REPORT

Elia Asset N.V.

Belgian Offshore Grid

Environmental Impact Assessment: Numerical Modelling of Dredging Plume Dispersion

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International Marine & Dredging Consultants

Colophon

International Marine & Dredging Consultants

Address: Coveliersstraat 15, 2600 Antwerp, Belgium

☎: + 32 3 270 92 95

🗐: + 32 3 235 67 11

Email: info@imdc.be

Website: www.imdc.be

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1. INTRODUCTION

1.1 THE ASSIGNMENT

The development of the Belgian Offshore Grid (BOG) aims to optimise the transport of future offshore electricity production to land. Elia Asset N.V. is responsible of that development and awarded International Marine and Dredging Consultants NV and its partner Tractebel Engineering the contract for Marine Consulting services. This order was issued based on the European Tender N°4074323 and the contract notice N° 2012/S 33-053758.

1.2 AIM OF THE STUDY

The overall aim of the Marine Consulting services is related to the following tasks:

- General coordination; project management and project planning;
- Feasibility study of the platform locations and submarine cable routings;
- Preparation of the input to the design basis;
- Preparation of and support to the seabed survey and sampling campaign;
- Follow-up of the seabed survey and laboratory tests;
- Identification of existing and any proposed third party crossings necessary to facilitate the laying of the submarine and land cables;
- Conceptual design of all required third party crossings (offshore and onshore), including the deliverance of all the relevant ‘Letters of no Objection’ for the crossings, necessary for permits and consents, management and preparation of all third party crossing agreements;
- Conceptual design of the land-fall solutions and the definition onshore cable routing;
- The preparation of all necessary permits and consents required to be submitted to the concerned Belgian Authorities, including all on-shore permits;
- Produce and deliver the Environmental Impact Assessment (EIA) for the marine aspects of the project;
- Formulation of an offshore foundation and submarine cable route maintenance programme;
- HS&E support conform to the Belgian and Flemish legislation;
- Ensure the coordination for safety and health.

1.3 OVERVIEW OF THE STUDY

The present study is part of the Environmental Impact Assessment (EIA). The description of the initial reference situation and the possible natural evolution of the subsurface is an important element of the EIA. In order to assess the autonomic evolution of the seafloor a numerical model had to be set up that simulates the tidal currents, wave action and sediment transport in and around the island location. The impact of the island with relation to these phenomena is also examined. In addition, the dredging and disposal methods for the construction of the artificial island will likely cause turbidity and sediment dispersion. In order to assess this impact of the dredging activities on the background turbidity and suspended sediment levels, a dredging plume model study is performed. A numerical model is applied that simulates the tidal currents and sediment transport in the project area.

The sediment transport modelling study and plume dispersion study are part of the EIA. Both reports are put integrally as attachment at the back of the EIA, the main results are presented in chapter 5.1 ‘Soil and Water’ of the EIA.

The overview of these reports is listed below:

- Environmental Impact Assessment: I/RA/11413/12.266/CPA (IMDC, 2013a);
- Numerical Modelling of Sediment Transport: I/RA/11413/13.006/LWA (IMDC, 2013b);
- Numerical Modelling of Dredging Plume Dispersion: I/RA/11413/13.167/LWA (IMDC, 2013c).

The present study describes the numerical modelling of the dredging plume dispersion.

1.4 STRUCTURE OF THE REPORT

Chapter 2 describes the numerical flow and sediment transport model. Chapter 3: discusses the simulation results, including description of scenarios and plume analysis. Conclusions are presented in Chapter 4.

2. DESCRIPTION OF NUMERICAL MODEL

The setup of the numerical model is also described in the report 'Numerical modelling of sediment transport' (IMDC, 2013b). The most important characteristics are outlined below, for more detail reference is made to the report (IMDC, 2013b). This numerical model has been converted to a 3D model in order to take the vertical processes related to the dredging and dumping activities into account.

2.1 HYDRODYNAMIC FLOW MODEL

2.1.1 Numerical grid and bathymetry

The model is called "SBR model" (Sea – Belgian Offshore Grid – River) and it is nested into a larger mother model called "KaZNO model" (Figure 2-1). The computational grid size of the KaZNO model is 2.600 m × 7.000 m to 100 m × 140 m, and that of SBR model is 1.800 m × 2.700 m to 20 m × 30 m.

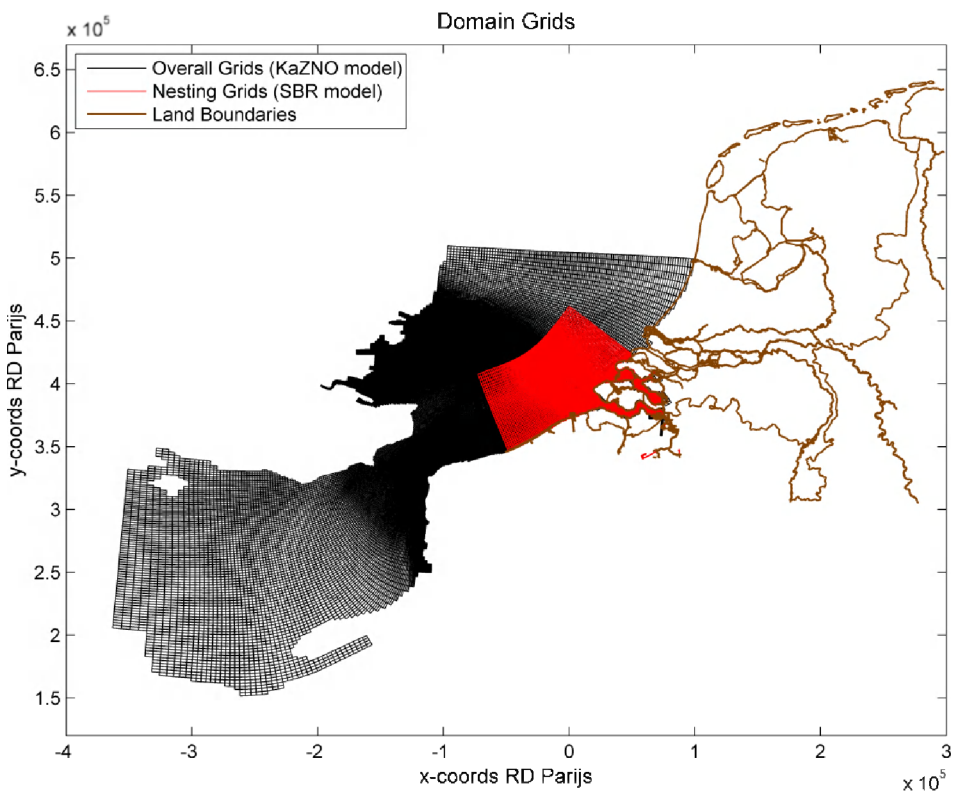

Figure 2-1: Layout of the model grids.

In order to obtain more detailed information in the project zone, a domain decomposition technique is employed to specifically refine this zone indicated by the green lines in Figure 2-2. In addition, domain decomposition is applied to the river domain but without any refinement, in order to reduce the computational time for the whole model domain. In the BOG domain, the grid size reaches 235 m × 340 m to 110 m × 180 m.

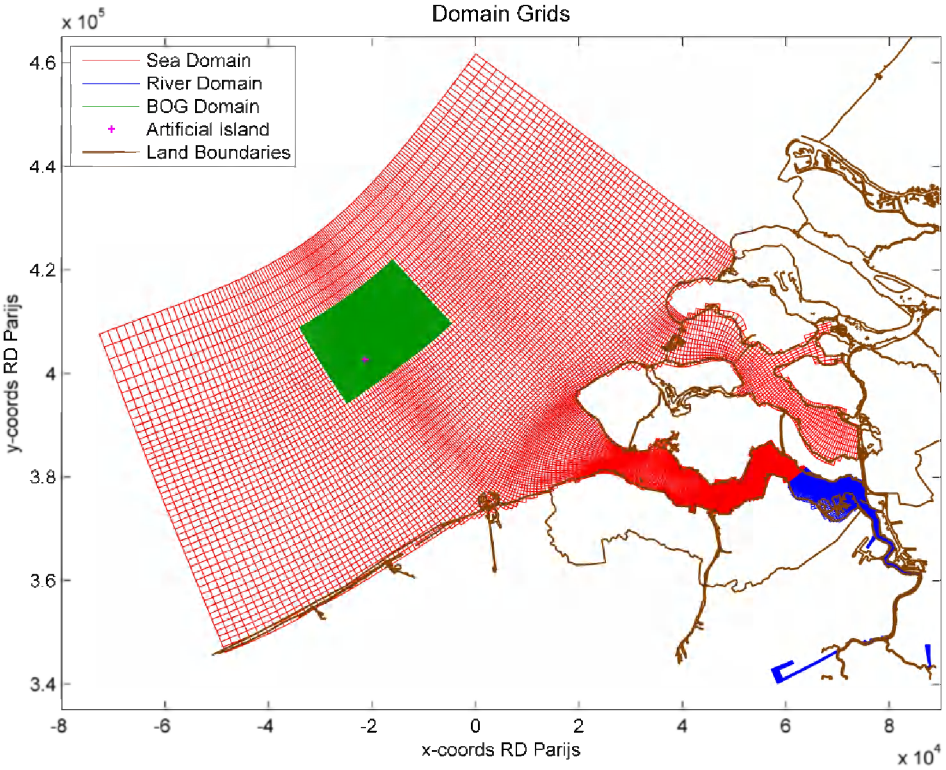

Figure 2-2: Three domains after domain decomposition.

The bathymetry map (Figure 2-3 and Figure 2-4) shows that the artificial island is situated at the Lodewijkbank with water depths around -20 to -30 m LAT[1].

[1] The model bathymetry is available in m NAP. For this reason, this vertical level is also used in the report and not only the project vertical reference level LAT. NAP = TAW + 2,333. At the project site, NAP = LAT + 2,08.

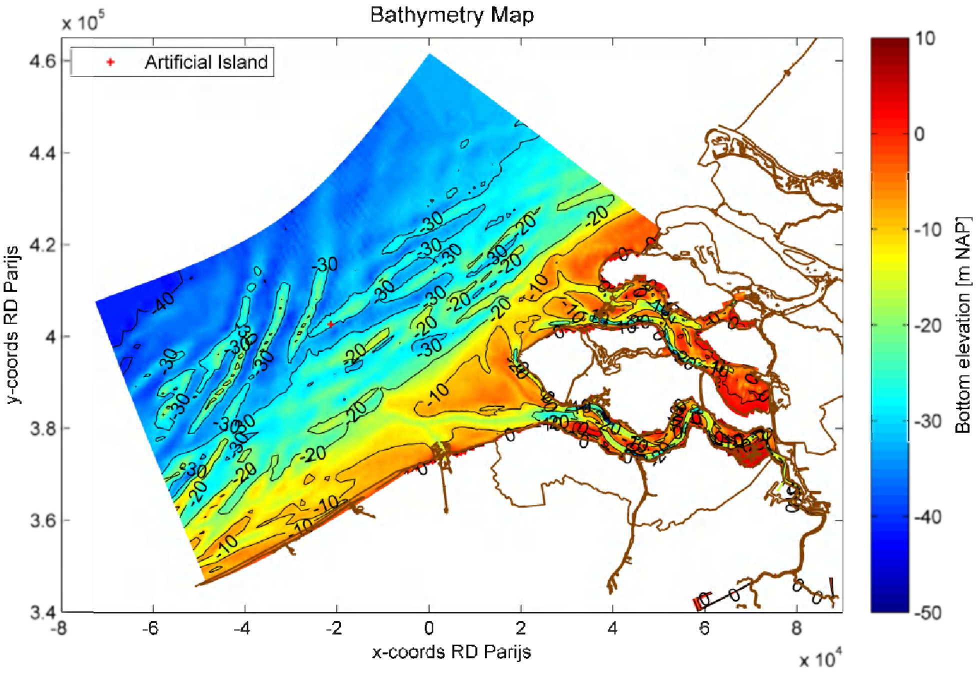

Figure 2-3: Bathymetry map of the flow model domain.

