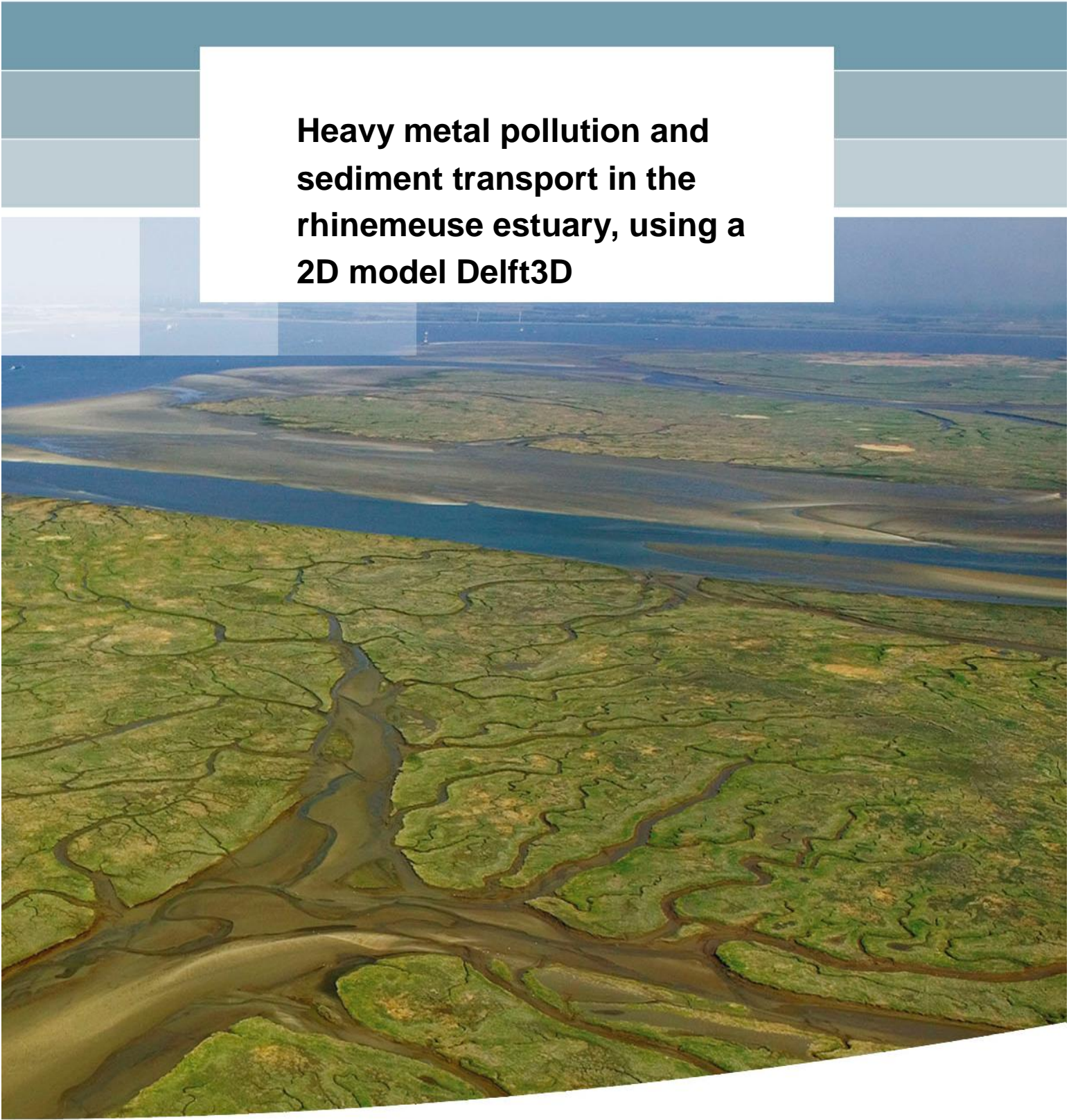


**Heavy metal pollution and
sediment transport in the
rhinemeuse estuary, using a
2D model Delft3D**



Heavy metal pollution and sediment transport in the rhinemeuse estuary, using a 2D model Delft3D

Water quality and calamities. Case study Biesbosch.

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Summary

The aim of this study is to get more insight in the transport and final destination (spatial distribution) of the eroded material from the Brabantse Biesbosch during extreme high discharges. Next to this, the study focuses on the influence of the contaminated material in suspension on the water quality of the rivers. The exact determination of the extent of erosion or concentration of pollutants in the water are not part of this study. The project is executed within the framework of the Delft Cluster project "Waterquality and Calamities" (WP4).

Because there was no suitable existing schematization of the study area in a Delft3D model, a new set up was made using the BASELINE database, which describes in detail the characteristics of the geographical area concerned. The initial step in the development of the water quality and sediment transport numerical model is the setup of the 2D hydrodynamic model using Delft3D-Flow, where the water flow rate of the study is the result of a combination of river discharge and to a lesser extent the sea water level. Then comes the definition of relevant sediment processes using the Delwaq processes library. Finally, the results of the model simulation are analyzed to give an idea of the influence of the contaminated material in the soil that can be resuspended due to high flows. As a proof of concept the high flow event of January 1995 is studied, which is close to a once in 100 year flow event.

For this particular event, shear stresses at the water bed in the main channel are very high compared with the shear stresses in the floodplains. The range of shear stresses in the main channel is 0 - 12 N/m² for the floodplain areas the shear stresses are often less than 0.1 N/m² that is the critical sheer stress for sedimentation that was applied for the coarsest sediment fraction. Assuming an initial thickness of the soil layer of 10 cm, erosion is observed in the upper part of the main river where all material is removed. This needs not necessarily reflect the real situation, because the water bed in the main channels at the upper part of the model may have been clean initially. Due to the lower velocities in the Hollands Diep and in the Haringvliet areas, sedimentation takes place at the end of the simulation in small magnitudes in local sections of the area. Increased amounts of heavy metals at the end of the simulation occur mainly in the Hollands Diep and the Haringvliet areas and also in the Biesbosch area where the water velocities are low enough. The initial thought that erosion in the floodplains of the Biesbosch area should generate an additional transport of heavy metals may have to be adjusted.

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1 Introduction

1.1 Background of the study

Different measures will be executed in the framework PKB “Room for the River” in order to lower the water levels in the river area during normative high discharges. The plan Ontpoldering Noordwaard is one of them and has as aim to inundate parts of the Noordwaard during high discharges. Water coming from the Nieuwe Merwede as result of high water levels will flow into the Noordwaard and leave the area through the south part. As consequence the creeks in the Brabantse Biesbosch will process more water and flow velocities will increase. This may result in higher sediment transport en possible erosion of the gullies.

Dankers et al. (2008) studied the flow velocities in the Brabantse Biesbosch under different discharge conditions and the possible effects of the velocities on erosion and transport of contaminated bed material. This study was a combination of computer model simulations and expert judgment. The model simulations were obtained with the combination of boundary conditions for discharges with a return period of once in 100 year for the Rhine and Meuse and a water level of the sea of 1 m above normal. In this case flow velocities higher than 1 m/s and shear stresses higher than 1 N/m² were found at different locations of the Brabantse Biesbosch. This means that a transition may occur from a situation without spreading of contaminated bed material towards a situation where spreading can occur. By comparing the quality of the top layer of the areas with risk of erosion according to De Straat (2004) with the intervention values for river beds (“Circulaire Sanering Waterbodems 2008”) and the MAC_{sediment} (Maximum Allowed Concentration in the Sediment), Dankers et al. (2008) found that different areas in the Brabantse Biesbosch may exceed the intervention values and/or the MAC for sediments. The areas Gat van de Visschen, Gat van Den Kleine Hil and Gat van de Noorderklip present concentrations of metals in the top layer that are higher than the intervention values and the MAC. In the areas Gat van Van Kampen, Gat van de Binnennieuwensteek and Spijkerboor a small violation of the MAC_{sediment} was observed. This study concluded that there are unacceptable risks of spreading of contaminated mud to the surface water.

1.2 Objectives of the present study

The aim of the present study is to get more insight in the transport and final destination (spatial distribution) of the eroded material from the Brabantse Biesbosch during extreme high discharges. Next to this, the study focuses on the influence of the contaminated material in suspension on the water quality of the rivers. The exact determination of the extent of erosion or concentration of pollutants in the water are not part of this study.

The project is executed within the framework of the Delft Cluster project “Waterquality and Calamities: (WP4).

1.3 Research Questions

The research questions are the following:

1. In cases of inundation of Noordwaard during extreme high discharges: Where is the eroded material transported to?
 - Is the eroded material transported towards the North Sea and will it settle near the Haringvliet sluices?
 - Or does the material settle in the Hollandsch Diep and in the Haringvliet?
2. How does the quality of the eroded material affect the quality of the water of the river downstream of the Noordwaard?
 - How are the concentrations of the material in suspension from the inflow of the Noordwaard in relation to the concentrations in the Nieuwe Merwerde, de Brabantse Biesbosch, the Hollandsch Diep and possibly the Haringvliet?
 - Once the material settles, what is the quality of it?

1.4 Methodology

The study consists of roughly the following components:

Because there was no suitable existing schematization of the study area in a Delft3D model, a new set up was made using the BASELINE database, which describes in detail the characteristics of the geographical area concerned. The initial step in the development of the water quality and sediment transport numerical model is the setup of the 2D hydrodynamic model using Delft3D-Flow, where the water flow rate of the study is the result of a combination of river discharge and to a lesser extent the seawater level. Then comes the definition of relevant sediment processes using the Delwaq processes library. Finally the results of the model simulation are analyzed to give us an idea of the influence of the contaminated material in the soil that can be resuspended due to high flows. As a proof of concept the high flow event of January 1995 is studied, which is close to a once in 100 year flow event.

1.5 Structure of the Report

This report broadly follows the format described in the methodology. The first chapter gives an introduction of the project, which addresses as main points the objective and the research questions of the project.

Chapter two describes the location of the Study Area, some background about metal pollution in the area and the availability of data for the modelling process.

Chapter three and four are respectively the description of the set-up and the approach of the hydrodynamic and sediment model.

Chapter five shows the most remarkable results. Finally some conclusions and recommendations that can be drawn from the project are given.

2 Study Area

2.1 Location

The project is located in the lower part of the river Rhine, in the Rhine–Meuse Delta, one of the larger river deltas in western Europe. The area is exactly the confluence of the Rhine and the Meuse rivers in the Delta.

This study covers the area of the Merwede (Boven Merwede, Beneden Merwede and the Nieuwe Merwede) merging with the Meuse through the Hollands Diep and the Haringvliet estuary.

After the closure of the Haringvliet dam in November 1970, this estuary no longer forms a link between the marine and the river ecosystem. Before the hydrodynamics was a vital element of this brackish ecosystem. After 1970 the study area became completely fresh, allowing only fresh outflow towards the sea at low water. This means that although the area is fresh, there is still a tidal influence noticeable. In last years attempts are made to alleviate this strict separation by allowing some opening for sea water to enter again. The study area can be seen in Figure 2.1.



Figure 2.1 Study area, Current situation (Vermeer & Mosselman, 2005).

The Biesbosch National Park is composed of several rivers, islands and a network of narrow and wide creeks and also contains 3 drinking water reservoirs. The area is one of the largest remaining fresh-water tidal natural areas in the Netherlands. Figure 2.2, shows the confluence of the river Rhine and Meuse.



Figure 2.2 Biesbosch area, areal view.

The Bergse Maas river and the Nieuwe Merwede river join to form the Hollands Diep, which is a wide river and an estuary of the Rhine and Meuse river. From the North the Dordtsche Kil connects the Rotterdam Harbour area to the Hollands Diep. Finally, there is The Haringvliet, which is a large outlet towards the North Sea Figure 2.3 shows the upper part of the Hollands Diep.



Figure 2.3 Hollands Diep areal view.

2.2 Background of heavy metal pollution

One can distinguish three different stages in the river pollution. The first stage is the pollution with heavy metals, being the combined result of mining and industrial activities. This heavy metal pollution in the Rhine-Meuse Delta started around 1900 and reached extraordinary high levels in the early 1970.

By the 1970s the accumulation of heavy metals in the Rhine's delta silt had reached the point that it exceeded by far the safe limits for zinc, copper, lead, cadmium and arsenic. Every time the delta flooded, this silt was deposited onto the nearby fields. The heavy metal contents were several times higher than the levels considered safe.

During the second phase major improvement in the water quality has been achieved over the last 30 years. Concentrations declined approximately with a factor of 10.

During the present third phase a stabilization at low concentration levels is obtained. Especially in the Rhine part however, existing contaminated river floodplains may enforce serious limitations on nature rehabilitation. The Meuse has always been relatively clean. A

closer look at the silt in the study area reveals the following pattern: high contamination levels have been detected in the flood plains of the Nieuwe Merwede and the Amer. The Hollands Diep has a thick layer of less polluted river sediment that was deposited in the years after 1975. The existing historical heavy metal pollution in the Biesbosch, Hollands Diep, Haringvliet and other parts is considered a major environmental problem.

Lately monitoring stations have shown that peak exposures of heavy metals occur rarely in the river Rhine. Nevertheless, pollution of the water bed sediments of the Biesbosch-Hollands Diep-Haringvliet is a serious problem due to the accumulation of severely polluted sediment after the closure of the Haringvliet in the 1970.

2.3 Available Data

The available data regarding water and sediment quality used for this project comes from two well organized sources. The first is Waterbase (<http://www.waterbase.nl>). This is a database that was constructed and maintained by the former RIZA (Institute for Inland Water Management and Waste Water Treatment of the Netherlands), currently the Waterdienst. The second source is the database of the ICPR (International Commission for Protection of the Rhine).

2.3.1 Flow Discharge regime

The river Rhine is a combined meltwater / rainwater river. According to Asselman & Wijngaarden (2002), high discharges in the Rhine-Meuse Delta in the Netherlands mainly are the result of excessive rainfall during the winter period. In those periods peak discharges may vary between 5,000 and 10,000 m³/s. The river Meuse is mostly a rainwater river, lacking a substantial base flow in dry periods. Figure 2.4 Shows daily flow discharges at the locations of Tiel (in a big Rhine branch) and Lith (in the Meuse) for the period of 01-12-1994 to 01-01-2001.

Flow Discharges at Tiel and Lith

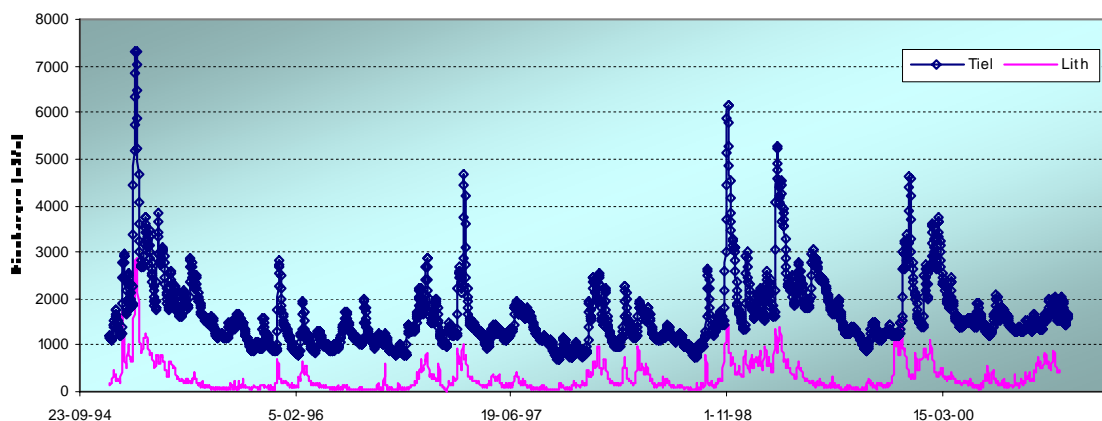


Figure 2.4 Flow discharges at the locations of Tiel and Lith

2.3.2 Sediment transport measurements

Suspended sediment concentrations are measured daily in the river Rhine at Lobith and in the river Meuse at Eijsden by the Ministry for Public Works and Waterways in The Netherlands (Rijkswaterstaat). Sediment concentrations are measured on a daily, weekly or bi-weekly basis. The concentration as measured is used in the model to estimate sediment delivery ratio's as a function of river discharge. Figure 2.5 shows the daily time series of suspended sediment concentrations in the stations of Lobith (where the Rhine enters the Netherlands) and Eijsden (where the Meuse enters the Netherlands) from 01-12-1994 to 01-01-2001. Note the correspondence of periods of high river flow and high sediment concentrations by comparing Figure 2.4 and Figure 2.5. This results in the delivery of a large part of the sediments to the river Delta during these high flow periods. Note also the relatively higher sediment concentration peaks in the Meuse compared to the concentration peaks in the Rhine.

Suspended Sediment Concentrations

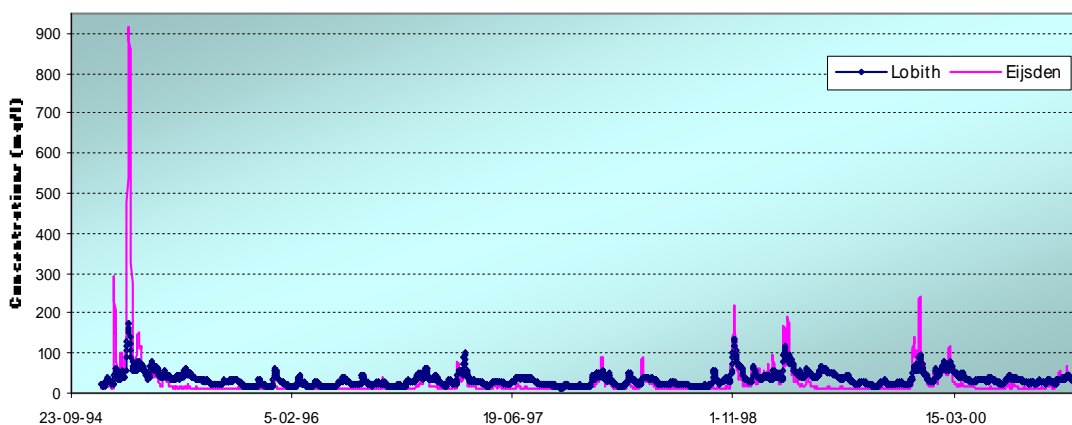


Figure 2.5 Concentrations of suspended sediment at Lobith and Eijsden

2.4 Previous studies

Several studies have preceded this study. Under the project number Q4453 a study named "Old contaminated sediments in the Rhine basin during extreme situations" has been conducted. Its main aim was to make an overview of relevant knowledge and to identify research directions. The study presented the following concluding remarks:

Insight is missing in the expected remobilization of contaminated sediments during extreme situations. For that reason, it is recommended that contaminated sediments during extreme situation need to be studied in a broader context, which includes historical and present contamination.

