Substantiation of additional humidification of drained peat bogs by canal locking as a way to combat the occurrence of natural underground fires

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Abstract. The main problem today is the fight against annual natural fires. Peat fires cause irreparable environmental and material damage, as a result of which the fertile horizon is completely destroyed, poisonous gases are released, residential buildings and warehouses are destroyed, and habitats for animals and plants disappear. A peat fire is difficult to extinguish, since peat is a powerful water absorber and most of the water sources are located at a considerable distance from the source of ignition, special equipment fails in places where it burns out. The aim of the work is to substantiate moistening by means of canal locking to restore a hydrological regime and to combat the occurrence of fire in the existing drained systems of the Moscow and Ryazan regions. The main locking indicators for 53 years were obtained for two options for moistening in comparison with standard dehumidification. The articles of the water balance were calculated and studied. The optimal variant of moistening the peat bog was chosen, which creates fire-prevention conditions and conditions for the development of agricultural conditions. According to the selected option, water supply is about half of the total drainage flow, there is no need to attract additional water resources.

1 Introduction

Wetlands of Russia occupy a tenth of its entire area. They predominate in low relief areas with groundwater levels close to the ground surface and high soil moisture. This territory includes peat waterlogged lands within the Moscow and Ryazan regions, located in the Meshcherskaya lowland. Klepikovskiy district of the Ryazan region is waterlogged by 42.7%, Orekhovo-Zuevsky district of the Moscow region - by 20%, Egoryevsky district of the Moscow region - by 17% according to the data at the end of the 20th century [1].

In Soviet times, creating a sustainable fodder base with a hay productivity of up to 40 centners per hectare and providing the industry with natural fuel - peat, measures were taken to drain the swamps. At present, most of the drainage systems are in an unsatisfactory condition, some of the hydraulic structures have been destroyed. During dry periods of

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summer, on the functioning parts of the drainage systems, the groundwater levels drop so that the capillary communication between it and the surface layer of peat breaks, and the humidity drops to a critical fire hazardous level below 50-60% of the total moisture capacity [2,3,4]. Under such conditions, peat in peat extraction sites and cultivated agricultural fields can ignite from a thrown cigarette butt or dross of a passing car, and also ignite spontaneously.

Wetland drainage changes the hydrological regime of watersheds, leading to large-scale peat fires. In 2005, natural fires were recorded on the territory of the Moscow Region on a total area of up to 100 hectares, in 2007 - up to 170 hectares. Great damage was caused by wildfires in 2010. The Moscow region is considered to be a fairly urbanized territory, natural fires destroyed 1700 hectares of peatlands and 15300 hectares of forests, which led to heavy smoke in the capital and adjacent cities [5].

The occurrence of annual fires on drained peatlands indicates the incorrect application of the fire prevention method and the further use of peatlands. Extinguishing a peat fire requires constant significant technical and financial costs. The main problem is the fact that peat is a combustible substance and a powerful water absorber, 1 kg of dry matter of peat can hold up to 15 kg of water [6]. Extinguishing requires a large volume and consumption of water (fire extinguishing agents) and the corresponding costs for its supply and delivery.

2 Objective

The objective of the work is to substantiate the additional moistening of the peatland by locking the existing channels to prevent the occurrence of a fire in the drained peatlands of the Moscow and Ryazan regions, as well as further regulation of humidity for the cultivation of herbs.

3 Research materials and methods

Extinguishing peat fires involves a whole range of works. Digging in a fire zone to limit the area of its spread. As well as digging up peat and filling the site with plenty of water. Usually, a lot of effort and resources are expended on fighting a peat fire, since the fire area is always quite large.

To maintain the required fire-fighting humidity on the existing drained peatlands of the Moscow and Ryazan regions, it is proposed to create systems for bilateral control of moisture by installing locks on canals to a more environmentally friendly system - water circulation. As a source of water for irrigation, it is proposed to use a storage pond that accumulates water from local and drainage flows, and in acutely dry years, with a lack of water, additional supply from external sources - rivers, lakes, etc.

To assess the main indicators of locking, we used mathematical modeling, specifically, a two-dimensional model of moisture transfer in the catena by A.I. Golovanov, tested by two-year field studies on drained peatlands of the floodplain of the Dubna River [7].

