Oceanological Studies
XXVI 4

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| Polish Academy of Sciences | | PL ISSN 0208-412X |
| National Scientific Committee | (123-132) | Institute of Oceanography |
| on Oceanic Research | 1997 | University of Gdańsk |


# SIMULATION OF SUSPENDED PARTICULATE MATTER TRANSPORT IN THE GULF OF GDAŃSK DURING 1996

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**Key words:** Gulf of Gdańsk, suspended matter transport, numerical modelling

## Abstract

The initial results of modelling of suspended matter (SPM) concentration are presented. The three-dimensional model proposed allows one to calculate the transport, erosion and deposition of a mineral part of seston in the Gulf of Gdańsk. The loads of SPM from rivers, atmosphere and the open sea, based on either real data or other model simulations, are included. In this model, the settling velocity of seston particles is assumed to be proportional to the Stokes' one computed for particles of 4 μm in diameter. Erosion and deposition rates depend on the bed shear velocity computed from hydrodynamic model.

Results of computations corresponding to a period of one year are compared with *in situ* observations carried out in the 1996 year and satellite data. In general, horizontal and vertical distributions of mineral SPM concentration computed from the model show a characteristic for this area pattern of water turbidity, however, quantitatively the results obtained are in rather poor accordance with real values.

## INTRODUCTION

Over past years, the increasing interest of oceanographers and marine engineers in studies on suspended particulate matter concentration in the sea has been observed because of its important role in marine environment. Particles suspended in the water column belong to main optically active constituents that

Supported by State Committee for Scientific Research, Grant No. 6 PO4E 036 09

affect the quality of water. Moreover, large amounts of contaminants are transported into estuaries while adsorbed onto or associated with suspended particles.

Here, suspended particulate matter (SPM) means the mass of fine solid material suspended in water with a particle diameter greater than 0.45 µm that can be determined by filtering of water samples on 0.45 µm pore-size filters (Kramer *et al.* 1994). Seston in the Gulf of Gdańsk consists of mineral particles and organic matter with diameter usually smaller than 30 µm (Bradtke *et al.* 1997). The mass-proportion of organic matter in SPM varies during a year.

In contrast to the transport of water and constituents dissolved in it, controlled by diffusion and advection, the transport of SPM is subject to additional processes like settling, deposition and erosion. The seston concentration is very heterogenous with respect to space and time. For obtaining satisfying maps of the SPM distribution, a high effort of field measurements by ships is necessary. However, synoptic coverage is not possible due to time required for sampling and laboratory analysis. Depending on the correct choice of equations describing transport processes, their parameters and boundary conditions as well as the model's grid size and time step, the results of model simulations yield more or less reliable spatial and temporal distributions of the suspended matter concentration.

It is not possible to derive a generic set of equations to describe completely the processes involved in SPM transport because of a large number of independently varying parameters affecting processes of settling, deposition and erosion. Developed models still contain many simplifications and empirical formulas.

The dispersion of suspended matter in the case of three-dimensional flow terms is described by the equation for conservation of mass of seston

$$\frac{\partial C}{\partial t} = \underbrace{-\frac{\partial(u\cdot C)}{\partial x} - \frac{\partial(v\cdot C)}{\partial y} - \frac{\partial(w\cdot C + w_s\cdot C)}{\partial z}}_{\text{advection + settling}} + \underbrace{\frac{\partial}{\partial x}\left(D_H\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_H\frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(D_V\frac{\partial C}{\partial z}\right)}_{\text{diffusion}} + F, \tag{1}$$

where:

*C,* SPM concentration; *x, y* and *z*, horizontal and vertical coordinates; *u, v* and *w*, horizontal and vertical velocity components; $D_H$ and $D_V$, horizontal and vertical diffusion coefficients; $w_s$, settling velocity; *F,* the source term.

Details of bed level changes can be studied by solving the bed continuity equation:

$$\rho_s \frac{\partial z_s}{\partial t} = F_D - F_E , \tag{2}$$

where:

$\rho_s$, sediment density; $z_s$, sediment thickness; $F_D$, quantity of material deposited on the bed; $F_E$, quantity of material picked up from the bed by the flow.