Attention has to be given to the development of 2D water quality models that includes suspended particulate matter, heavy metal pollutants and organic micro-pollutants

Commissioned by RIZA the studies Q4013 and Q4201 studies carried out based on the modelling of particulate matter. The first study (Q4013) dealt with two areas: the secondary channels in the Waal and in the Rhine-Meuse estuary. The model was designed to simulate erosion and sedimentation, and to deliver balances of the different simulated fractions.

The report of study Q4201 included a measurement plan to obtain data that would provide more insight into the behaviour of suspended matter in the Rhine-Meuse estuary. Based on these measurements the model was expanded and improved. Both studies used the WAQUA

model that is the Rijkswaterstaat version of the Delft3D hydrodynamic model that is used for this study.

2.5 Metal Pollution Risk

According to the ICPR, a study area is classified as an area of concern when sedimentation areas require particular attention. In our project, 2 areas of concern have been identified: 73) Nieuwe Merwede and 74) Sliedrechtse Biesbosch. See Figure 2.6. If there is no natural risk of resuspension then these areas do not present any risk for the downstream river.

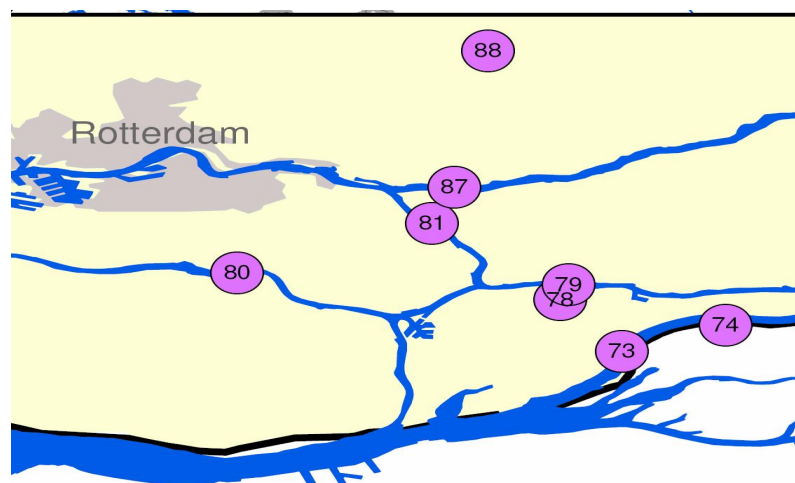


Figure 2.6 Areas of concern according to the ICPR

If sediments however can be remobilized due to floods, then such areas are classified as areas posing a risk. This risk is called type A and 3 of these locations have been identified in the study area 75) Dordtsche Biesbosch kleine kreken, 76) Dordtsche Biesbosch grote kreken and 77) Hollandsch Diep. See Figure 2.7

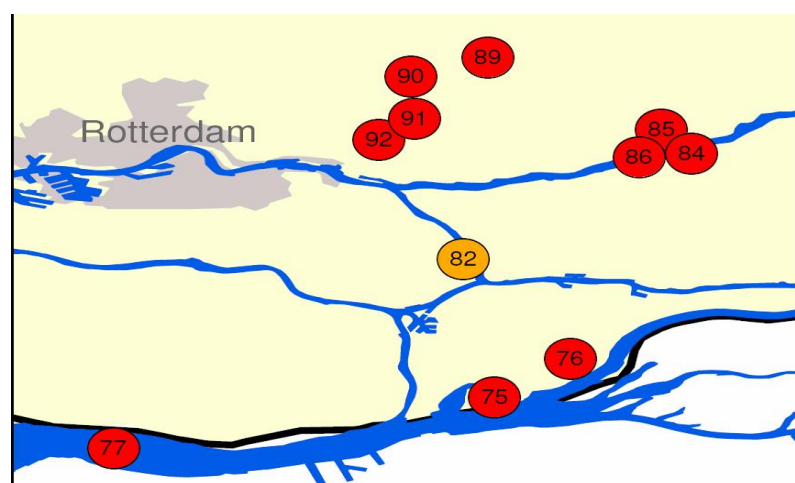


Figure 2.7 Type A area posing a risk according to the ICPR

3 Hydrodynamic Modelling

3.1 Introduction

This chapter describes the set-up of a 2D Hydrodynamic model, as an initial step in the development of the water quality and sediment transport numerical model. First the set-up of the model is discussed in detail, successively the model's results are presented and finally conclusions and recommendations are given.

3.2 Set-Up of the Model

3.2.1 General

The 2D hydrodynamic model has been developed in Delft3D software. Before describing the set-up in Delft3D it is good to mention that information about the area schematization was obtained from www.helpdeskwater.nl, where several files can be found that together with the corresponding generic software, such as SIMONA, Delft3D, etc. form the basis of a hydrodynamic model. The area schematization contains specific information about the geometry of the water system, the grid used, the conditions, roughness, the presence of weirs and other local physical characteristics.

The area schematization's information is stored in a field BASELINE database; this information describes in detail the characteristics of a given geographical area. The simona-nbd-2004-v1 database was used for this project. The GIS application BASELINE (baseline_331_d3d) was used to make the database projection in the selected grid of the study area.

After the completion of the baseline database projection to Delft3D input, the final step was to fix some inconsistencies in the resulting files stemming from the transformation.

3.2.2 Grid

The Cartesian computational grid of the model is an adaptation of the content of the simona-nbd-2004-v1 database. In Figure 3.1 in this figure also the area of interest for the current project can be seen. The grid numbering of the study area starts in the lower left (southwest) close to the Haringvliet Sluice, here the (M,N) starting point (1,31) is located. The number of grid points in the M-direction is 770 and in the N-direction 140. The grid distances are variable because of the curvilinear shape; the length of the grid cells in M-direction varies between 10m and 80m and in N-direction varies between 30m and 80m.

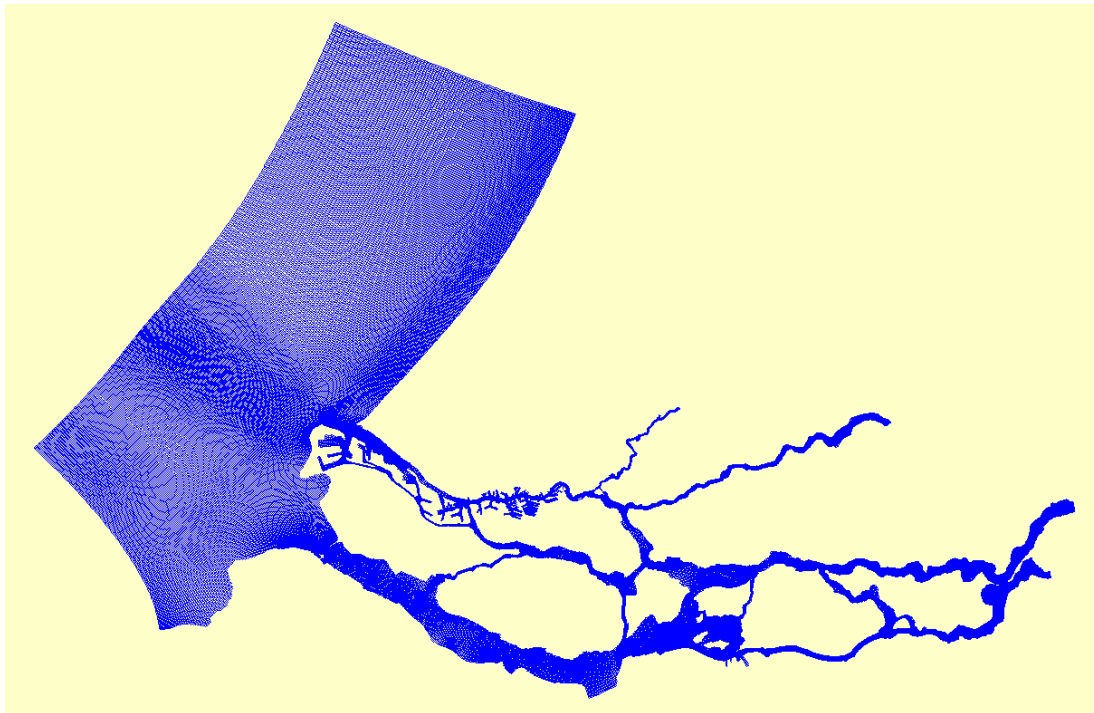


Figure 3.1 Simona-nbd-2004-v1 database computational grid.

3.2.3 Bed Topography

The bathymetry or depth schematization was taken from two sources, one from the projection of the baseline database and the other, finer, schematization from a WAQUA model for the Biesbosch Area.

Both observations were combined and averaging per grid cell was applied because there were more observations than grid points. Figure 3.2, shows the bed topography with the maximum depth ranging from approximately -40 m close to the Haringvliet Sluices up to some -20 m locally in the Beneden Merwede.

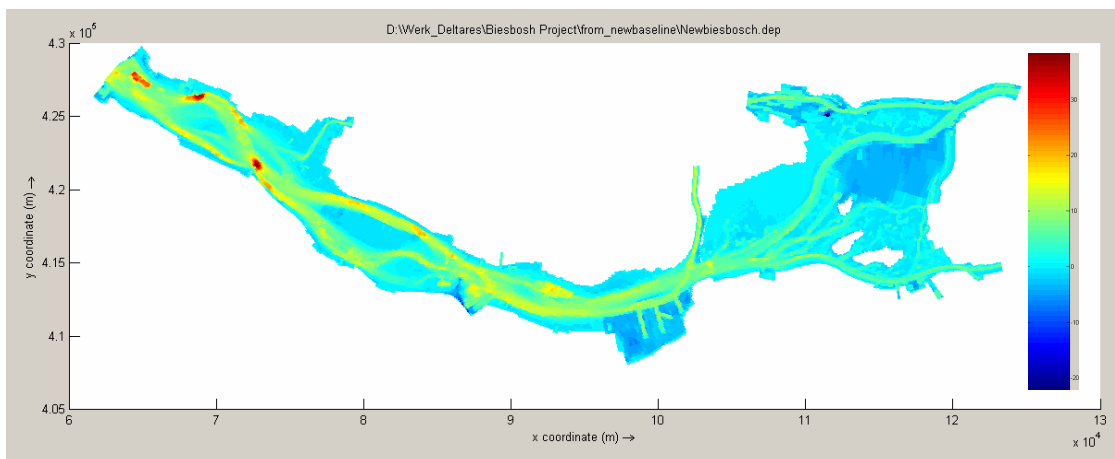


Figure 3.2 Depth schematization of the study area.

3.2.4 Roughness

Values for hydraulic roughness were obtained from the simona-nbd-2004-v1 database. These roughness values were transposed to the computational grid for the study area. Two files were derived from the GIS application for the database projection; the area files trachytopes in the U direction and in the V direction. The roughness may differ per direction because it includes not only the roughness of the bed material itself, but also the influence of fluctuations in bed elevation on a sub-grid scale on flow resistance. This trachytopes functionality allows using different types of roughness formulations at different locations. A definition file trachytopes was created for defining the different types of trachytopes and to associate these with roughness formulations.

3.2.5 Weir structures

Also the data on trespasses, weirs, dams and dikes is projected to the study area. This data can only be used in 2D model schematizations. Trespasses are modelled as sub-grid phenomena with dimensions much smaller than the grid size. Only their influence on the flow is taken into account.

A change had to be made in the file that resulted from the conversion before running the model. All values of crest height were sign changed, because of the difference between the Waqua and Delft3D file format.

Figure 3.3 shows the sub-grid with obstructions.

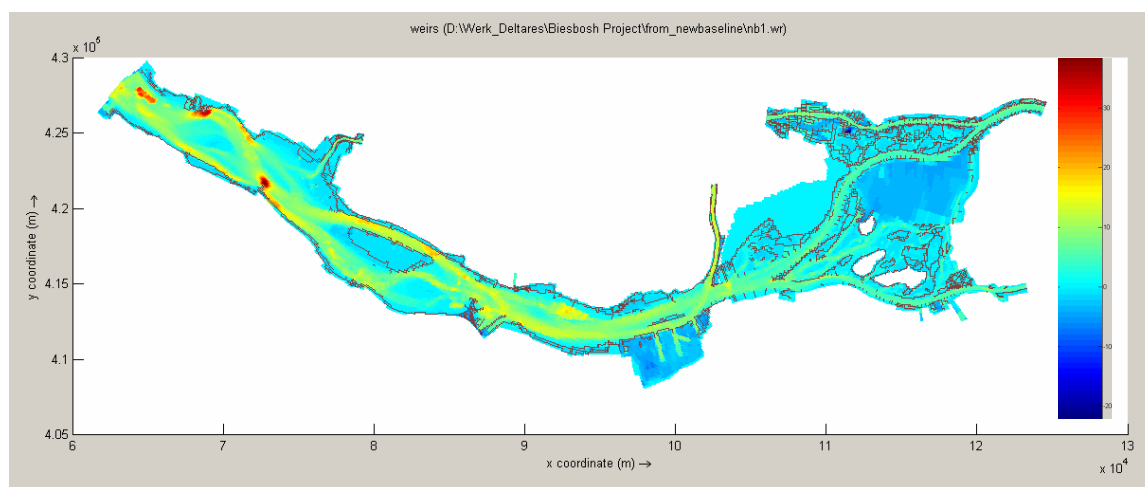


Figure 3.3 Obstructions data projected over the Study area.

3.2.6 Numerical settings

An important numerical setting is the time step; this should be chosen in such a way that movement of water in the model is modelled accurate enough. The computational scheme in Delft3D-Flow is stable, but a higher time step size will decrease accuracy. One criterion used here was the Courant-Friedrich-Lewy (CFL) condition. There are 2 of such conditions available for water flow. The first one gives the number of grid cells that the hydraulic surface wave travels per time step (the velocity of this surface wave is \sqrt{gh} or some 10 m/s at 10m depth). This Courant number is generally advised not to exceed 10. The second Courant number results when the actual water velocity (generally some 1 – 1.5 m/s in flowing rivers) is taken rather than the velocity of the surface wave. Then the number gives how often the volume of water in any grid cell is replaced within one time step by the water flow. This number is generally advised to be less than 1.0.

During the simulations it was found that when using a time step of 30 seconds, the results seem to be sufficiently accurate. See Table 3.1. for the model steering that is used. To learn more about time step considerations, see the Delft3D-Flow_User_Manual, section 4.5.3.

Table 3.1 Numerical settings of the model in Delft3D-Flow

Name	Value	Unit
Latitude	51.5	°
Simulation start time	23-01-1995	
Simulation Stop time	13-02-1995	
Time step	0.50	min
Gravity	9.81	m/s ²
Water Density	1000	kg/m ³
Eddy viscosity	0.10	m ² /s

3.2.7 Initial and Boundary conditions for water flow

The study area has 6 open boundaries where conditions from the surroundings and in- and outflows are imposed on the model see Figure 3.4.

The upstream discharge boundaries are at the locations:

- 1.- Bergse Maas for the water from the river Meuse
- 2.- Boven Merwede for the water from the river Rhine
- 3.- Beneden Merwede, an in/outflow interface with the Rotterdam Harbor
- 4.- Dordtsche Kil, an in/outflow interface with the Rotterdam Harbor
- 5.- Spui, an in/outflow interface with the polders South of Rotterdam

The downstream water level boundary lies at:

- 6.- Haringvliet Sluices a managed outflow towards the sea



Figure 3.4 Open Boundary locations of the model

The upstream model boundary are defined as discharge boundary, with two hourly data for the period of 23-01-1995 to 13-02-1995. See Figure 3.5, Figure 3.6 and Figure 3.7 where a total discharge is applied at the boundaries. The Bergse Maas (figure 3.5) reflects the discharge of the river Meuse during the 1995 high flow event. The Boven Merwede reflects the discharge of the river Rhine during this event.

This is a fresh water tidal area, so weak ripples on the flow from the rivers Meuse and Rhine reflect reduction in the river velocity during flood. The tidal effect is more noticeable in the outflow through the Beneden Merwede towards Rotterdam Harbour where flow may change direction.