Catena is a chain of interconnected elements of the catchment area, consisting of a hill, a slope, a low. The model uses a two-dimensional moisture transfer equation that takes into account the gravitational and frame-capillary components of incomplete saturation of soil pores with water under time-varying meteorological conditions, and also uses formulas for calculating the productivity of cultivated crops [8].

In the mathematical model, the thickness of the soil profile ranges from the ground surface to a mark 1 m higher from the aquiclude, is divided into horizontal layers h_j along a length of 0.1 m and into vertical layers forming blocks of constant width b. The moisture flow is considered as two-dimensional, its finite-difference analog is written according to the scheme, based on the moisture balance in the i, j block, and has the form:

$$Cw_{i,j}^{n+1}\frac{H_{i,j}^{n+1}-H_{i,j}^{n}}{\Delta t}=\frac{H_{i,j-1}^{n+1}-H_{i,j}^{n}}{h_jR_{i,j-1}^{\text{в}}}-\frac{H_{i,j}^{n+1}-H_{i,j+1}^{n}}{h_jR_{i,j}^{\text{в}}}+\frac{H_{i-1,j}^{n+1}-H_{i,j}^{n}}{b_iR_{i-1,j}^{\text{г}}}-\frac{H_{i,j}^{n+1}-H_{i+1,j}^{n}}{b_iR_{i,j}^{\text{г}}}-e_{i,j}^{n} \quad (1)$$

where $H_{i,j}^{n+1}$ – pressure at the estimated time n+1, m; e_(i,j)^n – evaporation of moisture; Δt – estimated time step, day; when counting the heads from the earth's surface at the highest point of the profile of the χ axis, directed downward, it has the form:

$$H_{i,j}^{n+1}=-\chi_{i,j}+\psi_{i,j}^{n+1} \quad (2)$$

where $\psi_{i,j}^{n+1}$ – head equivalent to the frame-capillary pressure in the zone of incomplete saturation (ψ<0) and equivalent to hydrostatic pressure in the zone of complete saturation, m;

$R_{i,j}^{\text{в}}$ – vertical resistance to water flow between centers i,j and i,j+1 blocks, day, is presented as:

$$R_{i,j}^{\text{в}}=0{,}5\left(h_j/K\omega_{i,j}+h_{j+1}/K\omega_{i,j+1}\right) \quad (3)$$

$R_{i,j}^{\text{г}}$ – horizontal resistance to moisture flow between centers i,j and i+1,j blocks, day:

$$R_{i,j}^{\text{г}}=0{,}5\left(b_i/K\omega_{i,j}+b_{i+1}/K\omega_{i+1,j}\right) \quad (4)$$

where $K\omega$ – moisture conductivity coefficient $m_{\text{в}}^3/m/day$, dependent on volumetric soil moisture ω:

$$K\omega=K_{\text{ф}}\cdot\left(\frac{\omega-BP}{p-BP}\right)^{3{,}5} \quad (5)$$

where BP – humidity of capillary rupture or maximum molecular moisture capacity according to A.F. Lebedev.

The model takes into account the daily amount of precipitation falling on the surface layer of the soil, evaporation depending on the weather, moisture content in the soil and the degree of salinity, the boundary condition is considered as evaporation from the soil surface and plant transpiration. In the model, water entering the soil infiltrates into the lower soil layer and is distributed in proportion to the water content in the soil and the density of the roots.

4 Results

Using a two-dimensional mathematical model, the following variants of the humidification measure for the Pavlovsky Posad weather station in the Moscow region were calculated for a period of 53 years:

- drainage by drainage, installed at a depth of 1.0 to 1.2 m, providing the required rate of groundwater drawdown;
- moistening of the peat bog by locking the canal by creating water backwater 0.8 m below the surface of the peat bog;
- moistening of the peat bog by locking the channel, by creating water backwater 0.5 m below the surface of the peat bog.

The main results of the forecast of the presented variants of moistening [7] and drainage are shown in Tables 1 and 2.

Table 1. The results of moistening of drained peatlands according to the data of meteorological stations Pavlovsky Posad in the Moscow region and Tuma in the Ryazan region (arithmetic averages from 1959 to 2011).