In this paper, the initial results of calculations of suspended matter concentration are presented. The model of SPM transport used for these simulations is a sub-model of *A model of matter exchange and flow of energy in the Gulf of Gdańsk ecosystem* developed at the Department of Physical Oceanography, University of Gdańsk.

## *IN SITU* DATA FOR MODEL VERIFICATION

The results of measurements of suspended matter concentration in the Gulf of Gdańsk gathered in 1996 were used for verification of the model. During 1996, every month, measurements were carried out at several stations located in Puck Bay (western part of the Gulf of Gdańsk). In October, two additional cruises in the area close to the Vistula river mouth took place. Fig. 1 presents locations of stations.

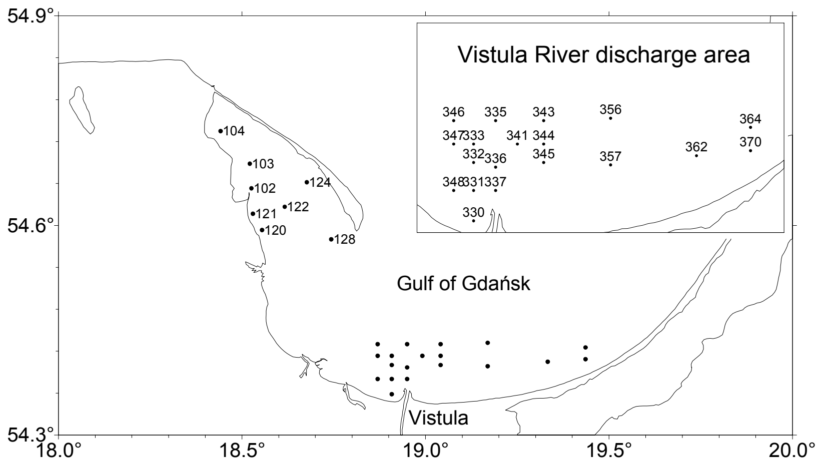


**Fig. 1.** Locations of sampling stations for determination of suspended matter concentration

In order to estimate seston concentration, samples of water up to 5 dm$^3$, were filtered through preweighed GF/F Whatman glass filters, dried at 60 °C and weighed again. Mineral matter content was determined by ashing the filters at 480 °C for *ca* 8 hours.

## MODELLING OF SPM TRANSPORT IN THE GULF OF GDAŃSK

SPM distribution model for the Gulf of Gdańsk is a sub-model of *A model of matter exchange and flow of energy in the Gulf of Gdańsk ecosystem*. In this model, advection and diffusion are computed jointly with the hydrodynamic model. Passive substances transport was verified based on salinity distribution (Kowalewski 1997). In the SPM transport module, a rate of settling, sediment deposition and erosion for a mineral part of seston are computed. Organic suspended matter is investigated separately (Ołdakowski and Renk 1997).

The settling of SPM is quantified by its velocity. The mean velocity of settlement of suspended spherical particles can be described by Stoke's law. Since particles in natural sea waters have different shapes, the computed settling velocity can differ from the real one (Lerman *et al.* 1974, Lau 1989). In the proposed model, a constant factor was used in order to correct Stoke's values

$$w_s = P \cdot \frac{g \cdot (\rho_s - \rho_w) \cdot D^2}{18\eta}, \tag{3}$$

where:

$g$, acceleration due to gravity; $\rho_s$ and $\rho_w$, particle and water density, respectively; $D$, particle diameter; $\eta$, viscosity; $P$, coefficient correcting Stoke's velocity for nonspherical set of particles.

Assuming particle diameter to equal 4 μm and density of mineral particles 2.1 $\mathrm{g\,cm^{-3}}$, the Stoke's velocity simulated for 1996 year period for the Gulf of Gdańsk was smaller than $7\times10^{-6}\ \mathrm{m\,s^{-1}}$.