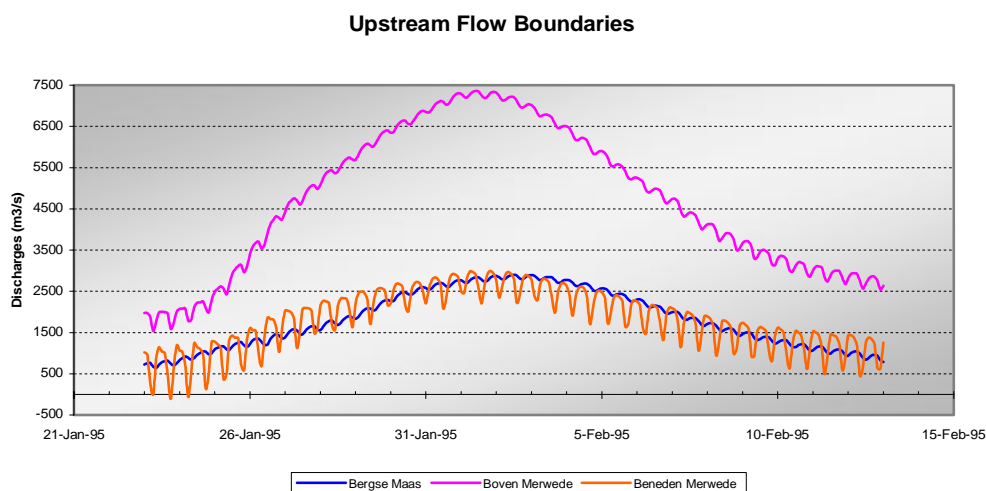


Figure 3.5 Boundaries in Bergse Maas, Boven Merwede and Beneden Merwede

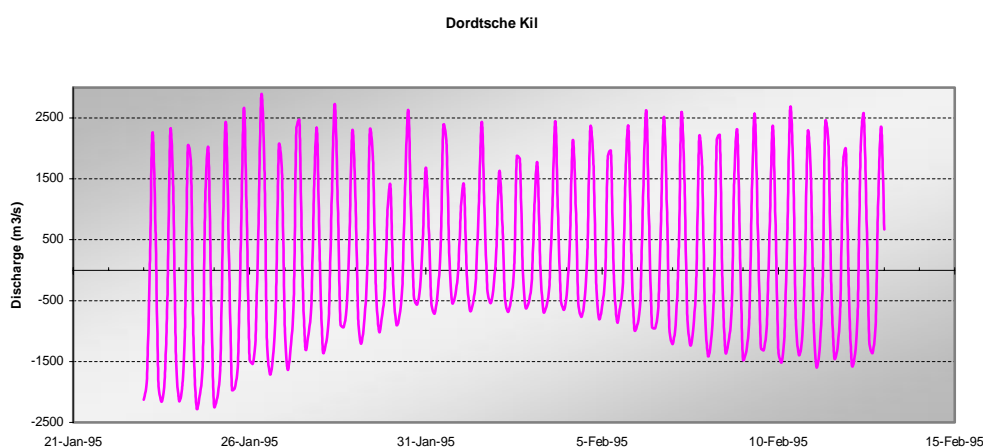


Figure 3.6 Boundary in the Dordtsche Kil

The Flow through Dordtsche Kil is generally to and fro, but during the peak discharge most flow consists of a return flow of water that left through Beneden Merwede.

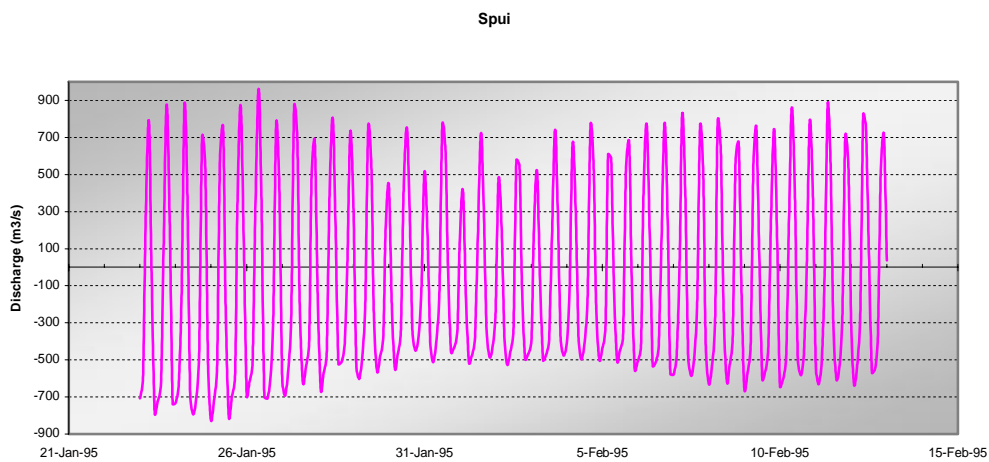


Figure 3.7 Boundary in the Spui

The flow through Spui is generally also to and fro, reflecting the tidal character of Rotterdam Harbour and the reduced tide in Haringvliet with the managed Haringvliet Sluices. During peak flow conditions of the river, Haringvliet Sluices are opened and the water level at both sides of the Spui get tidal elevation from sea superimposed on the increased river water level. This reduces the water level difference at both sides of the Spui as is seen from Figure 3.7.

The downstream boundary is defined as a water level boundary for this high flow period. This reflects the condition of open Haringvliet Sluices. Additional to the tidal influence at this downstream boundary a weakly reflecting boundary condition is applied with a reflection coefficient α equal to 500 s see Figure 3.8.

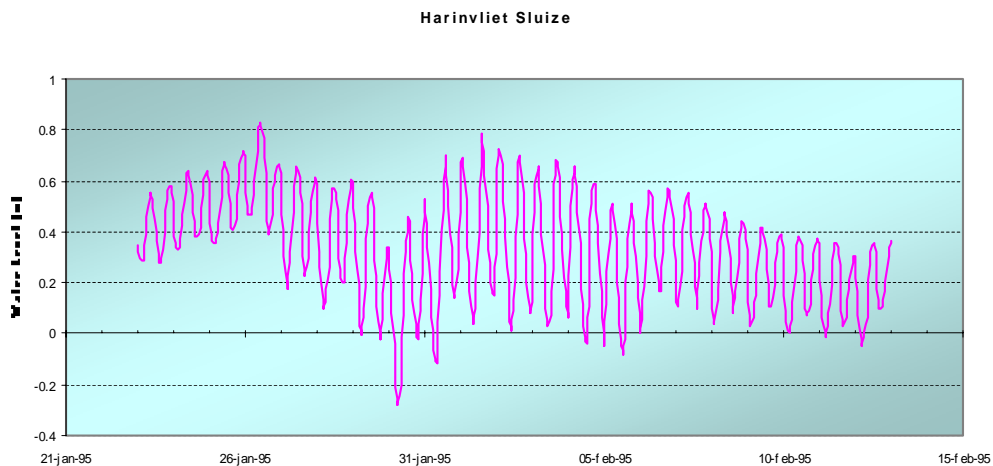


Figure 3.8 Water level boundary in the downstream Haringvliet sluice (m).

The flow through Spui is generally also to and fro, reflecting the tidal character of Rotterdam Harbour and the reduced tide in Haringvliet with the managed Haringvliet Sluices. During peak flow conditions of the river, Haringvliet Sluices are opened and the water level at both sides of the Spui get tidal elevation from sea superimposed on the increased river water level. This reduces the water level difference at both sides of the Spui as is seen from Figure 3.8.

The downstream boundary is defined as a water level boundary for this high flow period. This reflects the condition of open Haringvliet Sluices. Additional to the tidal influence at this downstream boundary a weakly reflecting boundary condition is applied with a reflection coefficient α equal to 500 s, see Figure 3.9.

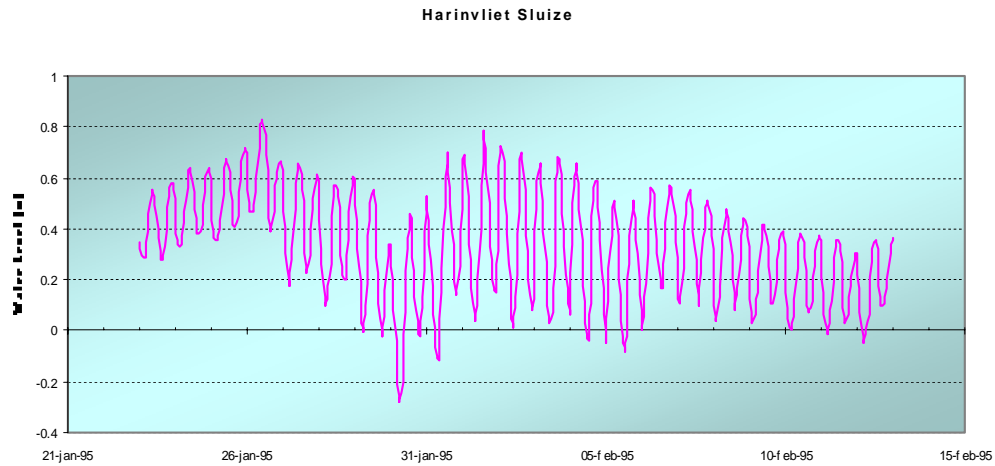


Figure 3.9 Boundary in the downstream Haringvliet sluice

3.3 Hydrodynamic results

The definition of the study area in the model consists of the total of the different components like bed elevation, roughness, structures, etc. and the provision of adequate flow boundary conditions for the simulation period. Once this has been set up successfully the hydrodynamics results can be seen in terms of water levels, bed shear stresses and depth averaged velocities. Figure 3.10 shows the depth averaged velocity field for February 2nd, when a high peak event happens. High velocities can be seen in the main channels with a maximum of 2.2 m/s in the upper part of the Beneden Merwede.

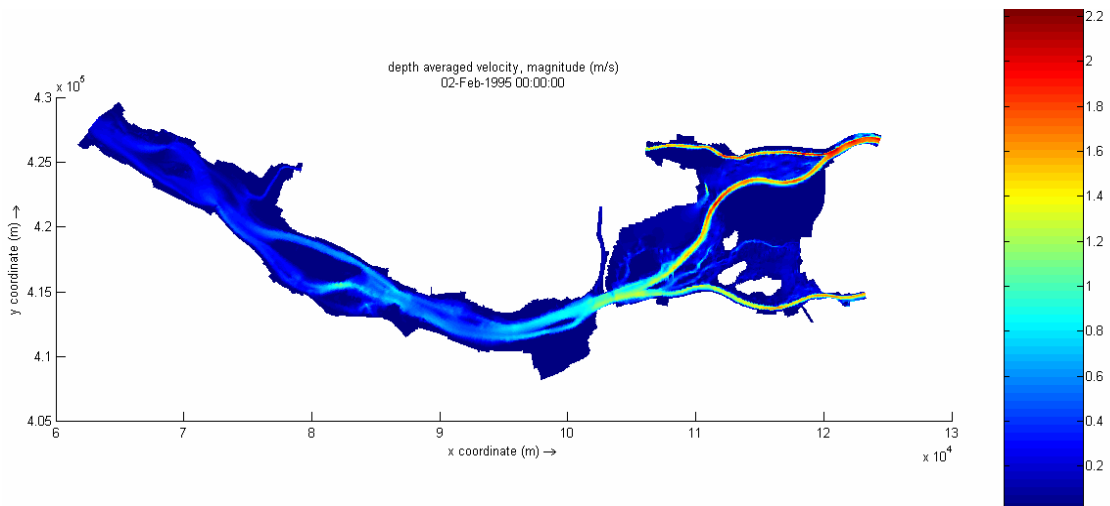


Figure 3.10 Depth averaged velocities in m/s

4 Sediment Modelling

4.1 Introduction

During flood events, a large quantity of sediments are transported to our study area the Rhine-Meuse Estuary, where the hydrodynamic conditions are determined by a combination of river discharge and tides. As a result processes of erosion and sedimentation become active.

In this chapter a sediment model for the study area is presented. With this model the sediment transport during the flood event of 23-01-1995 to 13-02-1995 was studied in detail. The model enhances the insight in the spatial distribution of the sediment particles in the area. It also describes some common design tools, such as: particle size fraction distribution of the sediment, the initial conditions of the model and the process coefficients that are the basis of the calculations. A better understanding of the erosion and deposition of polluted sediments during flood events is of great use for the evaluation of measures.

4.2 Description of the model

The sediment model as implemented in the Delft3D water quality module uses the Delwaq Processes Library as a central computational core. In the library the processes for the relevant sediment fractions and metals are contained. The actual design of the sediment model for this study consists of switching on the relevant sediment fractions and metals as well as the processes that need to act on these substances. The sediment model for this project has two main components:

1. Sediment Transport component
2. Sediment Quality component

The suspended solids model for this project uses three groups of sediment particles. This sediment fractions differ from each other in the vertical settling velocity of the particles and in the critical shear stress for sedimentation. This two parameters are different for sediment fractions because they reflect the distinction between the smaller particles and larger particles. For the smaller particles the water resistance, which is quadratic with the diameter, is higher compared to the weight, which has 3rd power relation with diameter, than for the larger particles. The resuspension velocity and the critical shear stress for resuspension apply to whole water bed with all three sediment fractions together. These three sediment fractions are assumed to be mixed within the sediment layer. The resuspension flux of each sediment fraction depends on the relative amount of the that specific fraction in the sediment layer.

The transport of sediments is based on the method of Krone - Partheniades for the resuspension – sedimentation behaviour. The shear stress at the bottom (τ) is a function of flow, the roughness of the soil and the water depth. A distinction can be made between three states of water flow and sediment transport (see Figure 4.1).

- Sedimentation occurs when the bottom shear stress is lower than the critical shear stress for sedimentation ($\tau < \tau_{crit, sed}$);
- Resuspension occurs when the bottom shear stress exceeds the critical shear stress for resuspension ($\tau > \tau_{crit, res}$);
- Sediment is completely transported with the water flow, when the bottom shear stress is higher than the critical shear stress for sedimentation and lower than the critical shear stress for resuspension is ($\tau_{crit, sed} < \tau < \tau_{crit, res}$).

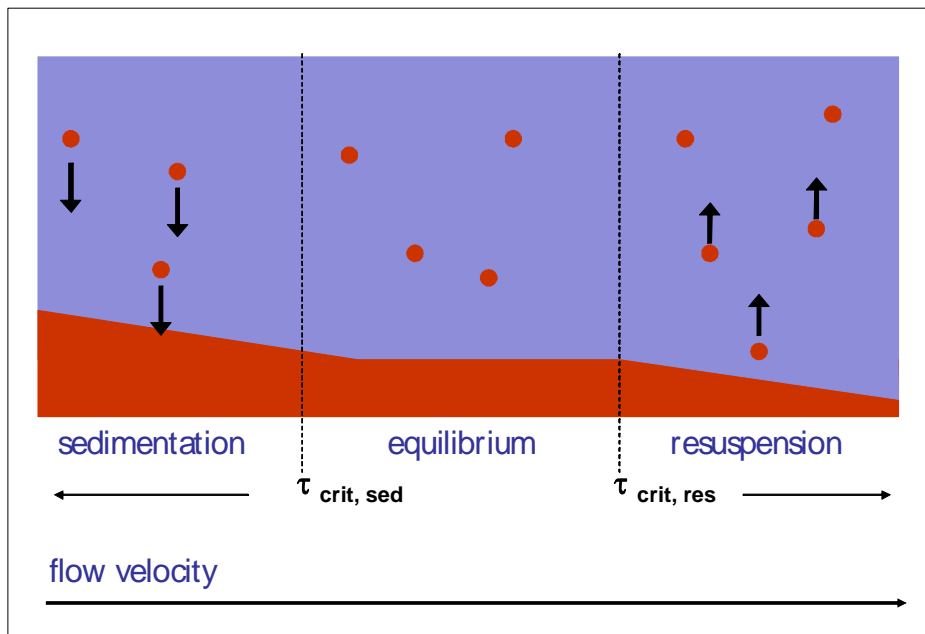


Figure 4.1 Resuspension–sedimentation in the sediment model

4.3 Heavy metals Pollutants

The number of substances added in the model and the level of detail of process formulations depend on the water quality problem to be investigated and of course on the behaviour of the water system. In the case of modelling heavy metals, their adsorption to inorganic suspended solids must be considered. Heavy metals ions bind to inorganic suspended sediments. These sediments allow binding with the iron(oxy) hydroxides, manganese(oxy) hydroxides and aluminium hydroxides as well as the clay surface. Adsorption to organic matter generally delivers a minor contribution. Together these components constitute the CEC (Cation Exchange Capacity) of sediment. The bigger particles have a smaller surface to weight ratio and consequently also a smaller amount of binding locations per unit of weight. Furthermore, the amount of adsorbed metal per unit of sediment weight is dependent on the ratio of metal ions to competing ions. The adsorption is linearly proportional to the dissolved metal concentration for given (average) chemical conditions. The proportionality coefficient is called the partition coefficient. However the partition coefficient depends on the presence of other ions as well and is thus generally lower at lower pH and is also lower for seawater with many competing ions. The affinity of heavy metals for a sediment fraction in particular is different and each affinity can be specified in the water quality model. Furthermore, it is possible to adjust the adsorption coefficient for each metal in the water and in the sediments.

The relationship is formulated as follows:

$$C_{\text{metal,particulate}} = k_d \cdot C_{\text{sediment}} \cdot C_{\text{metal,dissolved}}$$

If the dissolved and particulate metal concentrations are expressed in the same units and if the sediment concentration is expressed in mg/l then the k_d is expressed in l/mg.

Figure 4.2, shows some of the processes in a model for copper. The processes are similar for other metals, but the partitioning coefficients may be different. The pink box on the left side represents the dissolved copper. Suspended solid yellow box on the left side can also be understood as SPM (including particulate organic matter). The pink/yellow box on the right side gives the particulate phase of copper. A process that is missing is the complexation of copper with dissolved organic carbon.

The variables in the sediment quality model that were simulated are: arsenic (As), cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn) in the water column (as total concentrations) and in the sediment. These metals have an affinity for sediment and suspended matter, which varies per sediment fraction. The concentration of the particulate fraction of heavy metals in the model are determined by means of their partitioning coefficient.

