Modelling of ^{60}Co concentrations in the dissolved and particulate phases in the Loire estuary

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Abstract. EDF has initiated a program assessing the fate of radionuclides released by nuclear power plants located along the river basin. In order to estimate the behaviour of radionuclides associated with suspended sediment in the Loire estuary, a multivariate transport model has been developed. Several dissolved and particulate constituents can be simultaneously computed, the later being followed in the superficial sediment according to the deposition events. Modelling of salinity and suspended matter was included as having an influence on sorption kinetics, and on radionuclide transport. Indeed, the association of radionuclides with particle can affect their residence time in sedimentation zones of water systems. Partitioning of radionuclides between water and suspended matter is usually expressed as Kd, concentration ratio between particulate and dissolved phases. In the simulations presented, particulate and dissolved ^{60}Co behaviour were considered to interact with suspended solids and salinity trough sorption and desorption kinetics, distribution coefficients being considered as representing equilibrium conditions seldom reached in nature. Simulation was carried out for two river discharges (high river input and low river input). The computed results are compared with observed values for surface levels, salinity and suspended matter as well as ^{60}Co concentrations.

1. INTRODUCTION

EDF has initiated a program assessing the fate of radionuclides released by nuclear power plants located along the river basin. In order to estimate the behaviour of radionuclides associated with suspended sediment in the Loire estuary, a multivariate transport model has been developed. Several dissolved and particulate constituents can be simultaneously computed, the later being followed in the superficial sediment according to the deposition events.

Several runs have been carried out, for various tidal conditions. Results have been examined and compared to the data measurements, which have been collected, regarding water surface elevation, salinity, and suspended matter and ^{60}Co concentrations.

2. DESCRIPTION OF THE LOIRE ESTUARY

2.1 Geography of the estuary

The Loire estuary is located in the south on French Britain, in the area of Nantes and Saint-Nazaire (see figure 1). It can be divided into two parts: the internal estuary (down river from Saint Nazaire) and the external estuary. (Up river). The internal estuary can be divided into several parts. The bottom level inside the channel is about -14 m in the area of Saint-Nazaire (bottom level refer to the zero of French Charts, which is the lowest level of the free surface, corresponding to the low tide level of a high spring tide), and -13.25 m between Saint-Nazaire and Donges. From Donges to Nantes, the lowest level is -5.50 m.

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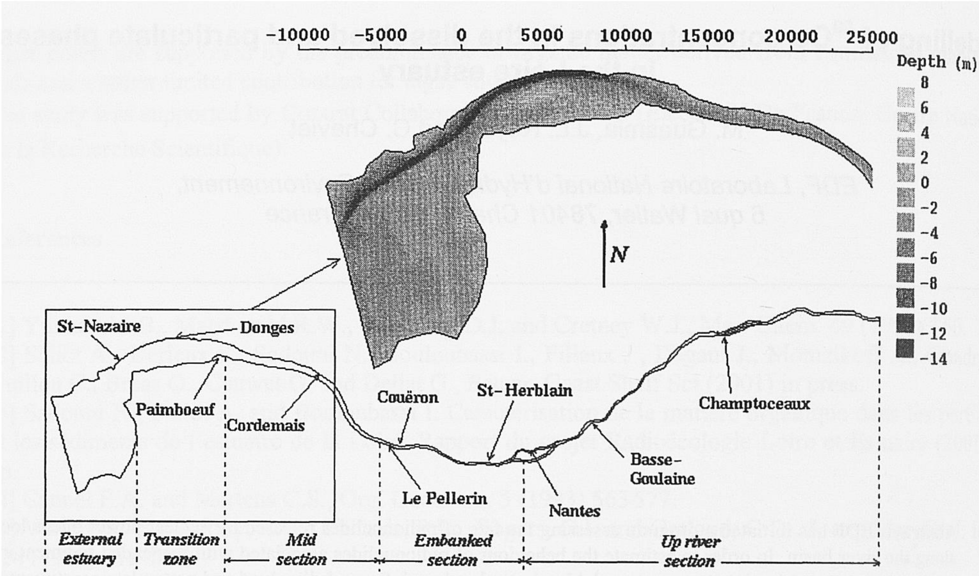

