The Spatial - temporal Evolution of Iron Dispersion in "River-type" Systems

GALINA MARUSIC[1], CONSTANTIN FILOTE[2], CALIN CIUFUDEAN[2]
[1] Applied Informatics Department, Technical University of Moldova, Blvd. Stefan cel Mare şi Sfant, nr.168, MD-2004, Chisinau,
Republic of MOLDOVA
[2] Computers, Electronics and Automation Department, Mechanical Engineering and Technologies, Ştefan cel Mare University 13, University Street, Suceava
ROMANIA
galinamarusic@yahoo.com   http://www.utm.md

Abstract: - This article presents the problem of water pollution in rivers. The consequences of using iron polluted water are examined. A scenario of iron dispersion for a sector of river Prut, town Ungheni (R.Moldova) is modelled. The results are useful for preventing water pollution in "river-type" systems and for determining the level of water quality.

Key-Words: - River, iron, hydrodynamics, pollutant dispersion, mathematical model, simulation program.

1 Introduction

„River-type” systems present a major source of drinking water, and, therefore, their pollution prevention is an important factor for the development of each country. The World Health Organization as well gives special attention to drinking water quality. Statistical reports of the World Health Organization state that one in four patients of the hospital are suffering from a disease transmitted through water. In Moldova, water quality, in many cases, does not correspond to the existing national standard [1, 2].

Iron water pollution presents a danger to the human body. The permissible concentration of iron in drinking water is between 0.15 to 0.2 mg/L. A prolonged consumption of water with increased iron concentration can cause vomiting, diarrheic, liver disease and may even be toxic [3 - 6].

In rivers, iron occurs from two sources: natural and artificial. The first source is iron because it is present in soil and rocks. In deep waters it occurs naturally in the form of organic iron. Each form can be found alone, and in combination with others. Iron is contained in rivers also because of industrial wastewater and acid rains, acting directly or indirectly on water systems [7 - 10].

The mathematical models of hydrodynamics for "river- type" systems and of pollutants transport were developed in this paper. Mathematical models were used to generate numerical models for a sector of river Prut of town Ungheni in order to determine the process of iron dispersion.

2 Problem Formulation

Freshwater rivers have a vital interest to the people around them. Given that the Prut is an important source of drinking water for Romania and Moldova, its pollution presents a major risk to health’s population of both countries.

The samples taken in July 2011 from a sector of river Prut, town Ungheni, showed that they significantly exceeded the maximum allowable concentration (MAC) of iron. To determine the temporal evolution of the pollutant, the modeling problem of pollutants dispersion on the river Prut, town Ungheni has been formulated

The hydrodynamics of the studied sector was modeled using the system of Navier-Stokes equations as Reynolds (1) and (2) together with the continuity equation:

$$h\frac{\partial u}{\partial t}+hu\frac{\partial u}{\partial x}+hv\frac{\partial u}{\partial y}-\frac{h}{\rho}\left(E_{xx}\frac{\partial^2 u}{\partial x^2}+E_{xy}\frac{\partial^2 u}{\partial y^2}\right)+gh\left(\frac{\partial H}{\partial x}+\frac{\partial h}{\partial x}\right)+$$

$$+\frac{gun^2}{\left(h^{1/6}\right)^2}\times\left(u^2+v^2\right)^{1/2}-\varsigma V_a^2\sin\psi+2h\omega v\sin\varphi=0 \qquad (1)$$

ISBN: 978-1-61804-148-7

$$h\frac{\partial v}{\partial t}+hu\frac{\partial v}{\partial x}+hv\frac{\partial v}{\partial y}-\frac{h}{\rho}\left(E_{yx}\frac{\partial^2 v}{\partial x^2}+E_{yy}\frac{\partial^2 v}{\partial y^2}\right)+gh\left(\frac{\partial H}{\partial y}+\frac{\partial h}{\partial y}\right)+$$

$$+\frac{gvn^2}{\left(h^{1/6}\right)^2}\times\left(u^2+v^2\right)^{1/2}-\varsigma V_a^2\sin\omega+2h\omega v\sin\phi=0 \quad (2)$$

$$\frac{\partial h}{\partial t}+h\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial h}{\partial x}+v\frac{\partial h}{\partial y}=0 \quad (3)$$