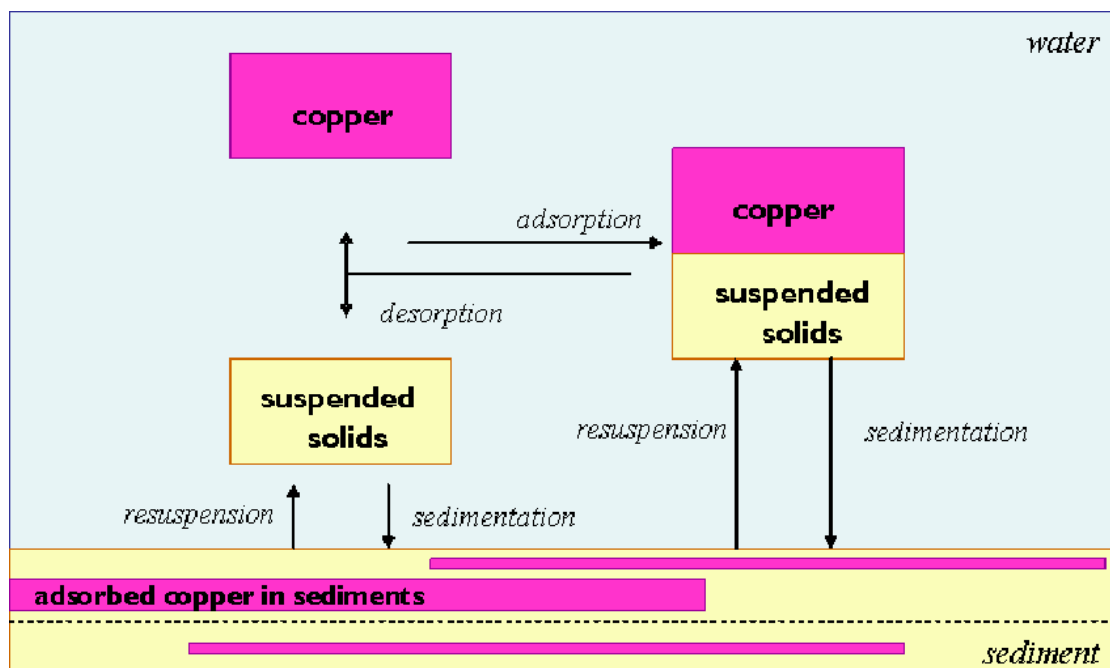


Figure 4.2 Model for copper in the water and in the sediment in Delwaq

4.4 Delwaq calculation of sedimentation and erosion

The resuspension and sedimentation behaviour of sediments in the Delwaq processes library leans on the comparison of the local bottom shear stress with critical shear stresses for sedimentation and resuspension. The local bottom shear stress is computed using:

$$\tau = \frac{\rho * g * V^2}{C^2}$$

τ = Bottom shear stress Pa (=kg/m/s²)

ρ = Water density (kg/m³)

g = Acceleration of gravity (m/s²)

V = Water velocity (m/s)

C = Chezy's coefficient (m^{0.5}/s)

The Chezy coefficient is a measure of roughness of the soil. The Chezy coefficient is from Delft3D-Flow to Delwaq.

Sedimentation takes place when the shear stress sinks below the critical shear stress for sedimentation according to:

$$R = v_{\text{settl}} \cdot \left(1 - \frac{\tau}{\tau_{\text{cr}}} \right) \quad \text{for } \tau < \tau_{\text{cr}}$$

The R (m/day) multiplied with the concentration (g/m³) gives the settled in g/m²/day. The coefficients used for the 3 size fractions of inorganic sediment can be found in Table 5.

Erosion of bed material takes place to a similar formula:

$$E = v_{\text{res}} \cdot \left(\frac{\tau}{\tau_{\text{cr}}} - 1 \right) \quad \text{for } \tau > \tau_{\text{cr}}$$

The erosion rate E has the dimension of g/m²/day. The erosion of the different fractions is obtained by multiplication of this rate with the relative fractional composition.

It must be noted that these processes, if applied for long term simulations, may cause a filtering of the bed material. If during high flow conditions sediment resuspends, then the coarse fractions may settle out soon again due to their higher settling velocity and higher critical shear stress for settling whereas the fines may be carried further along. Only at lower flows the finer fractions may start settling again. The water bed will be more or less in a dynamic equilibrium with the flow pattern and sediment concentrations of a river.

4.5 Sediment Composition

Suspended sediment has a wide grading of grain diameters within DELWAQ the distinction of suspended matter is made between three fraction of sediments. In this project, the following groups are applied: fine silt, coarse silt and fine sand, where each group has its own characteristics. This fraction distribution is based on (Delft Hydraulics, 2005) in which the suspended solids in Hollands Diep and Dordtse Biesbosch was investigated, see Table 4.1.

Table 4.1 Sediment fractions as considered in the model

Variable	Sediment Type	Units
IM1	Fine silt	gr/m ³
IM2	Coarse silt	gr/m ³
IM3	Fine sand	gr/m ³

In general the fine sands will settled already more upstream in the watershed where water velocities close to the bed are generally too high to make the fine fractions settle. During flood events however this coarser fraction may partly resuspend upstream enter the Delta area of this study. The coarse silt fraction will generally settle in the Delta area of this study. During flood events they may be carried along with the flow even in this area. The fine silts may form the particulate material that also under normal circumstances reaches the sea and will settle in the Delta area of this study only during low flow events.

The waterbed will be composed of all three fractions, because low flow periods, normal conditions and high flow conditions will have happened in the alternate preceding period in the past. Because the long term history is not modelled, the model must be initialised with conditions that sufficiently reflect this history.

4.6 Initial conditions

The initial state of the model largely determines the calculations results. The initial conditions establish the suspended solid concentrations and the heavy metal concentrations at the start of the simulation. During the simulation this material will start moving especially because we are studying approximately a once in 100 year high flow event.

Sediments that settle form a top water bed layer that is pretty loose and susceptible for resuspension. With time water is pressed out from between the pores and the material consolidates. This is increasingly more the case when new layers form on top. This so called consolidation process makes that the critical shear stress for resuspension generally increases with sediment depth. There is little knowledge on the thickness of the soil layer that is susceptible for resuspension in this case. Also the heterogeneity in the study area is big that is why initially an uniform layer thickness is assumed for this study. The initial mass of sediment on the bottom corresponds to a soil thickness of 10 cm, dry soil density of 2600 kg/m³ and a porosity of 0.80. With these values 52 kg sediment / m² is the initial condition. A complete overview of substances and initial conditions is given in Table 4.2.

Table 4.2 Initial conditions in the sediment and metal for the model.

substance	description	initial condition	units
IM1	fine silt in water	restart file	mg/l
IM2	coarse silt in water	restart file	mg/l
IM3	fine sand in water	restart file	mg/l
IM1S1	fine silt in sediment	33%	gDM
IM2S1	coarse silt in sediment	33%	gDM
IM3S1	fine sand in sediment	33%	gDM
Cd	cadmium in water	restart file	g/m ³
Cu	copper in water	restart file	g/m ³
Ni	nickel in water	restart file	g/m ³
Pb	lead in water	restart file	g/m ³
Zn	zinc in water	restart file	g/m ³
As	arsenic in water	restart file	g/m ³
CdS1	cadmium in soil	annex A	g
CuS1	copper in soil	annex A	g
NiS1	nickel in soil	annex A	g
PbS1	lead in soil	annex A	g
ZnS1	zinc in soil	annex A	g
AsS1	arsenic in soil	annex A	g
Continuity	Continuity	1	-

For the initial conditions of the suspended solid and metal concentrations in the water column, the model simulation was initialized with a restart calculation. In other words the first calculation was done only with suspended solid and metal concentrations at the boundaries to adjust the concentrations in the water phase to the boundary concentrations. For the second calculation these values were read from the restart files to act as initial conditions.

The water bed layer at the bottom is divided in equals proportions of sediment fractions (1/3) with a layer thickness layer of 10 cm. Initial conditions for metal concentration in the soil were taken from the report 9S8838.A0 "Suspended solid transport in the Brabantse Biesbosch" in chapter 7 Risk analysis. table 7.1 and figure 7.1 show us the quality of the top soil layer with various metal concentrations. in annex A can be found the used table and figure.

4.7 Quality of Soil conditions

According to the Order No DJZ2007124397 of December 13, 2007, rules are given for the use of soil depending on its quality. These rules apply for the threshold concentration levels of pollutants. A schematization of the classification can be seen in Figure 4.3.

Toepassen op bodem onder oppervlaktewater



Figure 4.3 Classification applied to dredge material from the water bed

The articles in Chapter 4 of these rules, give general provisions and classify the material in different classes, specifying tables with maximum values for classes

Table 4.3, gives background and maximum values for soil quality classes A and B.

Table 4.3 Maximum values for soil qualities

Metal in Soil in mg/kg	MAX FREE APPLICABLE Background value	MAX CLASS A intervention value	MAX CLASS B intervention value
arseen	20	29	76
cadmium	0,6	4	13
koper	40	96	190
lood	50	138	530
nikkel	0	50	100
zink	140	563	720

4.8 Model coefficients

Model coefficients are presented in this section and are derived from literature, where sedimentation, resuspension and transport with the flowing water are the main processes in the sediment model. The influence of each of these processes on the three sediment fractions in the water bed and in the water depends on the parameter values in the model. The main parameters in the suspended sediment model are the velocity of suspended particles and the critical shear stress for sedimentation and resuspension. For example, a higher settling velocity and a higher critical shear stress for settling that is common for sand will result in a higher net sedimentation. In the river as a whole the result will be that this material settles out more upstream in the water system. A lower settling velocity and a lower critical shear stress that is common for the fines will result in low net sedimentation and a larger part of the material may leave the water system at the downstream boundary. A higher resuspension velocity and a lower critical shear stress for resuspension will produce more resuspension.

The parameters porosity and density of the sediment particles only affect the calculated thickness of the soil layer. These two parameters do not affect the settling and resuspension of the particles or the mass balance in the water and in the soil. A summary of the parameters and the corresponding values can be seen in Table 4.4.

Table 4.4 Process coefficients in the sediment model.

coefficient	name	value	units
VSedIM1	sedimentation velocity IM1 (fine silt)	0.25	m/day
VsedIM2	sedimentation velocity IM2 (coarse silt)	10	m/day
VsedIM3	sedimentation velocity IM3 (fine sand)	25	m/day
TauScIM1	critical shear stress sedimentation IM1	0.005	N/m ²
TauScIM2	critical shear stress sedimentation IM2	0.03	N/m ²
TauScIM3	critical shear stress sedimentation IM3	0.1	N/m ²
ZResDM	zeroth-order resuspension flux	500	g/m ² /day
TaucRS1DM	critical shear stress resuspension	0.60	N/m ²
RHOIM1	density IM1	2.6 10 ⁶	g/m ³
RHOIM2	density IM2	2.6 10 ⁶	g/m ³
RHOIM3	density IM3	2.6 10 ⁶	g/m ³
PORS1	porosity sediment layer 1	0.80	-
MinDepth	minimum water depth for sedimentation	0.01	m
DMCFIM1	DM:C ratio IM1	1	-
DMCFIM2	DM:C ratio IM2	10	-
DMCFIM3	DM:C ratio IM3	100	-

The partition coefficients were derived from literature and from other project reports. These partition coefficients (K_d in l/g) are given for the three sediment fractions, both in the water column and in the water bed. As initial guess the values for IM2 and IM3 are derived using a multiplication factor to the value of IM1. Because no further information exists on the different fractions of sediment, it is just an assumption to illustrate the functioning of the model. If IM3 is sandy, then the values are likely too high. If IM3 is only gradually coarser than IM1, the given value may be realistic.

Table 4.5 Partition coefficients in the suspended matter and in the water bed

Metal	K _d field	K _d Suspended solid (l/g)			K _d Bed (= 1,5* K _d SS)		
		IM1	IM2			IM1	IM2
arseen		317	243	228	476	365	341
cadmium		138	107	102	207	160	153
koper		58	42	38	86	63	58
nikkel		12	8	7	17	12	10
lood		708	565	535	1062	847	802
zink		132	92	83	199	138	124

4.9 Boundary conditions

The number of monitoring stations with records of suspended matter observations, is limited. Since 1992 the number of stations is greatly reduced. This also applies to the measurement frequency. Measurements of suspended inorganic matter in the Rhine Meuse estuary are scarce. Therefore Rijkswaterstaat RIZA has derived relationships between suspended matter and river flow (Snippe et al, 2005).

Statistical relationships were derived from previous measurement periods for locations in the Rhine-Meuse estuary. For the pathway locations of Boven Merwede, New Merwede, Hollands Diep and Haringvliet, the relationship is based on the station of Lobith. For the pathway locations of Bergsche Maas, Amer, derived relationships are based on the location of Lith.

These relations were used to derive the boundary conditions of the suspended solids in the model, for the locations of Boven Merwede, Bergse Maas, Beneden Merwede, Kil, Spui and the Haringvliet Sluice, These relationships have been computed for the period from 1995 to 2001. Using these relationships daily discharge and suspended sediment concentration data in time series have been derived for the model.

The following relationships were used to generate daily suspended matter levels:

$$\text{SPM(Lith)} = 10.57 + 0.000015456 * \text{QLith}^{2.247}$$

After having obtained the SPM at Lobith and Lith, a statistic relation is used to derive values of suspended solid concentration for our boundary locations. The following relation were used:

$$\text{SPM(Vuren)} = -34 + 6.07 * \text{SPM(Lobith)}^{0.65}$$

$$\text{SPM(Hellevoetluis)} = -4.61 + 0.054 * \text{SPM(Lobith)}^{1.43}$$

$$\text{SPM(Keizerveer)} = -6.65 + 3.651 * \text{SPM(Lith)}^{0.671}$$

$$\text{SPM(Papendrecht)} = -25 + 11.18 * \text{SPM(Vuren)}^{0.505}$$

$$\text{SPM(Puttershoek)} = 4.15 + 0.67 * \text{SPM(Vuren)}$$

Figure 4.4, shows the suspended solids concentrations at the boundaries of the model.

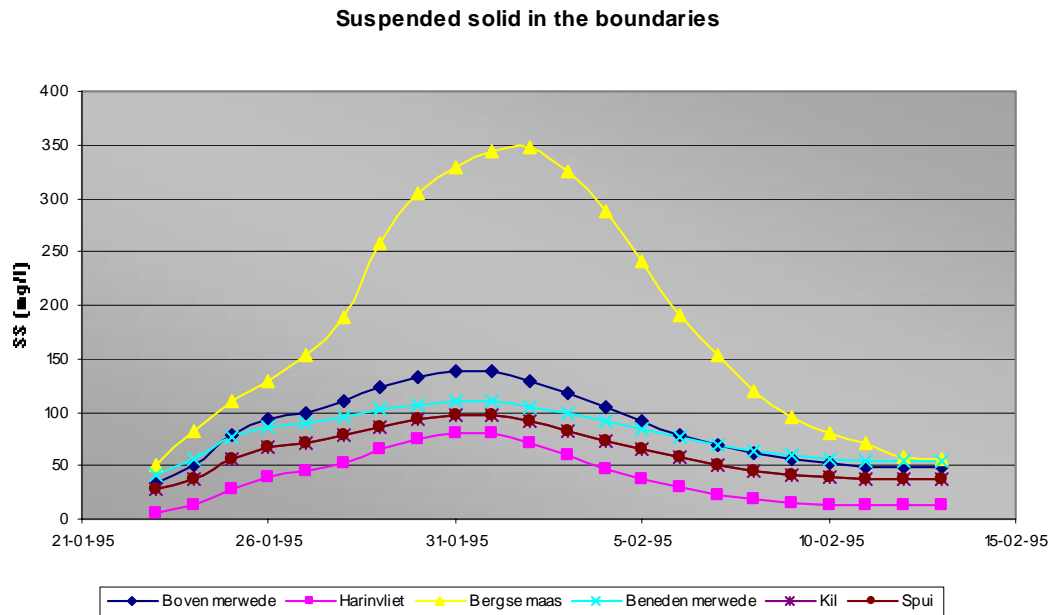


Figure 4.4 Concentration of suspended solids at the boundaries of the model

Report Q4201 “Suspended solid in the Rhine-Meuse estuary” provides a suspended solid fractional distribution based on measurements. The grain size distribution according to a Sedigraaf provides the particle size distribution, where there is the clearly existence of 2 dominant groups.

These are the fraction smaller than 10 micrometers and the fraction larger than 20 micrometers. Table 4.6, shows the distribution group for the edges.

Table 4.6 Distribution Group suspended solid according to the Sedigraaf

Fraction	Sediment Type	Grain Size	Distribution
IM1	Fine silt	< 10 µm	59%
IM2	Coarse silt	from 10 to 20 µm	5%
IM3	Fine sand	> 20 µm	36%

For the heavy metal concentrations at the boundaries, data was taken from the Waterbase database, with scarce values for this period and only for the Boven Merwede, Bergse Maas and the Haringvliet Sluice boundaries of the model.

Figure 4.5, Figure 4.6 and Figure 4.7 show the total heavy metal concentrations in the water in µg/l.

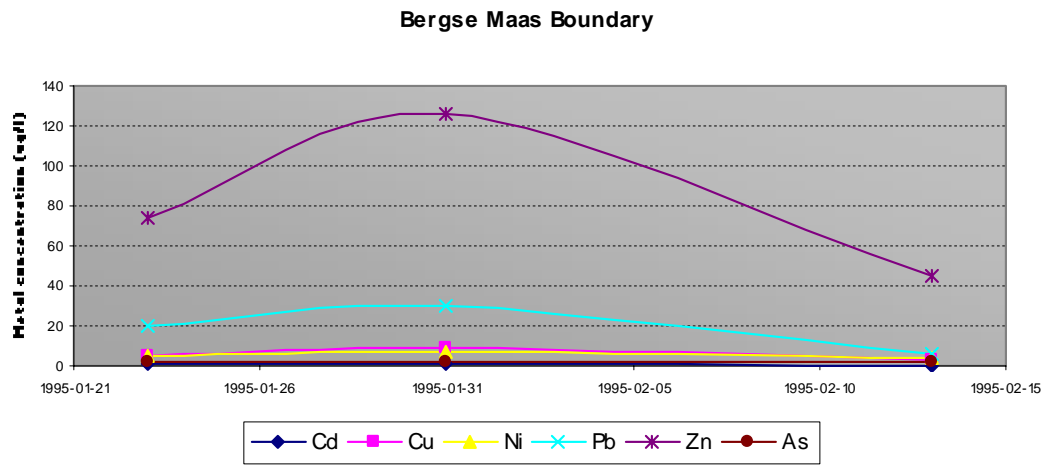


Figure 4.5 Metal concentrations at the Bergse Maas boundary.

