Aftereffects of environmental engineering of the 20th century in the forest-steppe zone of the Tambov Plain

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Abstract. The purpose of this study was to analyze the aftereffects of a set of engineering measures to implement the so-called "Nature Transformation Plan" on the territory of the forest-steppe zone of Central Russia (Tambov, Lipetsk, Voronezh oblasts) based on archival materials of drilling logs of 1900-1914, archival documents of 1949-1953, as well as the results of soil and hydrological studies in 2015-2023. The results of chemical analysis of groundwater 1914 and 2015 found that the chemical composition of the aquifer water - hydrocarbonate-sodium - has not changed significantly over the 100-year period, only a slight decrease in total water hardness and an increasing trend in sulfate and chloride content. It is shown that the stage of anthropogenic development of Tambov region by construction of ponds, forest strips and introduction of irrigation in the course of implementation of Stalin's plan of nature transformation without taking into account the specifics of hydrology of the region has led to the rise of the level of hydrocarbonate-sodium groundwater by 2-3 m, to the complete, not temporary, destruction of the "dead horizon" in chernozems and will contribute to further deterioration of their properties.

1 Introduction

In the late 1940s, against the backdrop of years of drought, a process of comprehensive changes in agricultural production began in many countries, later called the "green revolution". This process was aimed at combating hunger in the post-colonial world and included the development of more productive plant varieties, the expansion of irrigation, the use of mineral fertilizers and plant protection products, and the introduction of new farming and engineering technologies. In the USSR, on October 20, 1948, the Decree of the Council of Ministers of the USSR and the Central Committee of the All-Union Communist Party of Bolsheviks "On the plan of field-protective afforestation, introduction of grass-field crop rotations, construction of ponds and reservoirs to ensure high and stable yields in the steppe and forest-steppe regions of the USSR" was issued [1]. In general, the task was to start from 1949 "to start systematic and wide implementation of the system of agronomic measures to improve agriculture, based on the teachings of prominent Russian agronomists V.V. Dokuchaev, P.A. Kostychev and V.V. Kostychev. Dokuchaev, P.A. Kostychev and

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V.V. Williams". The Decree provided for the creation in 1950-1965 of a system of large state protective forest strips. system of large state protective forest belts, development of forest protection plantations on the fields of collective and state farms, consolidation and afforestation of sands, powerful development of a network of tree nurseries for the cultivation of planting material, a set of measures to complete the introduction and development of grass-field crop rotations in all collective farms of the steppe and forest-steppe zone of the European part of the country, further development of irrigation and construction of ponds and reservoirs, extensive mechanization of agricultural work, forest plantations and irrigation construction.

The purpose of this study was to analyze the aftereffects of engineering measures to implement the "Nature Transformation Plan" on the territory of the forest-steppe zone of Central Russia (Tambov, Lipetsk, Voronezh oblasts) based on the materials of drilling logs of 1900-1914, as well as 1940-1960 and the results of soil and hydrological studies in 2015-2023.

2 Materials and methods

The objects of the study were soil-engineering complexes of forest belts, ditches, shafts and ponds, created under the "Nature Transformation Plan" on the territory of Nikiforovsky, Michurinsky, Morshansky, Znamensky, Sosnovsky districts of Tambov region, Ostrogozhsky district of Voronezh region in 1949-1953, archival materials of drilling logs from the beginning of the 20th century - about 50 pieces, and reports from 1949-1953 (State Archive of the Tambov Region. Fund 1019) as well as soil and groundwater samples collected during field research in 2015-2022. It is important to note that the areas bordering Tambov Oblast in Lipetsk and Voronezh Oblasts, namely Lipetsk, Lebedyansky and Elatomsky uyezds were part of Tambov Province at the beginning of the last century.

The climate of the discussed region is temperate continental, annual precipitation is 430-650 mm, average temperature in January is -10.2-11.2 0C, average temperature in July is 19.4-20.3 0C. Precipitation is distributed unevenly, with predominance in the summer period (70% of the annual norm). A characteristic feature of the climate is the variability and inconstancy of the precipitation regime and alternation of perennial dry and wet periods [1]. Two to three years out of every 10 years are characterized by dry weather.

