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Three-dimensional Modeling of Large Water Bodies with Complex Geometry and Essential Density Inhomogeneity in Depth

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Résumé

L'étude est consacrée au développement d'un modèle hydrodynamique du plus grand bassin de rétention de la Région de Perm, situé à la confluence de deux rivières dont les régimes hydrochimiques sont substantiellement différents. La simulation de la propagation du mélange dans un écoulement turbulent tri-dimensionnel est réalisée en utilisant un modèle $k-\varepsilon$. Les résultats numériques sont utilisés pour l'optimisation des caractéristiques techniques et des modes opératoires du bassin de rétention de façon à améliorer la qualité de l'eau.

Abstract :

The study is devoted to the development of hydrodynamic model of the largest water intake of Perm Region, located in the zone of confluence of two rivers with significantly different hydrochemical regimes. The simulation of the admixture propagation in three-dimensional turbulent flow is conducted using $k-\varepsilon$ model. Numerical results will be applied for the optimization of technical characteristics and modes of operation of water intake in order to improve the quality of water.

1 Introduction

At present the simulation of hydrodynamic regimes of large water objects is conducted, as a rule, within the framework of two-dimensional approach, using the shallow water equations. Large number of software products is developed implementing the system of St. Venant equations in the two-dimensional approach. There exists large enough number of publications devoted to the simulation of the selective water intake from large water reservoirs.

For Chusovaya water intake the problem of the selective water intake was studied in [1] within the framework of Belolipetskiy model based on the analytical solution of the equations of hydrodynamics of ideal liquid in two-dimensional approach (in vertical section).

Specific feature of a water object under consideration is its very complex hydrological regime caused by the confluence of two rivers (Chusovaya and Sylva) and by the effect of Kama Hydropower Station. In this case the density stratification is not due to the temperature inhomogeneities but due to significant difference in the chemical composition of water of two rivers.

2 Presentation of the problem

For the description of complex hydrological regime of water object we consider the domain of Sylva and Chusovaya rivers from the place of their confluence to the end of Chusovaya water intake (Fig.1).

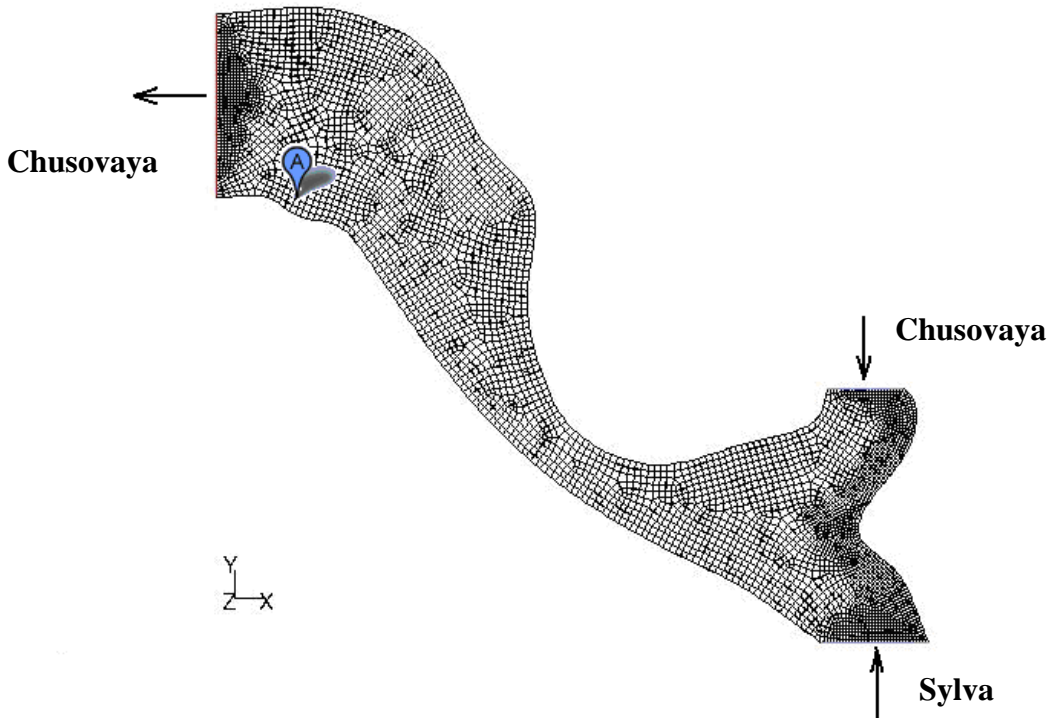


FIG.1. Scheme of the region (top view and example of computational mesh. The pointer shows the location of water intake

Some linear dimensions of the region

Width of Sylva river at the entrance of computational domain	≈ 1700 m
Width of Chusovaya river at the entrance of computational domain	≈ 1200 m
Width of Chusovaya river in the region of water intake	≈ 3100 m
The depth of the region	10 m

TABLE 1. Some hydrological parameters of Sylva and Chusovaya rivers

	Velocity of flow in the river at the entrance of computational domain, m/s	Background concentration of admixture, g/l
Sylva river	0.04	0.8
Chusovaya river	0.05	0.2

For the problem under consideration, the simulation within the framework of two-dimensional approach with averaging over the depth is incorrect because of the large density stratification.