Figure 1: Loire Estuary

2.2 Hydrological processes

The tidal signal in the Loire estuary is a semi-diurnal one, with surface levels varying from +6.25 m (high tide) to +0.20 m (low tide) for a strong spring tide. During the lowest neap tides, the levels change from 3.65 m (high tide) to +1.90 (low tide). The mean level is about +3.0 m, when the effects of storm surges are negligible. The period of the tidal signal is 12 hours and 24 minutes.

The river discharge shows large fluctuations. Available data prove that the mean discharge is about 825 $m^3.s^{-1}$. However, low discharges can occur during several years: the mean value between 1989 and 1992 was about 450 $m^3.s^{-1}$.

Salinity intrusion strongly depends on the tidal characteristics. The point where salinity is below 0.05 % moves up 70 km up river from Saint-Nazaire during flood for a spring tide. Stratification can occur for a neap tide if the river discharge is strong enough.

2.3 Sediment characteristics

Sand is predominant up river from Nantes, while cohesive sediments are mainly present in the internal estuary. The sediment carried out by the river discharge is mainly due to suspended matter (mud, 90% of the particles having a diameter smaller than 40 µm), more than bed load transport. The total mass of fluid mud in the estuary may be around 1,5 million tons.

Under the combined effects of tide and river discharge, the suspended matter has an oscillating motion, with an amplitude depending on the tidal components and the value of the discharge. For a mean tide and a discharge between 380 and 480 $m^3.s^{-1}$, the amplitude of particle motion is about 17.5 km, the effective motion down river being 3.9 km during one tidal period.

3. DESCRIPTION OF THE SIMULATION

3.1 Numerical model

Actually, two two-dimensional numerical models have been used: TELEMAC-2D, to compute the tidal currents, and SUBIEF-2D, to compute the several dissolved and particulate constituents, as well as the suspended particle matter.

TELEMAC-2D computes the non-permanent free surface flows in shallow water environments, and hence is devoted to studies involving coastal, estuarine or fluvial areas.

SUBIEF-2D is used for two-dimensional sediment and water quality applications. Hydrodynamics and tracers transport are uncoupled, velocity and water depth fields are results given by TELEMAC-2D computation.

Two simulations have been carried out, one for a river discharge of 1085 $m^3.s^{-1}$ combined with a spring tide, and the other for a river discharge of 280 $m^3.s^{-1}$ combined with a neap tide.

3.2 Initial and boundary conditions

The initial conditions for TELEMAC-2D are zero velocity and a free surface that has been deduced by a linear extrapolation from six points of measures along the estuary. A schematic sinusoidal tide is imposed at the mouth, and the river input at the upstream boundary.

When a steady state is reached, a tidal period is extracted for the currents and water depths to be used by SUBIEF-2D.

Initial conditions for sediment are imposed through a 20 cm thick layer of mud, extended over 65 km in the middle of the modelled area. They lead to an initial sediment mass of 800 000 tons.

The initial conditions for salinity have been deduced by a linear extrapolation from points of measures along the estuary. At the mouth, salinity was imposed at 35 g/l during flood and could leave the estuary during ebb.

The concentration for the dissolved ^{60}Co was imposed at 10^{-3} Bq/l, whereas the ratio between the ^{60}Co particle on site 1 and ^{60}Co particle on site 2 is imposed at the value of 14.