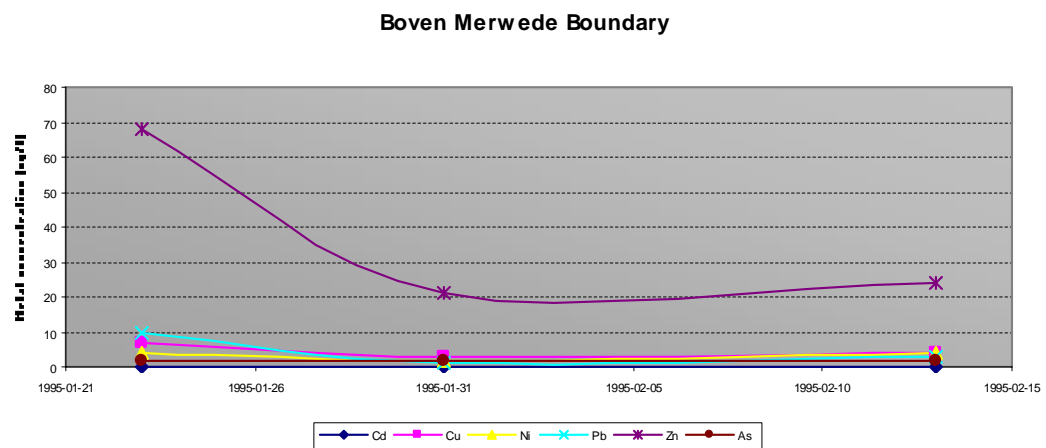


Figure 4.6 Metal concentrations at the Boven Merwede boundary.

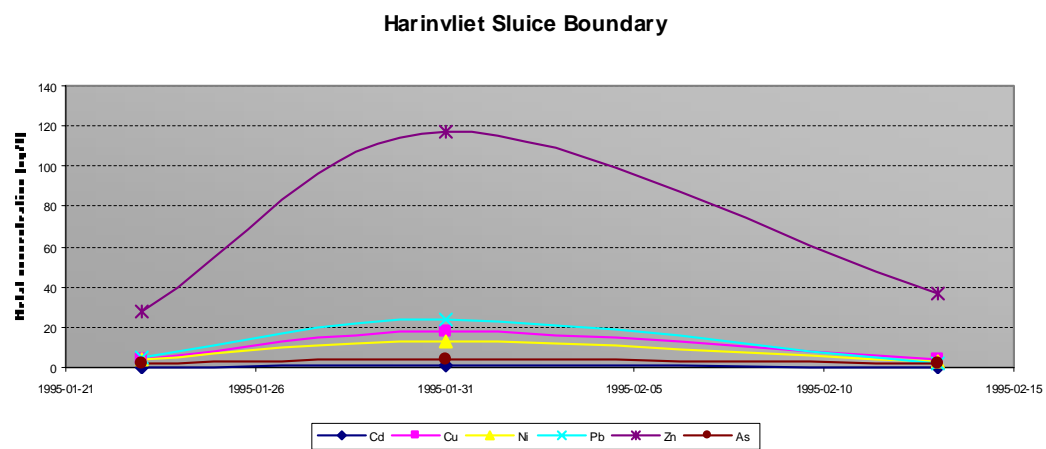


Figure 4.7 Metal concentrations at the Haringvliet Sluice boundary.

4.10 Simulation period

The inflowing discharges, the suspended particulate matter concentrations and the heavy metal concentrations at the boundaries of the model cover the event period from 23-01-1995 to 13-02-1995.

4.11 Scenario Analysis

Because we are interested in the behaviour of the water system during high flow events, the big event of January 1995 was selected as model event. Flow discharges are taken from measurement stations for this period at the boundaries of the model. Also using some statistical relationships helped to derive suspended sediment inorganic matter for the model's boundaries from measurement stations. Heavy metal concentrations at the boundaries of the model for this period is obtained from measurements.

Because of the relatively short simulation period the study focuses on the behaviour during high flow events only, given the actual state of the river and its water bed. A more complete assessment is obtained by long term simulations of the river system, where the water bed is allowed to reach a dynamic equilibrium with the water phase. However, such an assessment is however far beyond the current study objective.

We conclude that a major uncertainty in the model is the composition of the sediments in the water and in the water bed layer for the river and in the floodplains. Assumptions have been made to conduct the study, but results can only be relied upon if further verification can take place.

5 Modelling Results

5.1 Introduction

In this chapter the results of the Delft3D model calculation for the high flow event of January 1995 are presented. This model uses Delft3D-Flow to simulate the water movement in the study area, providing the hydraulic conditions. Subsequently, the resulting flow fields are used to calculate the bed shear stress. This bed shear stress is a measure for the erosion and sedimentation of sediments.

5.2 Shear Stresses Calculation

The reference calculation gives a quick overview of the spatial distribution of the shear stress at the bottom soil layer in the main river and the floodplains, these calculations are shown in integral maps. These maps show a snapshot at the highest flow discharges on February 2nd of 1995.

The highest flow rates occur in the main channel. Which translates in a high shear stress in the main channels (see Figure 5.1 and Figure 5.2), which can reach 12 N/m^2 . The shear stress in the floodplains is an order of magnitude lower than in the main channel. What is striking is the clear distinction between areas with a high shear stress and areas with low shear stress.

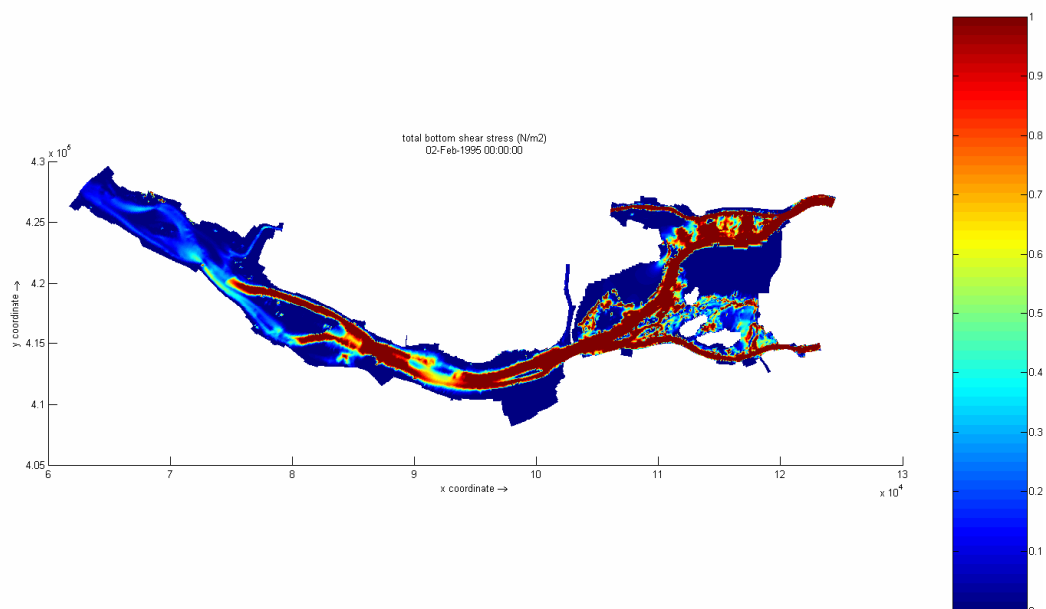


Figure 5.1 Shear stresses at the bottom layer from 0 to N/m^2 .

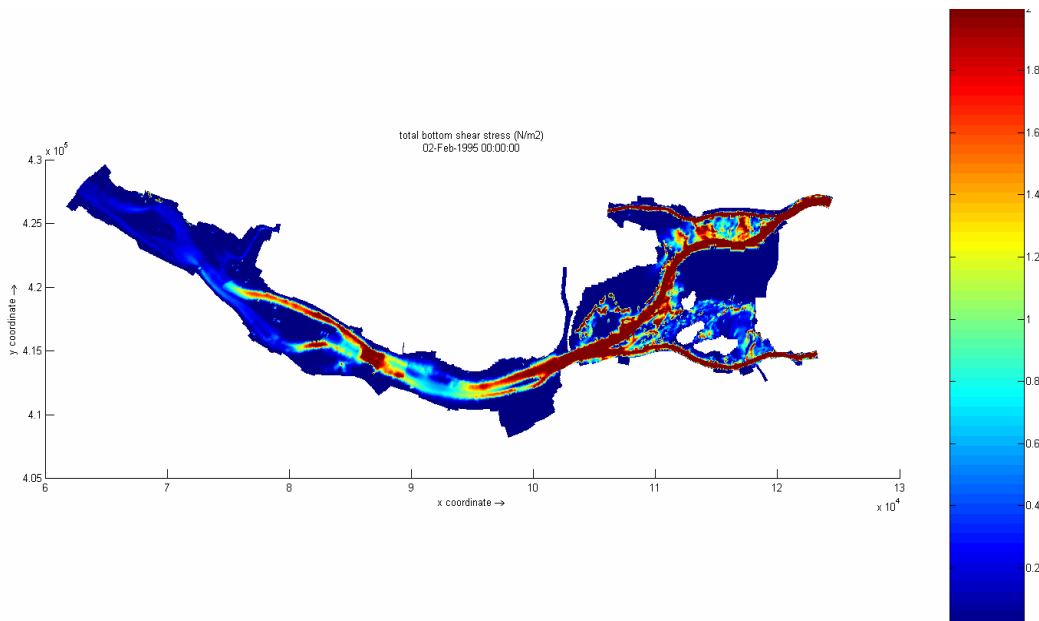


Figure 5.2 Shear stresses at the bottom layer from 0 to 2 N/m²

The above data provide insight into the likelihood that erosion will occur. It is not possible to display the amount of erosion. The resistance of the soil and sediment from the shear stress is highly dependent on the type sediment, the degree of consolidation, the history of the sediment, organic matter content and several other factors. This can only be determined by means of extensive laboratory experiments. In this study we therefore restrict an indication of the potential erosion.

Figure 5.3, shows the thickness of the top sediment layer at the end of the simulation period. At the beginning of this event with high discharges, the soil bottom layer was everywhere 10 cm thick. After the simulation period, we can note a clearly visible pattern. The sediment layer disappeared in the upstream part of the main channel while some sedimentation occurs in the downstream floodplains of the river.

It can also be seen in the figure below that some erosion and sedimentation happens in the floodplains of the Biesbosch area, but in small magnitudes compared to the main river channel.

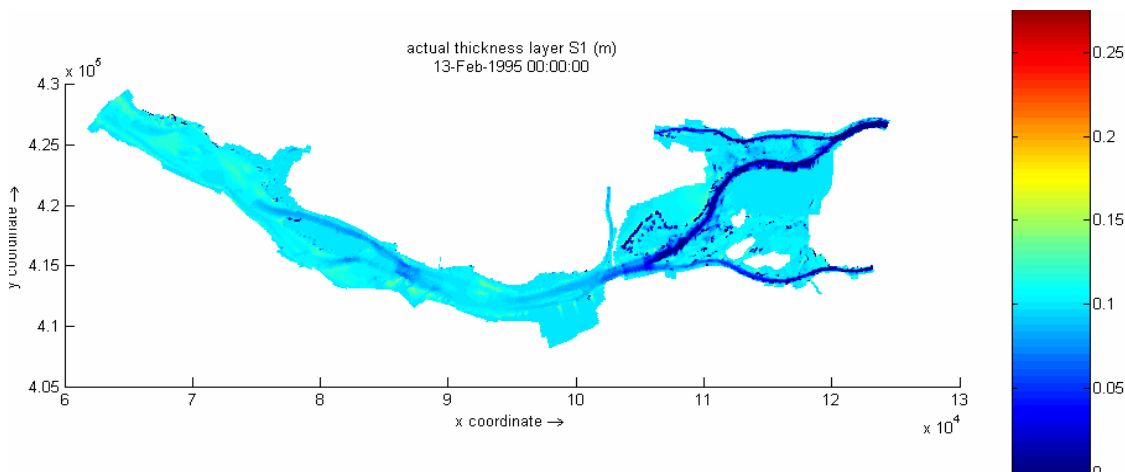


Figure 5.3 thickness of the soil layer at the end of the simulation.

5.3 Origin of water and sediments

It is interesting to know where the sediment at a certain location comes from, this allow us to say something about the possible recontamination. Also the incoming high river flows may have certain influence on the water body behaviour of some areas. Delwaq allows to simulate the origin of water and sediment without too much difficulty. This is done by applying a tracer in the water body.

Our first analysis consists of an identification where the water mass of the river flow comes from. Figure 5.4 and Figure 5.5 show the fractional distribution of water in a Rhine and a Meuse water fraction at the end of the simulation period. This fractional distribution will also determine the origin of the locally settled sediments.

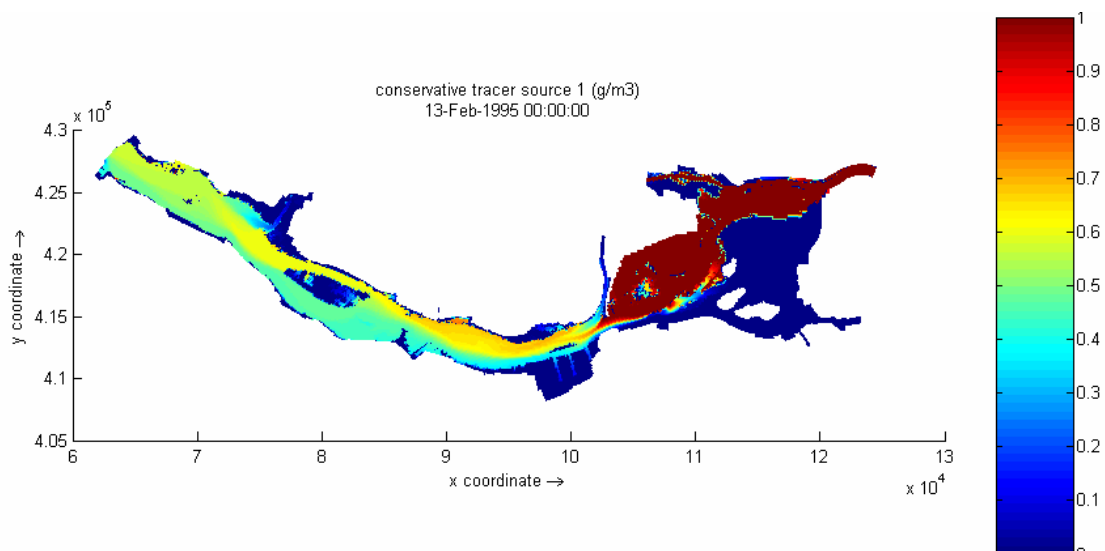


Figure 5.4 Fraction of Rhine water at the end of the simulation period.

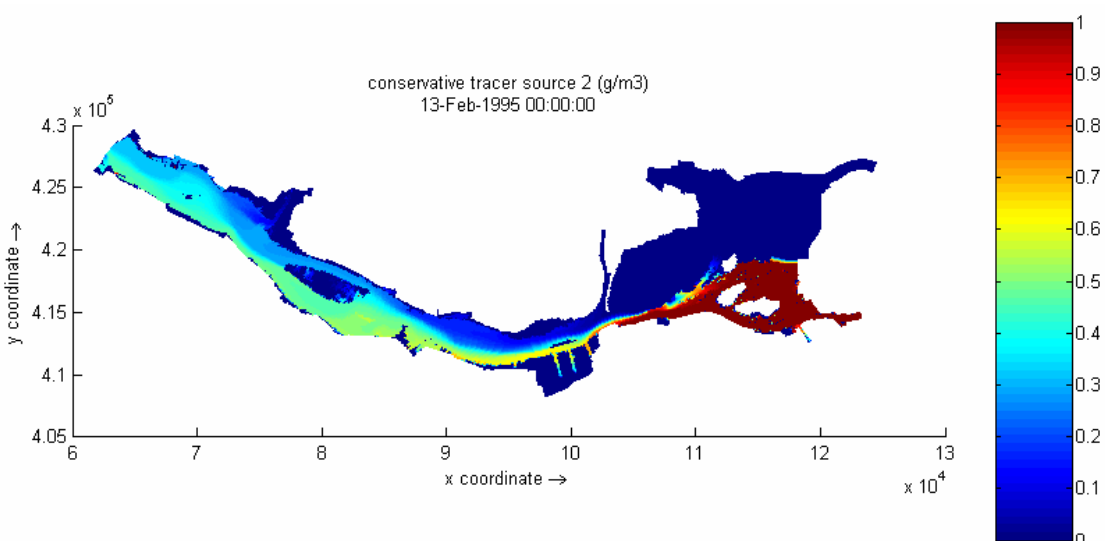


Figure 5.5 Fraction of Meuse water at the end of the simulation period.

5.4 Sedimentation flux of sediments

The sedimentation flux of the three groups are in Figure 5.6 to Figure 5.8. The fine silt fraction (IM1) settles in a very thin layer in shielded areas of the upper region. The sedimentation flux of the coarse silt and fine sand fractions (IM2 and IM3) is much higher than the sedimentation of fine silt. Analyzing the figures, we can say that the sedimentation patterns of the coarse silt and fine sand fractions in the model are very similar and take place at the location where the main river flow reduces its velocity.

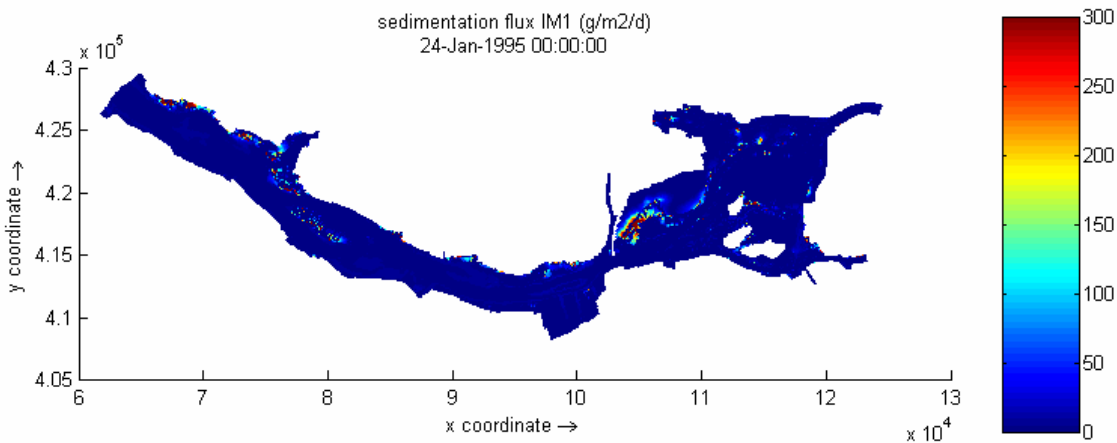


Figure 5.6 Sedimentation flux of IM1.