In the present work the propagation of admixture in turbulent flow is examined within the framework three-dimensional approach, using $k-\varepsilon$ model. The density is assumed to be depending on concentration according to the linear law $\rho = \rho_0 + 0.702 s$ where $\rho_0 = 1000.196 \text{ g/m}^3$ is environment density and s is the promille concentration of admixture. Numerical modeling was conducted with the help of commercial software package Fluent 6.3.26. The calculation domain and mesh were built in Gambit 2.3.16 software. The modeling was carried out in the frame of stationary approach, using the following models of Fluent package: k-epsilon model for turbulent flows, species transport model for admixture distribution. The non-slip conditions were applied for the velocity at the bottom and banks and the absence of tangential stress was imposed on the free river surface. The absence of mass flux was set for the concentration on rigid and free boundaries. Inlet velocities and initial concentrations of admixture were constant and different for two rivers.

3 Numerical results

Numerical results on the velocity and concentration fields in different cross-sections of calculation domain are obtained. Fig. 2 illustrates the distribution of concentration in a horizontal cross-section at height 10 meter from the bottom, which corresponds to the free surface.

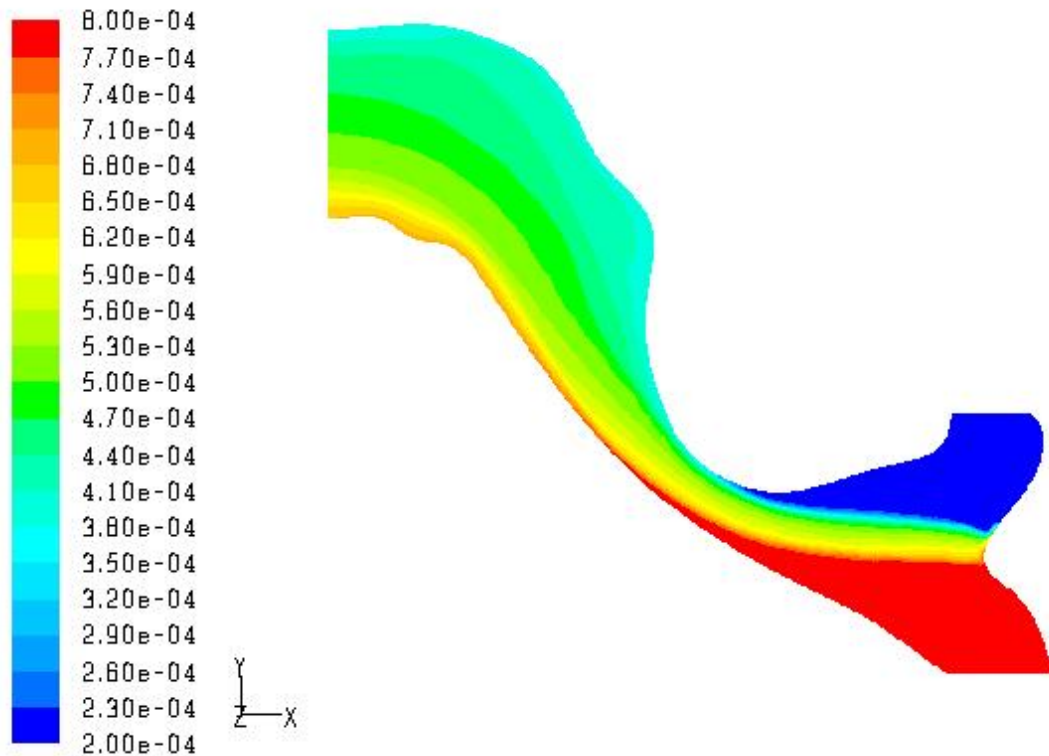


FIG.2. Distribution of concentration in the horizontal section at the height of 10 meters from the bottom

Conclusions

The difference in chemical composition of water in Sylva and Chusovaya rivers leads to the density stratification of water in Chusovaya river after the confluence of the two rivers. As a result, the quality of water coming into the region of water intake might be low. Numerical results will be applied for the optimization of technical characteristics and modes of operation of water intake in order to improve the quality of water.

References

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