Journal of Engineering Physics and Thermophysics, Vol. 80, No. 2, 2007

OPTIMUM CONTROL OF THE GROUND-WATER LEVEL WITH ACCOUNT FOR A RAIN OR SNOW FALL-OUT

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Optimum ground-water conditions of a drained mass of a polder system having one conducting channel were simulated with account for a rain or snow fall-out. The calculations were conducted with the use of an invariant (independent of the number of conducting open channels and their configuration) nonstationary mathematical polder system, involving a strategy for control of the ground-water level in a drained mass (a system of Saint-Venant differential equations for an open channel, a two-dimensional Boussineq equation, and a differential equation for the transfer of water in drains were simultaneously solved).

Introduction. An algorithm for optimum control of the ground-water conditions in a drained mass for the purpose of formation of a uniform distribution of the ground-water level (GWL) was derived for the condition that the rate of decrease in the ground-water level reach a maximum value at a minimum root-mean-square deviation of the ground-water level from a certain value for a definite period of time.

Problems on construction of polder systems were considered in [1]. The following main parameters were optimized: the capacity of the pumping plant, the diameter and depth of the place of drains, and the distance between the drains. In this case, it was assumed that, first, in the range of admissible values of the parameters, the rate of decrease in the ground-water level R tends to a maximum, i.e.,

$$f(F, Q_p, H_0, t, a, d, p, L_1, L_2, K_f, h_{off}, h_{on}, \mathbf{\Phi}) \to \max\,, \tag{1}$$

and the time necessary for decreasing the ground-water level to a certain value t tends to a minimum:

$$f(F, Q_p, H_0, a, d, p, L_1, L_2, K_f, h_{off}, h_{on}, \mathbf{\Phi}) \to \min\,. \tag{2}$$

As a criterion of the uniformity of the GWL distribution in a drained mass, we specified a local criterion characterizing the operation of control loops in the main region — a drained mass — in the form of the root-mean-square deviation of the ground-water level from a certain value for a definite period of time:

$$J = \frac{1}{T_c} \int_0^{T_c} (H_{dj} - H_j)^2\, dt\,. \tag{3}$$

It was assumed that the local controlling functional (3) has a minimum value in the region of admissible values of the parameters characterizing the quality of the polder systems:

$$J \to \min\,. \tag{4}$$

This method of optimum control of the ground-water level allowed us to determine the optimum values of the capacity of a pumping plant, the diameter and depth of the place of drains, and the interdrain distance at a minimum expenditure of energy and an effective vegetation of plants [2].

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 1062-0125/07/8002-0370

TABLE 1. Deviation of the Quality Indices of Polder Systems

Quality index	Required quality indices		Expectation and dispersion	
	Nominal value	Tolerance	Distribution center	Spread in values
Channel depth, m	3.0			
Channel width, m	2.0			
Pump capacity, m^3/sec	0.2	±0.2		
Rate of decrease in the GWL, m/sec	10^{-4}	$\pm 8 \cdot 10^{-5}$	10^{-4}	$0—10^{-3}$
Time of process, days	1.8	±1.5	1.8	0.5—3.0
Interdrain distance, m	30			
Diameter of drains, m	0.12	±0.1		
Depth of placing of drains, m	1.5			
Width of a drained mass, m	100			
Filtration coefficient, m/sec	10^{-5}			
Ground-water level, m	2.8	±0.05	2.8	2.83—2.88

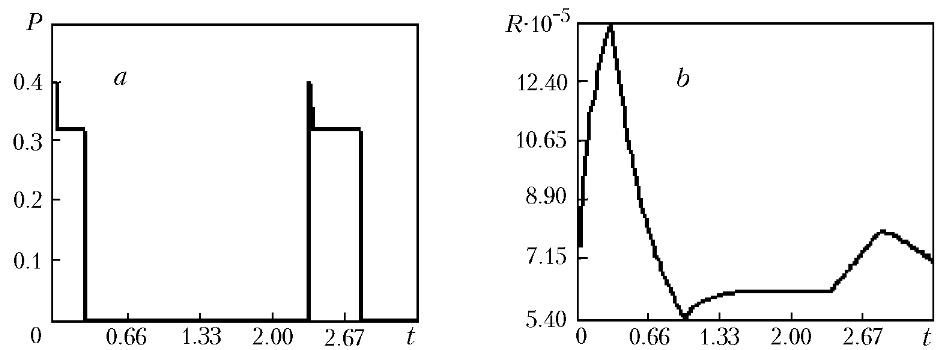

Fig. 1. Time dependences of the capacity of pumps (a) and the rate of decrease in the GWL (b). P, m^3/sec; R, m; t, h.