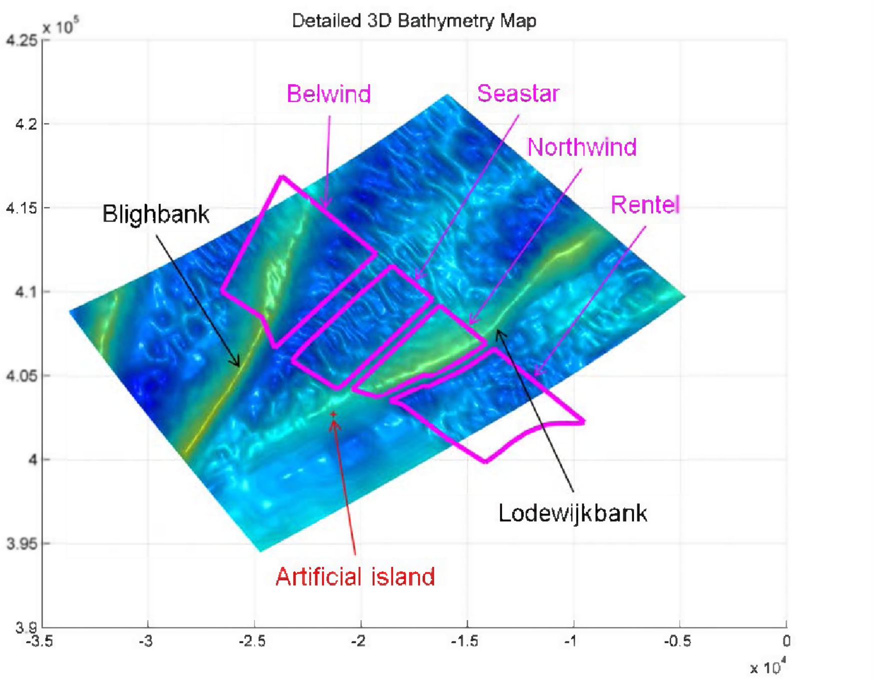

Figure 2-4: 3-dimensional bathymetry map of the BOG domain.

2.1.2 Vertical layer distribution

The BOG Domain and Sea Domain are calculated in 3D. The vertical grid is defined following the sigma coordinate approach (Figure 2-5) which allows the online calculation of sediment transport. Each layer is defined in percentages of water depth. Table 2-1 shows the applied layer distribution.

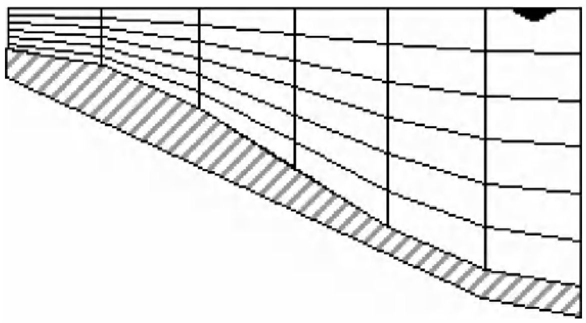

Figure 2-5: Vertical grid in Delft3D with the applied sigma coordinate approach.

Table 2-1: Layer distribution and average water depths at location of dredging activities.

Layer	% of Water depth	Corresponding height of layers [m] (total depth of 30 m)
1 (Top)	27,50	21,75-30,00
2	20,50	15,60-21,75
3	15,50	10,95-15,60
4	11,50	7,50-10,95
5	8,50	4,95-7,50
6	6,25	3,08-4,95
7	4,50	1,73-3,08
8	3,25	0,75-1,73
9 (Bottom)	2,50	0,00-0,75

2.1.3 Boundary conditions and model validation

The SBR model is supplied by tidal boundary conditions from the KaZNO model, no wave conditions are imposed on the model. In order to get a mean tidal forcing in this domain, one year of data of tidal ranges at three stations were statistically analysed and then a representative spring-neap tidal period was selected representing the mean tidal forcing of a whole year in the domain, i.e. 23-Jul-2009 14:00:00 to 07-Aug-2009 01:40:00. For more details about the choice of the representative cycle is referred to the sedimentation and erosion patterns report (IMDC, 2013b).

The model validation period is from 12 April 2010 to 19 April 2010. Three measuring points were used for the model validation (Figure 2-6). For more details and figures is referred to the sedimentation and erosion patterns report (IMDC, 2013b). The model gives a maximum overestimation of around 10% in terms of the tidal range for location Westhinder.

The model gives a satisfactory result compared to the observed data for location Scheur Wielingen. The variation pattern of tidal current magnitude is captured by the model successfully, and the direction of current velocity is reproduced by the model quite well.

At an observation point at the Lodewijkbank, the modelling result is slightly overestimated compared to the observed data. However, the variation characteristics of the tidal current are effectively reproduced by the model. The magnitude of the current velocity is overestimated approximately 25% by the model, and the bias and RMSE is 0,079 and 0,16 m/s respectively.

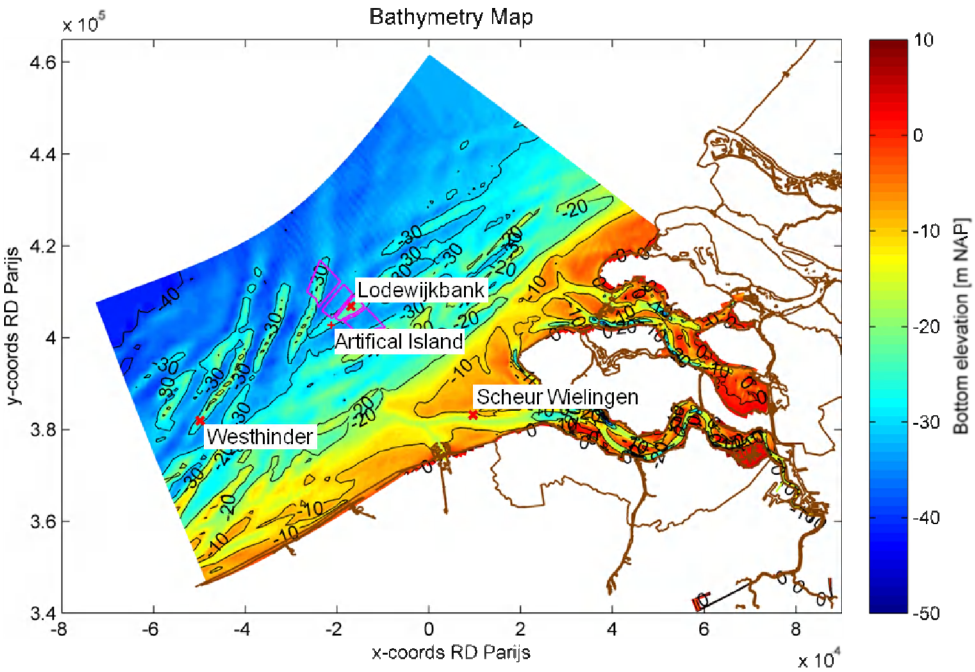

Figure 2-6: Location of observation points.

2.2 SEDIMENT TRANSPORT MODEL

2.2.1 Setup

In this model only the excess sediments, i.e. the sediments derived from the dredging activities (overflow, draghead losses, dumping), are considered in order to analyse the dispersion of dredged material and to determine the effect on the turbidity of the area. The only source of sediments is therefore the discharge of dredged material.

The natural background turbidity will be taken into account in the analysis of the model results, using it as a baseline value to which the excess suspended sediment concentration (SSC) will be compared. The background turbidity (SPM) at Blighbank and Lodewijkbank can be applied for the project zone and is about 4 mg/l (Van den Eynde et al., 2010).

For the sediment transport, the Van Rijn TRANSPOR2004 approach is employed in the model (Van Rijn et al., 2004). Based on the sediment characteristics of a channel between sandbanks (swale) in the Hinderbanken area (Verfaillie et al., 2006), the dredged material is assumed to have 3% fines (< 90 µm) (Depret-G-tec, 2009). On top of the sand bank, less fines are expected, so this value is expected to be conservative. These fine sediments are divided over four equal fractions as used in the Van Rijn approach specified in Table 2-2.

Table 2-2: Estimated sediment properties (median sediment diameters in µm) of fines at concession zone.

Fraction	D10 (µm)	D50 (µm)	D90 (µm)	Percentage
Sediment 01	5	10	20	0.75%
Sediment 02	20	30	40	0.75%
Sediment 03	40	50	60	0.75%
Sediment 04	60	75	90	0.75%
Total percentage of fines	-	-	-	3.00%

2.2.2 Sediment losses

According to the applied dredging method, equipment and activity, different fluxes of fine sediment will be discharged at different depths in the water column.

At this stage of the BOG project, dredging specifics during the construction of the artificial island are not yet known. However, as an illustrative example for the associated environmental impact, the dumping of sand at the island location is considered. Since no further details on the applied dredging technique are yet defined for this particular project, a general feasible dredging equipment which was used in comparable situations is chosen. There are two scenarios to be modelled for around 42 hours (see §2.2.3) of continuous dredging and dumping: one is a scenario for which sand is dredged and dumped by only one TSHD of 10.000 m³ and the other scenario for which sand is dredged and dumped alternatively by two

TSHDs of 5.000 m³. More detailed information about these two scenarios will be given in the first section of Chapter 3.

It is assumed that the TSHDs of 10,000 m^3 and 5,000 m^3 will both fill the hopper in about 45 minutes, including manoeuvring. Taking into account a bulking factor of 1.2, in-situ volumes of 6650 m^3 and 3330 m^3 can be respectively dredged by the TSHDs of 10,000 m^3 and 5,000 m^3 from the seafloor each time for the maximum in-hopper volumes of 8000 m^3 and 4000 m^3 (80% filling). So in 27 cycles a total in-situ volume of 180,000 m^3 is dredged by one TSHD of 10,000 m^3 or two TSHDs of 5,000 m^3. The in-situ dry density is assumed to be 1.591 tDS/m^3. (tDS: tons dry solids) So per load 10660 m^3 and 5340 m^3 are respectively dredged by the TSHDs of 10,000 m^3 and 5,000 m^3, of which 3% are fines (320 and 160 tDS dredged fines).Their sailing speed is about 1 knot during dredging and about 8 knots sailing between dredging and dumping sites.

Three potential sources of sediment losses are defined:

- Draghead losses at the head of the TSHD are estimated at 1% of the total amount of available fines, based on a study that collected results for more than 43 dredging projects (Anchor Environmental CA L.P., 2003).
- Overflow losses from the TSHD are estimated to be 67% of the total dredged fines. Remaining fines are assumed to be deposited in the hopper or trapped in layers of coarser material during loading before overflow (IMDC, 2009, 2010a, 2010b , 2011). Of this 67% in the water column, it is assumed that 1/4 stays in suspension as part of a passive plume and 3/4 settles at the bottom. Overflow discharge is at 8 m below the water surface after 20 minutes dredging.
- During dumping fine sediments will be lost, they go into suspension and form a passive plume. It has been observed on the Thorntonbank, that after dredging and dumping 30% of the initial dredged material was lost (Van den Eynde et al., 2010). Based on these data, a loss of 30% of the remaining fines is assumed, distributed in a logarithmic profile over the vertical (IMDC, 2007, 2009, 2010a, 2010b).

The different calculated fluxes, losses and assumptions are summarised in Table 2-3 and

Table 2-4.

Table 2-3: Overview of assumptions for loss of fines produced by TSHD of 10.000 m³.