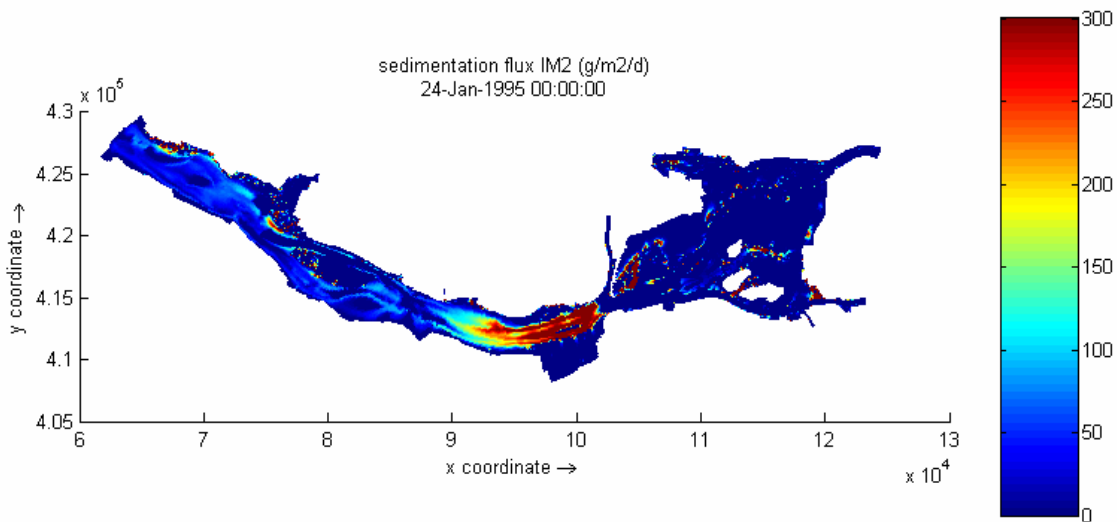


Figure 5.7 Sedimentation flux of IM2.

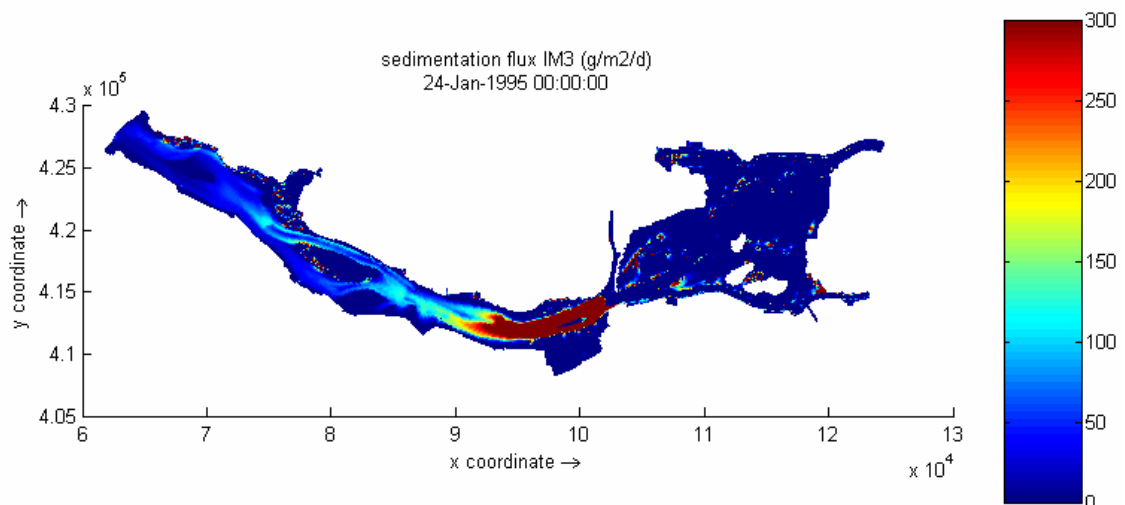


Figure 5.8 Sedimentation flux of IM3

5.5 Resuspension flux of sediments

The resuspension flux for the three fractions is nearly equal. Therefore only the resuspension flux of fine silt (IM1) is shown in this report (see Figure 5.9). The similarity of resuspension flux of the three groups has several causes:

- The model is initialized with a soil layer in which all three groups are present in equal proportion.
- The critical shear stress for resuspension is the same for all three fractions. Once this threshold is exceeded, resuspension in the same proportions happen to the fractions.
- Initially all these three groups will go equally into resuspension, then due to different sedimentation velocities, the bed composition will differentiate but the simulation period is too short too let this process have substantial effect.

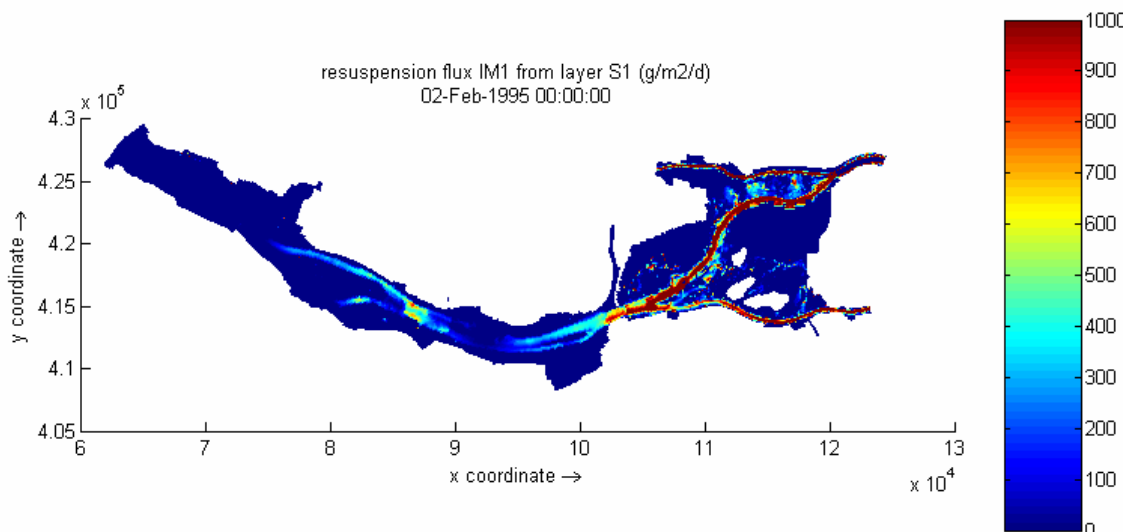


Figure 5.9 Resuspension flux for IM1

5.6 Heavy metal pollution in the top soil layer

Analysis was made for all the heavy metals, but results are only shown for Zinc. The other metals show the same simulation pattern.

In order to obtain initial conditions for the simulation measurement data of metal concentration in the top sediment layer in the Biesbosch floodplains was used for a very limited area (see Figure 5.10). The concentrations in this figure are expressed in g/m^2 . One of the objectives of the study is to see where the polluted sediment ends up after the event has passed. This analysis is conducted by the modelling of the total metal concentrations and the subdivision into fractions dissolved and particulate for the computation of settling and resuspension fluxes. The total metal concentrations were available as measurement values at the boundaries together with the total suspended sediment. In figure 20 it can be seen that in Bergse Maas the suspended sediment concentration runs from 50 mg/l through 350 mg/l to 50 mg/l again. In figure 21 it can be seen that the Zinc concentration of Bergse Maas runs from 75 $\mu\text{g}/\text{l}$ to 125 $\mu\text{g}/\text{l}$ and then to 40 $\mu\text{g}/\text{l}$. This means that the concentration Zinc per weight of suspended solids ran from 1.5 mg/g through 0.36 mg/g to 0.8 mg/g . Although not all zinc will have been adsorbed to the sediments, the lowest value coincides with the peak values for suspended solids. That may be caused by the fact that the peak contains more coarse material that has a lower partitioning coefficient and is thus will adsorb less metal per unit of weight.

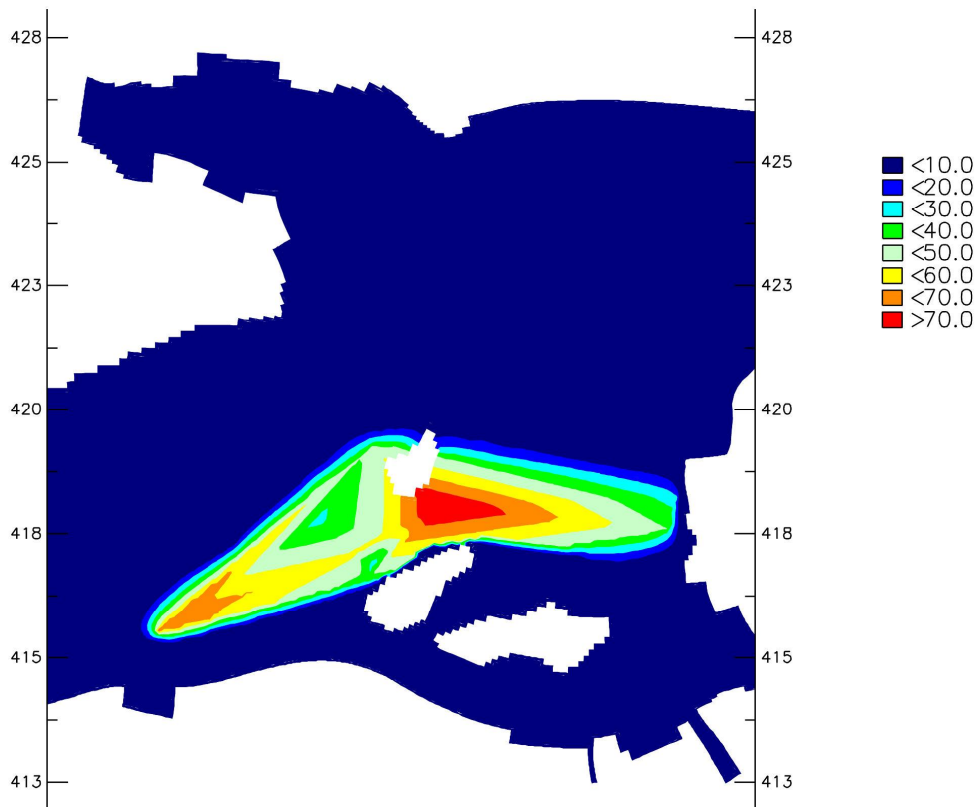


Figure 5.10 Initial Zn concentration in the water bed layer in g/m^2 .

The fractions Zinc adsorbed on particulate matter are computed using the partitioning coefficients of Table 6. For the bed material a similar partitioning is made but now with the coefficients for bed material. The sedimentation and resuspension fluxes as presented in chapter 5 thus produce proportional fluxes of heavy metals to and from the bed.

Figure 5.11 shows the zinc concentration in g/m^2 at the end of the simulation period and we can observe that polluted sediment is found in the Hollands Diep Area. Note that apparently material that entered through the upstream boundaries in suspension did not settle in the main channels around the Biesbosch, but in mainly in the Haringvliet area where the water velocities reduced

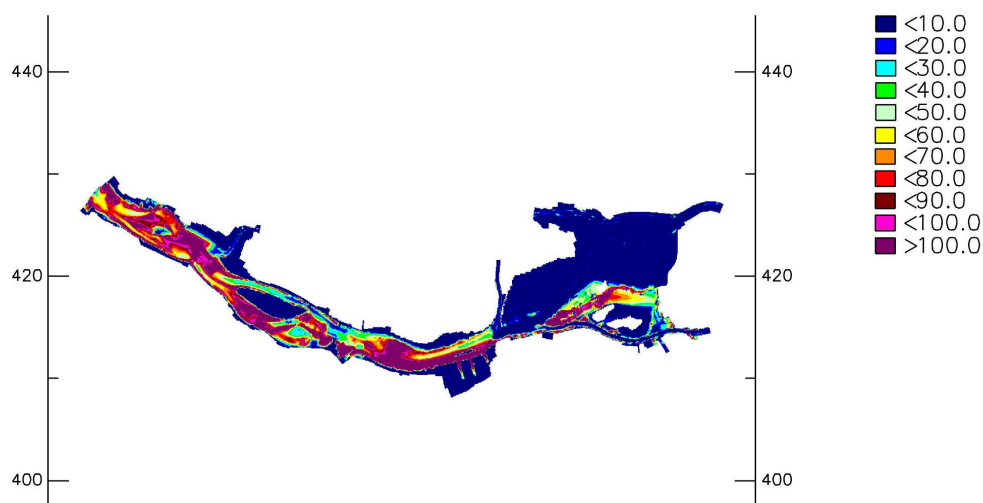


Figure 5.11 Final water bed amount of Zn in g/m^2 .

When we zoom in on our area with the specified initial condition we see Figure 5.12. This figure shows that not so much material of the initial condition has been removed, but that upstream material settled in this area with relative lower water velocities. Care should be taken that this first result is only indicative as a proof of concept, but requires more elaboration to ensure that all included processes are validated. It shows the abilities of the model, but many estimates were made with respect to sediment composition, partitioning coefficients and critical shear stresses, that should be further verified with additional data.

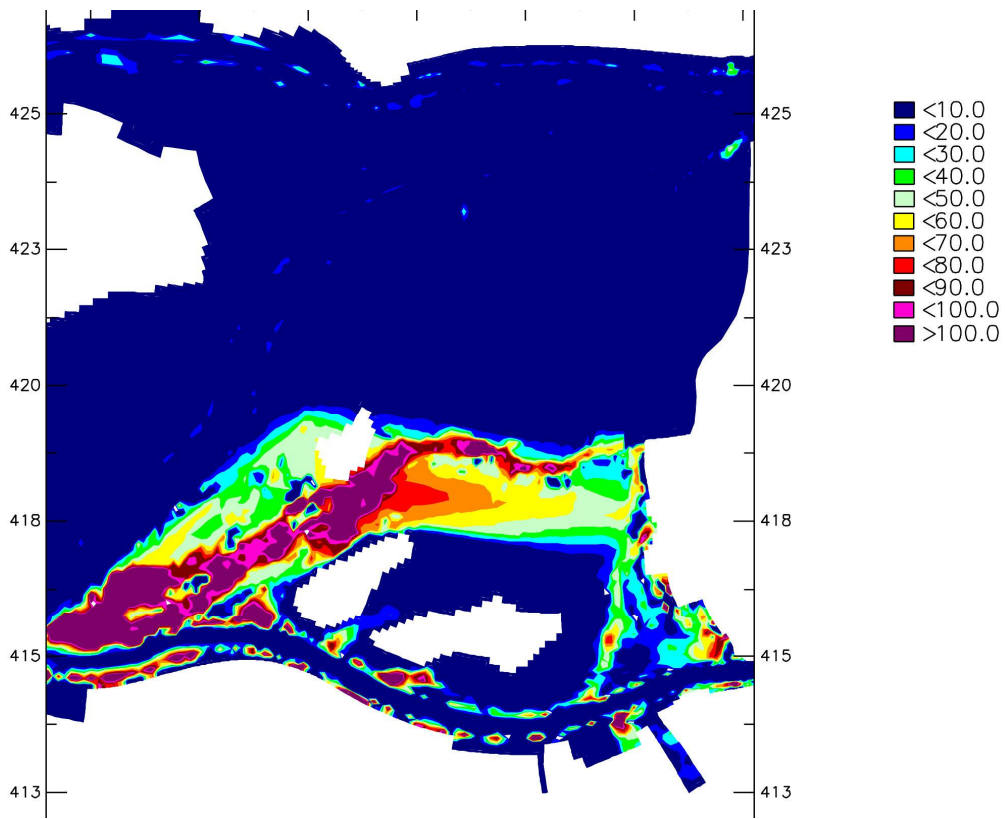


Figure 5.12 Final water bed amount of Zn in g/m^2 for the detail area of initial condition

6 Conclusions and Recommendations

6.1 Conclusions

The main conclusions of the study are as follows:

For this particular event, shear stresses at the water bed in the main channel are very high compared with the shear stresses in the floodplains. The range of shear stresses in the main channel is 0 - 12 N/m² for the floodplain areas the shear stresses are often less than 0.1 N/m² that is the critical shear stress for sedimentation that was applied for the coarsest sediment fraction.

Assuming an initial thickness of the soil layer of 10 cm, erosion is observed in the upper part of the main river where all material is removed. This needs not necessarily reflect the real situation, because the water bed in the main channels at the upper part of the model may have been clean initially.

Due to the lower velocities in the Hollands Diep and in the Haringvliet areas, sedimentation takes place at the end of the simulation in small magnitudes in local sections of the area.

Increased amounts of heavy metals at the end of the simulation occur mainly in the Hollands Diep and the Haringvliet areas and also in the Biesbosch area where the water velocities are low enough. The initial thought that erosion in the floodplains of the Biesbosch area should generate an additional transport of heavy metals may have to be adjusted.

6.2 Recommendations

The main recommendations are the following:

The suspended particulate matter at the boundaries of the model is based on statistical relationships, derived only from two measurement stations in the Rhine and the Meuse respectively (Lobith and Lith). Measurements of suspended particulate matter in a higher spatial resolution provide a better picture. It is therefore recommended to install more measurements sites specially in the Biesbosch area. Furthermore attention should be paid to the grain size distribution and the associated partitioning coefficients.

For the implementation of the previous recommendation, it is also interesting to refine the time scale to identify the tidal effects in the measurements. Sediment structure is one of the largest uncertainties. Assumptions were made for this study. Further improvement of the model could include the spatial variation and composition of the soil.

Improvement of the 2D model as setup using Delft3D could consist of: the incorporation of spatial variation in soil composition and in heavy metal concentration in the areas of concern. Furthermore, more scenarios dealing with different sources of heavy metal pollution during this extreme flow event and a further study of the partition coefficients for this area are important.