The main purpose of the studied soil-engineering complexes consisting of forest strips and hydraulic structures is to ensure soil productivity and resistance of agrolandscapes to erosion, accumulation of productive moisture and reduction of wind speed. Transit forest belts allow streams of local runoff to pass through them, reducing their speed and freeing them from erosion products. To increase the efficiency of surface runoff retention and its conversion into ground runoff, flow-regulating strips are combined with the simplest hydraulic structures - earthen berms and ditches. Water accumulates in the ditches, which seeps through the forest belts and from there gradually infiltrates into the soil [2, 3]. Water-retaining forest belts (Michurinsky district of Tambov oblast, Ostrogozhsky district of Voronezh oblast) are combined along the forest edge with canals, and canal cavaliers perform the function of earthen ramparts. The depth of the canal is 0.5 m, width at the top is 0.75 m, slope embedment on the forest belt side is 0.5 m, on the rampart side - 1 m, rampart height is 0.8 m. Water-directing forest belts are located on slope landscapes subject to gully formation, provide reduction of surface runoff velocity, direct excess runoff to places of their safe discharge (Morshansky rayon). In Sosnovsky district, wind-protective forest belts of open-work type prevail (15-45 % of through gaps along the front), oriented from north to south and also equipped with channels on both sides of the plantations. The results of the study of changes in soil properties under the influence of forest belt organization are presented in our recent work [4]. In the Tambov region, soil sections revealing podzolized chernozems were laid both in the central part of forest belts and on ramparts-cavaliers. Meadow-chernozem soils were uncovered 1 m from the canals (at the edge of forest belts). Arable lands adjacent to the forest belts are represented by leached chernozems (Michurinsky rayon), ordinary (Tambovsky rayon) and segregated (Morshansky rayon, Znamensky rayon) (Luvic Chernozems). In Voronezh region, a soil transect uncovered malt in the forest belt, and carbonate chernozem on the adjacent arable land.

In addition to forest plantations on the territory of collective farms of the Tambov region, ponds were massively constructed to provide water for the irrigation systems being created.

Groundwater samples from wells were taken in the villages of the former Lebedyansk and Lipetsk uyezds of the Tambov province and now Lipetsk region - Bolshiye Khomyaki, Bolshiye Izbishchi, Trubetcheno, Telezhenka - as the drilling logs had data on the chemical composition of water for these settlements. Determination of groundwater quality by pH, total alkalinity, hardness, sodium, calcium, magnesium, iron, hydrocarbonates, sulfates, chlorides and nitrates was performed by potentiometric, titrimetric, atomic-adsorption and chromatographic methods. The obtained results are comparable with the results of determining the chemical composition of water in 1900-1914, as the German methods used are the basis of modern high-tech methods of analysis.

3 Results and discussion

Analysis of the materials of drilling logs of the early XX century revealed that the aquifer is located at a depth of 0-36 m and is confined to the Kudeyarovsko-Lebedyansky layer of Devonian sediments. At the same time, there is a hydrostatic connection between groundwater, which directly affects soil formation, and bedrock aquifers due to the pressure character of bedrock water. Sandy aquifers are uncovered by the Chelnova, Polny and Lesny Voronezh, Matyra, Savala, Bityug and other rivers. As the materials of drilling logs reveal, sandy deposits are overlain by a layer of loess-like carbonate loams with thickness from 3 to 15, which increases from watersheds to depressions. Some horizons of loess-like loams are characterized by increased alkalinity and salinity as a result of their wetting by capillary groundwater in the past.

The aquifer depth in Trubetcheno is 16.3 m from the ground surface, in Telezhenka - 23.76 m, and in Bolshiye Izbishchi varies from 21.93 to 38.70 m along the slopes of modern river valleys. Absolute elevations of groundwater mirror levels vary from 149.88 to 179.05 m above sea level, the level of carbonate occurrence varies from -10 m in Kirsanovsky district to 200 m in Lebedyansky district (Figure 1). According to the data of chemical analysis given in the drilling logs of the XX century (Table 1), the waters of the Kudeyarovsko-Lebedyansky aquifer are hard and very hard with neutral or slightly alkaline reaction of the medium, namely, hydrocarbonate with a small content of chlorides and sulfates.