Source	Estimated loss of available fines	Flux (kg/s)	Duration (min)	Total flux (tDS)	Theoretical distribution of sediments in water column
Draghead	1%	0.9	45	2.5	Uniformly distributed in lower 2 m above sea bed
Overflow	(67% in overflow of which 1/4 in suspension) 17%	59.2	15	53	In layer at 8 m below surface
Dumping	30%	53.3	10	32	10% in top 75% of water column, 40% in intermediate 20% of water column and 50% in lower 5% of water column

Table 2-4: Overview of assumptions for loss of fines produced by TSHD of 5.000 m³.

Source	Estimated loss of available fines	Flux (kg/s)	Duration (min)	Total flux (tDS)	Theoretical distribution of sediments in water column
Draghead	1%	0.5	45	1.2	Uniformly distributed in lower 2 m above sea bed
Overflow	(67% in overflow of which 1/4 in suspension) 17%	29.7	15	27	In layer at 8 m below surface
Dumping	30%	26.7	10	16	10% in top 75% of water column, 40% in intermediate 20% of water column and 50% in lower 5% of water column

2.2.3 Simulation period

The simulations are run during spring tide of the representative period in order to capture the strongest currents (24/07/2009 14u50 – 26/07/2009 16u30, the red line in Figure 2-7). An initial condition file is used to accelerate spin-up of the model, and in this dredging-plume model the first 6 hours are also used for the spin-up to make sure that the model is really warmed up and effects of initial conditions are completely eliminated before the dredging activities start. 27 dredging-dumping cycles are simulated in following more than 42 hours.

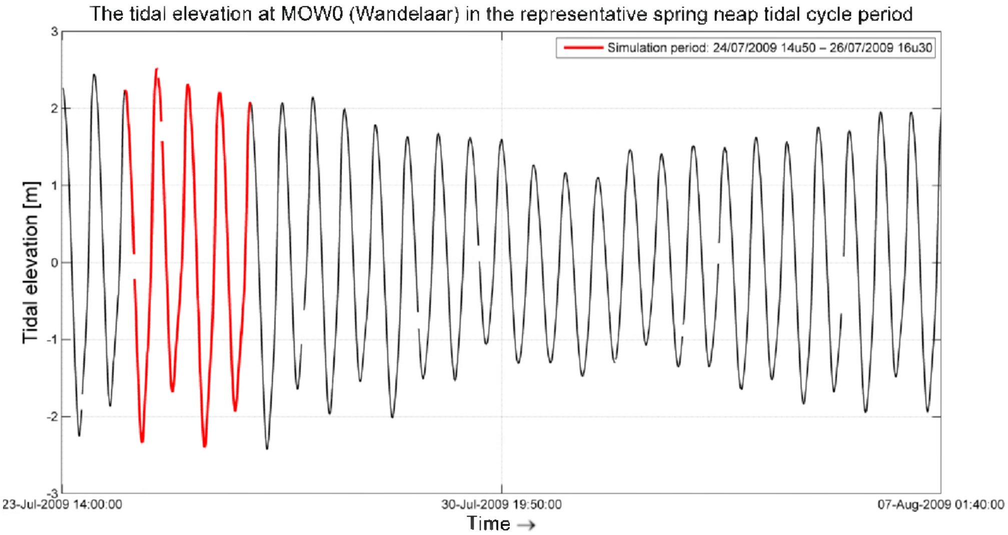

Figure 2-7: Spring tidal cycles selected for the simulation.

3. SIMULATION RESULTS

3.1 SCENARIOS

The dredging activities consist of dredging at top of the Blighbank and dumping the material at the location of the artificial island, which are around 5 km apart. (Figure 3-1). The Blighbank is currently not an official sand extraction area, but has been chosen in consultation with BMM/MUMM as possible sand extraction area for the Alpha project. IMDC is currently preparing a separate EIA for sand extraction on the Blighbank. Hence, a concession for exploration and exploitation of sand on the Blighbank has not yet been obtained.

Two scenarios have been derived which represent dredging and dumping activities executed by only one TSHD of 10.000 m³ and by two TSHDs of 5.000 m³ at same dredging and dumping sites, both scenarios are calculated for spring tide:

- **Scenario 1**: The construction is executed by only one TSHD of 10.000 m³. In each cycle it spends 45 minutes dredging, 20 minutes transit to dump site, 10 minutes dumping, 20 minutes transfer back to dredge site, which are performed repeatedly in total ca. 42 hrs. The time point of the start of each dredging and dump activity is listed in Table 3-1, and visualised on the tidal elevation curve in Figure 3-2.
- **Scenario 2**: The construction is executed alternatively by two TSHDs of 5.000 m³. The same dredging-dumping cycle as scenario 1 is performed. Each TSHD spends 45 minutes dredging, 20 minutes transit to dump site, 10 minutes dumping, 20 minutes transfer back to dredge site. TSHD A starts the cycle 45 minutes prior to TSHD B, and then they execute the construction alternatively in total ca. 42 hrs. Same information as scenario 1 with regard to the time points of dredging and dumping activity could be equally found in Table 3-2 and Figure 3-3.

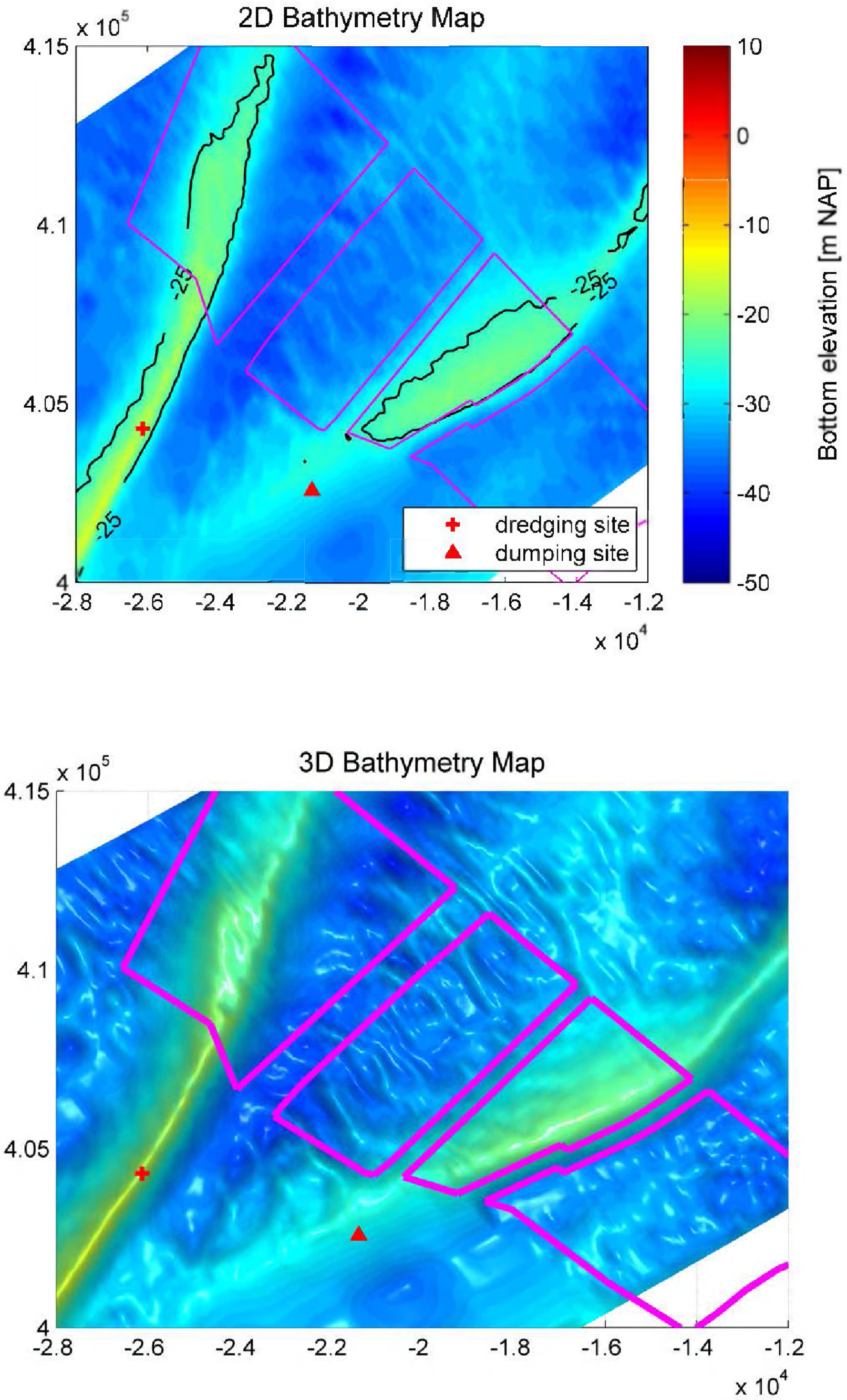

Figure 3-1: Dredging and dumping locations.

Table 3-1: Time points of dredging and dumping in Scenario 1.

cycle	Start of Dredging	Start of Dumping
1	24/07/2009 20:50	24/07/2009 21:55
2	24/07/2009 22:25	24/07/2009 23:30
3	25/07/2009 00:00	25/07/2009 01:05
4	25/07/2009 01:35	25/07/2009 02:40
5	25/07/2009 03:10	25/07/2009 04:15
6	25/07/2009 04:45	25/07/2009 05:50
7	25/07/2009 06:20	25/07/2009 07:25
8	25/07/2009 07:55	25/07/2009 09:00
9	25/07/2009 09:30	25/07/2009 10:35
10	25/07/2009 11:05	25/07/2009 12:10
11	25/07/2009 12:40	25/07/2009 13:45
12	25/07/2009 14:15	25/07/2009 15:20
13	25/07/2009 15:50	25/07/2009 16:55
14	25/07/2009 17:25	25/07/2009 18:30
15	25/07/2009 19:00	25/07/2009 20:05
16	25/07/2009 20:35	25/07/2009 21:40
17	25/07/2009 22:10	25/07/2009 23:15
18	25/07/2009 23:45	26/07/2009 00:50
19	26/07/2009 01:20	26/07/2009 02:25
20	26/07/2009 02:55	26/07/2009 04:00
21	26/07/2009 04:30	26/07/2009 05:35
22	26/07/2009 06:05	26/07/2009 07:10
23	26/07/2009 07:40	26/07/2009 08:45
24	26/07/2009 09:15	26/07/2009 10:20
25	26/07/2009 10:50	26/07/2009 11:55
26	26/07/2009 12:25	26/07/2009 13:30
27	26/07/2009 14:00	26/07/2009 15:05

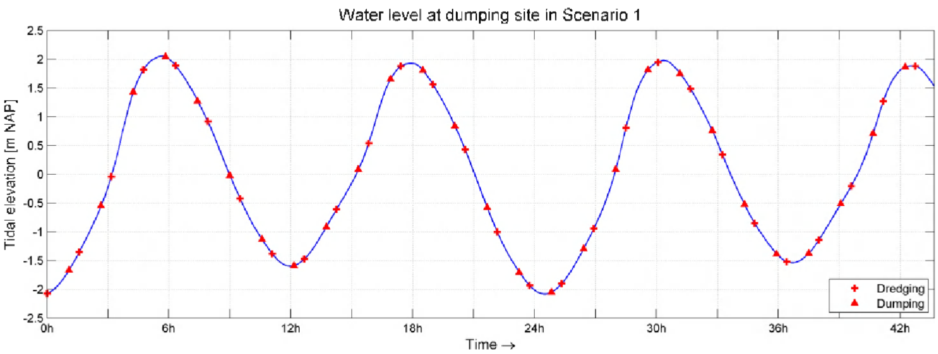

Figure 3-2: Time points of dredging and dumping in Scenario 1.