Variants	**Precipitation, mm**	**Evaporatio n, mm**	**Lateral inflow, mm**	**Groundw ater depth, m**	**Moisture content of peat, in fractions of porosity**
Pavlovsky Posad					

Standard Wetland Drainage	373	354	77	1.1	0.54
Humidification with channel sluice up to 0.8 m	373	361	46	0.82	0.64
Humidification by channel locking up to 0.5	363	365	25	0.57	0.75
Tuma					
Standard Wetland Drainage	340	368	68	1.16	0.53
Humidification with channel sluice up to 0.8 m	340	377	26	0.85	0.62
Humidification by channel locking up to 0.5	331	382	6	0.60	0.73

Table 2. Results of drainage flow during sluicing of peatlands in the Moscow region (arithmetic averages from 1959 to 2011).

	Drainage flow, мм			**Relative yield, %**
	Reset from the regulating network	**Resetting from the safety net**	**Supply to drains**	
Pavlovsky Posad				
Standard Wetland Drainage	215	56	0	81
Humidification with channel sluice up to 0.8 m	342	68	170	94
Humidification by channel locking up to 0.5	440	80	305	74
Tuma				
Standard Wetland Drainage	153	42	0	73
Humidification with channel sluice up to 0.8 m	306	54	206	96
Humidification by channel locking up to 0.5	407	66	343	75

According to Table 1, fire dampness is provided in both proposed options for canal locking in two regions on average over 53 years compared to standard drying, at which the humidity reaches minimum critical values, and during dry periods it can significantly decrease, leading to fire hazardous conditions. When moistening with the help of canal locking up to 0.5 m from the ground surface, waterlogging of the peat profile is observed. This leads to a decrease in the yield of crops (forbs) by 27-28%, as well as additional supply of a valuable resource - water 1.7-1.8 times more compared to canal locking up to 0.8 m from the edge (table 2). The highest yields of all calculation options are achieved with moisture up to 0.8 m from the surface of the peat bog.

Humidification of a peat bog changes the articles of the water balance (Table 1 and 2). An increase in humidity when moistening the peat leads to a slight entrainment of evaporation up to 11 mm, as well as a decrease in the lateral inflow into drains to 62 mm for two meteorological stations in comparison with the drainage of the peat bog. The total drainage flow is determined by the difference between the discharge from drains (systematic and trapping) and the supply of water for humidification. The total drainage flow decreases as a result of locking to a maximum value of up to 65 mm for Tuma station. This indicates a decrease in the washability of the entire peat deposit, which means a decrease in the removal of water-soluble substances.

When locking, the water supply is approximately half of the total drainage flow, which means that there is no need to involve an additional third-party water source. But in extremely dry years, there may be a lack of water for moistening, then to eliminate the deficit, it is necessary to attract another additional source of water.

As a result of the locking of drained peatlands, the hydrological regime is restored, which has a positive effect on the preservation of natural fertility, the flow of polluted drainage water to the water intake is reduced, special fire conditions are created, and the biological productivity of the land is increased up to 96% while maintaining water in the canal up to 0.8 m from the edge for Tuma station.

With the help of the locking of drained territories, it is possible to regulate moisture reserves in the aeration zone, but due to the low rate of filling the canal to the selected level, the efficiency of the measures taken suffers. This condition must be taken into account when organizing fire safety, as well as constant monitoring of the state of the facility and verification of regulated indicators.

5 Conclusion

To combat fires on drained peatlands in the Moscow and Ryazan regions, it is proposed to restore the channels of the drainage network and its reconstruction to systems of bilateral regulation of the water regime using additional hydraulic structures of sluice-regulators.

With the help of a two-dimensional mathematical model of moisture transfer, the use of moistening of drained peatlands of the Moscow and Ryazan regions within the Meshcherskaya lowland is substantiated according to calculations for 53 years for three options: standard drainage, moistening by means of canal locking up to 0.8 m and 0.5 m from the surface of the peat bog. Maintaining the water level in the channel up to 0.8 m from the edge provides fire-fighting moisture up to 0.64 of the porosity fraction and allows you to get a yield of up to 0.94. The selected method of moistening allows maintaining the required fire-fighting humidity during dry periods, as well as growing perennial grasses.

According to calculations, no additional water resources are required to moisten peatlands, since the drainage flow from the territory is approximately 2 times greater than the water supply. There are some extremely dry years in which there may be a shortage of water to provide backwater in the canals. For such years it is necessary to attract additional water sources.

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