Identification of the model of pollutants distribution in the surface waters based on field studies

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Introduction

Identification of the mathematical model of pollutants distribution in rivers and reservoirs is necessary for forecasting the impact of environmentally hazardous facilities on surface water [Kovalchuk P.I.]. Use of these models in the decision support systems when calculating of pollutants transport in the surface waters [Yevdin E.O.] is associated with the determination of hydrological model parameters (flow rate, diffusion coefficients, self-cleaning and so on. [Velner H.A.]). Identification of a pollution source function, which makes boundary conditions of a current task, is particularly topical. There are point and diffuse pollution sources. The main point sources of anthropogenic load on surface water bodies are industrial enterprises discharges. The diffuse pollution sources are tailing dumps and accumulating reservoirs for waste and discharge mine waters, which cause the pollution of adjoining water bodies through their infiltration into ground water and surface wash-off. The task is to determine a filtration rate of pollutants from groundwater according to field observations.

Aim

Identification of a pollutants distribution model based on the field observations for modeling and forecasting emergency situations. Testing and implementing the model at the pilot facility to determine the effect of Dombrovsky open pit as a diffuse source of saline solutions filtration and surface wash-off on the water quality in the Sivka River.

Method

Modeling of pollutants distribution is based on mixing and transferring solutions filtered through groundwater. The model takes into account the interaction of pollutants with suspended particles in the watercourse (sorption and desorption processes) and their settling down to the bottom as sludge deposits. The model is represented as a system of differential equations:

$$\begin{cases} \dfrac{\partial U}{\partial t} = \dfrac{\partial}{\partial x} a(x) \dfrac{\partial U}{\partial x} - V_1(x) \dfrac{\partial U}{\partial x} - \lambda(x, V_1)U + \mu_2(x, V_1)S + f(x,t); \\ \dfrac{\partial S}{\partial t} = \lambda(x, V_1)U - \dfrac{V_2(x)\partial S}{\partial x} - (\mu_1(x, V_2) + \mu_2(x, V_1))S; \\ \dfrac{\partial R}{\partial t} = \mu_1(x, V_2)S. \end{cases}$$

where U (x, t) - concentration of pollutants in the watercourse; S (x, t) - concentration of pollutants in the suspended sediments; V (x) – flow rate; a (x) - coefficient of molecular or turbulent diffusion; f (x, t) - function of the source of pollution into the water flow; R (x) - function of accumulating pollutants in the sediments; λ (x) – sorption coefficient of pollutants at their transferring from the flow into the suspended sediments; μ1 (x) – sedimentation coefficient of pollutants at their transferring from the flow into the bottom sediments; μ2 (x) - coefficient of sorption-desorption in "water-suspended sediments" system; t - time; x - coordinate in the direction of pollutants moving in the watercourse.
The system of equations is solved using the method of finite-difference approximation at choosing appropriate boundary conditions. Hydrological parameters of the model are determined by measurements. The identification of a pollution source function is carried out on the base of water sampling for hydrochemical parameters.
The calculation of mixing contaminated groundwater with river water for each elementary cell is made using the formula:

$$U_i^{n+1} = \frac{U_{\mathrm{p}_i}^n Q_{\mathrm{p}_i} \tau + U_{\mathrm{rp}_i}^n Q_{\mathrm{rp}_i} \tau + (W - Q_{\mathrm{p}_i}\tau - Q_{\mathrm{rp}_i}\tau) U_{\mathrm{rp}_i}^n}{W}$$

where: W - water volume in the elementary cell; $U_{\mathrm{p}_i}^n$ – pollutants concentration in the river flow; Q_{p_i} – river discharge; $U_{\mathrm{rp}_i}^n$ - pollutants concentration in the water filtered from the soil; Q_{rp_i} - water discharge from the soil; τ - time step.

Results

Implementation on the pilot facility. The highly mineralized water is accumulated in Dombrovsky open pit (Kalush town, Ivano-Frankivsk region, Ukraine). The pit acts as a diffuse source and affects water quality in the Sivka River as a result of filtering saline solutions and surface wash-off (Fig. 1).