3.3 Results of the model

3.3.1 *Spring tide*

The first simulation has been carried out for a river discharge of 1085 m3.s^{-1} and a spring tide.
Comparisons of surface elevations show a good agreement between measured and computed results.
For salinity, numerical simulations were checked by the mean of salinity curves available at Donges. Comparisons of salinity between computed and measured results are given in the table below:

	Salinity at High level ($g.l^{-1}$)	Salinity at Ebb ($g.l^{-1}$)	Salinity at Low level ($g.l^{-1}$)	Salinity at Flood ($g.l^{-1}$)	Salinity at high level ($g.l^{-1}$)
Surface	5.4	1.3	0.7	6.8	3.3
Half of total depth	15.5	4.5	-	11.9	23.1
Mean values	10.4	3.	0.7	9.3	13.2
Computed results	10.3	2.6	0.2	0.3	7.6

During the first phases of the tide, the computed results are in the good range of values, but during the second phase of flood, the computed mean values underestimates the observed values. This discrepancy can be explained by the fact that for a high river input, quality of 2D models results is questioned because of the assumption of vertical homogeneity. Indeed, when the river input increases, salt stratification appear that are not modelled by SUBIEF-2D.

For the sediments, the turbidity maximum is oscillating between St-Nazaire and down the river from Le Pellerin and at low water level it is partially expelled in the external estuary. Inside the turbidity maximum, sediment rates are the highest at low water level, with a value reaching 2 g/l at Donges (maximum value of 1 g/l at high water level). If we consider the turbidity distribution in the channel established with the help of measures done in 1981 during a spring tide with low river discharge (Migniot 1993), the turbidity maximum seems more spread at high water level than at low water level, with, at high water level, a very slow decrease of the sediment concentrations in the up river part. Consequently, localising the exact maximum upstream extension of the turbidity maximum is difficult, because it corresponds theoretically to a sudden decrease of sediments rates. We must also take into account that for a high river input, quality of 2D models results is questioned because of the assumption of vertical homogeneity. Indeed, when the river input increases, stratification appear, generating an invertal residual circulation between surface (fresh water) and bottom (salt water), they contribute to the creation of the turbidity maximum.

For the ^{60}Co, we have compared the simulated coefficient of distribution Kd with the equilibrium coefficient. Indeed, partitioning of radionuclides between water and suspended matter is often described in terms of distribution coefficients (Kd), expressed as the concentration ratio between the particulate phase and the dissolved phase under equilibrium conditions. Figure 2 shows the temporal variation at Donges of the computed and analytical coefficient of distribution. The equilibrium condition is instantaneously reached either for the simulated and the analytical coefficient. The concentration of the dissolved ^{60}Co is maximum when the salinity is maximum, and minimum when the salinity is minimum.

3.3.2 *Neap tide*

A condition of neap tide (tidal range of 2.1 m) with a low river discharge (280 m.s^{-1}) has also been simulated.

Comparisons of surface elevations show a good agreement between measured and computed results. For salinity, numerical simulations were checked by the mean of salinity curves available at Cordemais. At this point, we can see that the variation of salinity is correctly reproduced, with a maximum value at high water level and a minimum value at low water level. However, the numerical model overestimates the salinity at this point, with a value of 16 g/l, whereas the measurements give a value of 13 g/l.

For sediment, the turbidity maximum is oscillating between Le Carnet and the upstream of Cordemais. Inside the turbidity maximum, sediment rates are the highest at low water level, with a value reaching 1.7 g/l at Cordemais. At high water level, the maximum of concentrations is lower, and the turbidity maximum seems more spread.

We have compared the simulated coefficient of distribution Kd with the equilibrium coefficient. Figure 3 shows the temporal variation at Cordemais of the computed and analytical coefficient of distribution. The equilibrium condition is instantaneously reached either for the simulated and the analytical coefficient.

