Numerical analysis of migration and accumulation of pollutants near to bottom of water bodies

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ABSTRACT
Scientific and methodological problems are examined of the pollutant dispersion within inland water bodies and water courses by interaction between the fluxes at the divides of water, atmosphere and near-to-bottom areas (Putyrsky, 1993). With the use of a semi-empirical turbulent diffusion equation, regularities in the pollutant area from technogenic sources were investigated with taken into account the sedimentation processes. Mathematical models have been developed for modeling the processes of accumulation of pollutants in the bottom sediments off-shore and water systems in river valleys. Analyzed were also the data on migration of the carcinogenic components within Lake Valday (North-western Russia). A method has been proposed for the quantitative estimation of a number of hydro-physical factors through an approximation of experimental data by any equations theoretically proved as well as mathematical solutions of the inverse problems.

KEYWORDS
Pollutant dispersion; numerical analysis; water bodies; near-to-bottom areas.

1. INTRODUCTION

Divides of water bodies, particularly the bottom, are reformers, accumulators and sources of substances and energy. In relation to the consequences of technogeneous impact on water bodies, there often appear the cases when the bottom sediments become a dominant factor of pollution, which affect the phone concentration of pollutants. Until the time, a non-significant attention was paid to the studies of the flux properties on the borders with diverse hydro-physical conditions. It is true about the processes at the "water – bottom" divide. However, investigations in the area are greatly upraised at this time, that is caused with certain achievements of modern science, and is related to a need of solving the problem of secondary pollution. The problems of this type appear by accumulation of technogeneous pollutants within bottom sediments.

2. METHODS

Investigations are based on a theoretical description of the space-and-time inhomogeneities in migration and accumulation of suspended particles. Main stages of the work are:

1) analysis of the nature data available,
2) development of a hydrodynamic model for interaction between fluxes within the near-to-bottom zone,
3) realization of the model based on numerical algorithms.

Besides, the methodological problems are discussed of the pollutant dispersion, with an accent on the bottom sediment pollution areas as well as their accumulation within silt. Evaluations were done of advection and diffusion of technogeneous pollutants.

Macro-scale hydro-physical dispersion of pollutants was studied with the use of the following differential equation:

$$\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}+(w-w_{\Pi})\frac{\partial c}{\partial z}=\frac{\partial}{\partial x}(K_x\frac{\partial c}{\partial x})+\frac{\partial}{\partial y}(K_y\frac{\partial c}{\partial y})+\frac{\partial}{\partial z}(K_z\frac{\partial c}{\partial z})-\frac{c}{\tau}+ \tag{1}$$

$$+Q(t)\ \delta(x-a)\delta(y-b)\delta(z-d),$$

Where c is concentration of the pollutant; w_n its gravitation velocity; τ is the constant of biochemical destruction; δ is the "delta"-function; t is the time elapsed; x, y, z are the co-ordinates with basis at the water surface; u, v, w are the components of the flow velocity by the relative co-ordinate axis; K_x , K_y , K_z are the turbulent diffusion coefficients for longitudinal, transversal and vertical directions; $Q(t)$ is the power of the pollutant source at the point $A\ (a, b, d)$.

In the most of cases, which arise by pollution of shallow water and off-shores, we neglect the vertical transport of pollutant. Used widely is a consideration about the so-called "solid lid" for the cases when the surface water deformations are small in comparison with deep. Considering also are the deep average changes of the hydrodynamic and hydro-chemical parameters without attention to the "buoyancy", i.e. the averaging procedure is simply:

$$\bar{c}(x,e,t)=\frac{1}{H}\int_0^H c(x,y,z,t)dz \tag{2}$$

where H is the deep of the shallow water body.

The vertical transfer in such "bulk" models is described through the boundary conditions on free water surface and bottom. Turbulent fluxes of the pollution particles are as follows:

$$q_x=-\rho\overline{u'c'},\quad q_y=-\rho\overline{v'c'}, \tag{3}$$

where u′, v′, c′ - the turbulent fluctuations of the liquid velocity and the concentrations of the pollutant across their average values u, v, c; the hyphen above signifies averaging over the ensemble.

Transfer of pollutants across the boundary "water-air" through the molecular film is described by the following equation:

$$q_A=\frac{M_{1d}\beta}{\delta_A}(\kappa_r c_A-c),\ z=0, \tag{4}$$

where q_A is the mass transfer through the film; β is the factor rendering chemical reaction; δ_A the film deep; K_r the pollutant solubility; M_{1d} is the molecular diffusion coefficient within the surface layer above the water. Investigations of the factors are critically important and will be a focus of the future efforts.