References

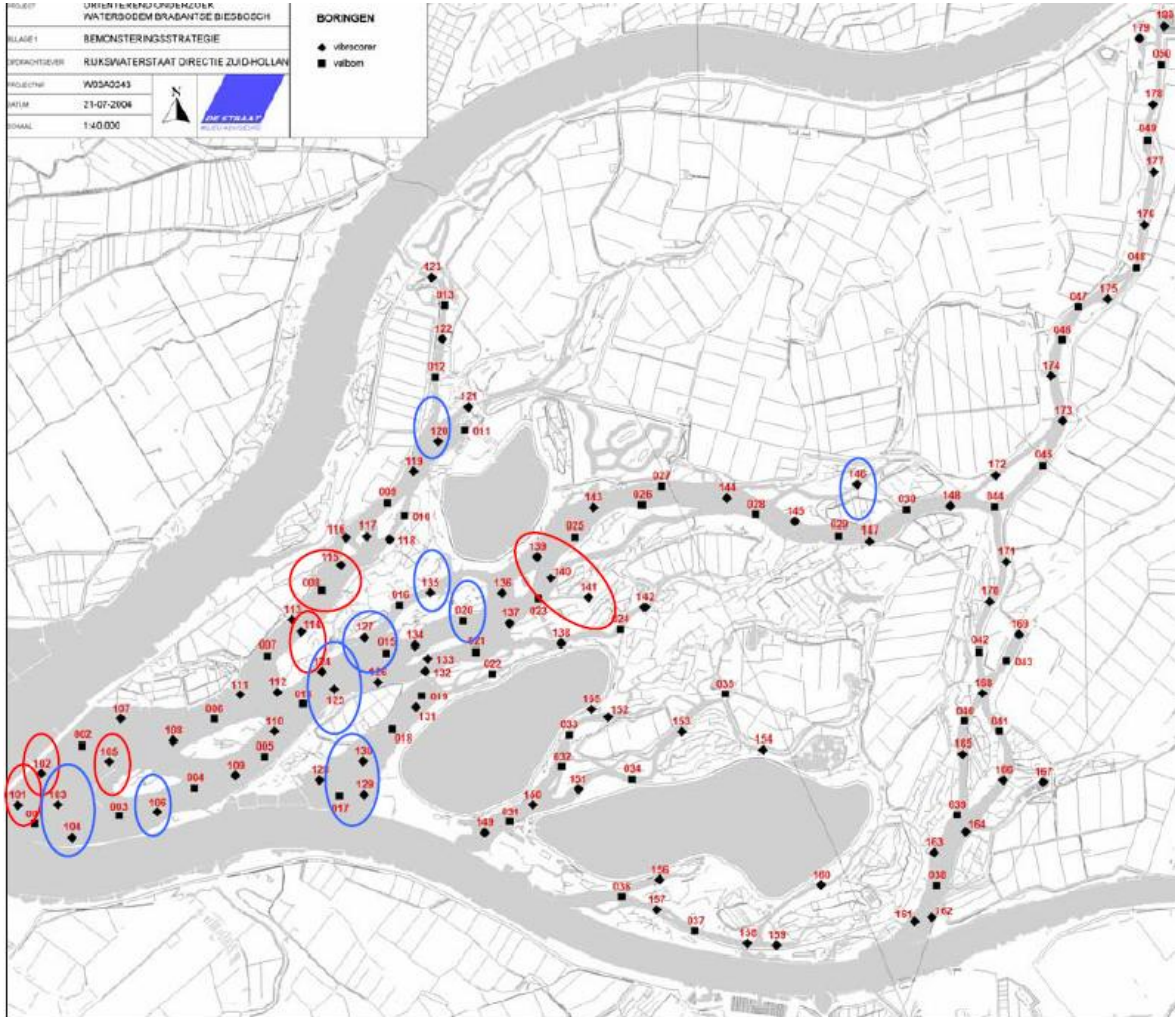
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A Quality of the top layer

The following table and graph were extracted from the final Report number 9S8838.A0 "Slibtransport in de Brabantse Biesbosch" chapter 7.

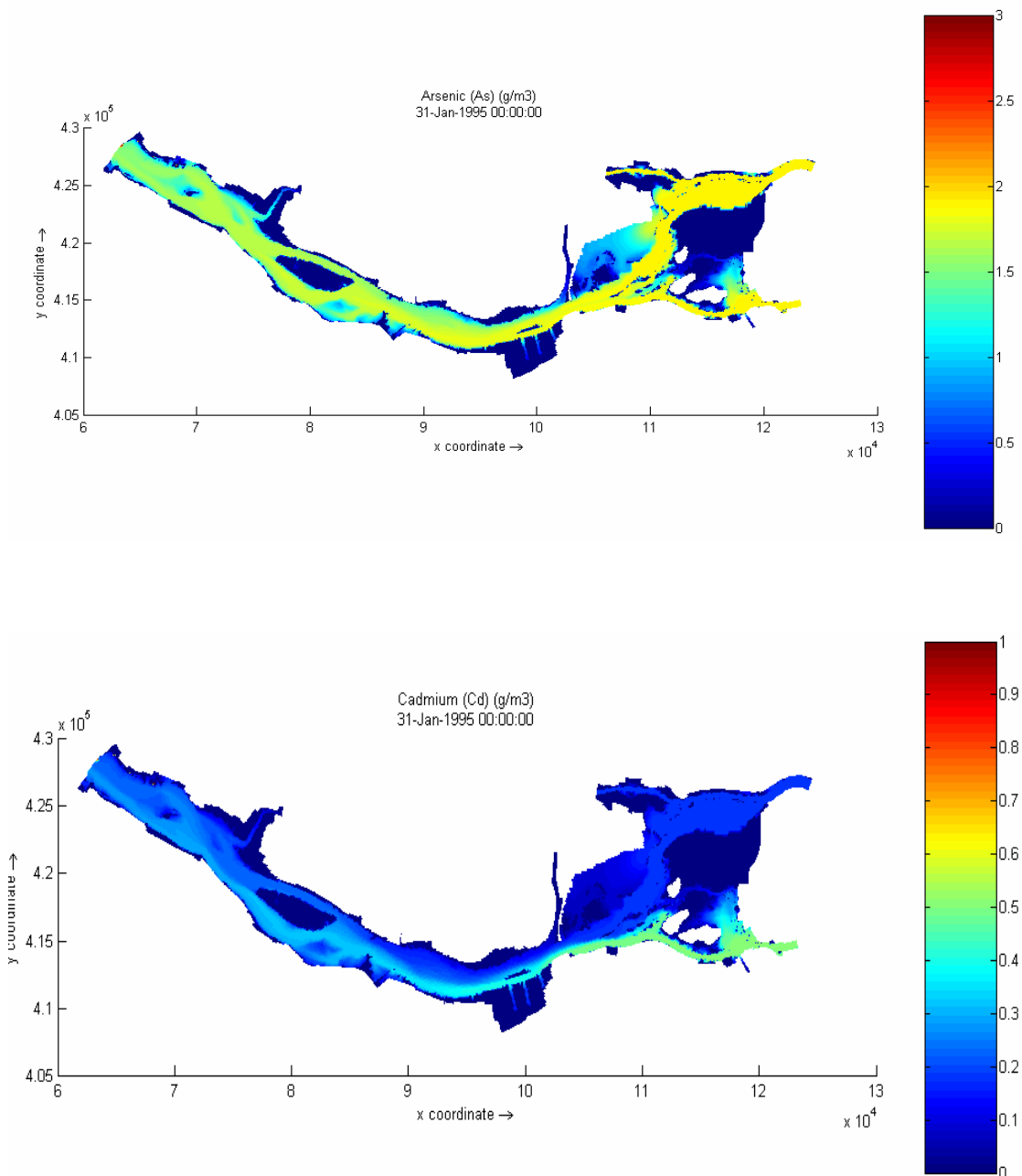
This chapter includes an analysis of the potential risk of heavy metal spreading and the quality of the top layer. the table data is from the "Exploratory research of the sediment in the Brabantse Biesbosch" (De Straat, 2004) where the level of heavy metals compared with the intervention values, are higher.

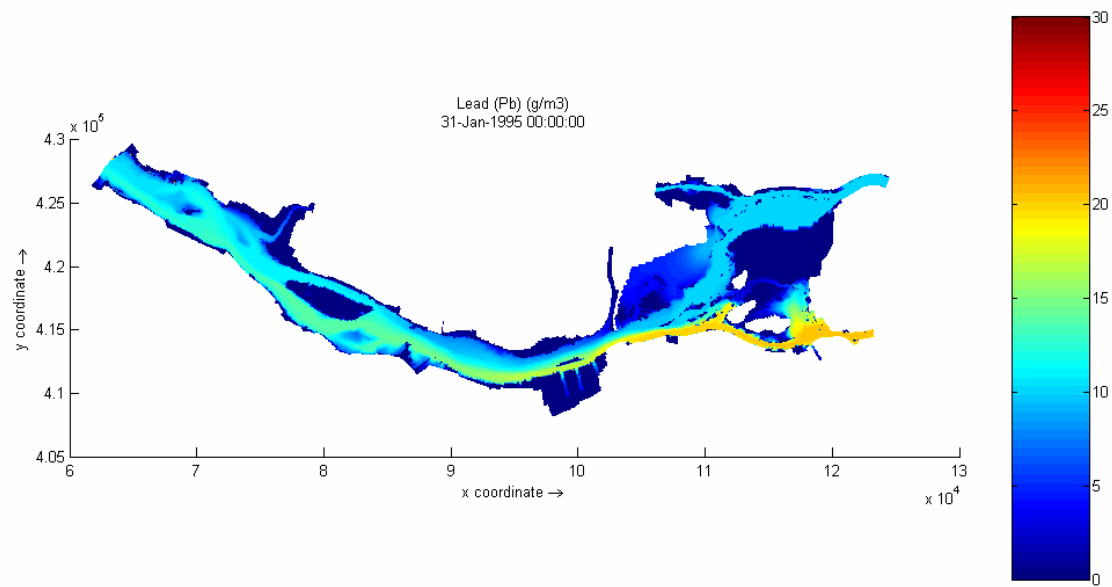
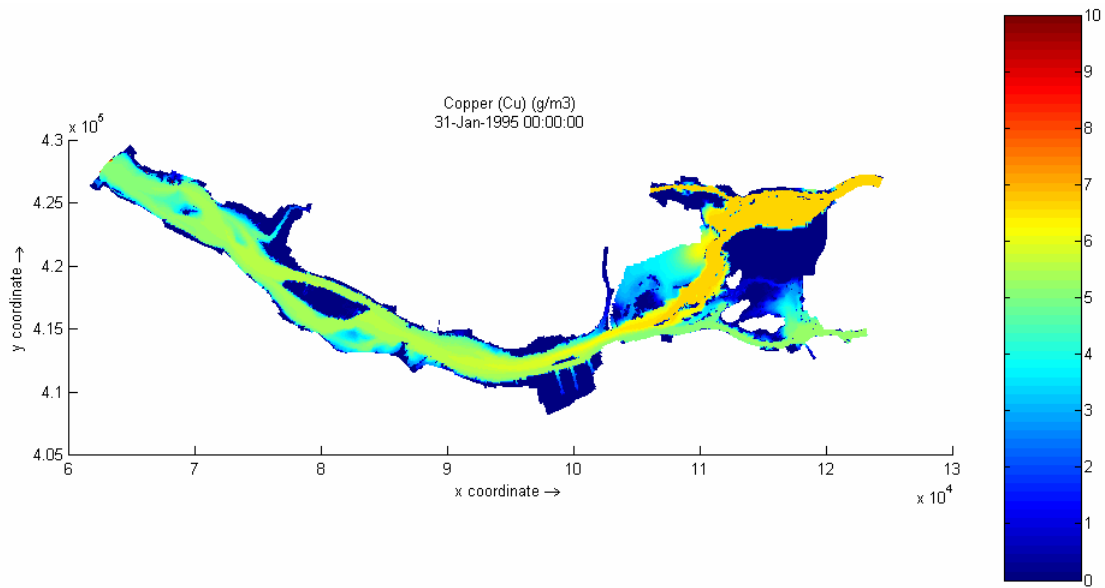
Mengmonster samenstelling (zie fig. 2)	Type	Deelgebied	Cadmium	Anorg. kwik	Koper	Nikkel	Lood	Zink	Chroom	Arsen	PCB's
101, 102, 105	slib	Gat v.d. Visschen	14	4,9	154	51	212	1328	256	58	372
103, 104, 106	slib	Gat v.d. Visschen	10	2,0	93	60	180	1260	129	28	140
107, 108, 002	zand	Gat v.d. Visschen	2	0,3	15	31	36	392	37	10	62
109, 110, 112	zand	Gat v.d. Visschen	2	0,3	16	26	41	480	34	14	31
007, 113	slib	Gat v. Den Kleine Hil	1	0,1	7	19	17	39	25	7	6
114, 115, 008	zand	Gat v. Den Kleine Hil	4	1,1	45	25	81	516	63	27	1010
116, 117, 118	zand	Gat v. Den Kleine Hil	2	0,5	21	27	45	481	44	20	6
120	zand	Gat v. Den Kleine Hil	4	2,4	71	49	142	811	102	41	163
011, 012, 121	slib	Gat v. Den Kleine Hil	1	0,3	15	30	43	238	36	16	63
014	slib	Gat v.v. Kampen	2	0,2	20	24	28	294	29	8	239
015, 124, 125	zand	Gat v.v. Kampen	8	1,1	63	33	124	705	71	18	184
020, 127, 135	zand	Gat v.v. Kampen	11	2,4	96	47	195	1003	104	26	135
021, 136, 137	slib	Gat v.v. Kampen	4,1	1,4	44	37	71	569	64	20	267
139, 140, 141	zand	Gat v.d. Noorderklip	19	4,5	109	54	277	1603	153	39	221
025, 143, 144	slib	Gat v.d. Noorderklip	4	0,6	33	40	63	550	38	13	127
026, 027, 028	zand	Gat v.d. Noorderklip	2	0,2	16	31	36	423	29	10	61
146	slib	Gat v.d. Noorderklip	7	1,2	100	55	166	868	86	20	121

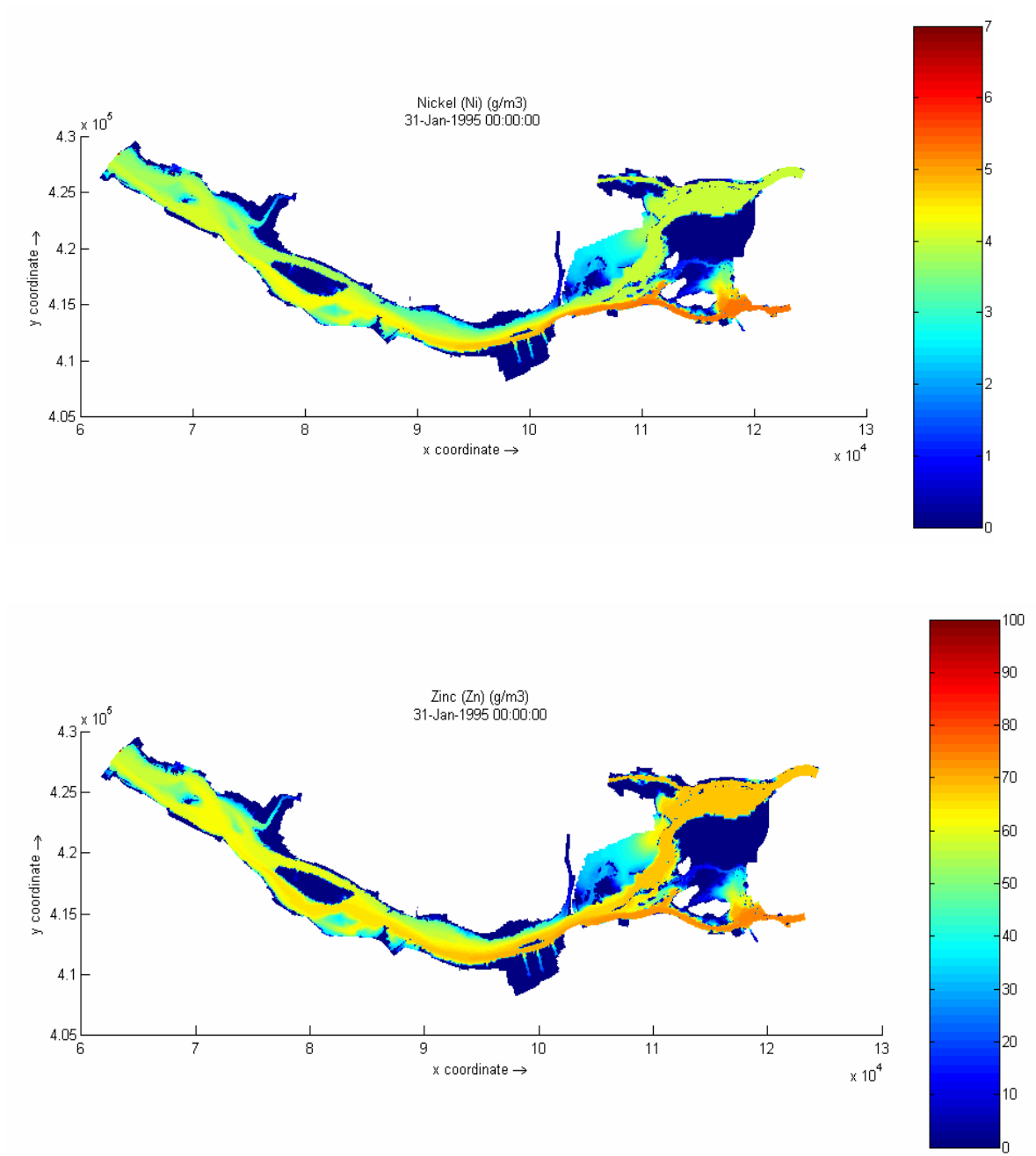


B Heavy Metal pollution in the Suspended particulate matter

The following figures show the concentration of heavy metals (As, Cd, Cu, Pb, Ni, Zn) in the suspended particulate matter for the high flow event.