In the case of the near bottom layer, settling SPM can be deposited on the bed. Whether deposition occurs or not depends on the bed shear velocity $v^*$ and the critical bed shear velocity for deposition $v^*_{\mathrm{crD}}$. Deposition occurs if $v^*$ is smaller than $v^*_{\mathrm{crD}}$. Deposited mass of suspended matter is given according to Puls and Sündermann (1990) by

$$F_D = \left[1 - \left(\frac{v^*}{v^*_{\mathrm{crD}}}\right)^2\right] \cdot C_b \cdot w_s, \tag{4}$$

where:

$C_b$ is the near bed SPM concentration.

One of the sources of SPM is near bottom flux of matter from eroded sediments. Process of erosion depends on the bed shear velocity $v^*$ and the critical bed shear velocity for erosion $v^*_{\mathrm{crE}}$ and occurs when $v^* > v^*_{\mathrm{crE}}$. The amount of eroded fine sediment is calculated from the formula

$$F_E = M \cdot \left[ \left( \frac{v^*}{v^*_{crE}} \right)^2 - 1 \right], \tag{5}$$

where:
$M$ is the erosion constant.

Values of critical bed shear velocities, $v^*_{crD}$ and $v^*_{crE}$, depend on sizes of suspended and sediment particles. In the case of suspended matter with particle size below 10 µm, deposition is not possible if flow velocities near the bed are greather than 0.1 cm s$^{-1}$ (Gradziński 1986). Fig. 2 shows bed shear velocities simulated in the hydrodynamical model for two stations in Puck Bay and near the Vistula river mouth in relation to the critical bed shear velocities assumed for erosion and deposition in SPM transport simulations.

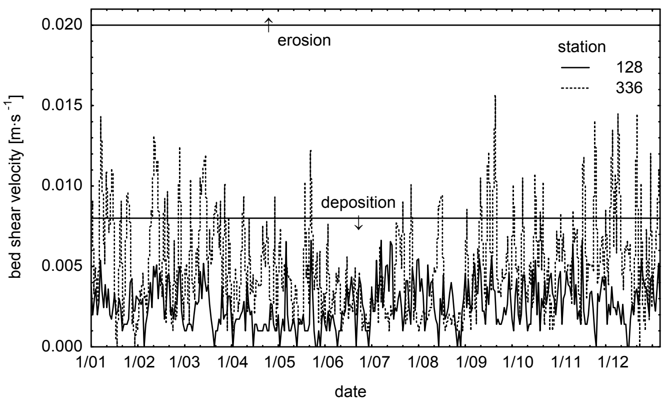


**Fig. 2.** Time series of bed shear velocity modelled for stations: 128 (depth *ca* 50 m) and 336 (depth 20 m) during 1996

## INPUT PARAMETERS

SPM found in the Gulf of Gdańsk originates from rivers, cliff erosion, dumping of sewage sludge or from atmosphere. The loads of SPM from Reda and the Vistula rivers considered in the model are daily averaged loads based on IMGW data. The input from smaller rivers and sewage collectors was assumed to be constant (average annual values based on IMGW data for 1995 according to Cyberska *et al.* 1995). It was additionally assumed that all mass of SPM carried by rivers consists only of mineral particles.

The input of substances from the atmosphere to marine environment in the Gulf of Gdańsk according to Pęcherzewski (1991) amounts on average to 0.0023 mg m$^{-2}$ s$^{-1}$ per annum. Loads of SPM from other sources are not included in the present version of SPM transport model.

Because simulations of any processes taking place in the Gulf of Gdańsk require defining of the boundary conditions at its open side, SPM concentration was first simulated for the whole Baltic Sea area using smaller resolution grid size.

Parameters for settling, deposition and erosion are listed in Table 1. Other parameters were results of other sub-models.