Table 3-2: Time points of dredging and dumping in Scenario 2.

cycle	Start of Dredging	Start of Dumping
1A	24/07/2009 20:50	24/07/2009 21:55
1B	24/07/2009 21:35	24/07/2009 22:40
2A	24/07/2009 22:25	24/07/2009 23:30
2B	24/07/2009 23:10	25/07/2009 00:15
3A	25/07/2009 00:00	25/07/2009 01:05
3B	25/07/2009 00:45	25/07/2009 01:50
4A	25/07/2009 01:35	25/07/2009 02:40
4B	25/07/2009 02:20	25/07/2009 03:25
5A	25/07/2009 03:10	25/07/2009 04:15
5B	25/07/2009 03:55	25/07/2009 05:00
6A	25/07/2009 04:45	25/07/2009 05:50
6B	25/07/2009 05:30	25/07/2009 06:35
7A	25/07/2009 06:20	25/07/2009 07:25
7B	25/07/2009 07:05	25/07/2009 08:10
8A	25/07/2009 07:55	25/07/2009 09:00
8B	25/07/2009 08:40	25/07/2009 09:45
9A	25/07/2009 09:30	25/07/2009 10:35
9B	25/07/2009 10:15	25/07/2009 11:20
10A	25/07/2009 11:05	25/07/2009 12:10
10B	25/07/2009 11:50	25/07/2009 12:55
11A	25/07/2009 12:40	25/07/2009 13:45
11B	25/07/2009 13:25	25/07/2009 14:30
12A	25/07/2009 14:15	25/07/2009 15:20
12B	25/07/2009 15:00	25/07/2009 16:05
13A	25/07/2009 15:50	25/07/2009 16:55
13B	25/07/2009 16:35	25/07/2009 17:40
14A	25/07/2009 17:25	25/07/2009 18:30
14B	25/07/2009 18:10	25/07/2009 19:15
15A	25/07/2009 19:00	25/07/2009 20:05
15B	25/07/2009 19:45	25/07/2009 20:50
16A	25/07/2009 20:35	25/07/2009 21:40
16B	25/07/2009 21:20	25/07/2009 22:25
17A	25/07/2009 22:10	25/07/2009 23:15
17B	25/07/2009 22:55	26/07/2009 00:00
18A	25/07/2009 23:45	26/07/2009 00:50
18B	26/07/2009 00:30	26/07/2009 01:35
19A	26/07/2009 01:20	26/07/2009 02:25
19B	26/07/2009 02:05	26/07/2009 03:10
20A	26/07/2009 02:55	26/07/2009 04:00
20B	26/07/2009 03:40	26/07/2009 04:45
21A	26/07/2009 04:30	26/07/2009 05:35
21B	26/07/2009 05:15	26/07/2009 06:20
22A	26/07/2009 06:05	26/07/2009 07:10
22B	26/07/2009 06:50	26/07/2009 07:55

cycle	Start of Dredging	Start of Dumping
23A	26/07/2009 07:40	26/07/2009 08:45
23B	26/07/2009 08:25	26/07/2009 09:30
24A	26/07/2009 09:15	26/07/2009 10:20
24B	26/07/2009 10:00	26/07/2009 11:05
25A	26/07/2009 10:50	26/07/2009 11:55
25B	26/07/2009 11:35	26/07/2009 12:40
26A	26/07/2009 12:25	26/07/2009 13:30
26B	26/07/2009 13:10	26/07/2009 14:15
27A	26/07/2009 14:00	26/07/2009 15:05
27B	26/07/2009 14:45	26/07/2009 15:50

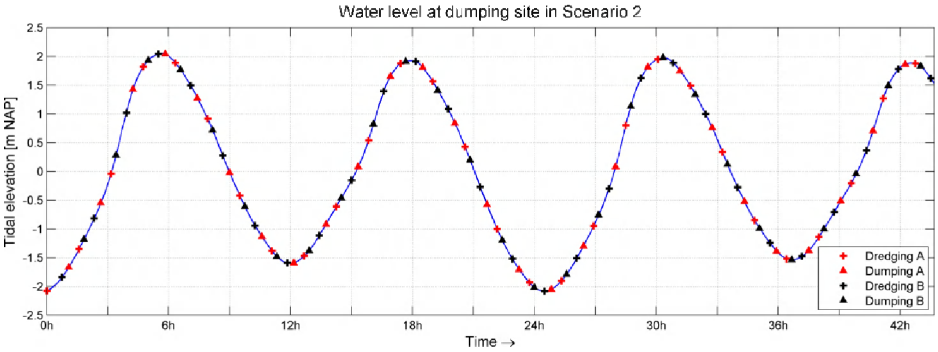

Figure 3-3: Time points of dredging and dumping in Scenario 2.

3.2 HYDRODYNAMICS

The modelled tidal current velocity and elevation at the dredging and dumping sites in the project zone (cf. Figure 3-1) are presented in Figure 3-4 and Figure 3-5. The time series are displayed for the selected spring tide during which the dredging and dumping take place. The currents are driven by tidal forcing only without any meteorological forcing.

The dumping site at the location of the artificial island shows a little stronger flood currents than the dredging site located at top of the Blighbank, which can probably be attributed to effects of the local topography. The current velocity at the two sites does not exceed over 1,0 m/s for the spring tide.

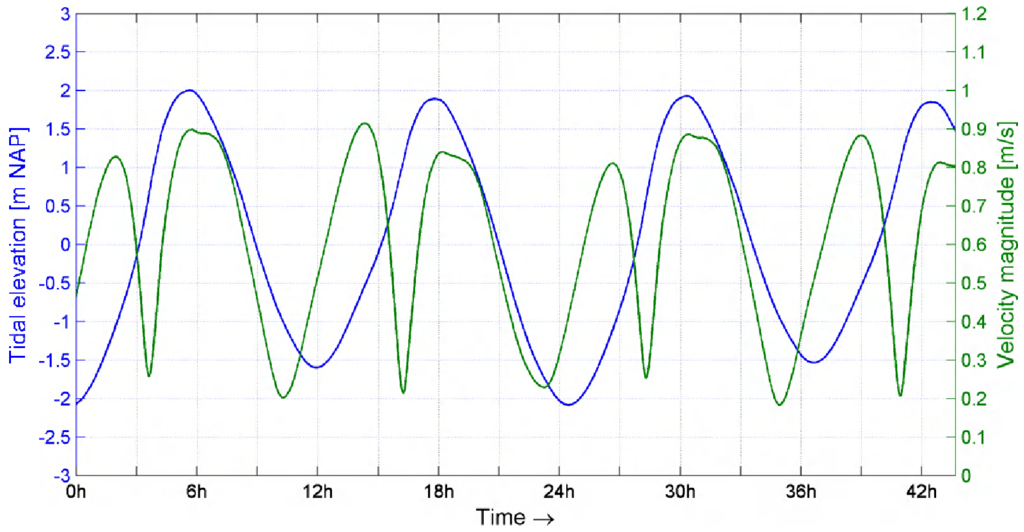

Figure 3-4: Time series showing tidal elevation and velocity magnitude at the dredging site.

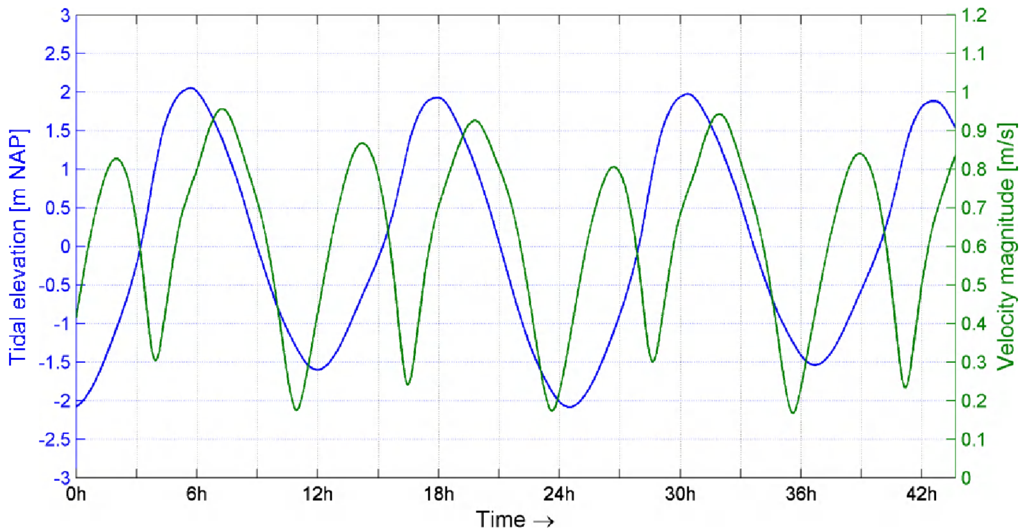

Figure 3-5: Time series showing tidal elevation and velocity magnitude at the dumping site.

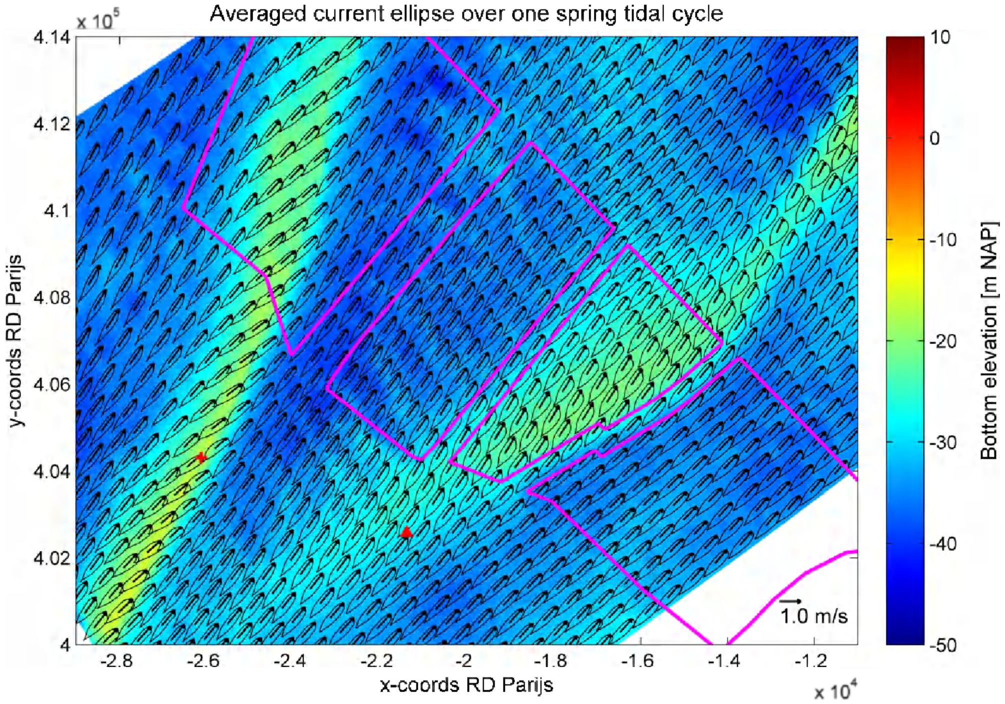

Figure 3-6: Map of averaged current ellipses at the spring tide with bathymetry as background; the averaged current ellipses are calculated over one spring tidal cycle; red cross and triangle points mark the dredging and dumping sites respectively; the grid resolution of one ellipse is about 600m × 350m.

Figure 3-6 displays the tidal current ellipses in and around the project zone. Currents in the Seastar concession zone (deeper part in between two sand banks) show a large eccentricity with smaller velocity at the minor axis during the flow reversal, while those at the top of the banks (shallower water) are more rotary with larger velocities at the minor axis during the flow reversal, in particular at the Lodewijkbank nearby the location of the artificial island. The tidal currents are NE-SW aligned.