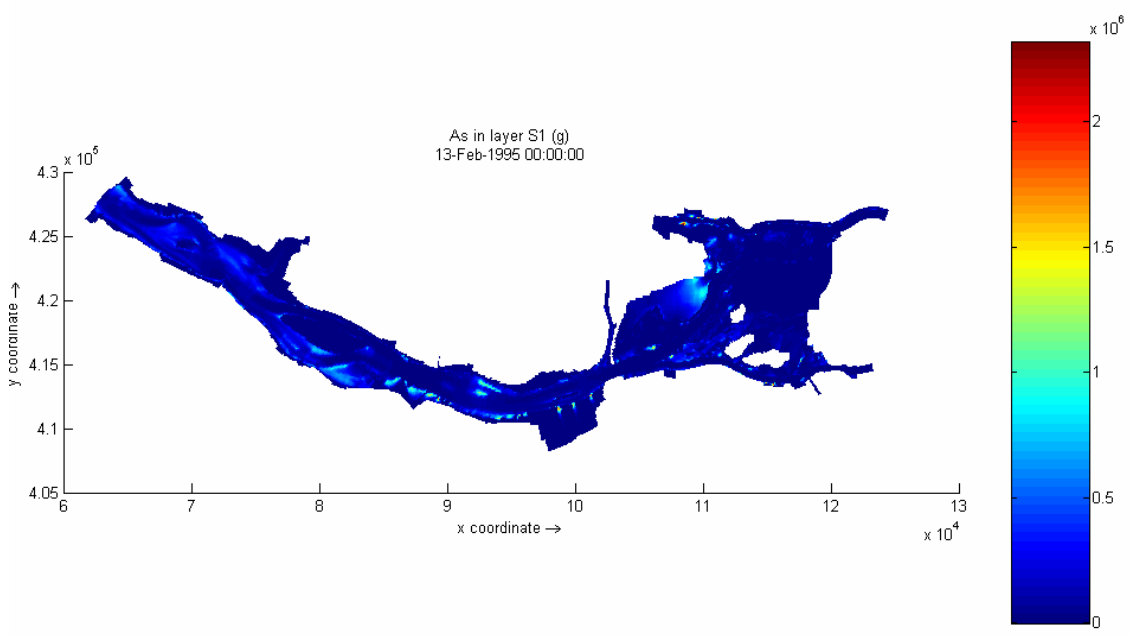
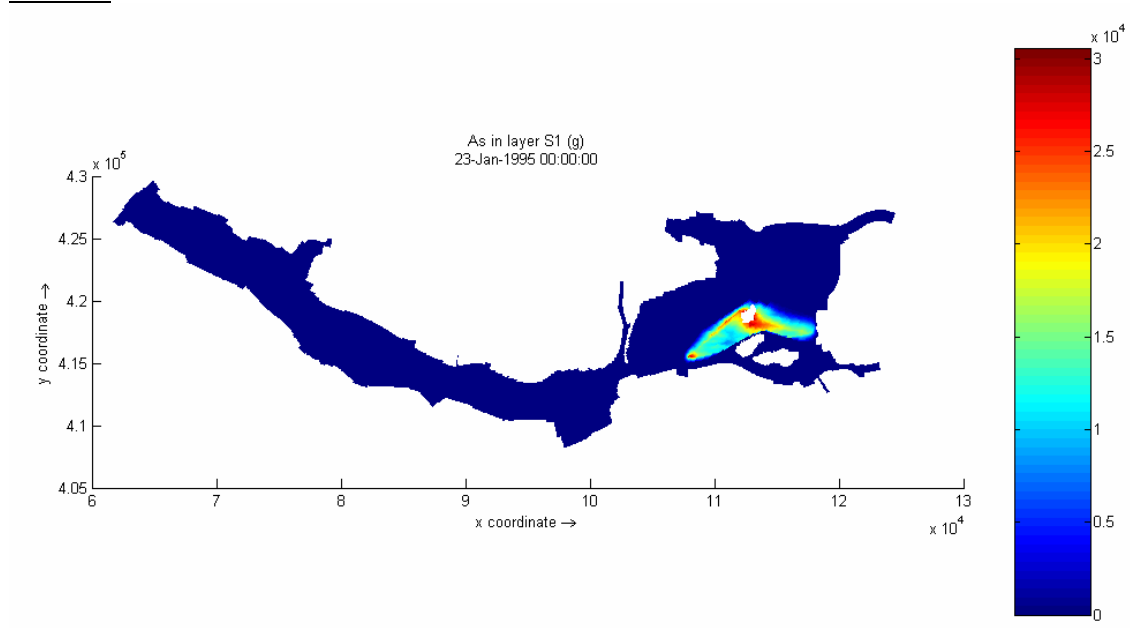




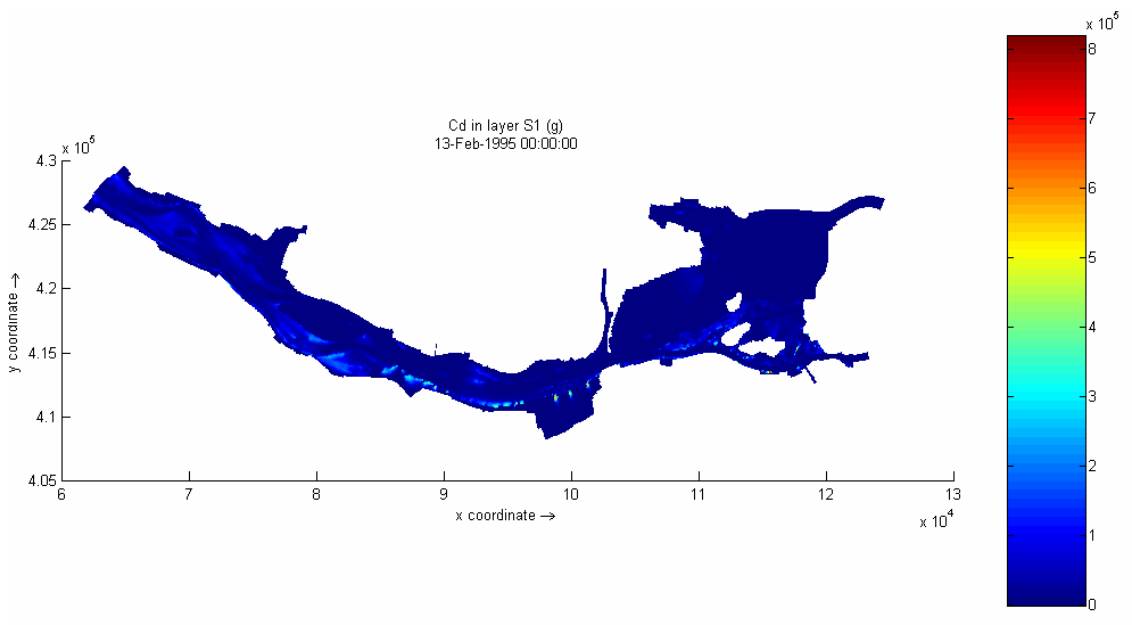
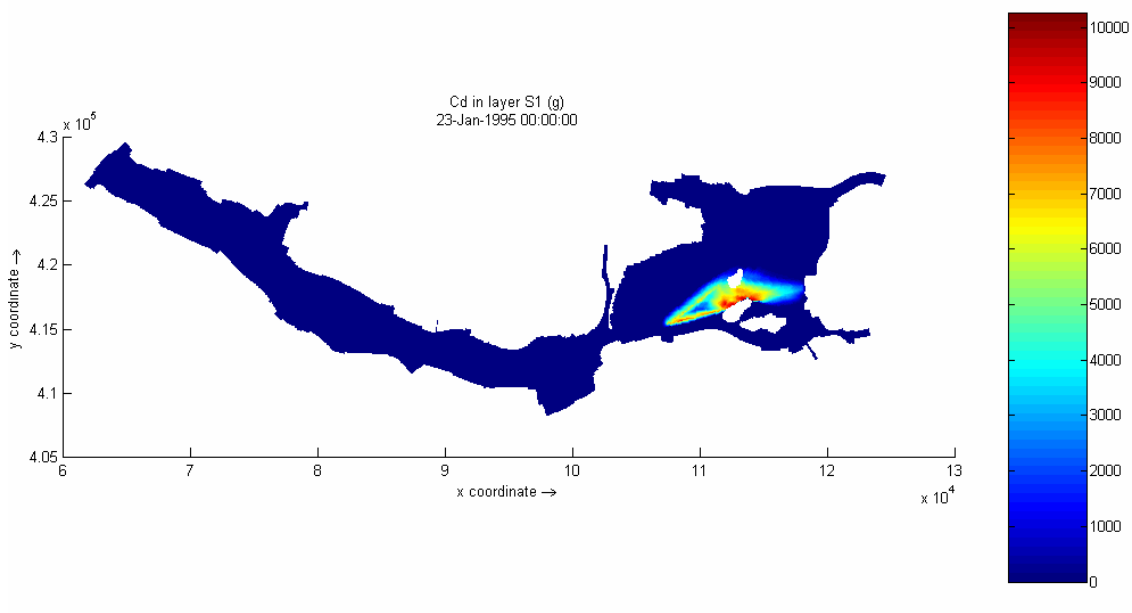
C Heavy Metal concentrations in the soil at the beginning and end of the simulation

It was shown in the report the graphs for the Zinc, now it is included the rest of he metals.

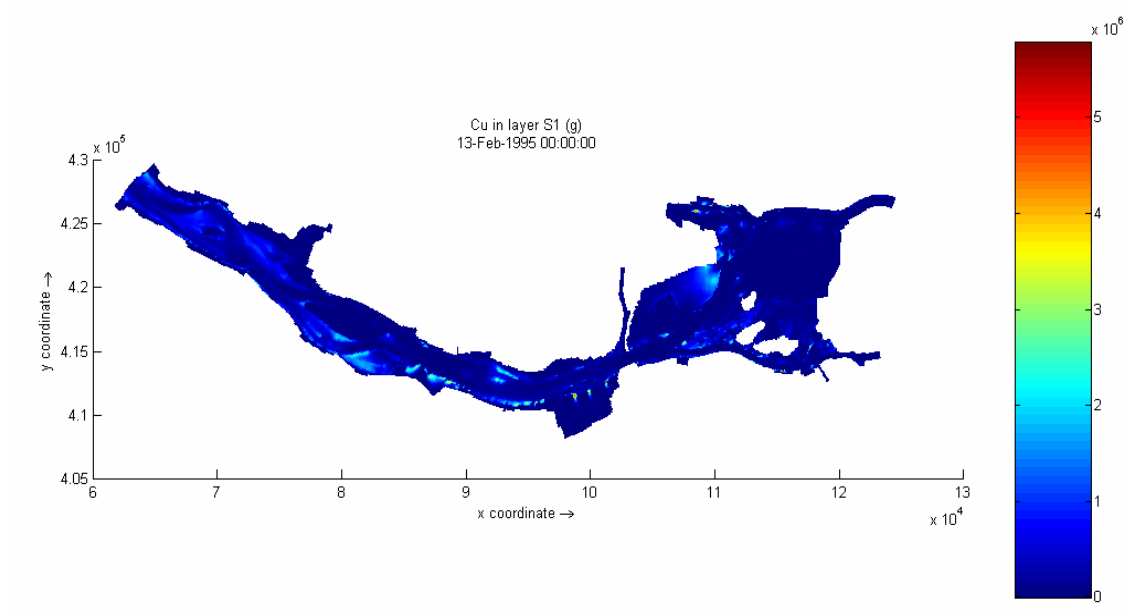
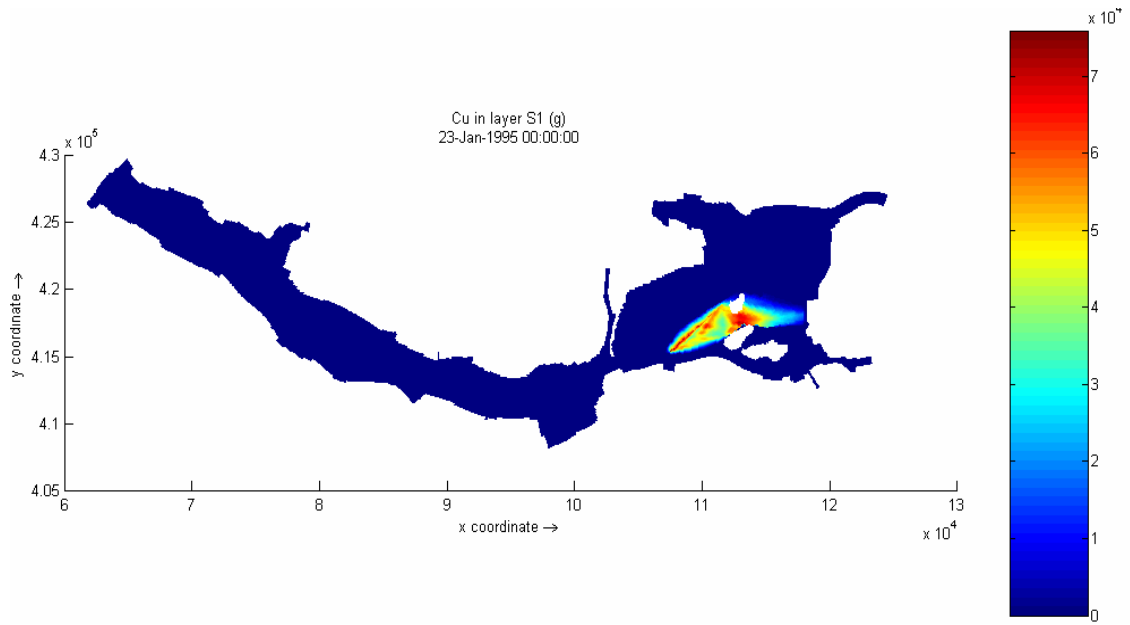
Arsenic:



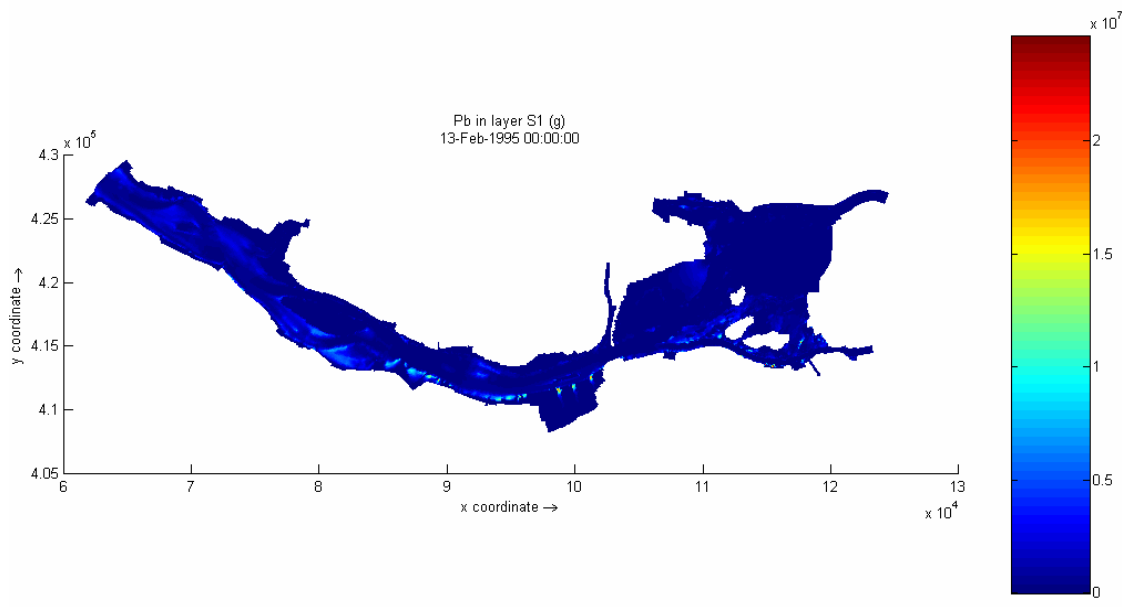
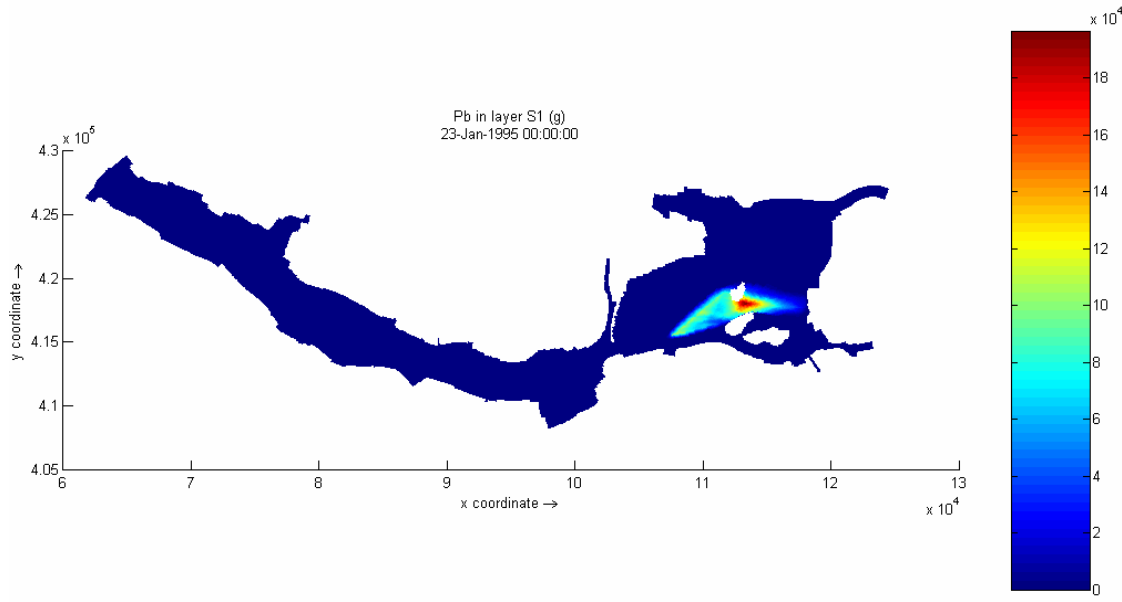
Cadmium:



Cooper:



Lead:



Nickel:

