Drainage system construction influence on the groundwater level of reclaimed soils

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Abstract. The influence of the drainage system construction on the formation of the regime of groundwater levels has been studied. The results of statistical processing of the data from parallel observations of meteorological parameters and groundwater levels over a 32-year period have demonstrated that groundwater levels are most closely correlated with the hydrothermic coefficient (HTC) of the previous period. With an increase in the degree of moisture, the groundwater level rises most rapidly in the first decade of May and is less subject to variations in the third decade of May. The highest groundwater level in the 1st decade of May with the long-time annual average HTC equal to 2 was observed in the shallow drainage option – 35 cm, the lowest – in the two-tiered drainage option – 70 cm. In an excessively humid year (HTC = 3.5), groundwater in the options of shallow drainage and collectors with filling the drainage trench with sand-gravel mixture (SGM) rise into the plough layer; and, when the HTC exceeds 4.5, in the options of shallow drainage and collectors with SGM, they reach the soil surface. In a wet year, the rate of groundwater decline is from 1.25 cm/day – in the option of two-tiered drainage to 2.00 cm/day – in the option of collectors with wood chip. In modern conditions of climate change, the most advanced drainage systems are the structures of two-tiered drainage and collectors with wood chip, which ensure timely drainage of groundwater. In a high-water year, the use of wood chip instead of a sand-gravel mixture in the collector structure will increase the rate of lowering of the groundwater level by 5%.

1. Introduction

In the Novgorod region, most of the agricultural fields are located on excessively humid lands. This is due both to the meteorological conditions of the territory and the flat relief and poorly water-permeable soils. Therefore, without carrying out reclamation measures, it is impossible to use these lands for growing crops. Currently, the area of drained land is 181.4 thousand hectares [1, 2]. A significant influence on the efficiency of closed drainage, one of the main parameters of which is the level of groundwater, is exerted by its construction features [3]. Studies carried out in Iran on the influence of such structural elements as organic shells on the efficiency of closed drainage have revealed an increase in their filtration capacity [4]. The groundwater level affects ecological state of the soil, determines biotic processes occurring in it [5].
Information on groundwater levels is used in many prediction calculations, and also has a direct impact on soil properties and their changes resulting from precipitation and evaporation [6].

2. Research objects and methods
The research object is closed drainage systems. In the experiment, the following constructions of reclamation systems have been used:
– collectors with the drainage trench filled with sand-gravel mixture;
– collectors with wood chip-filled drainage trench;
– two-tiered drainage;
– shallow drainage.

The experiments have been carried out on heavy loamy soil. The depth of the drains in the options of the collectors and two-tiered drainage is 1.1 m; in the option of shallow drainage, it is 0.7. The width of the drainage trench in all structure options is 0.2 m. The distance between collectors is 14 m; in structures of shallow drainage, it is 12 m. The upper tier of two-tiered drainage is located perpendicular to the lower one, 0.5 m deep, with a distance of 6 m between non-cavity drains. In all structure options, material plastic drainage with a diameter of 63 mm, preliminary reinforced with glass fibre, is laid.

3. Results and discussion
In 1989 in the Novgorod region, an experimental production site was put into operation, on which experimental structures of closed drainage were located in 3-fold repetition. In the same year, research and observation of the performance of these experimental systems began. Thus, the observation period is currently 32 years. During this time, meteorological conditions have been very different: from severely arid hot years to excessively humid and cool ones. At the same time, in the Novgorod region, in recent years, there has been a tendency for an increase in heat and moisture supply [7].

Analysis of meteorological information for the observation period showed that the annual amount of precipitation increased in the third decade by 134 mm, while during the growing season the growth was 100 mm, and during the active growing season (when temperatures were above 10 °C) – 72 mm. Along with the increase in precipitation, there was also an increase in the average annual temperature by an average of 0.45 °C per decade. The heat supply of the growing season increased by 73 °C on average, and the amount of temperature above 10 °C – by 69 °C per decade (table 1).

