**Designing a Control System for Underground Water Intakes**

A V Malkov¹, I M Pershin², I S Pomelyayko¹

¹Narzan-hydro resources, Kirov Street 43, Kislovodsk, 357700, Russia
²Chapter Management in technical systems, North-Caucasian Federal University, a branch in Pyatigorsk, 40 years of October Street, Pyatigorsk, 357500, Russia

E-mail: i.pomelyayko@yandex.ru

**Abstract.** The hydrolytosphere as a multicomponent system is very complex in its structure. Management of hydrolysis processes involves consideration of three aspects: improving the methods for determining the parameters of hydraulic communication of aquifers, capacitive and filtration properties; improvement of methods for constructing mathematical models; development and improvement of principles and methods for constructing control systems for hydrolytospheric processes. It is known that mathematical models describing hydrolytospheric processes, as a rule, do not have an analytical solution. To describe the dynamic characteristics of the object under consideration, the structure of a non-standard approximating link is considered. The technique for determining the parameters of the link in question is used to describe the static and dynamic characteristics of the “production well-formation” process. The distributed hydrolytospheric process and the concentrated, scalar effect on this process are considered. The input influence on the control object is the production well output, the output function is the deviation of the level at the well sampling point. The parameters of the approximating link can be calculated either using the results of the experiment at the working well or using the simulation results of the process under consideration.

1. **Introduction**

Within the framework of the system analysis of the ecological condition of the resorts of the Caucasian Mineral Waters (CMW), the state of a number of natural environments, including groundwater, was assessed [1]. Processing of the received information was carried out by means of mathematical modeling. The modeling task was the forecast and dynamics of halos spreading pollutants, confined to areas of increased anthropogenic load. The results indicate strong groundwater in the resort is heavily polluted for both natural and anthropogenic reasons [2].

Practically on the whole territory, in groundwaters there is an element of the second hazard class - barium (1-9 MPC). The second element most common in groundwater is strontium. Its content usually does not exceed (1-6 MPC). A dangerous concentration of heavy metals is contained in groundwater near the landfills of landfills. The main pollutants are titanium, manganese, lead, beryllium, iron, lithium and vanadium. Groundwater in the area of the gas station is characterized by a dangerous and moderately dangerous degree of pollution by oil products (3-12 MPC). Pollution of groundwater with nitrates, nitrites and ammonium salts (2-15 MPC), has anthropogenic character. Stormwater contains sulfates up to 6 MPC, nitrites up to 17 MPC, phosphates up to 7 MPC, petroleum products up to 20 MPC [3].
Information of engineering and geological survey for construction in Kislovodsk for a thirty-year period (93 sites in various districts of the city) was collected and analyzed. The information obtained indicates a flooding of most of them. The chemical composition of groundwater has also undergone significant transformation (an increase in the total mineralization by a factor of 2). The south-western, western and north-western parts of the city refer to technogenically flooded areas with groundwater level (UWW) less than 2 m from the surface of the earth. The thickness of the aeration zone in a number of regions was reduced by a factor of 3. The rise in the level contributed to the salinization of the hypergenesis zone and, as a consequence, to an increase in the mineralization of groundwater. With the regionalization of the territory, the graduation proposed by IK was accepted as a basis. Gavich. In this case, the first zone with a capacity of up to 5 m was divided into 2 zones with 0-3 m of UGW and 3-5 m of UGW. The allocation of such zones facilitates more detailed zoning and assessment of the dynamics of the processes of flooding and salinization of the territory. According to the status of the groundwater table, 4 zones are identified in the city [3]. The performed mathematical modeling of geofiltration and migration of contaminated ground allowed to determine that over the 20-year period the halos of the distribution of pollutants from filling stations and uncalculated areas will increase more than twice [4]. In the southern part of the city, where groundwater is in hydraulic communication with aquifers, bacteriological and chemical contamination of mineral waters can occur [5,6]. To determine the chemical composition of groundwater, samples of water were taken in the recreational and industrial zones of the city of Kislovodsk. The test results indicate increased concentrations in strontium, barium, aluminum, iron, manganese and phosphate groundwater. Groundwater contains such a dangerous superecotoxicant as arsenic (up to 2 MPC). The water pollution index corresponds to dirty and extremely dirty waters - V-VII grade quality. The index of pollution of groundwater collected in the industrial zone is 4 times higher than the value of the water quality of water taken from the park zone. The state of groundwater significantly affects the overall ecological situation of the hypergenesis zone of Kislovodsk. According to the activity of hydrodynamics of levels and concentrations of pollutants, the situation with groundwater in the resort should be regarded as critical [1].

2. Materials and Methods
Description of the object of management. The construction of control systems for the parameters of hydrolytospheric processes is associated with the solution of the following problems: the determination of the dynamic characteristics of the object under consideration; approximation of dynamic characteristics using special models; design of control systems. It is known that the hydrolytospheric processes are described by partial differential equations. Such control objects belong to the distributed class [7-11]. The application of classical approximation methods to the class under consideration leads to significant errors [12-14], making it difficult to solve the synthesis problem. The input impact on the control object is the production well rate. The function of the output is to lower the level in the well location zone. In the literature, the distributed hydrolithospheric process and the distributed one are considered, which is realized by a set of producing wells [12-16]. In this case, the reaction of the system to the selected spatial modes is investigated [12-14,17,18]. Consider the case where there is one producing well (distributed hydrolytosphere process and concentrated control). In this case, there is the possibility of either a physical experiment on a real object, or a numerical experiment using a mathematical model of the object. As an example, consider the Kislovodskoye mineral water deposit. Several enterprises are involved in the extraction of hydromineral raw materials and, as a rule, they have separate wells that are remote from each other. Three types of narzans (Narzan, Dolomite Narzan and Sulphat Narzan) are extracted from the three aquifers. In the article, we shall limit ourselves to the consideration of a single layer, from which the total narzan is extracted. The mathematical model of the object under consideration is given in [12-14].

Groundwater

\[ \eta_1 \frac{\partial h_1(x,y,z,\tau)}{\partial \tau} = k_{1,x} \frac{\partial^2 0.5 \cdot h_1^2(x,y,z,\tau)}{\partial x^2} + k_{1,y} \frac{\partial^2 0.5 \cdot h_1^2(x,y,z,\tau)}{\partial y^2} + k_{1,z} \frac{\partial^2 0.5 \cdot h_1^2(x,y,z,\tau)}{\partial z^2} \]
\[0 < x < L_x; 0 < y < L_y; 0 < z < L_z,\]

Narzan

\[
\frac{\partial H_2(x, y, z, \tau)}{\partial \tau} = \frac{1}{\eta^2} \left( k_{2,x} \frac{\partial^2 H_2(x, y, z, \tau)}{\partial x^2} + k_{2,y} \frac{\partial^2 H_2(x, y, z, \tau)}{\partial y^2} + k_{2,z} \frac{\partial^2 H_2(x, y, z, \tau)}{\partial z^2} \right) - F_{2,x} \frac{\partial H_2(x, y, z, \tau)}{\partial x} + V(\tau) \cdot \delta(x_0, y_0, z_0);\]

\[0 < x < L_x; 0 < y < L_y; 0 < z < L_z,\]

where \(h_1\) - pressure in the groundwater horizon, m; \(H_2\) - pressure in the aquifer under study, m; the filtration coefficients for the corresponding coordinates: \(k_{1,x} = 0.192\) m/day, \(k_{1,y} = 0.192\) m/day, \(k_{1,z} = 0.0195\) m/day, \(k_{2,x} = 0.19\) m/day, \(k_{2,y} = 0.19\) m/day, \(k_{2,z} = 0.019\) m/day; \(\eta = 0.00101\) m. - the elastic capacity of the formation; \(F_{2,x} = 0.01168\) m/d. - flow velocity in the aquifer; \(V(\tau)\) - pressure decrease, caused by the impact of the production well; \(\delta(x_0, y_0, z_0)\) is a function equal to one if \(x = x_0, y = y_0, z = z_0\) and equal to zero in other cases; \(x, y, z\) are the spatial coordinates; \(\tau\) - time.

The boundary conditions (Darcy conditions) between the layers are given in the form:

Groundwater - upper layer:

\[h_1\ x, y, L_{z_1}, \tau = h_1\ x, y, L_{z_1}, \tau + h_1\ x, y, 0, \tau - h_1\ x, y, L_{z_1}, \tau,\]

\[H_2\ x, y, 0, \tau = H_2\ x, y, 0, \tau - b_2\ x, y, 0, \tau - h_1\ x, y, L_{z_1}, \tau,\]

where \(b_2 = 0.00003\) syt.\(^{-1}\) - flow parameter.

Lower boundary of the formation: \(\partial H_2\ x, y, L_{z_2}, \tau \mid \partial z = 0\)

Side faces: \(h_1\ 0, y, z, \tau = h_{1,0}; H_2\ 0, y, z, \tau = H_{2,0},\)

\(\partial h_1\ L_x, y, z, \tau \mid \partial x = 0; \partial H_2\ L_x, y, z, \tau \mid \partial x = 0.\)

When forming the boundary conditions with respect to the \(y\) coordinate, we assume that the thickness of the seams is such that perturbations from the sampling wells do not affect the state of the formation at the boundary points:

\[h_1\ 0, z, \tau = h_{1,0}; H_2\ 0, z, \tau = H_{2,0},\]

where \(h_{1,0} = 0 < z < L_{z_1}\), \(H_{2,0} = 220\) m. - initial states of unperturbed groundwater and reservoir.

Geometric data of the deposit are given in table 1 in Fig.1.

| \(L_x\) | \(L_y\) | \(L_{z_1}\) | \(L_{z_2}\) |
|--------|--------|-----------|-----------|
| 250 m. | 200 m. | 90 m.     | 105 m.    |

3. Results and Discussion

The input effect on the control object is the production well output \(Q(\tau)\), which is related to the function \(V(\tau)\) by the following relation \(V(\tau) = K^*Q(\tau)\). The value of the coefficient \(K\) is chosen as follows: at the well, which produces the hydro-mineral raw material, the production rate was sharply increased by 100 m³/day. The decrease in the level in the steady state, in the area of the location of the sampling device of the well, was 0.51 m. Using the numerical model of the control object, we simulate the hydrologospheric process with the input action \(Q(\tau) = 100\) m³/day. Having chosen the initial value \(K = 0.025\). Correcting the value of \(K\), we achieve a steady-state level drop of 0.51 m, in the region of the location of the sampling device of the well. The target value is \(K = 0.0030748\).
Based on the results of modeling the hydrolytospheric process, the graphs shown in Fig. 2 (input effect $Q(\tau) = 100 \text{ m}^3/\text{day} = 100/(3600*24) = 0.001157 \text{ m}^3/\text{s}$) and in Fig. 3 ($Q(\tau) = 0.001157 \sin (\omega_1 \tau), \omega_1 = 0.00001$).

Figure 1. The scheme of the deposit.

Figure 2. The reaction of the object to the static input effect.

Figure 3. The response of the object to the dynamic input effect.
Using the simulation results, we determine the static transfer factor of the control object $K_1 = \frac{\text{level change in the steady state}}{\text{input effect}}$, $K_1 = 0.4997/0.001157 = 431.8496$.

Using the dynamic characteristics (Fig. 3), we determine the phase shift of the output signal relative to the input signal (the period of the oscillations of the input signal is 174.53 hours.) $\Delta \varphi_1 = -2\pi*22.43/174.53 = -0.80749 \text{ rad}$.

Method for determining the parameters of the approximating link. The studies presented in [19, 20] show that special approximating links can be recommended to describe the dynamic characteristics of the objects under consideration. We will form a similar link for describing the characteristics of the system - the "distributed hydrolytospheric process and the concentrated effect on this process":

$$W_c(s) = \frac{K}{\beta + 1} \cdot \exp(-\beta \cdot \beta) = \left(\frac{s}{a} + G\right)^{\frac{1}{2}},$$ (1)

where $G$ is the parameter taking into account the radius of influence of the well. In the case under consideration, $G = (\pi/200)^2$, $K$ and $a$ are the parameters whose values are determined in accordance with the following procedure:

1. Setting $s = j (\omega = \omega_1)$ in (1), we write the relation for determining the phase of the approximating link:

$$\Delta \varphi_1 = -\text{Im}(\beta_{\omega_1}) - \arctan(\text{Im}(\beta_{\omega_1})/(\text{Re}(\beta_{\omega_1}) + 1)), \beta_{\omega_1} = \left(\frac{j\omega_1}{a} + G\right)^{\frac{1}{2}}$$ (2)

2. Substituting $\omega_1 = 0.00001$, $\Delta \varphi_1 = -1.0548$ into the initial equation (2) and solving numerically, we obtain: $a = 0.00001105$.

3. Setting $\omega = 0$ in (1) and equating the static gain of the approximating link to the value of $K_1$, we obtain:

$$431.8496 = \frac{K}{\beta + 1} \cdot \exp(-\beta \cdot \beta) = (\pi/200)^2$$

Solving equation (3) we obtain $K = 438.68663502$.

The approximating link, for the object considered above, is written in the form

$$W_c(s) = \frac{438.68663502}{\beta + 1} \cdot \exp(-\beta \cdot \beta) = \left(\frac{s}{0.00001105 + (\pi/200)^2}\right)^{\frac{1}{2}}$$ (4)

Design of the control system. In accordance with the method, the parameters of the approximating link of the "production well-reservoir" hydrolytospheric process were determined. The input effect on the process is concentrated. Using (4), a regulator realizing a proportional-integral-differential control law was synthesized. The transfer function of the synthesized controller is written as:

$$R(s) = 0.160732 + 0.000031/s + 323.474897 \cdot s$$

The input effect on the control system was set in the form $H_{2,0} = 0.5$. By supplying the regression function with the disagreement function $\Delta H(s) = (H_{2,0} = 0.5) - H (x_0, y_0, z_0, s)$ and writing the result in space states, we obtain a control algorithm:

$$Q(\tau) = 0.160732 \cdot \Delta H(\tau) + 0.000031 \cdot \int \Delta H(\tau) \cdot d\tau + 323.474897 \cdot d\Delta H(\tau)/d\tau.$$

The structural diagram of the control system is given and the graphs of the transient process, constructed from the results of the simulation of a closed system, are shown in Fig. 4. The results of the simulation show that the regulator controls the hydrolytospheric process quite effectively.
4. Conclusions
1. The article considers a distributed hydrolytospheric process and a concentrated, scalar, impact on it. A technique for determining the parameters of the approximating link is presented, to describe the static and dynamic characteristics of the "production well-formation" process. As an input, the well output is considered. The output function is the deviation of the level at the well site. The parameters of the link can be calculated either using the results of the experiment at the working well, or using the simulation results of the process under consideration.
2. The approximating link under consideration describes the relationship between the production well production rate and the reduction level at the point of abstraction of the hydromineralic raw material. In fact, this link represents a hydraulic model of the process under consideration in the operator form.
3. Since the approximating link under consideration sufficiently fully reflects the characteristics of the object, the design of control systems can be performed by known methods.

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