In equations (1) - (3), h is water depth (m), u - local velocity in the x direction (m/s), v - local velocity in the y direction (m/s), t - time (s), ρ - water density (kg/m^3), g - gravity acceleration (m/s^2), E - coefficients of turbulent viscosity (Pa.s or kg/m/s), H - geodetic share of the river bed (m), n - Manning's roughness coefficient, ζ - empirical coefficient on air friction, V_a - wind speed (m/s), ψ - wind direction (degrees counterclockwise from the positive x-axis), ω - angular velocity of rotation of the Earth (rad/s), φ - place latitude [11-13].

In order to model the pollutant dispersion, the two-dimensional equation of advection - dispersion was used, applied to the turbulent flow regime [14]:

$$h\left(\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}-\frac{\partial}{\partial x}D_x\frac{\partial c}{\partial x}-\frac{\partial}{\partial y}D_y\frac{\partial c}{\partial y}-\sigma+kc+\frac{R(c)}{h}\right)=0 \quad (4)$$

In equation (4) c is the concentration of pollutant (mg/L), D_x and D_y - turbulent diffusion coefficients in the x and y, k - decay constant (s^{-1}), σ - local term source of pollutant (concentration unit/s), $R(c)$ - precipitation/evaporation (concentration unit×m/s) [15].

3 Problem Solution

The numerical simulation was performed using the program Surface-water Modeling System (SMS) v.10.1.11.

We used the iron sample value C = 0.02 mg/L, taken in July 2011, which exceeded the maximum permissible concentration.

There were established the following boundary conditions:

- Q = 54.3 m^3/s - the constant flowrate (was assigned for the arc group at the inflow (top) cross sections);
- H = 4.6 m – the constant geodetic rate (was assigned for the arc group at the outflow cross sections).

The obtained hydrodynamics is shown in Figures 1-2.

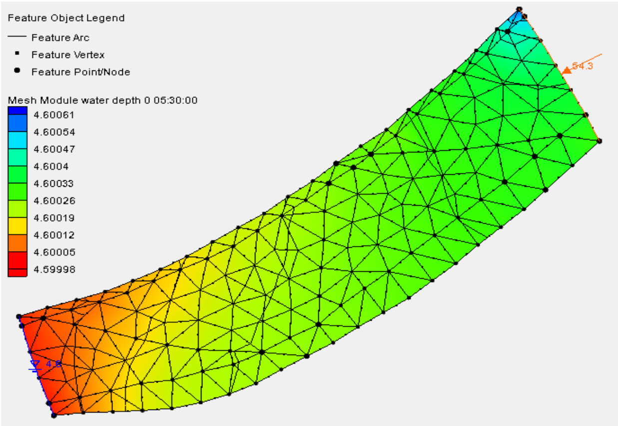

Figure 1. Variation in the depths of the sector studied.

The field distribution of depths throughout the study is observed in figure 1.

The velocity variation of water particles in all the finite geometry elements of the studied domain is shown in the figure below.

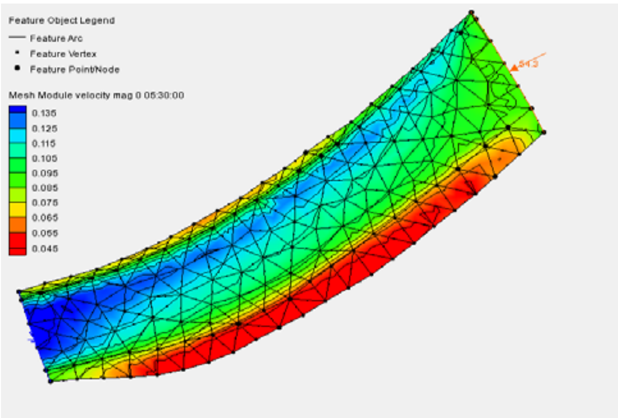

Figure 2. Distribution of the resulting velocity vectors.

