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CONTROL OVER VOLUME AND QUALITY OF SEWAGE WATER IN THE RIVER WATERWAY

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Abstract – The paper considers the task of control over volume and quality of sewage water in the river, based on data of natural measurement with the application of the dynamic two-dimensional spatial model of river processes. The mathematical algorithm, calculation expressions and an example illustrating practical realization of this algorithm had also been suggested. The suggested algorithm of control is not sensitive to accidental errors, arising while measuring.

Keywords: control, pollution, water.

1. INTRODUCTION

If unpredictable damping of sewage occurred in the river, and the discharge, level of pollution and the place of damping are known exactly, this allows to apply the specific measures as for the source of pollution aimed at avoidance of such damping in the future. But the situation is quite different if the place of damping is the only thing known, that is, when, for instance, such kind of a pollution is peculiar only to sewage from a certain enterprise, or the direct measurements in waterway showed the presence of stick-slip deterioration of river water at a certain reach. Than there is the task of control of fouling value caused by sewage discharged into the river. Fouling value here and further in the text shall mean the product of the concentration value of the certain contaminant in the water into the value of the discharge of this water.

Solution of the task of fouling value control of river water pollution should be preceded by the following:

- model identification of self-purification and pollution processes of the river water;
- development of the control algorithms on the basis of the suggested model;
- natural measuring of the river water pollution in the numbers of reaches.

Measuring is to be conducted with the consideration of the scheme of fitting of the elementary reaches (ER) of the river given in work [1]:

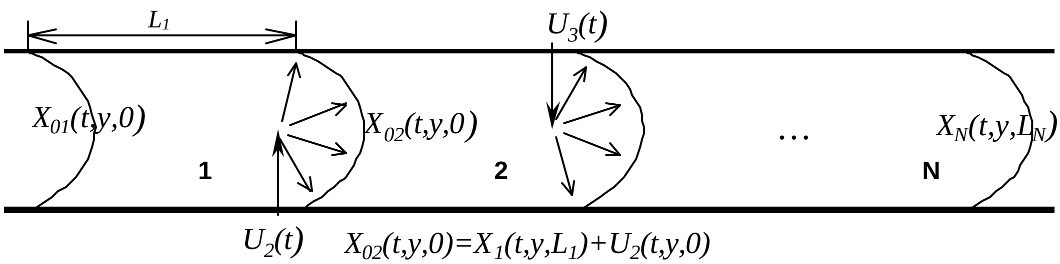

Fig. 1. Scheme of fitting of elementary river reaches

Fig. 1 shows that on each the i^{th} elementary reach (i = 1, 2, ..., N) with the length L_i damping of sewage with pollution U_i , considered within the boundary conditions X_{0i}, causes the pollution X_i in river water. Axis z runs along the averaged width and depth of the river flow streamwise. Axis y is directed perpendicularly to axis z from the coordinate center to the right bank of river; t – time.

The first version of solving of this task was suggested by the authors in work [2]. The application of this version of solution has several limitations. First, the suggested algorithm is too sensitive to measuring errors. Second, the change of water pollution in the river was analyzed only with the one-dimensional spatial model.

To eliminate the above shortcoming, the given work suggests, first of all, to apply the least-squares method to determine the averaged values on the set of data and, second of all, to use the developed in paper [3] the dynamic two-dimensional spatial mathematical model of the river self-purification processes to describe the response to sewage disposal. This model takes into account different nature of dilution processes on the width of flow – in turbulent streaming and laminar littoral zones.

The turbulent zone in which dominate the processes of intermingling and turbulent diffusion is located in the middle of the flow, whereas the boundary laminar zone in which the water flows in separate elementary streams which are not mixed up with each other, is located closer to the bank (fig. 2). The right laminar zone is located near the right bank and the left laminar zone is located near the left bank of the river correspondingly [3].