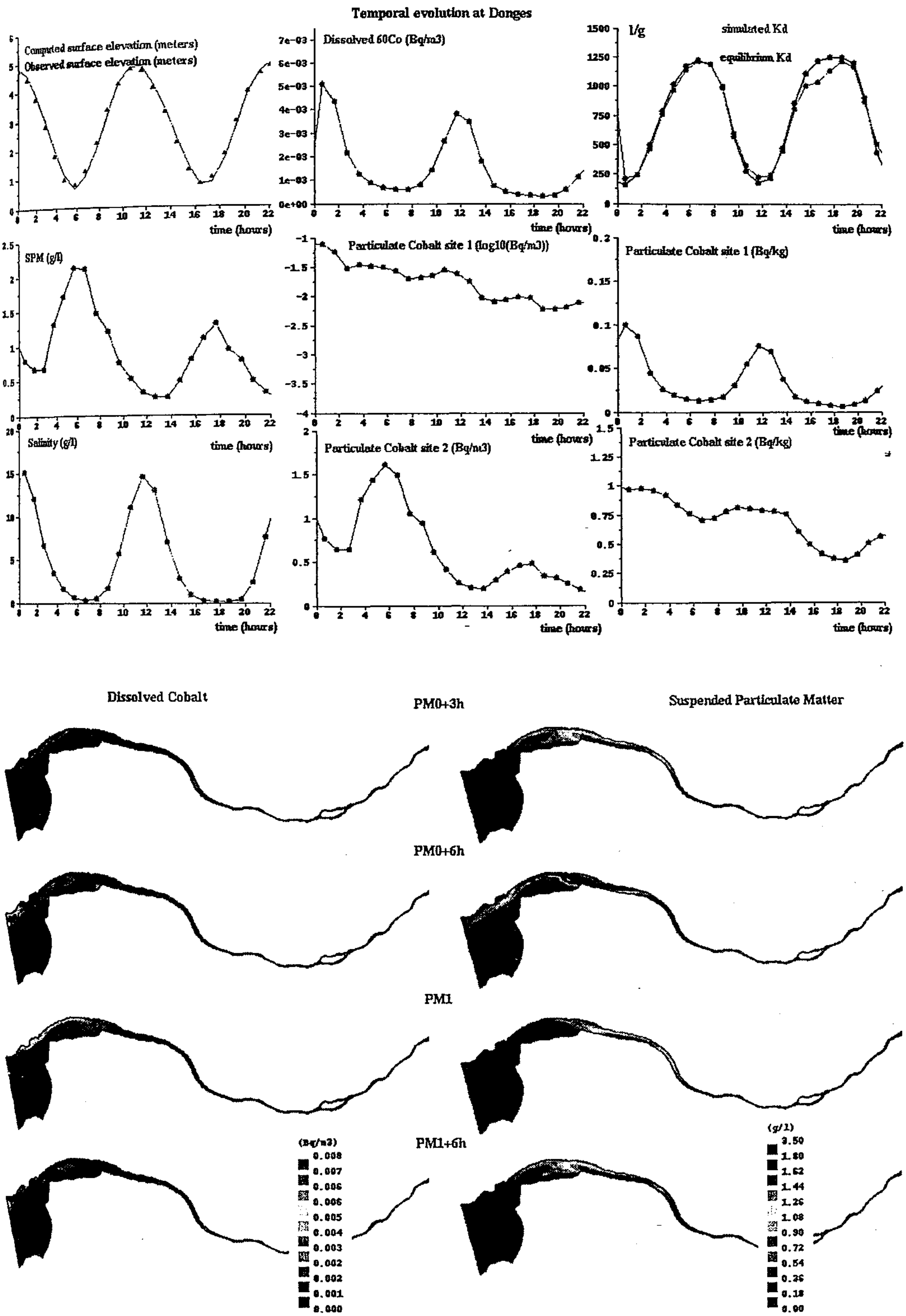

Figure 2: Spring tide simulation at water river discharge of 1085 m3/s

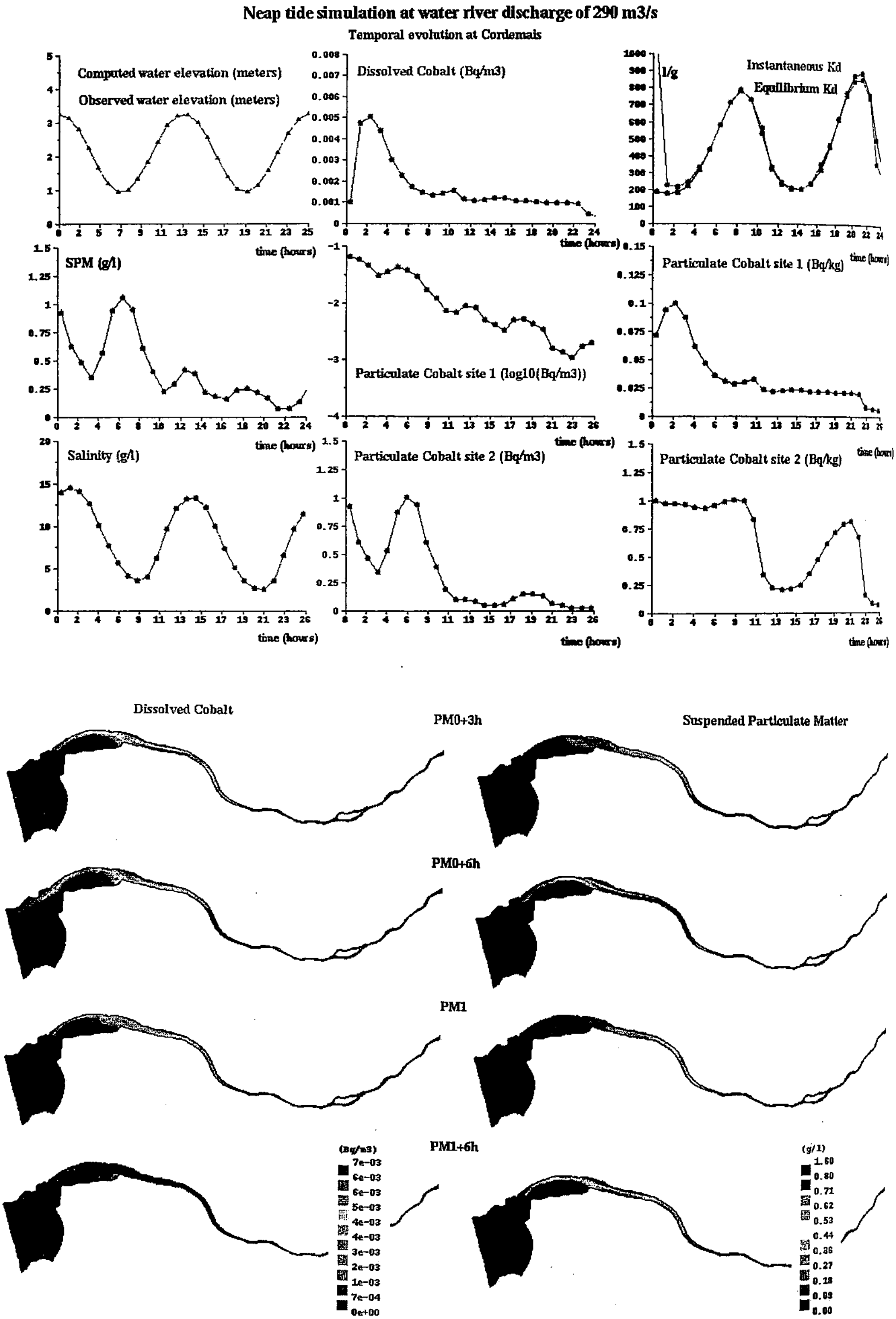

Figure 3: Neap tide simulation at water river discharge of 290 m3/s

4. CONCLUSION

The particulate radionuclides transport model has proven to be a great help in understanding sediment dynamics, interactions between the particulate and the dissolved phase, the residence time of particles in sedimentation zones of water systems. The model has been used in order to estimate the behaviour either of the dissolved and particulate ^{60}Co. Simulation was carried out for two river discharges and two tidal conditions. Now, the model has to be improved in order to perform a long time simulation.

References

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