Measurements and three-dimensional modelling of mercury cycling in Minamata Bay and in the Gulf of Trieste

RUDI RAJAR[1], SHINICHIRO YANO[2], AKIHIDE TADA[3], HIROKATSU AKAGI[4], HIDEO OSHIKAWA[3], DUŠAN ŽAGAR[1], MATJAŽ ČETINA[1], MARIO KRZYK[1], MATEJ BRECELJ[1]

[1]University of Ljubljana, Slovenia; E-mail: rrajar@fgg.uni-lj.si.
[2]Kyushu University, Japan; E-mail: Yano@civil.kyushu-u.ac.jp.
[3]Nagasaki University, Japan.
[4]National Institute for Minamata Disease, Japan.

Abstract: Both Minamata Bay (Kyushu, Japan) and Gulf of Trieste (Northern Adriatic) are still contaminated by mercury. Measurements of currents by ADCP (Acoustic Doppler Current Profiler) were first carried out in both coastal seas. Further on, 3D modelling of circulation and mercury cycling were done by the PCFLOW3D model, measurements were partly used for verification of the model. Transport and diffusion of dissolved and particulate mercury was simulated for different weather conditions. Future trends of mercury transport and transformations are determined. The mass balance of mercury in both coastal seas shows the most important sources and sinks of different forms of mercury.

Key words: Three-dimensional mercury model, ADCP measurements, Mercury cycling, Minamata Bay, Gulf of Trieste.

INTRODUCTION

Two case studies of mercury contamination are presented in this paper. The first is the Gulf of Trieste (Northern Adriatic), where the main source of mercury pollution is a former mercury mine, situated along a river, which transports contaminated water and sediments to the Gulf (HORVAT ET AL., 1999). By combining hydrodynamic and geochemical measurements with modelling it was possible to describe distribution and transport of mercury and its species in the Gulf of Trieste and to calculate the mass balance for total and methyl-mercury (RAJAR ET AL., 2004).

The second case is Minamata Bay in Japan, where contamination with MMHg by a factory caused an environmental catastrophe around 1958. Some mercury has been transported from Minamata Bay to the adjacent Yatsushiro Sea. Concerns persist about further possible mercury contamination of this sea, where fishing is an important activity.

DESCRIPTION OF THE MODEL AND SIMULATION METHODOLOGY

PCFLOW3D model is a three-dimensional circulation and transport and fate model. It integrates hydrodynamic module, transport dispersion and sediment transport modules. Smagorinski principle, and the Mellor-Yamada turbulence model are included. The simulation of some biochemical processes

has also been included. The model is described in detail in RAJAR AND ČETINA (1997), RAJAR ET AL. (2000).

In order to predict the mercury dynamics we need to get a fundamental knowledge of physical mechanism of mercury transport in coastal areas. Although the main goal of the research was to investigate long-term trends of mercury pollution, the calibration of the model demanded real-time simulations, which means the modelling of shorter unsteady processes. Also, since it was found that most mercury transport is related to suspended sediment particles, the sediment transport module was applied.

As the transport of any pollutant depends greatly on the HD velocity field, a lot of research had to be done to determine it properly. Both modelling and measurements were used for this purpose. Thus, it was necessary to carry out an oceanographic observation for hydrodynamics and transport sediment, especially a long-term simultaneous measurement of vertical profiles of tidal current and suspended sediment (SS). "Acoustic Doppler Current Profilers" (ADCP) fits this objective. As the first trial of in situ measurement of mercury transport, we carried out ADCP measurement in Minamata Bay (YANO ET AL., 2004). Similar measurements were carried out in the northern part of the Gulf of Trieste in 2003.

RESULTS AND DISCUSSION

Hydrodynamic simulations were carried out first in both cases. Main results are described in (RAJAR ET AL., 2004).

Minamata Bay is an integral part of the adjacent Yatsushiro Sea. As it was not possible to obtain reliable boundary conditions for simulation of circulation inside the Minamata Bay, simulations were carried out for the whole region. The Yatsushiro Sea is an almost enclosed sea, along the E side of Kyushu Island, its length being about 70 km. There are five straits connecting the Yatsushiro Sea with the neighboring seas. As the tidal range is over 4 m, the peak velocities at some straits can reach 6 knots.

Fig. 1 presents comparison of the measured and simulated velocities during rising tide at strait B. The agreement of the measured and simulated velocities is good both in the deep southern and the shallow northern part of the Yatsushiro Sea.