It is noted that at the banks the water particle velocity is lower than in the middle of the river. On the right bank it reached the lowest value - 0.045 m/s. In some parts of the middle river water particle velocity reached a maximum of 0.135 m/s.

The obtained results in the determination of iron concentration field evolution are presented in Figures 3-5.

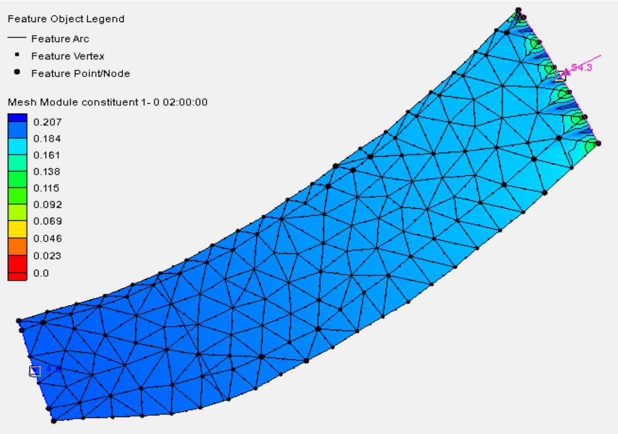

Figure 3. Iron dispersion after 2 hours from the water confluence.

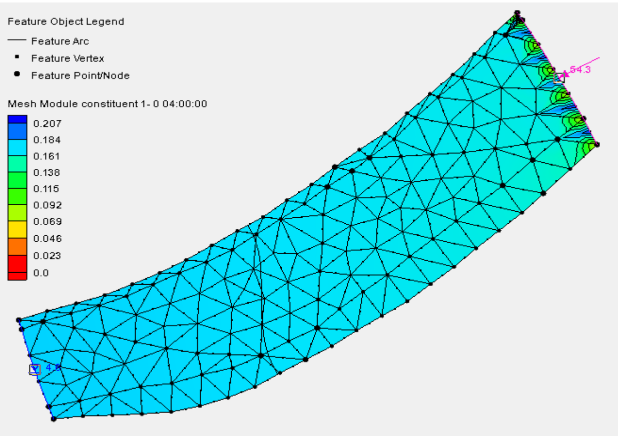

Figure 4. Iron dispersion after 4 hours from the water confluence.

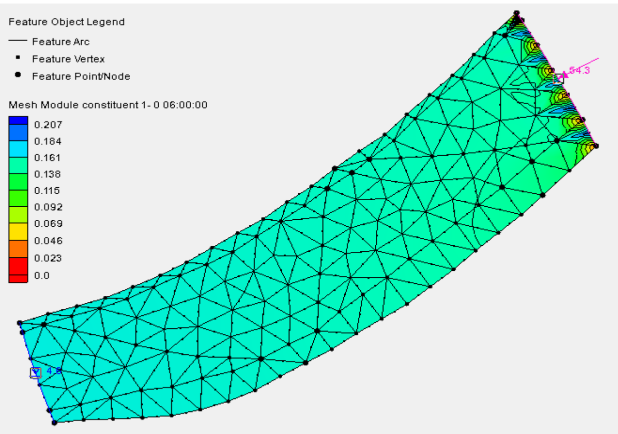

Figure 5. Iron dispersion after 6 hours from the water confluence.

After 6 hours, we observe a decrease in the value of iron concentration throughout the studied sector. At this point, the pollutant transport became stationary.

Time variation of iron dispersion in the confluence zone is shown in Figure 6.