The pollution transport to the bottom for the time T is as follows:

$$Q = q_B T,\ \ T = n\,\Delta t \tag{5}$$

And the averaged concentration within the bottom silt is

$$\bar{c}_* = Q/h_*, \tag{6}$$

where h_* is the silt deep.

The pollutant flux within silt is described by the following equation: $q_{B*}=M_{2d}\frac{\partial c_*}{\partial z},\ \ H<z<H+h_*$ (7)

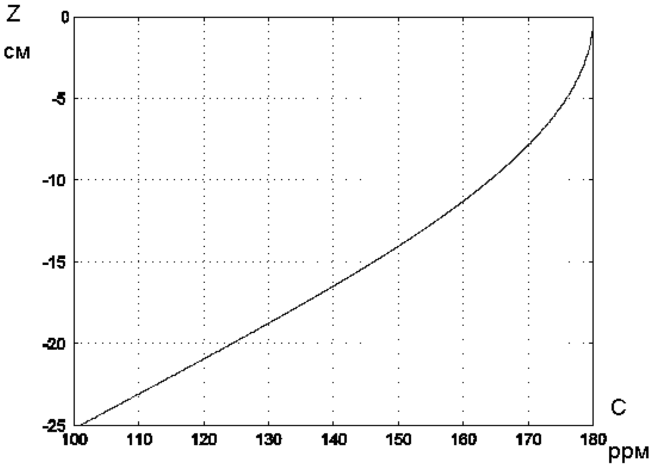
where M_{2d} is the coefficient of molecular diffusion. And by integration, we have

$$c_* = A\ +\ z\ q_*\ /\ M_{2d}\ . \tag{8}$$

3. STUDY RESULTS

Investigating the large-scale hydro-physical dispersion of suspended particles, we have solved the problem of modeling the advection from a source situated in the Vistula lagoon (Putyrsky, Frolov, 2004). Degree of pollution of the shallow lagoon, which is peculiar collector for waste water, is the utmost for the Baltic region. Character of the water exchange between the lagoon and the Baltic See is mainly affected by river runoff, that has been proved by absence of vertical stratification of salinity.

Granulometrical composition of the suspended particles is mainly *alevrolythres*. Particles of the sizes are able to be suspended during a long time and moved within the lagoon water over significant distances. All the above mentioned allows to consider the Vistula lagoon as a quasi-stationary source for pollution of adjacent areas.



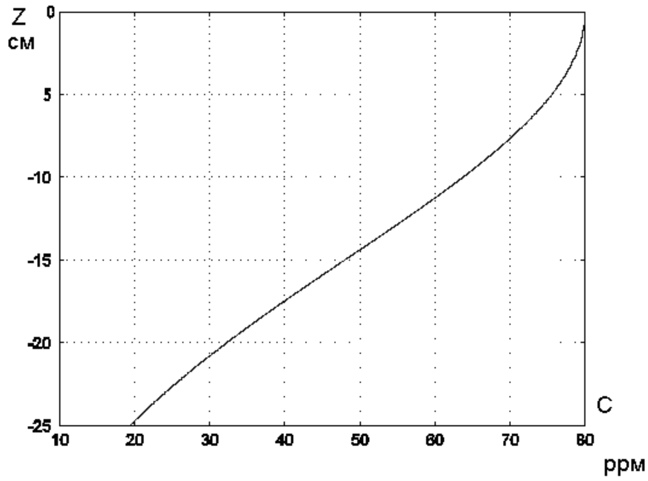


Figure 1. Calculated distribution of concentration (ppm) within the sea bottom Sediments formed by diffusion for different deeps (Z, cm): left – for lead, right – for zinc.

The results obtained have led to a conclusion about a significant influence of the waste water from the Vistula lagoon on the quality of off-shore water of Kaliningrad Region of Russia. Important values of the pollutant fluxes to the bottom are observed over the aquatic area between Baltiysk (Russia) and Liepaya (Latvia). Areas of the bottom technogeneous pollution are formed even by only short-time period which is the synoptic period. The results are given and labeled on the Figure 1.

The best fit for zinc and lead of experimental and computed data has been achieved by the following parameters of the diffusion equation:

$tM_{2d} = 270$ cm^2 for zinc and $tM_{2d} = 110$ cm^2 for lead

where tM_{2d} is diffusion coefficient and t is time.

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