**Table 1**

Values of constants and units as used in the model

| parameter | unit | value | comments |
|---|---|---|---|
| $D$ | μm | 4 | |
| $\rho_s$ | $g\,cm^{-3}$ | 2.1 | Silica density |
| $\eta$ | $g\,cm^{-1}\,s^{-1}$ | 0.014 | Dera 1992 |
| $P$ | - | 1 | |
| $v^*_{crD}$ | $m\,s^{-1}$ | 0.008 | Pohlman and Puls 1994 |
| $v^*_{crE}$ | $m\,s^{-1}$ | 0.02 | Puls and Sündermann 1990 |
| $M$ | $g\,m^{-2}\,s^{-1}$ | 0.04 | Puls and Sündermann 1990 |

Model simulations for the Gulf of Gdańsk area were carried out for one year period starting from 01.01.1996 00:00 GMT with a time step of 20 minutes and grid cell size of 1 $km^2$. Initial mineral SPM concentration field was assumed homogenous (horizontally and vertically) with value 1 $mg\,dm^{-3}$. Bed sediments were treated as mud in the whole area.

## RESULTS OF SIMULATION

The most significant feature of SPM concentration in the Gulf of Gdańsk is a plume of high values near the Vistula river mouth and relatively low SPM concentration in western part of the Gulf. Horizontal distributions of mineral SPM concentration computed from the model show a characteristic for this area pattern of water turbidity. The example of model results in relation to satellite data are presented in Fig. 3.

Quantitative comparison of computed and measured *in situ* concentrations at surface layer are in poorer agreement. Generally, the computed values in the area of the Vistula outflow are too high (Fig. 4). Because the greatest differences were observed for stations located nearest the mouth of the river, these discrepances are most probably caused by the fact that fluvial suspended matter does not consist of organic particles. In Puck Bay, the greatest differences were observed in the second half of March (Fig. 5) when relatively big amount of SPM was measured. Similar situation was noticed in December but the differences were smaller. In spring-summer months simulated values were mostly higher than real ones. Due to assumption that the inflow of waters from land in this region is time independent, the model is not sensitive to real variations of turbidity.

a) b)

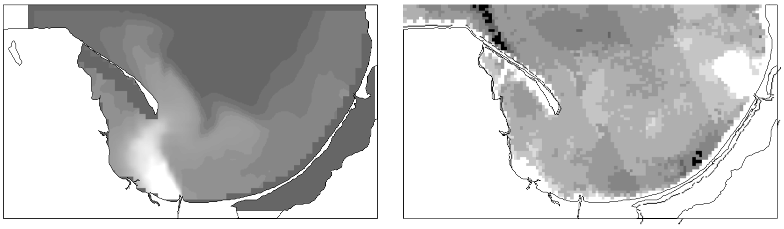

**Fig. 3.** Spatial distribution of SPM concentration; results from model simulations (panel a, mineral matter only) and satellite AVHRR data (panel b, all SPM) for 08.08.1996 11:00 GMT; colour scale shows increasing SPM concentration from black to white (in the both drawings different scales were used)