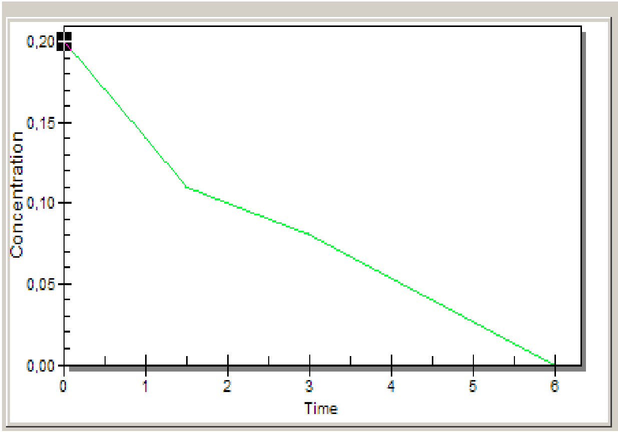

Figure 6. Iron dispersion in the confluence.

4 Conclusion

The problem of iron water pollution has been studied in “river- type” systems. The problem of the negative influence of iron on the human body was presented.

There were developed mathematical models of hydrodynamics and pollutants dispersion for "river-type” systems. Mathematical models were generated from two numerical models for a sector of river Prut, town Ungheni.

The numerical model of hydrodynamics determines the depths and velocities field in all the finite elements of geometry of the studied sector. It also serves as input data for generating the numerical model of iron dispersion. The obtained model can help to determine the evolution of iron concentration field in space and time throughout the studied sector.

The results are useful for determining the correct level of water quality and pollution prevention. The use of the pollutants dispersion model will contribute to take environmental measures for wastewater.

References:

[1] Gh. Duca, Water management in Moldova, *Expertiza A.Ş.M. Akademos*, No. 2 (17), 2010, pp. 26-27.

[2] Health analysis of the Moldova’s population in terms of statistical indicators (for the period of

2005-2009) the project "*Strengthening the National Statistical System"* PNUD Moldova Chişinău, 2010, p. 9, pp.27-28, pp.54-58.
[3] Gh. Duca, Gh. Mihailă, N. Goreaceva, P. Chetruş, *The chemistry of natural waters*, Chişinău, 1995.
[4] N. Goreaceva, V. Gladchi, *Health and water*, Chişinău, 2002.
[5] T. V. Guseva and others, Background materials on hydrochemistry, *Electronic variant*. *„Ecolain".*
[6] K. M. Vuori, Direct and indirect effects of iron on river ecosystems, *Annales Zoologici Fennici*, Vol. 32, No. 3, 1995, pp. 317-329.
[7] Barbara E. Brown, Effects of mine drainage on the river hayle, cornwall a) factors affecting concentrations of copper, zinc and iron in water, sediments and dominant invertebrate fauna, *Hydrobiologia*, Vol. 52, No. 2-3, 1977, pp. 221-233.
[8] A. Gavrilaş, M. Doliş, *Ecology and environment*, Alfa ed., Iaşi, 2006.
[9] M. Diudea, S. Todor, A. Igna, *Aquatic toxicology*, Dacia ed., Cluj Napoca, 1986.
[10] N. Milenkovic, M. Damjanovic, M. Ristic, Study of Heavy Metal Pollution in Sediments from the Iron Gate (Danube River), Serbia and Montenegro, *Polish Journal of Environmental Studies*, Vol. 14, No. 6, 2005, pp.781-787.
[11] L. Gavrilă, *Transfer phenomena*, Vol.I, Alma Mater ed., Bacău, 2000.
[12] *** *„SMS Tutorials*", SMS v.10.1.11, AquaVeo, 2011.
[13] *** *„Surface Water Modeling System - RMA2"*, US Army Engineer Research and Development Center, AquaVeo, 2011.
[14] S. A. Socolofsky, G.H. Jirka, *Special Topics in Mixing and Transport Processes in the Environment (5th Ed.),* A&M University, College Station, Texas, 2005.
[15] *** *„Surface Water Modeling System - RMA4"*, US Army Engineer Research and Development Center, AquaVeo, 2011.