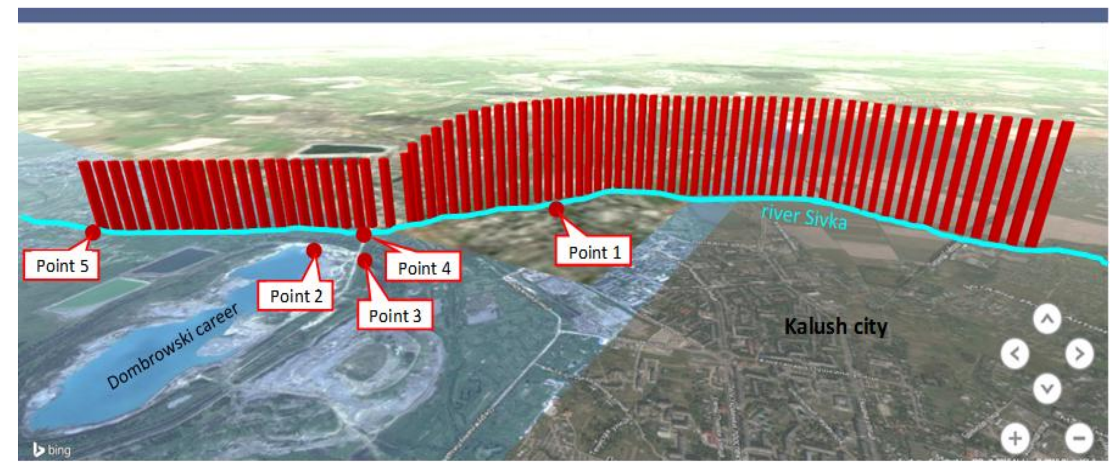

Fig.1. Pilot facility layout.

Legend: Point 1 - measuring point; - calculated pollutants concentration.

Considering the fact that bottom sediments in the Sivka River are large gravel-pebble formations where sorption processes are not intensive ($\lambda \to 0$ and $\mu \to 0$), they can be ignored when building the model. Then for given conditions a difference model will be the following:

$$U_i^{n+1} = U_i^n + \frac{\tau}{\Delta x}\left[\left(a^2(x)\frac{U_{i+1}^n - U_i^n}{\Delta x} - V_1 U_i^n\right) - \left(a^2(x)\frac{U_i^n - U_{i-1}^n}{\Delta x} - V_1 U_{i-1}^n\right)\right] - \tau\lambda U_i^n + \tau\left(U_i^n + \frac{(U_{\mathrm{rp}i} - U_i^n)\tau Q_{\mathrm{rp}i}}{W}\right), i = 1, \dots, m.$$

The identification of pollutants distribution model was made on the base of field observations. In the affected area the flow rate ranges 0.1-0.3 m/s and flow discharge is 0.2-0.4 m3/s. For the modeling the values were taken as following: V (x) = 0,2 m/s, Q (x) = 0,3 m3 /s, elementary cell Δx = 100 m, filtration area – 1000 m.

Boundary condition is left $U_i^0 = U_\Phi$ - background, that is the background concentration is maintained; at the right border (modeling section is 5km) the concentration is equal to the previously calculated one. To calculate a polluted groundwater discharge (Qhri) using the error method it is set some initial value Q_i^0 of a saline solution concentration by chlorides, sulfates and dry residue in the upper part of Dombrovsky open pit.

Hydrochemical parameters in point (date 28.08.2014)

Point	Dry residue, mg/l	Chlorides, mg/l	Sulfates, mg/l	Longitude	Latitude
1	1104	408	116	24°19'49.93"B	49° 2'52.55"C
2	55100	26588	5810	24°19'20.18"B	49° 1'58.25"C
3	2960	922	409	24°19'32.98"B	49° 2'2.36"C
4	607	163	38	24°19'13.40"B	49° 2'16.16"C
5	535	142	40	24°17'44.14"B	49° 1'37.84"C

The calculations revealed that the volume of polluted water which fell into the Sivka River within the section of 1000m is 0.0004 l/s (34560 l/day).

Conclusion

The developed mathematical model of pollutants distribution and their interaction with the suspended and bottom sediments in rivers allows simulating different scenarios of accidental releases of pollutants into rivers and reservoirs to take preventive actions.

The proposed method allows identifying the function of point and diffusing sources in the model of pollutants distribution in streams and reservoirs.

The carried out research at the pilot facility on the Sivka River proves the effectiveness of model parameters identification based on the field observations. The model allows considering different emergency scenarios for Dombrovsky open pit.

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