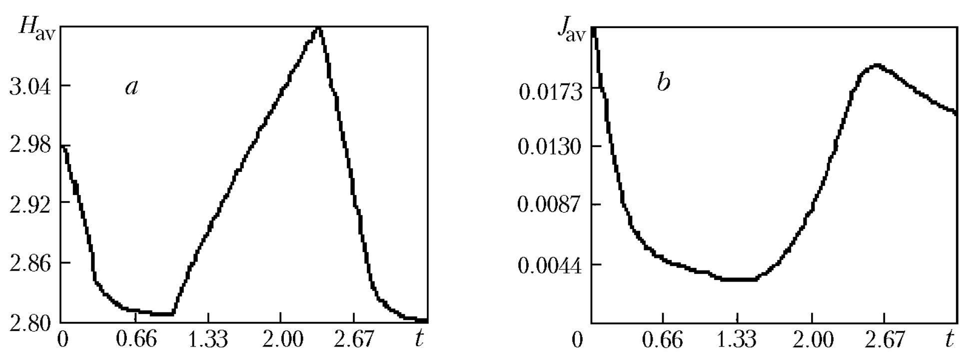

Fig. 2. Time dependences of the average GWL (a) and its root-mean-square deviation (b). H_{av}, m; J_{av}, m^2; t, h.

The nominal values of the control parameters and their tolerance as well as the mathematical expectations and the dispersions of goal functions are presented in Table 1. The numerical calculations of the parameters of a polder system in an extremal case — a fall-out of rain or snow of definite intensity — were performed on the basis of the data presented in this table with the use of the strategy for optimum control of the ground-water level (1)–(4).

It should be noted that the model system of differential equations was integrated with a time step of 60 sec, and, after 1 h, a fall-out of intensity $7.14 \cdot 10^{-5}$ m/sec and duration 1 h 20 min was included. As follows from the time

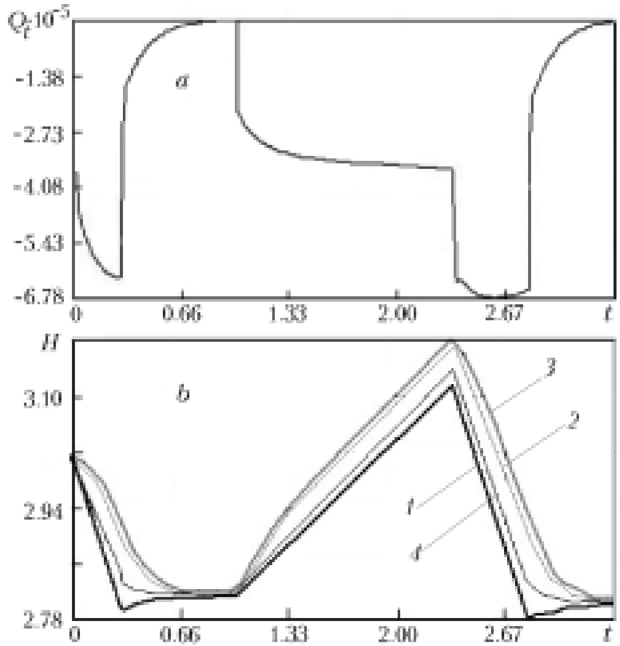

Fig. 3. Time dependences of the flow rate in drains Q_t (a) and the water level in a channel H_h (curve 1) and in a drained mass for three values of H_j: 2) H_1 = 20 m; 3) H_2 = 100 m; 4) H_3 = 200 m (b). t, h; Q_t, m^3/sec; H, m.