3.3 PLUME ANALYSIS

In this section, the plume analysis is described. First probability maps of exceedance over 4 and 10 mg/l are presented for Scenario 1 and 2 respectively. As a value of 4 mg/l is the background suspended particulate matter (SPM) concentration monitored on the Thorntonbank and Blighbank, sandbanks near to the project area (Van den Eynde et al., 2010), this turbidity is used as reference level. The boundary of 10 mg/l is the upper limit of clear water (Fettweis, pers. comm., May 2012). These probability maps show the percentage of time for 27 dredging-dumping cycles, where a certain depth averaged excess (above background) suspended sediment concentration (SSC) (4mg/l or 10mg/l) is exceeded.

The evolution of the sediment plume is shown by maps presenting the modelled depth averaged excess (above background) sediment concentrations, and an indication of the 4 mg/l contour. In these two scenarios a worst case is respectively described: a flood event which leads to the most NE-ward extent of the plume.

One example of a slack water event (transition from flood to ebb current) from Scenario 1 is additionally given. Finally, in the appendix, a full dredging-dumping cycle at an ebb event can be found for respectively Scenario 1 (one TSHD of 10.000 m³) and Scenario 2 (two TSHDs of 5.000 m³).

In all figures shown hereafter, the magenta solid lines delineate windmill concession zones, the black solid ones label isobath lines of -25 m NAP, the brown dash ones denote submarine cables, and the black dash ones mark pipelines.

3.3.1 Probability of exceedance

The contour of the exceedance map over 4 mg/l shows that the plume is aligned around the centre of the dredging and dumping location in the direction of the main tidal currents. Outside the dredging and dumping areas, the time of exceedance above the background value of 4 mg/l, drops fast and stays below 20% of the total time in Scenario 1 (8.7h) below 30% of the total time in scenario 2 (13.2h) where dredging and dumping activities occur more frequently (Figure 3-7 and Figure 3-8). The dredging seems to be able to cause much larger plume than the dumping in the both scenarios. Although Scenario 2 is shown to produce more intensive plumes than Scenario 1, the size of the plumes in Scenario 2 seems to be smaller than those in Scenario 1. Probability of exceedance over 10 mg/l is limited to the dredging and dumping areas in Scenario 1 and only the dredging area in Scenario 2 (Figure *3-9* and Figure 3-10). For Scenario 1 the turbidity exceeds the clear water limit at the dredging site for less than 18% of the total time (7.9h), while for Scenario 2 less than 15% of the total time (6.6h). The plume caused by the dredging in Scenario 2 seems to be less intensive and also smaller than that in Scenario 1.

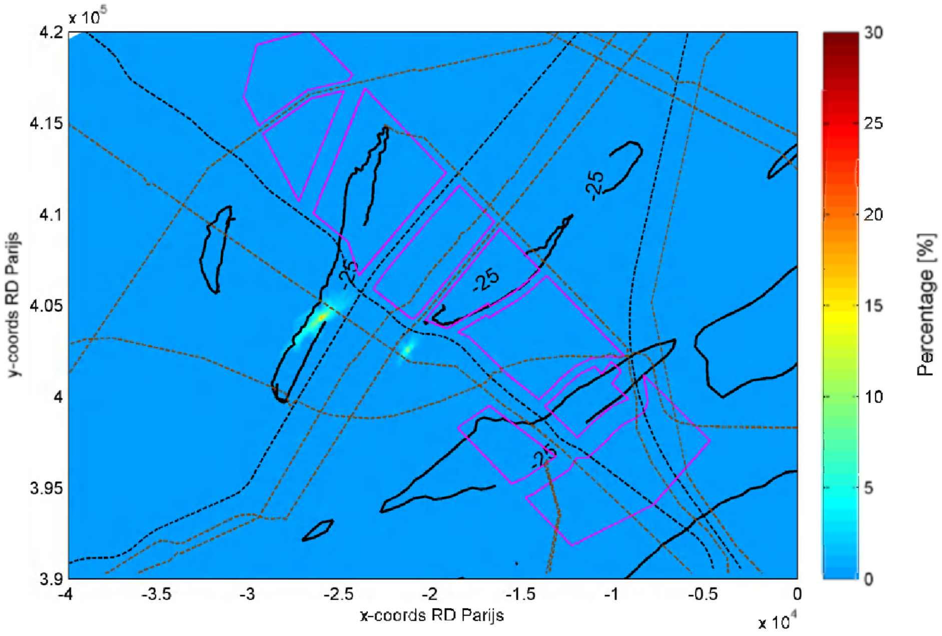

*Figure 3-7: Probability of exceedance of excess SSC over 4 mg/l in Scenario 1 (*one TSHD of 10.000 m³*).*

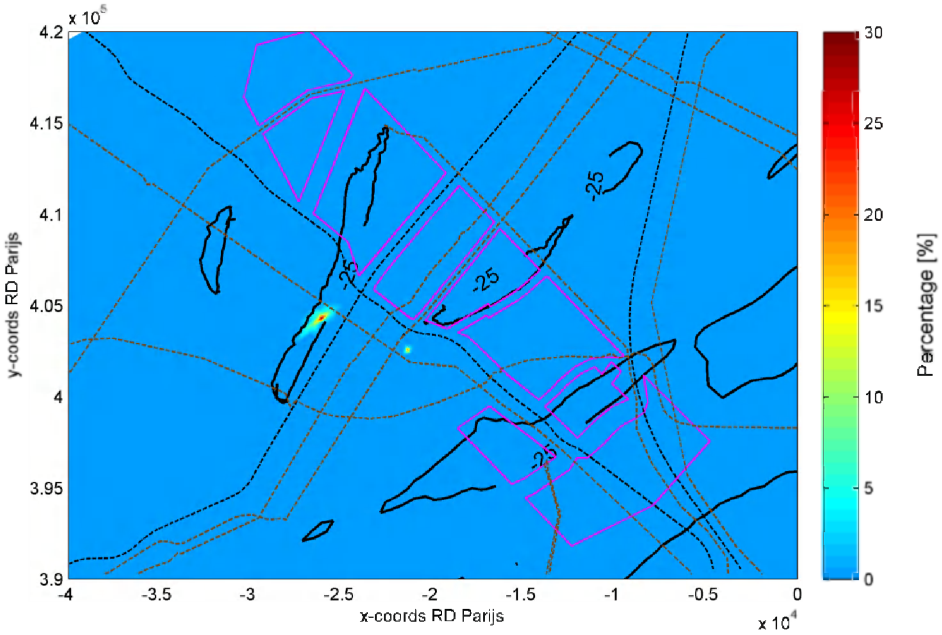

Figure 3-8: Probability of exceedance of excess SSC over 4 mg/l in Scenario 2 (two TSHDs of 5.000 m³).

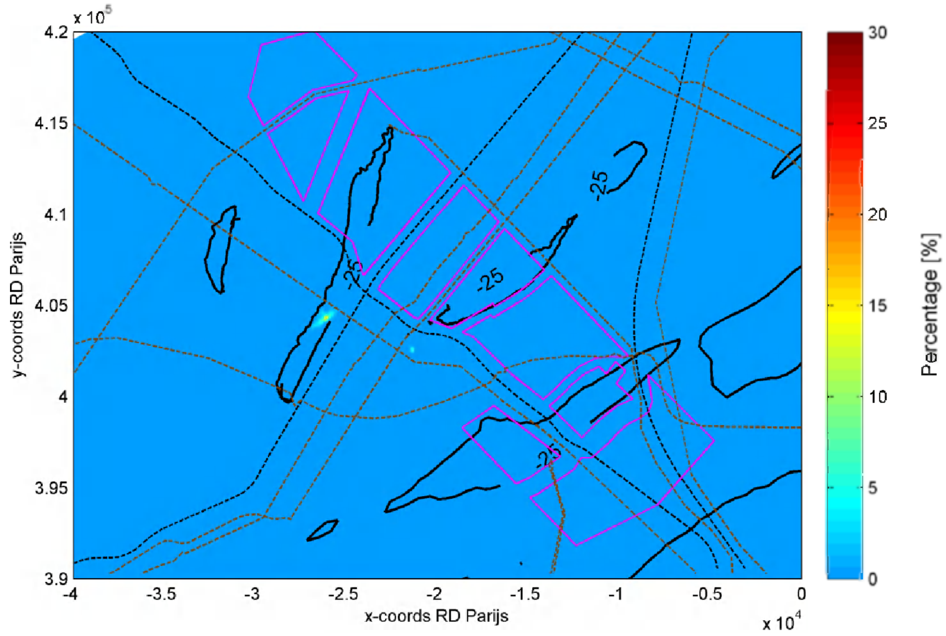

Figure 3-9: Probability of exceedance of excess SSC over 10 mg/l in Scenario 1 (one TSHD of 10.000 m³).

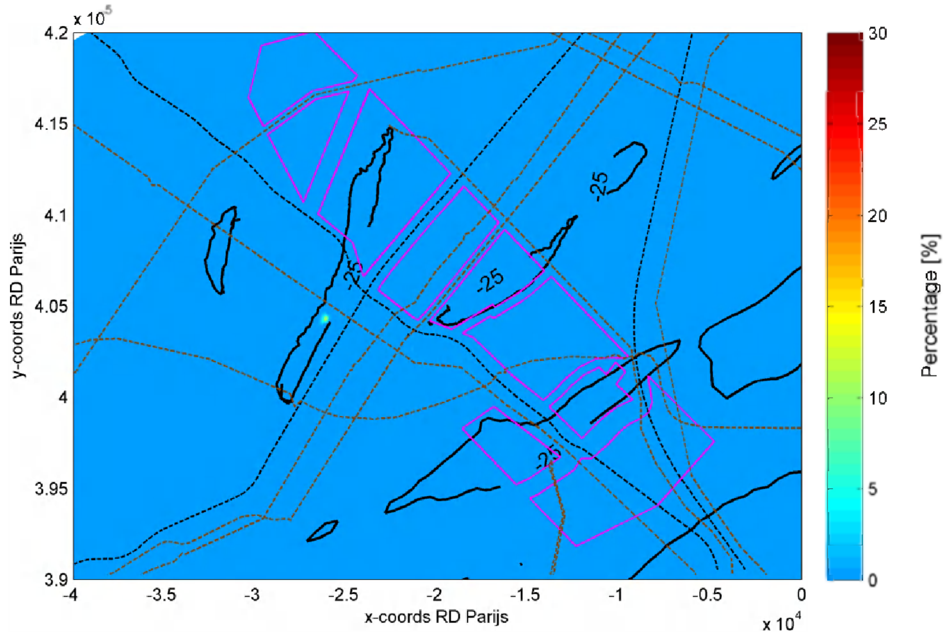

Figure 3-10: Probability of exceedance of excess SSC over 10 mg/l in Scenario 2 (two TSHDs of 5.000 m³).

3.3.2 Worst case

The worst case for Scenario 1 and Scenario 2, both takes place at a strong flood current, i.e. the farthest extent outside the project area. Figure 3-11 to Figure 3-13 and Figure 3-14 to Figure 3-16 display the occurrence of the first 4 mg/l-contour line and the dispersion of sediment plume until vanishing of the 4 mg/l contour line during the dredging-dumping activity respectively in Scenario 1 and 2. Contour lines of 4 mg/l are shown in red in the figures. In the lower panels of the figures, a red point marks the water level and tidal current at the dumping site. The same figure description accounts for all subsequent figures (Figure 3-17 to Figure 3-19).

3.3.2.1 Scenario 1 (one TSHD of 10.000 m³)

Figure 3-11 shows the situation 5 min after overflow in cycle 21. The SSC exceeds the background level of 4 mg/l. In Figure 3-12 the 4 mg/l contour is still visible and the overflow plume drifts to the NE and meanwhile the dump plume of cycle 21 has been produced. Figure 3-13 shows how the overflow plume of cycle 21 has reached levels below background concentration.