The increase in precipitation over decades exceeded the evaporation rate, which led to an increase in the degree of wetting over the observation period by 20%. A steady trend in all meteorological parameters suggests that this trend will continue in the future. And this will lead to a constant increase in the degree of soil moisture and a rise in groundwater. A similar trend on climate change is observed in other regions of the world. This problem is noted by US scientists who have conducted studies on the impact of changes in climatic conditions on the dynamics of groundwater in Illinois [8]. Under the influence of precipitation, the level of groundwater is formed, which, when rising, can cause flooding of the root layer of the soil. Drainage systems are aimed at accelerating subsurface runoff in order to lower the level of groundwater [9, 10]. Our research has been aimed at studying the influence of the drainage system construction on the formation of the regime of groundwater levels. For scientific research, the method of parallel observations of the groundwater level and meteorological parameters has been used. The experience of long-term observations of the groundwater regime has shown that the closest to the soil surface, groundwater rises at the beginning of the growing season, which invariably leads to a delay in the spring field work. Thus, in the conditions of the Novgorod region, the most critical period in terms of the degree of soil moisture, as a rule, is the month of May. In addition to precipitation, the groundwater level can also be affected by evaporation from the soil surface, the rate of which depends on temperature. The hydrothermal coefficient (HTC), which shows the
ratio of precipitation to the amount of evaporated moisture, can serve as a complex indicator of the degree of moisture.

Table 1. Meteorological conditions of m/s Novgorod.

| Year | Annual precipitation, mm | Average annual temperature, °C | Amount of precipitation during the growing season (t>5°C) | Amount of temperature of more than 5 degrees | Amount of precipitation for the period from t>10°C | Amount of temperature of more than 10 degrees | HTC |
|------|--------------------------|-------------------------------|------------------------------------------------------|---------------------------------|---------------------------------|----------------------------------------|-----|
| 1990 | 550                      | 5.3                           | 358                                                  | 2610                             | 274                              | 2445                                   | 1.12|
| 2000 | 611                      | 5.5                           | 405                                                  | 2735                             | 317                              | 2553                                   | 1.24|
| 2010 | 684                      | 6.2                           | 458                                                  | 2757                             | 346                              | 2583                                   | 1.34|
| Norm | 550                      | 4.4                           | 385                                                  | 2501                             | 301                              | 2375                                   | 1.27|
| Coupling equation, coefficient of determination | $y = 67x + 481$ | $R^2 = 0.9973$ | $y = 0.45x + 4.7667$ | $R^2 = 0.9067$ | $y = 50x + 307$ | $R^2 = 0.9988$ | $y = 36x + 73.104x$ | $R^2 = 0.9988$ | $y = 240.33$ | $R^2 = 0.8594$ | $y = 2554.3$ | $R^2 = 0.9876$ | $y = 69.157x + 2388.8$ | $R^2 = 0.9024$ | $y = 0.11x$ | $R^2 = 1.0133$ | $y = 2375$ | $R^2 = 0.9973$ | $y = 1.27$ |

The results of statistical processing of the data from parallel observations of meteorological parameters and groundwater levels over a 32-year period have demonstrated that groundwater levels are most closely correlated with the HTC of the previous period. The analysis of the results has showed that during the growing season the correlation between these parameters weakens due to the lowering of groundwater below 1 m and the breaking of the hydraulic connection with the soil water formed after precipitation. Therefore, May has been taken as the period under review. A strong dependence of the groundwater levels on the HTC (April + previous decades of May) is observed on the lands drained by two-tiered drainage in the 1st and 3rd decades of May; in the other options, the correlation strength is average. A closer regression dependence, as a rule, has a curvilinear shape (table 2).

Analysis of the research results has made it possible to conclude that, in the 2nd decade of May, the groundwater levels quite closely correlate with the HTC of the two decades of May, and the groundwater level in the 3rd decade of May quite closely correlate with the HTC of the 2nd decade of May.