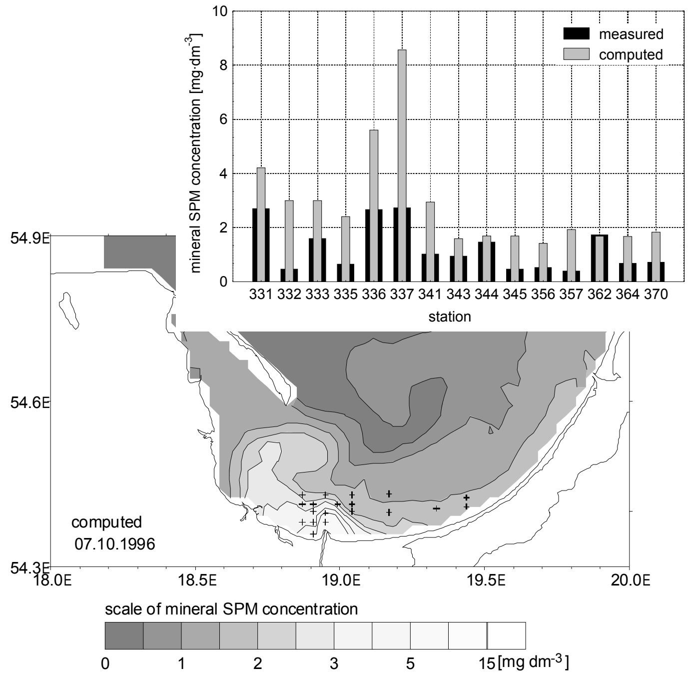


**Fig. 4.** Comparison of computed and measured mineral SPM concentrations in the Vistula river discharge area

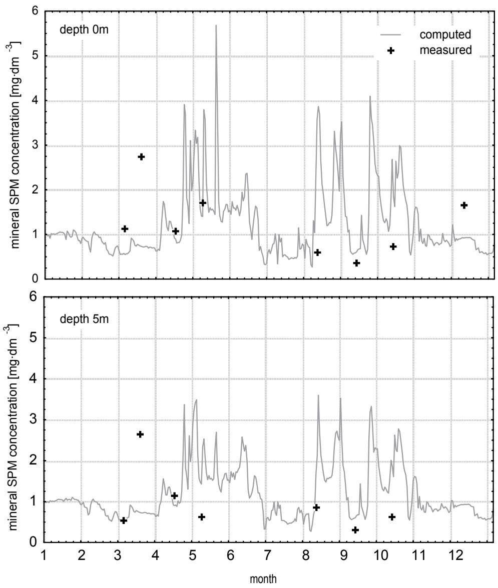


**Fig. 5.** Time series of computed and measured mineral SPM concentration at station 128

In vertical profiles, the agreement between modelled and real values is rather poor. Simulated profiles show a characteristic for the Gulf of Gdańsk shape with maximum values near surface then decreasing with depth. Near the bed, a characteristic increase of SPM concentration due to resuspension occurs (Fig. 6). However, computed values are sometimes higher and sometimes lower than the measured ones and no correlation between simulated and real values could be found.

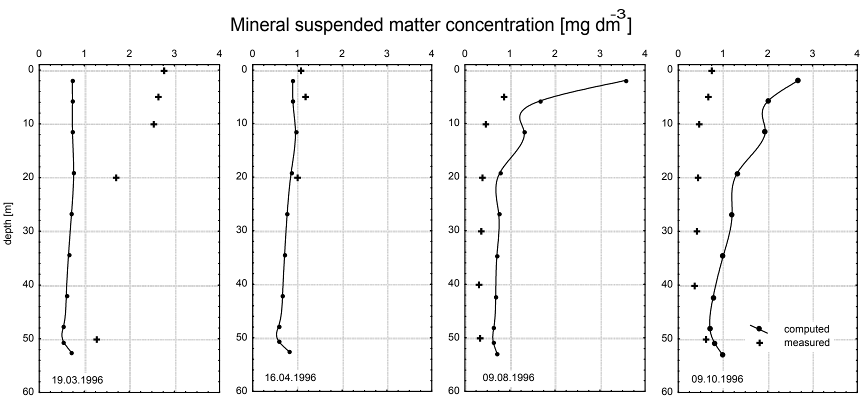


**Fig. 6.** Observed and computed vertical profiles of mineral SPM concentration at station 128

## CONCLUSIONS

First results of simulations show that the presented model of SPM transport requires calibration based on more *in situ* data. In further tests, more detailed input data should be included if better simulation results for Puck Bay are to be expected.

In order to get more precise simulation of vertical SPM concentration profiles, more sensitive calibration of the formula describing settling processes should be done. In natural waters, due to flocullation, adsorption and other geochemical processes as well as the fact that particles are not homogenous in respect to their sizes, shapes and material (Bradtke and Latała 1997), settling of suspended particles do not follow strictly Stoke's law. It is difficult to model these processes because of the absence of satisfactory models dealing with those chemical properties of water that influence the particles behaviour. They must be included indirectly by calibration coefficients.

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