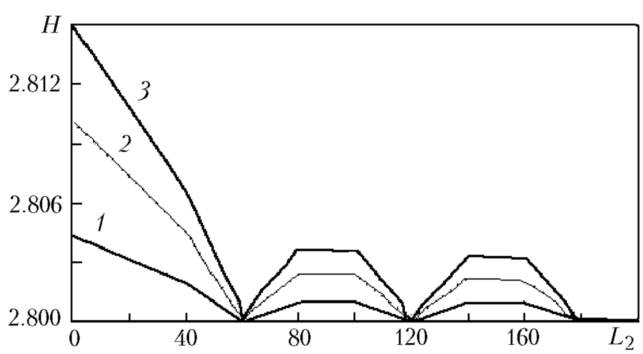

Fig. 4. GWL distributions in a drained mass along a channel (x axis): 1) H_1 = 10 m; 2) H_2 = 40 m; 3) H_3 = 100 m. H, L_2, m.

dependence of the capacity of pumps (Fig. 1a), this capacity has a maximum value of 0.4 m^3/sec in the initial period, which leads to a sharp increase in the rate of decrease in the ground-water level (Fig. 1b).

Accordingly, the average ground-water level decreases to the required value, equal to 2.8 m (Fig. 2a), and minimizes the root-mean-square deviation of the ground-water level from a certain value for a definite period of time (Fig. 2b). Then the pump capacity decreases to zero.

The rate of a water flow in drains increases at the initial instant of time (Fig. 3a), which provides the removal of water from the drained mass to an open conducting channel (Fig. 3b), from which it is pumped out by pumps with a maximum capacity (Fig. 3a). This leads to a sharp decrease in the ground-water level, which follows from the results of our calculations.

When the ground-water level reaches the required value (2.8 m), the pumps are switched off and the flow rate of water in the drains sharply decreases to zero (the level of water in a channel is equal to the level of water in the drained mass). In this case, the level of water in the open conducting channel is somewhat increased due to the inflow of water from the drained mass (Fig. 3b, curve 1). Then, after 1 h, a fall-out of high intensity ($7.14 \cdot 10^{-5}$ m/sec) occurs and the control of the ground-water level is disrupted; it begins once again only after the fall-out stops. In this case, the pumps begin to work with a maximum capacity and the flow rate of water in the drains approaches a maximum value, with the result that the maximum amount of water is removed from the drained mass to the conducting channel.

Figure 4 shows the optimum ground-water levels H determined using the strategy proposed for control of the ground-water level in a drained mass.

Conclusions. The strategy proposed for control of the optimum ground-water level in a drained mass makes it possible, even in extremal situations, where rain or snow of high intensity falls, to provide a definite ground-water level in the drained mass and in a conducting channel during a minimum period of time, which allows the conclusion that this strategy can be used to advantage for control of the optimum conditions of moistening of the root-inhabited layer of a soil and, therefore, for creation of conditions necessary for vegetation of plants in partially flooded soils at a minimum expenditure of energy.

This work was carried out with financial support from the Russian Basic Research Foundation (project No. 06-01-00396-a).

NOTATION

a, interdrain distance; d, diameter of the place of drains; F, open areas of channels; H, optimum ground-water level, m; H_{dj}, definite ground-water level in a drained mass at points along its width (y axis) (j = 0, 1, ..., M), m; H_h, water level in a channel, m; H_j, current value of the ground-water level at points along the y axis, m; H_0, initial value of the ground-water level; H_{av}, average value of the ground-water level; h_{on}, water level in the channel at which a pumping plant is switched on; h_{off}, water level in the channel at which the pumping plant is switched off; J_{av}, root-mean-square deviation of the ground-water level; K_f, filtration coefficient; L_1 and L_2, length and width of a drained mass; p, depth of placing of drains; Q_t, flow rate of water in drains, m^3/sec; Q_p, definite capacity of the pumping plant; P, capacity of pumps, m^3/sec; R, rate of decrease in the ground-water level; T_c, control period (hour, shift, etc.), sec; t, physical time of the process of draining of a mass, h; $\mathbf{\Phi}$, vector of the secondary parameters influencing the ground-water level. Subscripts: on, switch on; off, switch off; p, pump; av, average; c, control; f, filtration; 0, initial; d, definite.

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