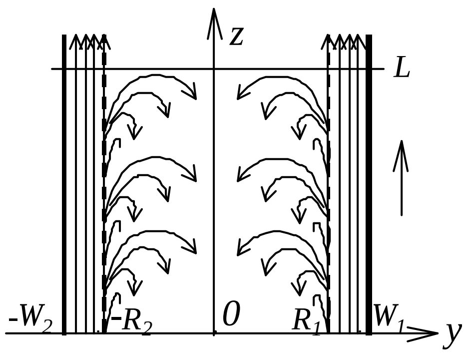

Fig. 2. Scheme of the direction of the separate streams in the river flow

Fig. 2 shows the dependent on the river flow the Cartesian display, centre of which is at the beginning of the river reach with the length *L*, in the middle of the averaged as for the width and depth river flow. The axis *z* passes lengthwise the middle of the averaged as for the width and depth river flow streamwise; the axis *y* is directed perpendicularly to the axis *z* from the coordinate center to the right bank of the river; W_1, W_2 — distances from the coordinate center to the right and to the left banks of the river correspondingly, R_1, R_2 — distances from the coordinate center to the bounds between the turbulent zone and the right and the left laminar zones of the river correspondingly (see fig. 2).

The work [3] presents the built separate models for the dynamic of the processes in all the three zones of the river flow and also shows how to combine them and to assume their solutions. The main advantage of this model is that the equations have analytic solution [3]. Let's give an example of it for the simplified case, that is when the scheme of the river flow direction and its parameters according to fig. 2 are absolutely symmetrical to the fairway, sewage discharges in the waterway of the river and sewage gets mix up on the width with the river water.

2. MATHEMATICAL MODEL

In case if river waterflow is on the same distance *O* from the right and the left banks, distance *R* from it to boundary of turbulent and laminar zones is equal (see Fig. 2), and processes of self-purification in both two laminar zones have the same character, model may be simplified to the expression (for i^{th} ER):

- for littoral laminar zones:

$$X_i(t,y,z) = X_{0i}(t,y,0)\cdot e^{-K_i^*(y)z}, \quad t\in[0,T],\ y\in[R,W],\ z\in[0,L_i], \tag{1}$$

- for streaming turbulent zone:

$$X_i(t,y,z) = X_{0i}(t,0,0)\sec \beta R\, e^{-K_i^*(R)z}\cos \beta y, \quad t\in[0,T],\ y\in[-R,R],\ z\in[0,L_i], \tag{2}$$

$$b=\sqrt{\frac{l}{d_i}}, \qquad l = \begin{vmatrix} v_iK_i^*(R)-g_i,\ y\in[0,R], \\ v_iK_i^*(-R)-g_i,\ y\in[-R,0], \end{vmatrix} \tag{3}$$

where $K_i^*(y)$ – factors of intensities of biochemical processes of water self-purification that characterize the action of processes along axes *z* and *y* in laminar zones of i^{th} ER; d_i – factor of turbulent diffusion; v_i – river flow velocity along axis *z*, γ_i – factor of biochemical self-purification in turbulent zone in direction of axis *z* of the river.

The model in the kind of equations (1)–(3) can be generalized as follows:

$$X_i(t,y,z) = X_{0i}(t,y,0)\cdot M_i(t,y,z), \quad t\in[0,T],\ z\in[0,L_i],\ y\in[-W,W],\ i=\overline{1,N}, \tag{4}$$

where $M_i(t, y, z)$ – factor that takes into account the reduction of the initial pollution that had spread on the whole width of the i^{th} ER of the river, along the axes *y* and *z* with the time *t* as the result of the river self-purification processes.

3. CONTROL OVER CHANGER OF THE FOULING VALUE OF WATER

Model (4) makes it possible to solve the inverse problem when the measured values of water pollution in the river $\tilde{X}_{i-1}(t, y, L_i)$ and $\tilde{X}_i(t, y, z)$ are known, and it is necessary to find the fouling value $U_i(t, y, 0)$ that came from sewage. If measuring is thoroughly conducted, we would obtain the following:

$$U_i(t,y,0) = \tilde{X}_i(t,y,z)/M_i(t,y,z) - X_{i-1}(t,y,L_{i-1}), \quad t\in[0,T],\ y\in[-W,W]. \tag{5}$$