The results of chemical analysis of water in 2015 revealed that water composition is mainly sulfate-hydrocarbonate magnesium-calcium with a total mineralization of 0.4-0.6 g/l. In Trubetcheno village the water composition is chloride-hydrocarbonate sodium-calcium with total mineralization of 1.0 g/l, in Bolshie Khomyaky - chloride-sulfate-hydrocarbonate sodium-magnesium-calcium with a total mineralization of 0.6 g/l, in Bolshie Izbishchi - chloride-sulfate-hydrocarbonate sodium-magnesium-calcium with a total mineralization of 0. 4 g/l, in Telezhenzhenka - chloride-sulfate-hydrocarbonate sodium-magnesium-calcium with a total mineralization of 0. 4 g/l, 4 g/l, in Telezhenka - chloride-sulfate-hydrocarbonate sodium-magnesium-calcium with total mineralization 0,4 g/l, in Trubetcheno - sulfate-chloride-hydrocarbonate magnesium-sodium-calcium with total mineralization 1,0 g/l. Thus, to the north of the region under consideration, the sulfate content increases slightly, sodium partially displacing calcium from the soil absorption complex. An increase in chloride or sulfate content in water is a diagnostic sign of a greater or lesser degree of plastering of waterbearing sediments. Total water hardness varies within 5.1-7.3 mmol/l (moderately hard), reaching in Trubetcheno values of 9.8 (very hard, unsuitable for drinking) (Table 2).

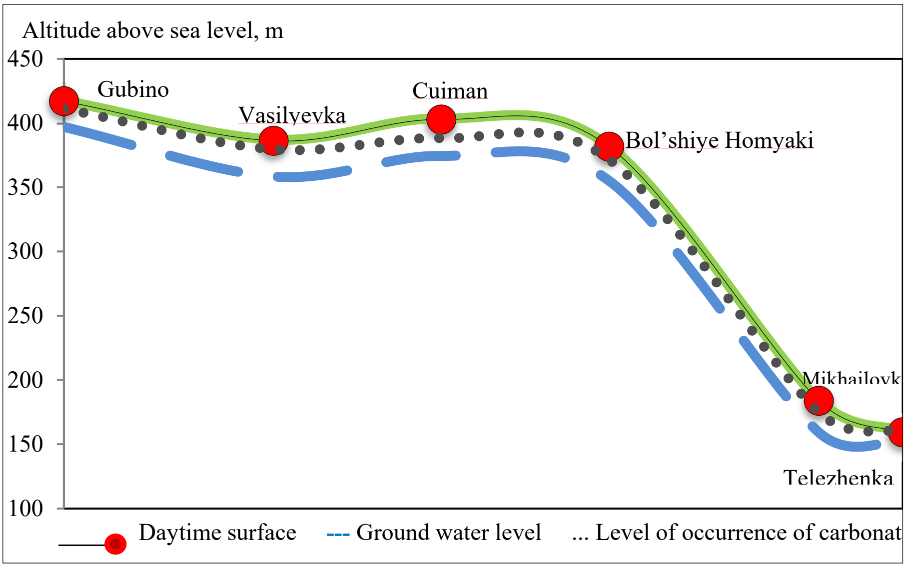


Fig. 1. Hydrological profiles of some districts of the Tambov province in the 20th century.

It is known that the composition of natural waters is a function of their mineralization. At the initial stage of water salinization process, when the concentration is 0.5-5 g/l, its composition is usually hydrocarbonate-sodium with admixture of sulfates and sodium chlorides. Soil-soil waters of the Ox-Don lowland are classified as hydrocarbonate-calcium. However, in accumulative landscapes waters acquire higher mineralization, become hydrocarbonate-magnesium-sodium, hydrocarbonate-sodium, sulfate-hydrocarbonate-sodium, chloride-hydrocarbonate-sodium. As follows from the results of chemical analysis of groundwater in 1914 and 2015, the composition of aquifer water has not changed significantly over the 100-year period, with only a slight decrease in total water hardness and an increasing trend in sulfate and chloride content.

Table 1. Chemical composition of water, according to drilling logs of 1914.