The SSC in the sediment plume caused by the dredging is shown to drop below 4 mg/l in a period of 1h15min, during which the sediment plume travelled a distance of around 2.500 m to the northeast during the strong flood current (Figure 3-11 to Figure 3-13). The size of the contour reaches maximally about 1.300 m before the SSC drops below 4 mg/l. In Figure 3-12 the sediment plume due to the dumping in the project zone can be seen, the SSC also exceeds the background level of 4 mg/l, and in the same manner falls below 4 mg/l when the 4 mg/l contour of the overflow plume disappears (Figure 3-13).

3.3.2.2 Scenario 2 (two TSHDs of 5.000 m³)

Figure 3-14 shows the situation 5 min after overflow of TSHD A in cycle 21 for Scenario 2. The SSC exceeds the background level of 4 mg/l. In Figure 3-15 the 4 mg/l contour is still visible and the overflow plume drifts to the NE. Figure 3-16 shows how the overflow plume caused by TSHD A in cycle 21 has reached levels below background concentration, and meanwhile the dump plume caused by TSHD A in cycle 21 has been also produced.

In Scenario 2, the sediment plume caused by the overflow of TSHD A has moved approximately 1.400 m to the northeast by the strong flood current in a period of 40 minutes, during which the size of 4 mg/l contour was limited to 1.000 m and the SSC already gradually fell below 4 mg/l (Figure 3-14 to Figure 3-16).

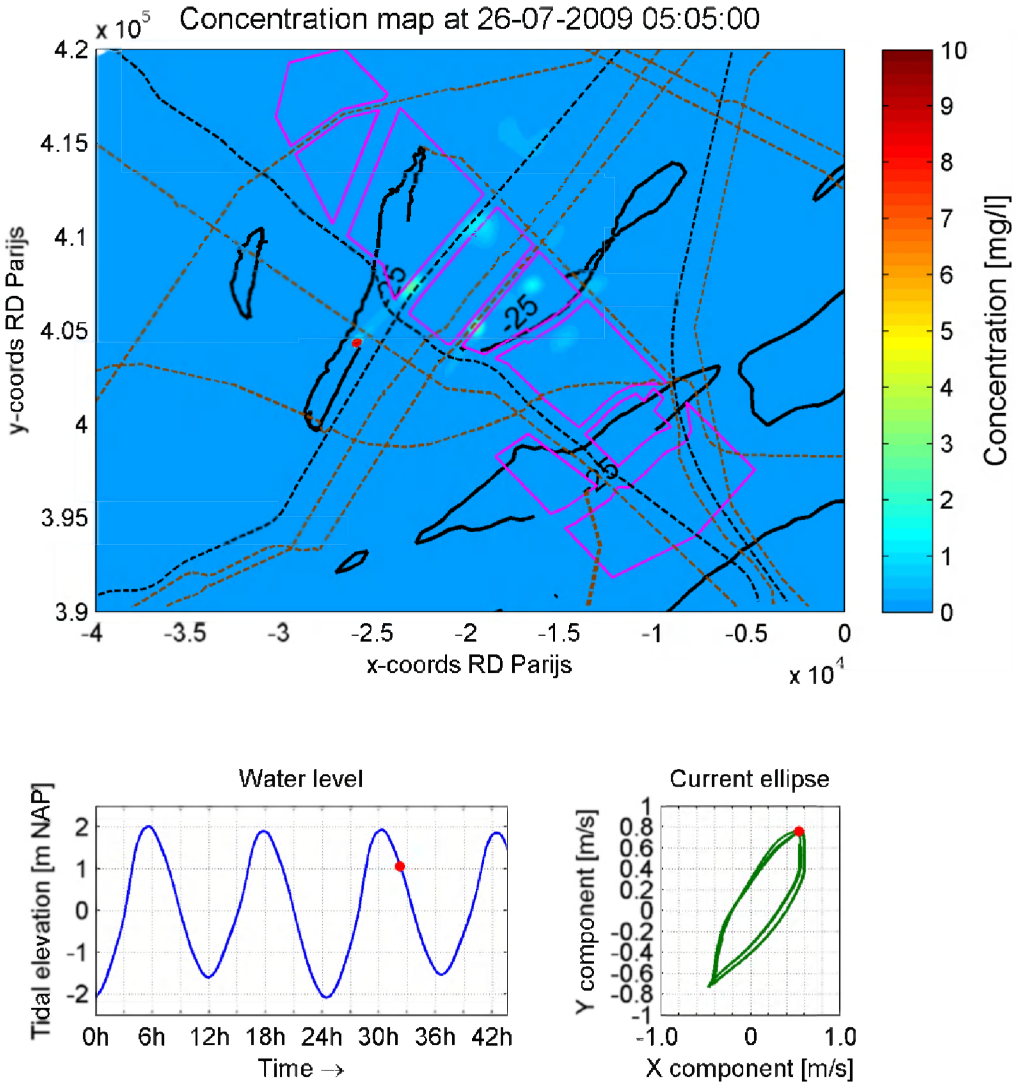

Figure 3-11: Excess SSC, water level and tidal current 5min after overflow started for cycle 21, in Scenario 1 during flood.

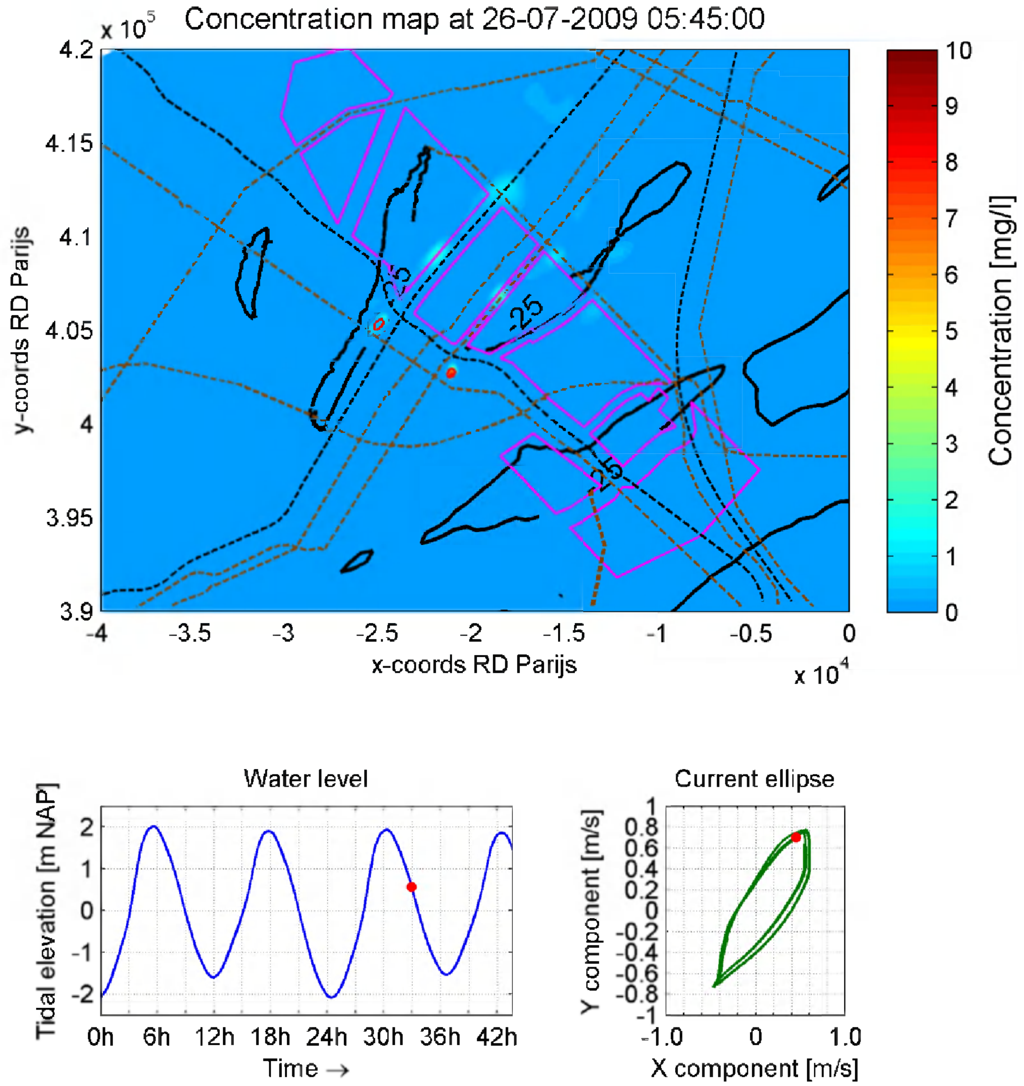

Figure 3-12: Excess SSC, water level and tidal current during dispersion of sediment plume produced by overflow in Scenario 1 (cycle 21) for a flood event.

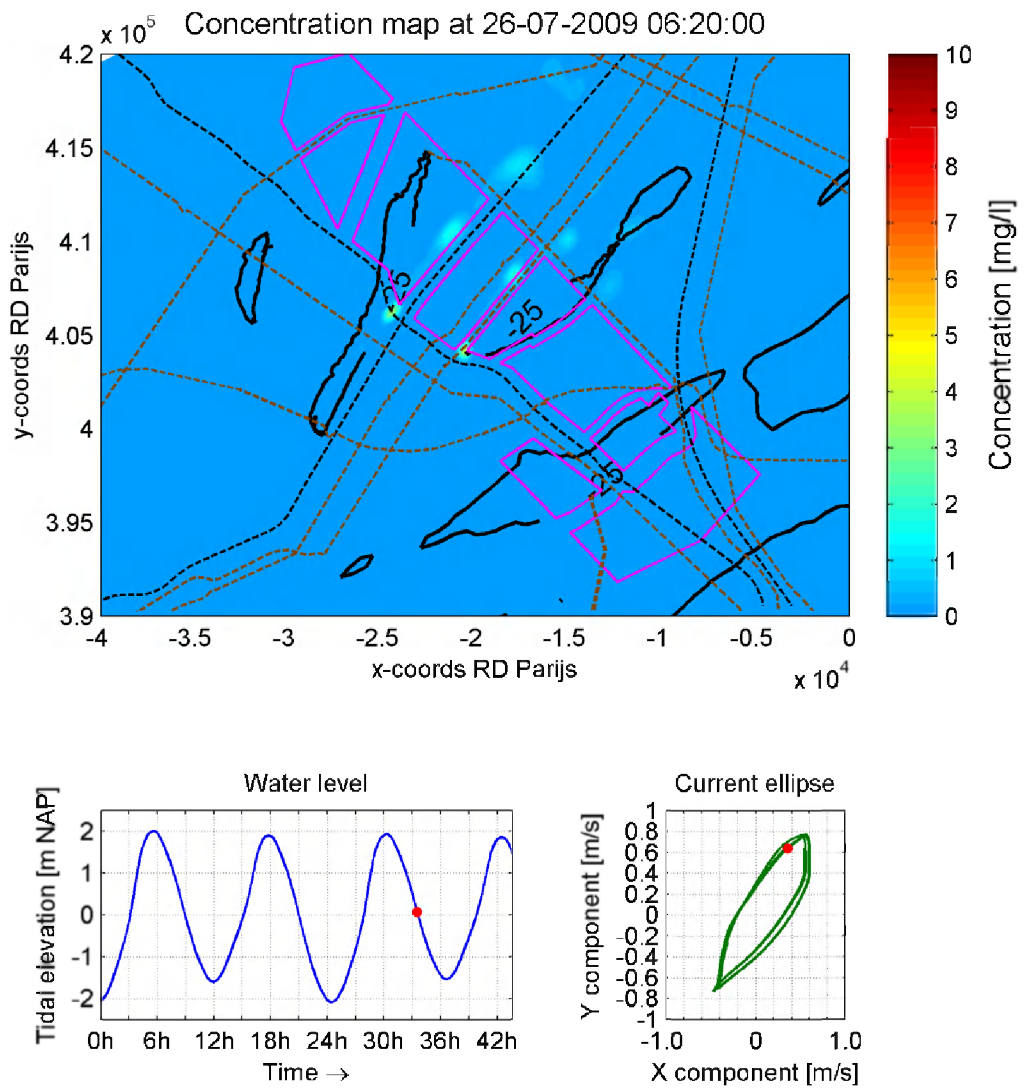

Figure 3-13: Excess SSC, water level and tidal current at disappearance of 4-mg/l contour for overflow plume in Scenario 1 (cycle 21) at a flood event.