However, in practice measuring always has its error (while water sample splitting, analyzing the water pollution, etc.). That's why the solution of the task should be held on the basis of series with P_i metering $\tilde{X}_{ij}(t_{ij}, y_{ij}, z_{ij})$ on each the i^{th} ER with the application of the least-squares method. Inasmuch as

$$U_i(t, y, 0) = \tilde{X}_{0i}(t, y, 0) - \tilde{X}_{i-1}(t, y, L_{i-1}), \tag{6}$$

then to determine the value $U_i(t, y, 0)$ it is necessary to find the components of the expression (6) (see fig. 1): $\tilde{X}_{i-1}(t, y, L_{i-1})$ – as for measuring on $(i-1)^{th}$ ER and $\tilde{X}_{0i}(t, y, 0)$ – as for measuring on the i^{th} ER.

$$X_{0,i-1}(t,y,0) = \frac{1}{P_{i-1}}\sum_{j=1}^{P_{i-1}}\frac{\tilde{X}_{i-1,j}(t_{i-1,j},y_{i-1,j},z_{i-1,j})}{M_{i-1,j}(t_{i-1,j},y_{i-1,j},z_{i-1,j})},\ z\in[0,L_{i-1}], \tag{7}$$

$$X_{0,i}(t,y,0) = \frac{1}{P_i}\sum_{j=1}^{P_i}\frac{\tilde{X}_{i,j}(t_{i,j},y_{i,j},z_{i,j})}{M_{i,j}(t_{ij},y_{ij},z_{ij})},\ z\in[0,L_i]\ . \tag{8}$$

From (7) we find $X_{i-1}(t,y,L_{i-1}) = X_{i-1,0}(t,y,0)\cdot M_{i-1}(t,y,z)$ and from (6) and (8) we calculate $U_i(t, y, 0)$. The task on the fouling value is solved.

4. CONTROL OVER CHANGER OF THE WATER DISCHARGE

The suggested algorithms and controlling models allow to research and to find the fouling value of water in general.

As it was mentioned above, the fouling value in this paper means the product of concentration of the certain contaminant in water on value of this water discharge. But the practice makes it interesting to identify not the changes of the fouling value in general, but the changes of the sewage water discharge which brings the contaminant to the river and the quality of this water, that is the concentration of the contaminant in it.

Let's introduce the indications (fig. 3, 4):

$$U_i(t, y, z) = q_i \cdot u_i(t, y, z),$$
$$X_i(t, y, z) = Q_i \cdot x_i(t, y, z),\ X_{0i}(t, y, z) = Q_i \cdot x_{0i}(t, y, z), \quad (9)$$
$$\tilde{X}_{ij}(t_{ij}, y_{ij}, z_{ij}) = Q_i\, \tilde{x}_{ij}(t_{ij}, y_{ij}, z_{ij}),$$

where q_i — the discharge of the sewage water that come into the river at the beginning of i^{th} ER; $u_i(t,y,z)$ — concentration of some contaminant in the sewage water on the beginning of i^{th} ER; Q_i — discharge of the river water on the i^{th} ER; $x_{0i}(t, y, z)$ — concentration of contaminant in the river in the

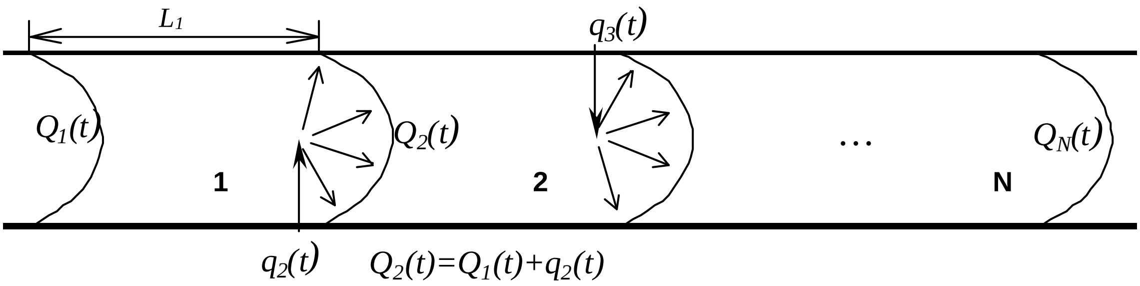

Fig. 3. Discharge water balance on the fitted elementary reaches of the river

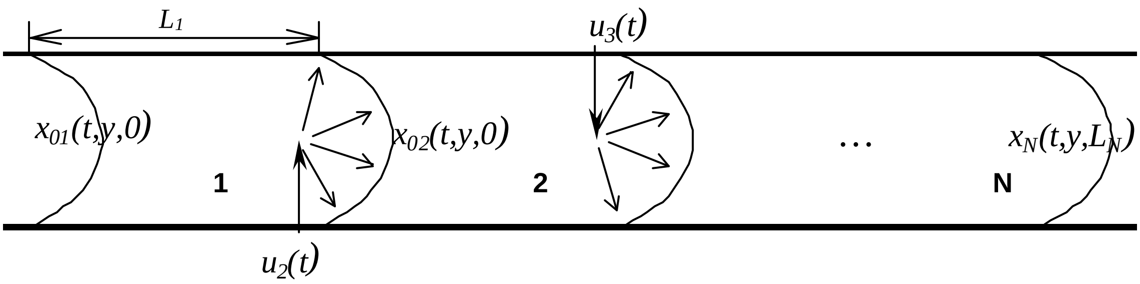

Fig. 4. Symbols of the quality factors of the river water and sewage

beginning of the i^{th} ER; $x_i(t,y,z)$ — concentration of the contaminant in the river in any point of the i^{th} ER; $\tilde{x}_{ij}(t_{ij}, y_{ij}, z_{ij})$ $(j = i,\ldots, P_i)$ — j^{th} concentration measuring of the contaminant in the river in any point of the i^{th} ER.

The symbols in the expressions (9) and on fig. 3, 4 consider the following assumptions and relations:

1. Q_i are considered constant within one reach of the river, which has no natural or anthropogenic in- or outflows. This, of course, causes definite error, conditioned by neglecting the processes of water evaporation from the river surface, replenishment with subterranean waters and water infiltration into the soil. But this error can be eliminated if at the beginning of each elementary reach there will be the correction ΔQ_i to the value $X_{0i}(t, y, z)$.

2. Constant discharges of the river flow-off Q_i in any point of the river and constant within the river cross-section in the place of effluent disposal the discharges of this water q_i may be changed in time t.

3. The connection between the discharges and the values of the concentration of the certain factor of the river water quality and the quality of the sewage before and after the water discharge is described in our symbols by the known relations:

$$(Q_i(t) + q_i(t)) \cdot x_{0i}(t,y,0) =$$
$$= Q_i(t) \cdot x_{i-1}(t,y,L_{i-1}) + q_i(t) \cdot u_i(t,y,0). \quad (10)$$

If the product of two values is known, so to determine all its factors, we have to find at least one of them. The other is easy to determine then. So let's determine the values of the discharge of the sewage, which comes into the river. It's clear that this task should also be solved by mathematical method, as the water cannot be measured by the direct measurement.

We suggest the following algorithm to determine the unknown sewage discharge $q_i(t)$ on the i^{th} elementary reach of the river:

1) to determine the river hydrological regime on this elementary reach of the river, determine the meteorological conditions changes within the time of research; the obtained data allow to determine how the evaporation processes from the river surface, supply with the subterranean waters and water infiltration into the soil influence the general balance of the water of the i^{th} elementary reach of the river; the correction factor $\Delta Q_i(t)$ is determined correspondingly;

2) to compare the measured discharge of the river water at the beginning of this $\tilde{Q}_i(t)$ and the following $\tilde{Q}_{i+1}(t)$ elementary reaches: the deviation between them, which is bigger then the correction $\Delta Q_i(t)$, allows to assert that there is additional unprognosticated sewage water disposal;

3) to determine the value of the discharge of the discovered sewage disposal according to the formula (see fig. 3):

$$q_i(t) = \tilde{Q}_i(t) - \Delta Q_{i-1}(t) - \tilde{Q}_{i-1}(t). \quad (11)$$

The higher accuracy of this algorithm can be obtained if the calculations according to the formula (11) will be done during the definite period of time, based on the series with P_i metering of the discharge $\tilde{Q}_{ij}(t)$ and values $\Delta\tilde{Q}_{ij}(t)$ with the following averaging according to the least-squares method like in the expressions (7), (8).

5. CONTROL OVER CHANGES OF THE WATER QUALITY

Having determined according to the relationship (6)–(8) the fouling values $U_i(t, y, 0)$ ($i = 1, \ldots, N$), which came together with the sewage waters to all the elementary reaches of the river, we may now work out in details this result (of course, only when $U_i(t, y, 0) \neq 0$).

Following the suggested in the previous chapter algorithm, we build the balances of the water discharges on the elementary reaches of the river under research, and determine corresponding discharges $q_i(t)$ of the discovered sewage sources.

Then we easily determine the last unknown factor (9) — the value of the quality factor of the sewage water $u_i(t, y, 0)$, for example, the concentration of the nitrates in the water, — according to the formula:

$$u_i(t, y, 0) = U_i(t, y, 0)/q_i(t),\ i = 1,\ldots, N. \quad (12)$$

The task is solved.

Turning back to the assumptions as for the symmetry of the scheme of the directions of the river flow and other simplifications of the model, made at the beginning of the second chapter we can assume that the suggested technology to control the value and the quality of the nonofficial dumping of sewage water into the river will come true for the general model of the dynamic two-dimensional spatial model of the river processes, developed in the work [3], but all the expressions shall essentially complicate, as all the calculations have to be made separately for the right and the left part of the river on each side of the fairway line.

6. AN EXAMPLE OF SOLVING THE TASK OF CONTROL

Let's consider an example. Let's assume, that the following pollution takes place:

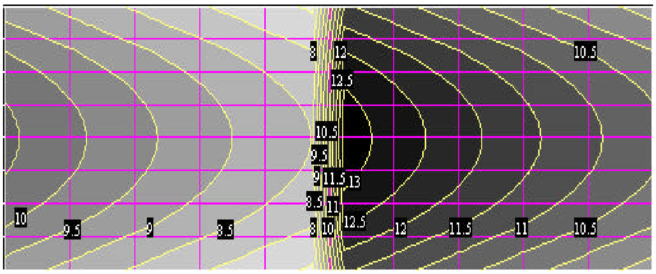

Fig. 5. The picture of river pollution on two elementary reaches

For the specified time $t = t_f$, within which the experiment was conducted, the calculations according to the correlations (6)–(8) resulted $U_2(t_f,y,0) = 2{,}652$ (thousand $m^3 \cdot$mg)/(s·*l*). While, in fact, this value was 2,684 (thousand $m^3 \cdot$mg)/(s·*l*). It means that an error of 1,2% is acceptable.

Measuring the discharges at the beginning of the 1st and the 2nd elementary reaches of the river resulted accordingly: $\tilde{Q}_1(t_f) = 0{,}10$ (thousand m^3)/s and $\tilde{Q}_2(t_f) = 0{,}14$ (thousand m^3)/s. Special research of the period of changes of the water discharge allowed to estimate that the value of the correction is to be determined at the rate of $\Delta Q_2(t_f) = 0{,}015$ (thousand m^3)/s. So, according to the formula (11) we determine

$$q_2(t_f) = \tilde{Q}_2(t_f) - \Delta Q_1(t_f) - \tilde{Q}_1(t_f) = 0{,}140 - 0{,}015 - 0{,}100 = 0{,}025 \text{ (thousand } m^3\text{)/s} = 25\ (m^3/s).$$

Using the formula (12) we determine

$$u_2(t_f, y, 0) = U_2(t_f, y, 0)/q_2(t_f) = 2{,}652/0{,}025 = 106{,}08\ (\text{mg}/l).$$

In actual fact the value was $u_2(t_f) = 103$ mg/*l*. So the error equals approximately 3% is accepted.

7. CONCLUSION

There had been developed an algorithm of control over the pollution of river water, caused by sewage waters, thrown out into the river, using the dynamic two-dimensional spatial model of river processes. There is also the example of the algorithm application. The suggested algorithm is not sensitive to random errors, which occur when conducting measurements, due to averaging on the set of number of measurements using the least-squares method. The limits as for the application of the model are the same as for the model (1)-(3): a river with the bed similar to the rectilinear, the fairway of which is situated in the middle of the stream; sewage takes place straight into the fairway with the use of the dispersive discharge which provides for the fast mix of the sewage waters with the river waters.

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