodwater, and where the level of subsoil water does not fall below 3 m.

Variations in the water edge position in the dynamical block within the vegetation period can reach 1 m with respect to the mean position over the vegetation period. The steppe vegetation in all TPs is replaced here by meadow vegetation. The soil also became meadow.

Experimental field studies of 2004 allowed the examination of the ecotone systems of the Tsimlyansk Reservoir coasts that form in all seven types of nearby landscapes.

Typical and similar structures of the water–land ecotone is characteristic of them. The fluctuation block is a zone of seasonal drawdown of the reservoir and has virtually no vegetation. In some years, a bed zone with a width of up to 1.5 km near the Tsimlyanskie Peski Natural Park emerges from water, as a result of which mobile eolian formations appear. The most complete landscape representation of the fluctuation block took place on the coast composed of sand deposits, whereas in the coasts with abrupt shore, composed of dense rocks, its representation is the least adequate.

For the more successful solution of the problem of protecting the segments of shoreline subject to erosion, it is proposed to introduce remote monitoring of the dynamics of vegetation cover as an indicator of exogenic processes: local increase in shore abrasion (wave-induced phenomena), excessive grazing at the coastal areas subject to erosion, defective sewerage systems in populated localities and recreation centers on the coast, and other types of anthropogenic load. In addition to the widely used methods, it appears beneficial to protect the shoreline and artificial levees with the use of vegetation, which will require a definite level regime to be maintained in the reservoir. An "autocatalytic" effect can appear later—the mature vegetation becomes less sensitive to short-time variations in water level and forms a stable microenvironment in the coastal areas of concern.

REFERENCES

1. Bogush, I.A., Kalinchenko, V.M., and Tret'yak, A.Ya., Study of the Present-Day Dynamics of the Geological Environment in the Rostov NPP Area, in *Problemy razvitiya atomnoi energetiki na Donu* (Issues of the Development of Nuclear Power Engineering in the Don Area), Rostov-on-Don: Izd. RGSU, 2000, vol. 1, pp. 105–118.
2. Vendrov, S.L., Avakyan, A.B., D'yakonov, K.N., and Reteyum, A.Yu., *Rol' vodokhranilishch v izmenenii prirodnykh uslovii* (Contribution of Reservoirs to Changes in Natural Conditions), Moscow: Znanie, 1968.
3. Vendrov, S.L. and D'yakonov, K.N., *Vodokhranilishcha i okruzhayushchaya prirodnaya sreda* (Reservoirs and the Environment), Moscow: Nauka, 1976.
4. Davydov, M.G., Klimenko, G.G., and Povarov, V.P., Program of Radiological Monitoring of Terrestrial Ecosystems in the Area of Rostov NPP, in *Problemy razvitiya atomnoi energetiki na Donu* (Issues of the Development of Nuclear Power Engineering in the Don Area), Rostov-on-Don: 2000, vol. 2, pp. 181–190.
5. Zaidel'man, F.R., Tyul'panov, V.I., Angelov, E.N., and Davydov, A.I., *Pochvy mocharnykh ladshaftov -formirovanie, agroekologiya i melioratsiya* (Soils of Mohar Ladscapes: Formation, Agroecology, and Melioration), Moscow: Mosk. Gos. Univ., 1998.
6. *Landshaftnaya karta SSSR. M 1 : 2500000* (Landscape Map of the USSR. Scale of 1 : 2500000), Gudilin, I.S., Ed., Moscow: GUGK, 1987.
7. Luchsheva, A.A., *Prakticheskaya Gidrometriya* (Practical Hydrometry), Leningrad: Gidrometeoizdat, 1983.
8. *Mikroochagovye protsessy – indikatory destabilizirovannoi sredy* (Microfocal Processes as Indicators of Environmental Instability) Novikova, N.M., Ed., Moscow: RASKhN, 2000.
9. Osipov, V.I. and Kutepov, V.M., Geologicla Environment and the Consideration of Its Features in the Project of Rostov NPP Construction, in *Problemy razvitiya atomnoi energetiki na Donu* (Issues of the Development of Nuclear Power Engineering in the Don Area), Rostov-on-Don: 2000, vol. 1, pp. 106–115.
10. *Tsimlyanskoe, vodorazdel'nye i Manychskie vodokhranilishcha* (Tsimlyansk, Water-Divide, and Manychskie Reservoir), Znamenskii, V.A. and Geitenko, V.M., Eds., Leningrad: Gidrometeoizdat, 1977.
11. *Ekotony v biosfere* (Ecotones in Biosphere), Zaletaev, V.S., Ed., Moscow: RASKhN, 1997.
12. *Yugo-Vostok Evropeiskoi chasti SSSR* (Southeastern European Russia), Gerasimov, I.P., Ed., Moscow: Nauka, 1971.