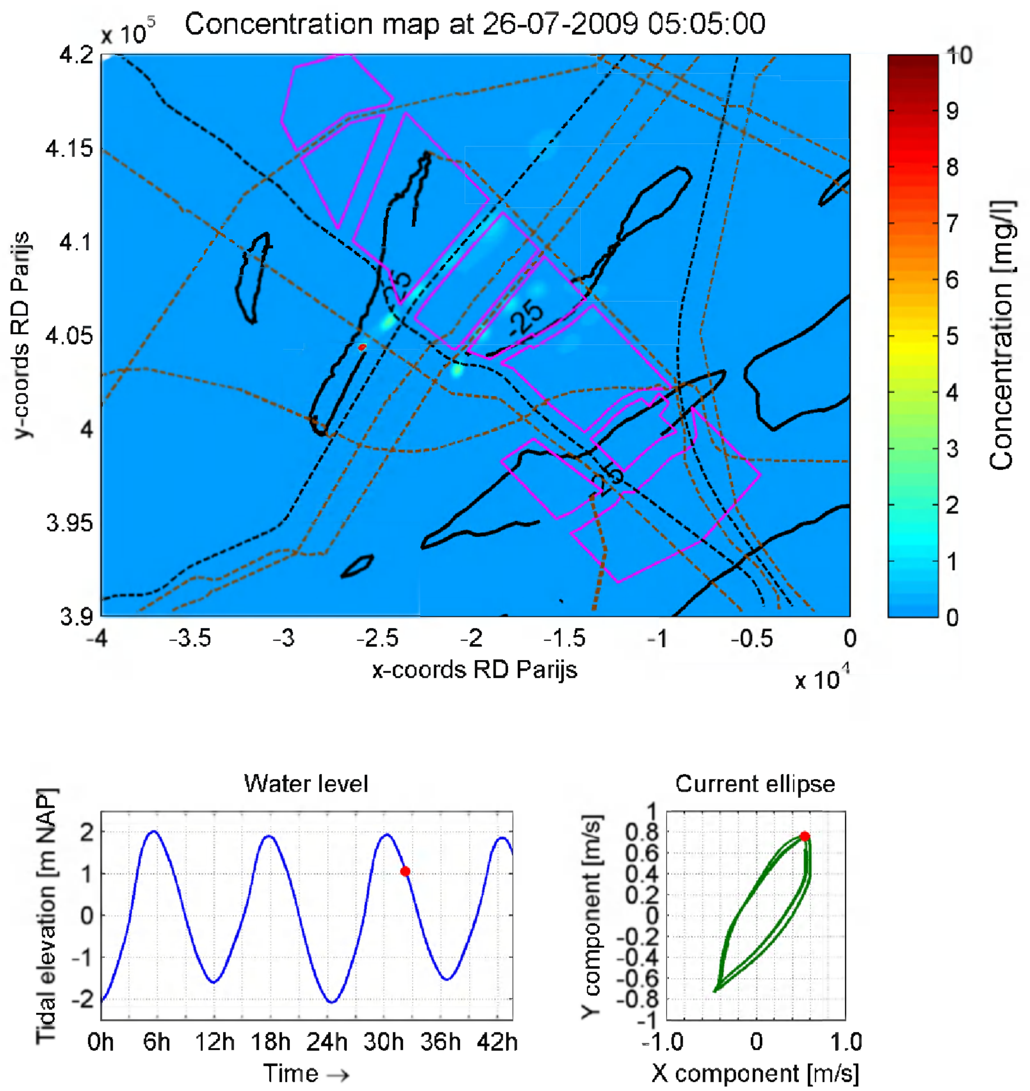

Figure 3-14: Excess SSC, water level and tidal current 5min after overflow started by TSHD A for cycle 21, in Scenario 2 during flood.

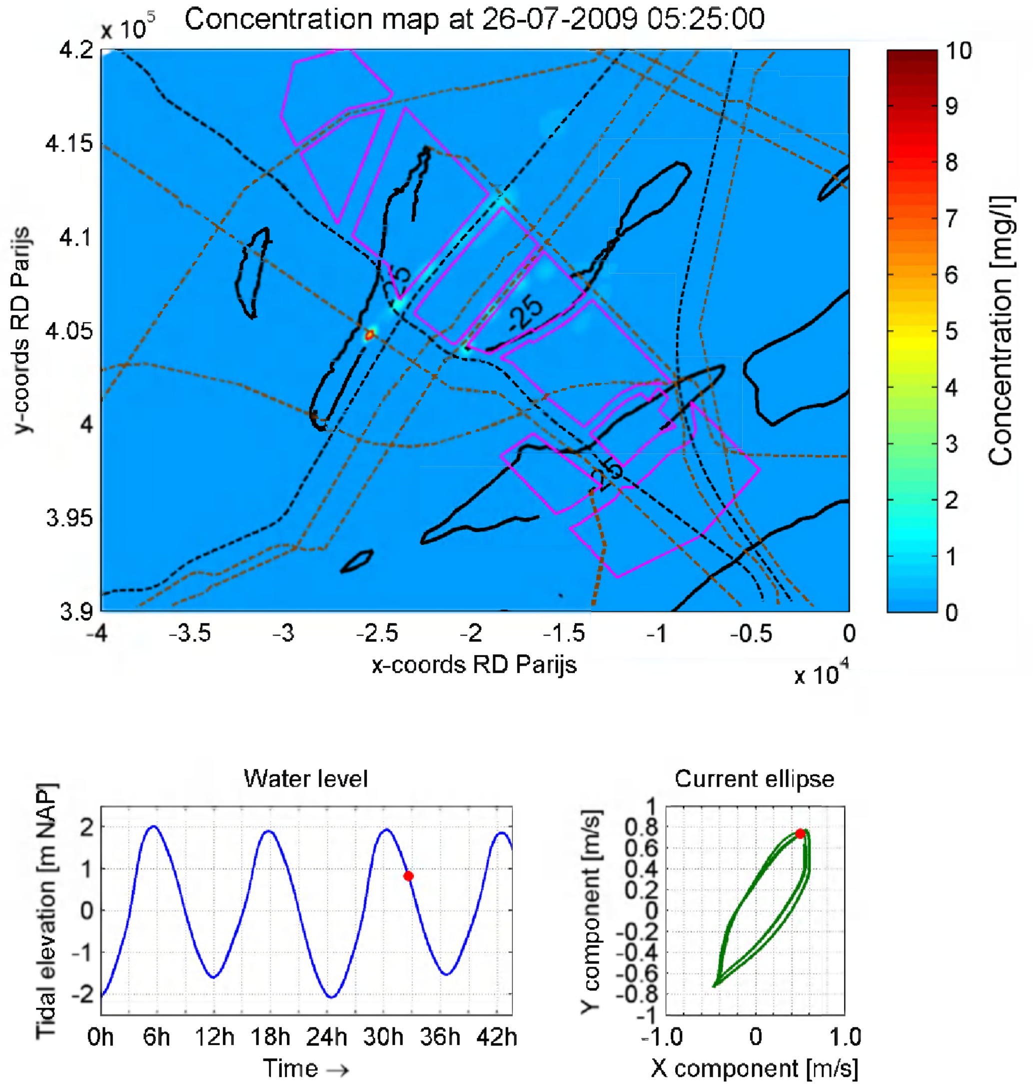

Figure 3-15: Excess SSC, water level and tidal current during dispersion of sediment plume produced by overflow of TSHD A in Scenario 2 (cycle 21) for a flood event.

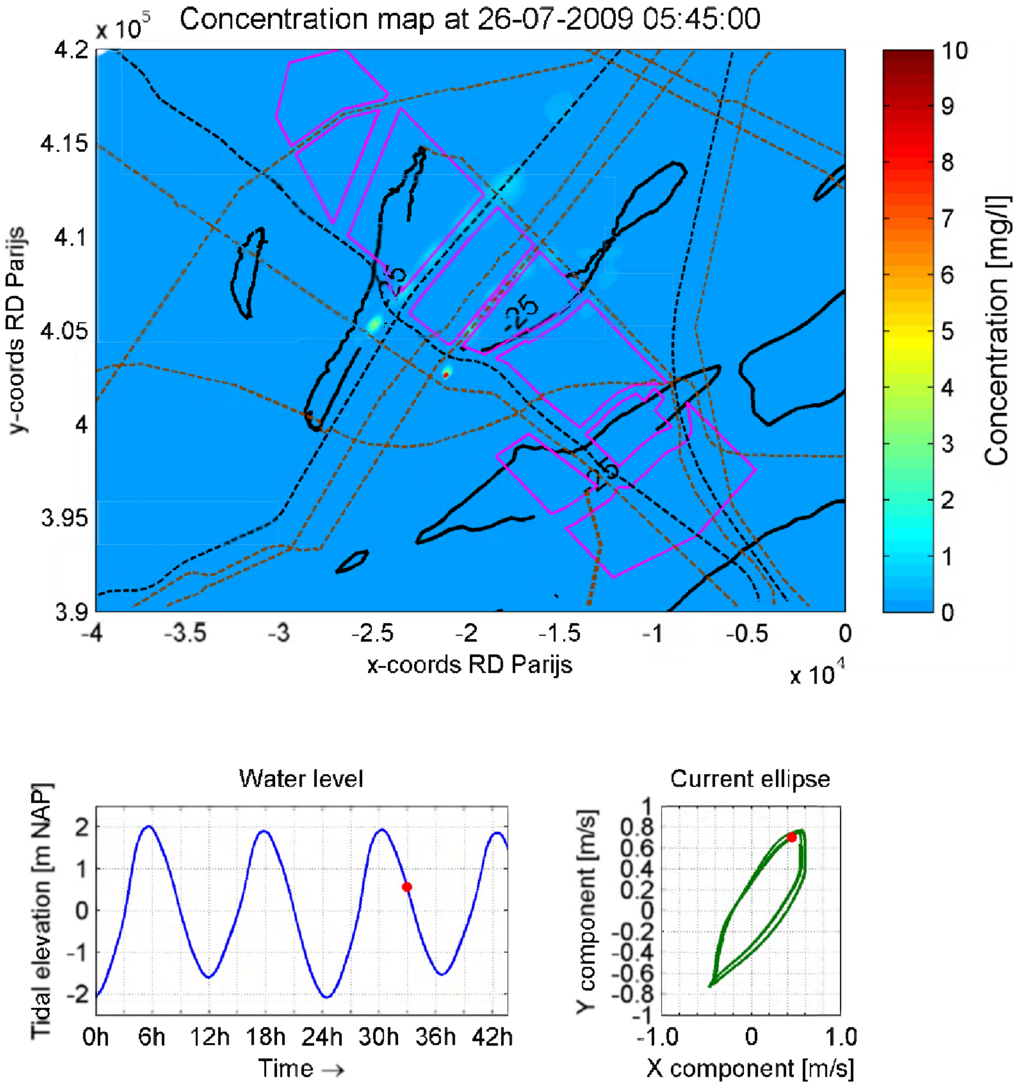

Figure 3-16: Excess SSC, water level and tidal current at disappearance of 4-mg/l contour for overflow plume produced by TSHD A in Scenario 2 (cycle 21) at a flood event.