The hydrothermic coefficient for these periods during the 32-year observation period varied from 0.17 to 5.99. The figure demonstrates graphic interpretations of the obtained dependencies for the options of the experiment, which show that in all options the groundwater level rises most rapidly with an increase in the degree of moisture in the first decade of May and is less subject to variations in the 3rd decade of May in all options, except for lands drained by collectors with SGM (figure 1). In this option, the groundwater level is most inert in the 2nd decade of May.
Table 2. Dependence of the groundwater level (GWL) of the experimental systems on the HTC.

| Option                      | Dependence of the GWL (1st decade of May) on the HTC of April+1st decade of May | Dependence of the GWL (2nd decade of May) on the HTC of April+1st, 2nd decades of May | Dependence of the GWL (3rd decade of May) on the HTC of April+May |
|-----------------------------|---------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-----------------------------------------------------------------|
|                            | Equation form                                                                   | R²                                                                                 | Equation form                                                                   | R² |
| Shallow drainage            | y = -10.03x + 64.323                                                             | 0.25                                                                              | y = -14.199x + 76.338                                              | 0.29 |
|                            | y = -16.59ln(x) + 53.043                                                         | 0.26                                                                              | y = 79.613e^{-0.313x}                                             | 0.31 |
| Collector with wood chip    | y = -8.7835x + 76.149                                                            | 0.16                                                                              | y = -8.5354x + 80.324                                             | 0.18 |
|                            | y = -0.0156x^2 – 8.7212x + 76.1                                                  | 0.16                                                                              | y = -0.5088x^2 – 6.4227x + 78.59                                  | 0.18 |
| Collector with SGM          | y = -15.699x + 82.668                                                            | 0.38                                                                              | y = -19.033x + 93.108                                             | 0.38 |
| Two-tiered drainage         | y = -15.159x + 97.901                                                            | 0.52                                                                              | y = -9.0021x + 91.254                                             | 0.19 |
|                            | y = -28.82ln(x) + 84.547                                                         | 0.65                                                                              | y = -17.08ln(x) + 82.732                                         | 0.25 |

The highest groundwater level in the 1st decade of May, with the long-time annual average HTC equal to 2, was observed in the shallow drainage option (35 cm), the lowest groundwater level was observed in the two-tiered drainage option (70 cm), in the collector options, the level was 45–60 cm. In the same decade, when the HTC is equal to 3.5, in the options of shallow drainage and collectors with SGM, groundwater rises into the plough layer, when the HTC is equal to 4.5 it is observed in the option of shallow drainage and, when the HTC is equal to 5, in the option of the collector with SGM, groundwater rises to the soil surface.

In the second decade of May, with the HTC norm equal to 1.35, the highest groundwater level is observed in the shallow drainage option – 45 cm, the lowest groundwater level is observed in the two-tiered drainage option – 80 cm, in the option of collectors with SGM – 55 cm, in the option of collectors with wood chip – 65 cm. In the third decade of May, in the average annual year, the HTC dropped by an average of 10–12 cm.
Figure 1. Dependence of groundwater levels on the hydrothermic coefficient.
Thus, in the average annual year, the drop in groundwater levels at the beginning of the growing season occurs at the rate of 1 cm/day. In a wet year, when the HTC is 4, the rate of groundwater level drop in the experimental systems ranges from 1.25 cm/day – in the option of two-tiered drainage to 2.00 cm/day – in the option of collectors with wood chip. The low rate of groundwater level drop in two-tiered drainage systems is correlated with their low initial level and, as a result, with an insignificant pressure of groundwater over the drain. This problem of low pressure over the drain also occurs in the option of shallow drainage, when at a high groundwater level the pressure over the drain is insignificant due to the shallow laying of the drains.

4. Conclusion

The analysis of the research results has allowed us to conclude that in the modern conditions of climate change, accompanied by an increase in humidity, the most advanced drainage systems are two-tiered drainage structures and collectors with wood chip-filled drainage trench, ensuring timely drainage of groundwater. In a wet year in terms of precipitation, the use of wood chip instead of a sand-gravel mixture in the collector structures will increase the rate of lowering of the groundwater level by 5%.

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