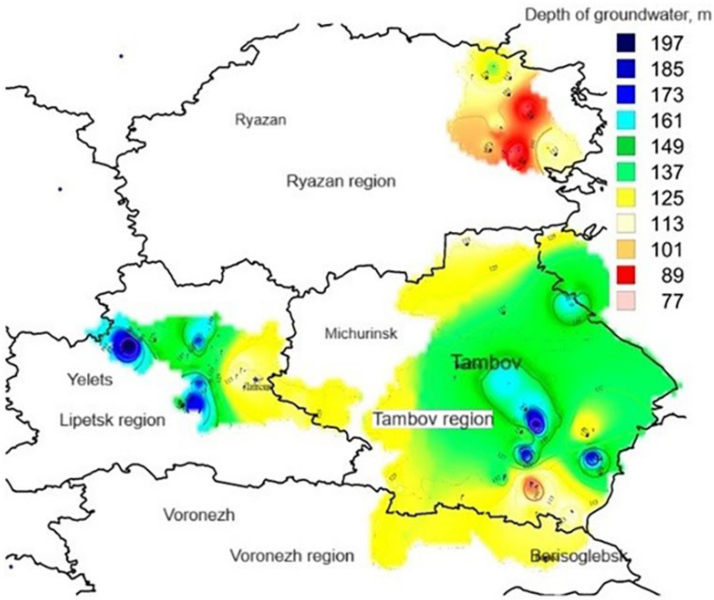
Indicator name	Bol’shiye Homyaki	Bol’shiye Izbishchi	Telezhenka	Trubetchino
pH	6.9	7.3	7.4	6.5
Total alkalinity, mmol-eq/l	8.4	7.1	14.8	8.9
Na^+, mg/l	0	14.5	0	89.0
SO_4^{2-}, mg/l	0	0	100.2	92.4
Cl^-, mg/l	21.8	0	10.0	70.2
Water quality	Moderately hard, fresh. Low risk of alkalinization and salinization. Suitable for watering.	Moderately hard, fresh. Low risk of alkalinization and salinization. Suitable for watering.	Moderately hard, fresh. Low risk of alkalinization and salinization. Suitable for watering.	Salty. Very tough. Low risk of alkalinization and medium risk of salinization. Suitable for watering

Table 2. Chemical analysis of groundwater, 2015.

Indicator name	Bol'shiye Homyaki	Bol'shiye Izbishchi	Telezhenka	Trubetchino
pH	7.3	6.8	7.0	7.1
Total alkalinity, mmol-eq/l	5.1	3.2	4.7	8.6
$HCO3^-$, mg/l	309.4	197.9	290.1	526.5
Total hardness, mmol/l	7.3	5.1	5.2	9.8
Na^+, mg/l	9.0	24.5	8.5	99.9
Ca^{2+}, mg/l	101.1	93.4	83.2	152.2
Mg^{2+}, mg/l	26.9	7.5	15.5	26.2
$Fe^{2+,3+}$, mg/l	0.3	0.1	0.2	0.1
SO_4^{2-}, mg/l	84.2	93.1	33.5	115.1
Cl^-, mg/l	26.8	31.1	8.6	74.2
NO_3^-, mg/l	69.5	100.3	25.0	342.4
Total mineralization, g/l	0.6	0.4	0.4	1.0
Water quality	Moderately hard, fresh. Low risk of alkalinization and salinization. Suitable for watering.	Moderately hard, fresh. Low risk of alkalinization and salinization. Suitable for watering.	Moderately hard, fresh. Low risk of alkalinization and salinization. Suitable for watering.	Salty. Very tough. Low risk of alkalinization and medium risk of salinization. Suitable for watering

Comparison of groundwater hydroisohyps maps (Figure 2), constructed on the basis of drilling logs of the early XX century, revealed that the activities on implementation of the "Nature Transformation Plan" in the studied regions of Tambov oblast (former Tambov uyezd) led to groundwater table rise by 2-3 m to the surface and increased the risk of soil salinization in relief depressions. Under solonetization chernozems lose their structure, their density increases, processing becomes difficult, water retention capacity and chemical properties deteriorate.

As our previous studies [4] have shown, the close groundwater level in the landscapes of the Tambov region distinguishes them from other chernozem regions by the periodic (2-3 times within 5 years) absence of a "dead horizon" between the strata moistened by precipitation and groundwater flow, and therefore makes them particularly sensitive to atmospheric moisture conditions. The type of water regime in the forest-steppe of the Tambov region is not the usual for chernozems non-leaching and periodically leaching, but variable leaching-desucc tive-washing. The upper one and a half meter thickness of these soils is only periodically dried and "ventilated". Therefore, the soils of Tambov region are called "meadow-chernozem" and "chernozem-meadow".