The second important forcing factor is wind. A typhoon can cause velocities which are everywhere, except in the straits, of the same order of magnitude or greater than tidal velocities.

With the ACDP measurements in the Minamata Bay time series of SS flux at each layer were obtained from the data of velocity and SS. It shows that the dominant direction of SS transport is between N and NW, that is the direction from the Minamata Bay to the Yatsushiro Sea. Rough order of annual mercury transport from the Minamata Bay to the Yatsushiro Sea was estimated from calculated net SS transport and the existing data of mercury concentration in bottom sediment as follows: Total-Hg transport is about 55-75 kg and Methylmercury is about 0.02-0.12 kg.

With both modelling and measurements the calculated mass balance of mercury in the Minamata Bay was calculated. It is presented in Fig. 2. The outflow from Minamata bay to Yatsushiro Sea was calculated to be 150 kg/year. This is about two times more as determined directly by ADCP measurements. The difference is due to the fact that the second calculation took into account sediment resuspension due to the strong typhoon winds, while it is not accounted for in the first evaluation.

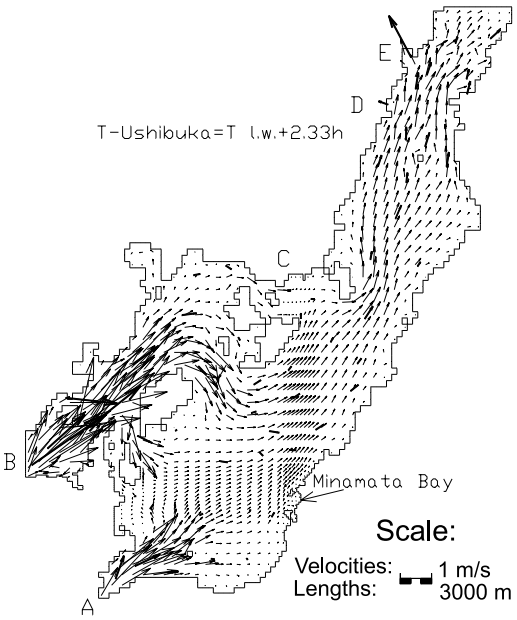

Figure 1. Comparison of simulated and measured (bold vectors) velocities in the Yatsushiro Sea at flood tide.

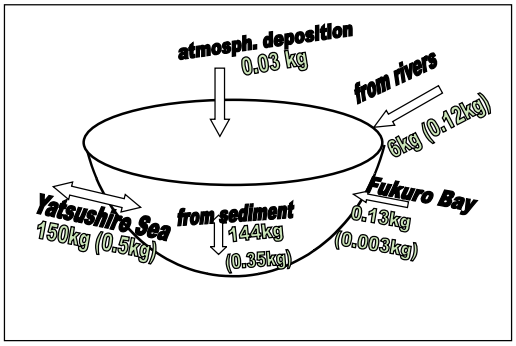

Figure 2. Mass balance of mercury in the Minamata Bay.

CONCLUSIONS

By both measurements and modelling some important conclusions were found.

Gulf of Trieste. The most important forcing factor in this region is wind. To diminish mercury contamination in the Gulf, measures are necessary to diminish washout of contaminated sediments from the mining region (Idrija), from the catchment area of the two rivers and from the flood plains of the river system, where mining residues have been deposited. As measurements during last 8 years do not show reduction of Hg concentrations in the Gulf, it seems that the mentioned regions in the catchment area are a long-term source of (inorganic) mercury.

An almost negligible flux of methymercury (MMHg) (0.14 kg/year) enters the Gulf from the Soča river, but 114 kg/year are formed in the bottom sediment of the Gulf. As contamination of fish is due to accumulation of MMHg, we can conclude that: (a) remediation could be partly successful if conditions for methylation in the bottom sediment were reduced, and (b) if there is future water quality degradation in the Gulf, contamination of fish with MMHg could even increase.

Minamata Bay. The outflow of Hg from Minamata Bay to the Yatsushiro Sea is mostly affected during storms. The maximum outflow is estimated to be.150 kg/year. Since prior to dredging in Minamata Bay measurements showed an outflow of about

1 to 5 t/year, the effectiveness of the clean-up works is again clearly confirmed. The present mass of total Hg in the bottom sediments of the Yatsushiro Sea is about 31 tons, while in the sediments of Minamata Bay there is 1.8 tons of Hg (in 1975 it was estimated at 150 tons). An important conclusion is that Minamata Bay presently represents an insignificant source of Hg to the Yatsushiro Sea.

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