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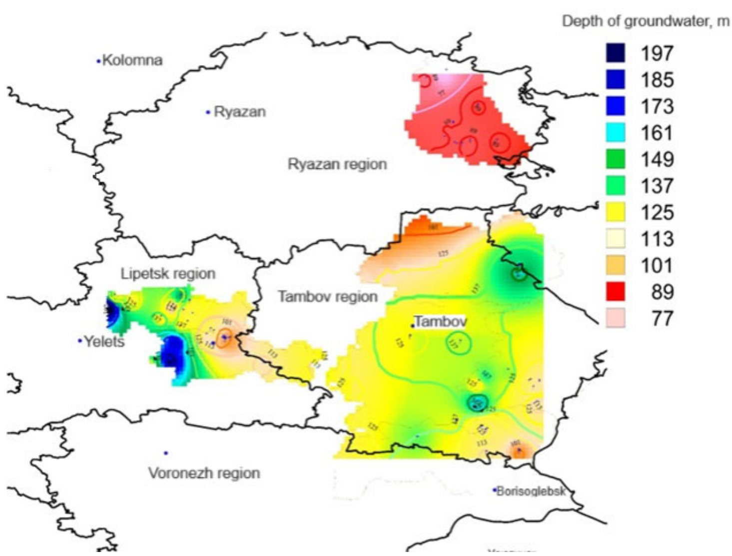

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Fig. 2. Map of groundwater hydroisohypses: A – 1914, B - 2015.

Climate change accompanied by increasing aridization in the forest-steppe zone [5] leads to the dominance of evaporation and desucction processes from weakly saline groundwater located close to the surface. Salts, especially sodium salts, rising up the profile, lead to destruction of valuable structure of chernozems. On the other hand, the coupling of atmospheric moisture with groundwater flow moisture leads to the formation of maltings in flooded depressions.

In our opinion, not only forest belts that preserve soil moisture [6, 7], but also the introduction of irrigation systems and large-scale construction of ponds on the territory of collective farms to provide water for irrigation complexes contributed to the rise in groundwater levels. The depth of ponds varies from 4 to 20 m, the type of water supply is melt water, local runoff, and springs. The analysis of stock materials allows estimating the volumes of hydrological construction (Table 3).

Table 3. State of artificial irrigation in the Tambov region (1948-1953), [1].

	1948	**1949**	**1950**	**1951**	**1952**	**1953**
Land with irrigation systems, ha	2477	8720	17496	22400	24876	27206
Irrigated, ha, %	691/28	2880/33	10092/58	8712/39	7166/29	3443/13

Table 4. Examples of pond construction on collective farms in Tambov Oblast.

Region	**Name of collective farm**	**Year of entry**	**Mirror area, km2**	**Water volume, m3**	**Water supply**	**Catch ment type**
Michurinskiy	Komsomolets	1945	8	250000	Melt water	open
Rzhaksinskiy	Druzhba	1940	8	300000	Local runoff, springs	open
Rzhaksinskiy	Druzhba	1948	6	200000	Melt water	open
Rzhaksinskiy	Engel'sa	1960	1.4	18000	Melt water	open
Sampurskiy	Engel'sa	1940	2.4	120000	Melt water	open
Sampurskiy	Borets	1949	8.8	130 000	Melt water	open
Rzhaksinskiy	Zavety Il'icha	1957	2.4	36000	Local runoff, springs	tubula r
Rzhaksinskiy	Putilovets	1953	0.3	500	Melt water	open
Rzhaksinskiy	im. Lenina	1950	2	310000	Local runoff, springs	dam
Rzhaksinskiy	im. Lenina	1951	1.5	96000	Local runoff, springs	open
Rzhaksinskiy	im. Kirova	1957	4	38	Local runoff	open
Rzhaksinskiy	im. Ponomareva	1952	2.5	40000	Melt water	open
Rzhaksinskiy	Putilovets	1953	0.2	400	Melt water	open
Rzhaksinskiy	im. Karla Marksa	1940	0.75	2250	Springs	open
Rzhaksinskiy	im. Karla Marksa	1940	1.05	4200	Local runoff, springs	open

4 Conclusion

Thus, the dynamic in time and space nature of the hydrological regime of the Tambov Plain makes the soil cover of this region, represented not so much by chernozems as by meadow-chernozem or chernozem-meadow soils, particularly sensitive to the peculiarities of agricultural development. The stage of anthropogenic development of Tambov region through the construction of ponds, forest strips and introduction of irrigation during the implementation of Stalin's plan of nature transformation without taking into account the specifics of the region's hydrology led to the rise in the level of hydrocarbonate-sodium groundwater, complete, rather than temporary destruction of the "dead horizon" in chernozems and further deterioration of their properties.

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