3.3.3 Example around slack water

The example shows the evolution of the sediment plume when overflow takes place around slack water in Scenario 1. Figure 3-17 shows the situation 5min after overflow in cycle 23. The SSC exceeds the background level of 4 mg/l. Figure 3-18 and Figure 3-19 show how the overflow plume of cycle 23 drifts to the SW. Figure 3-19 shows how the overflow plume of cycle 23 has reached levels below background concentration.

The sediment plume moved ca. 2.000 m in 1h35min during which the 4 mg/l-contour line of the overflow plume produced in cycle 23 dies out.

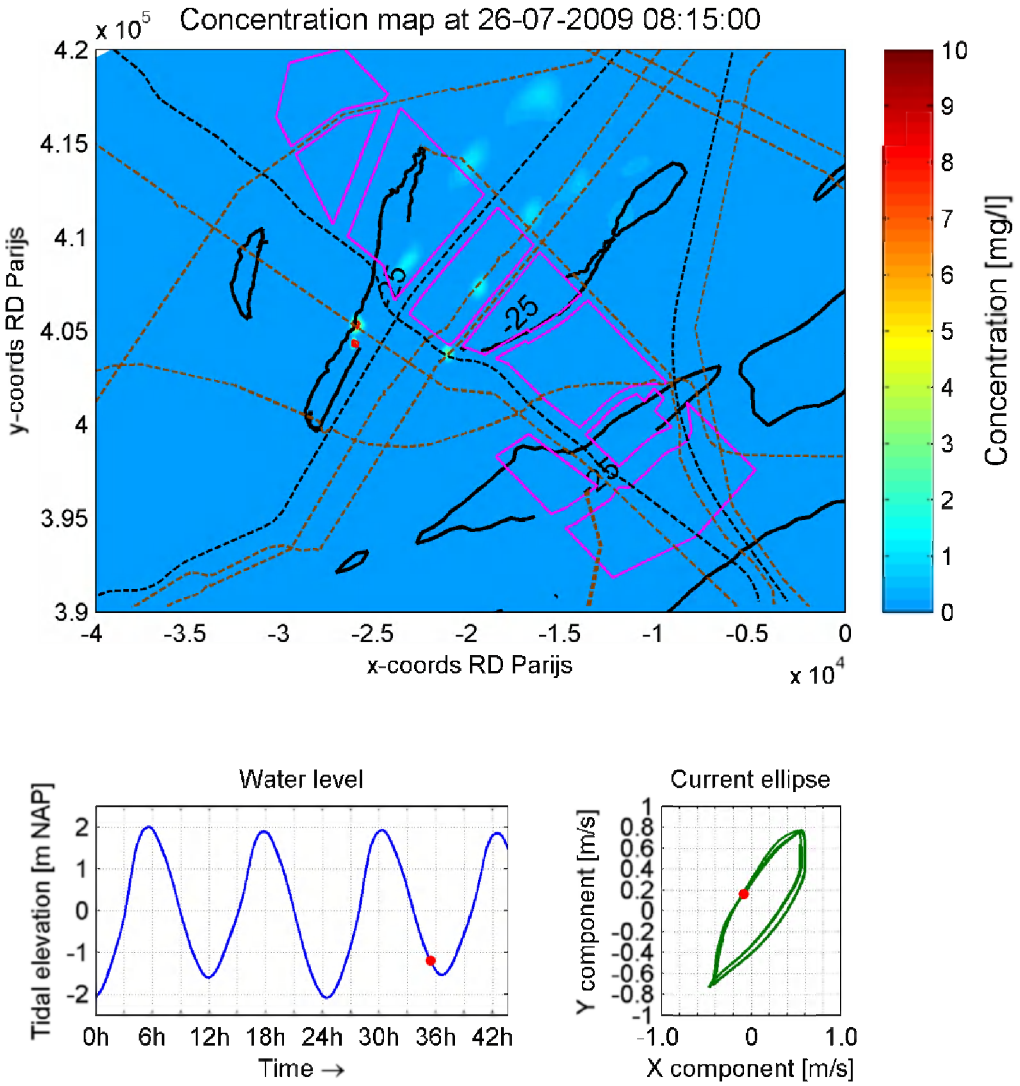

Figure 3-17: Excess SSC, water level and tidal current 5min after overflow started for cycle 23, in Scenario 1 during slack.

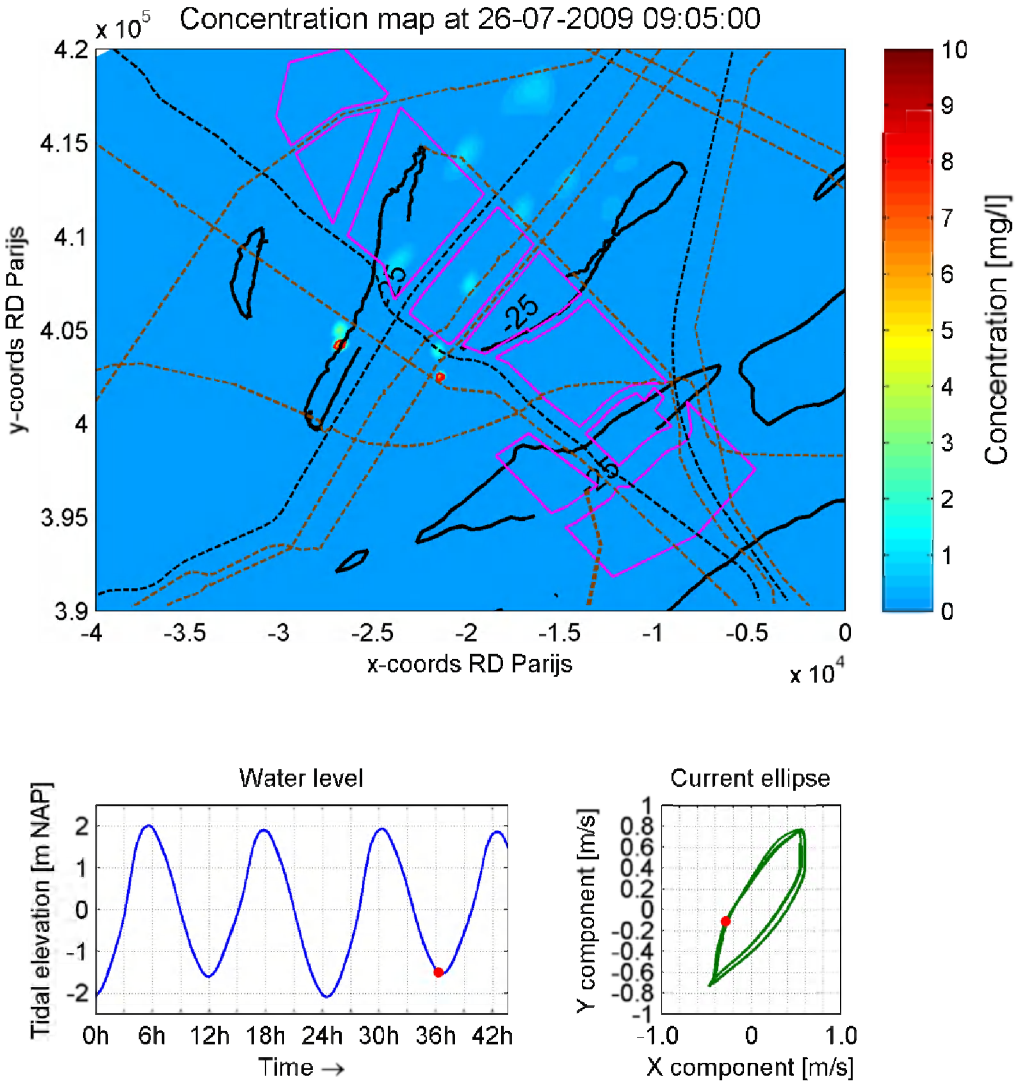

Figure 3-18: Excess SSC, water level and tidal current during dispersion of sediment plume produced by overflow in Scenario 1 (cycle 23) for a slack water event.

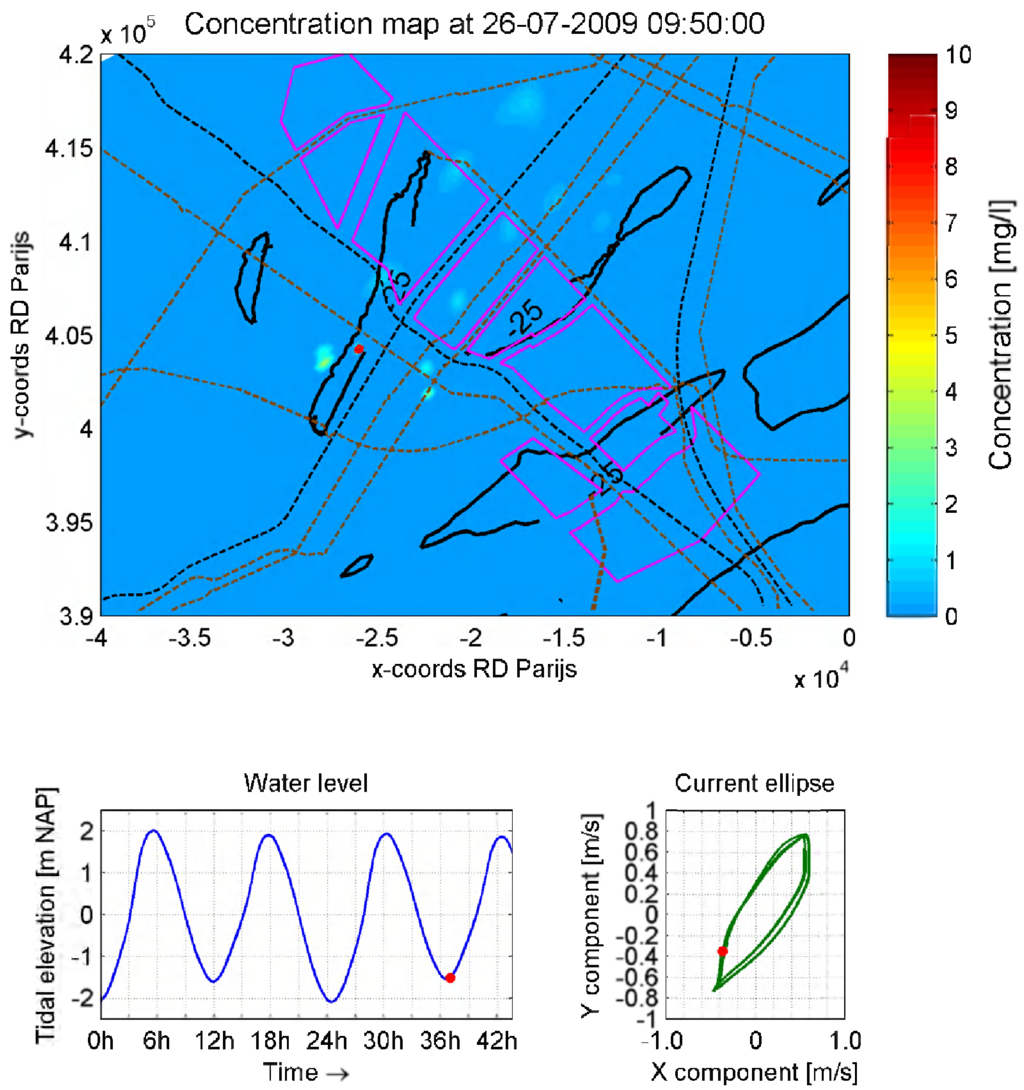

Figure 3-19: Excess SSC, water level and tidal current at disappearance of 4-mg/l contour for overflow plume produced in cycle 23 in Scenario 1 (cycle 23) at a slack water event.

4. CONCLUSIONS

In order to analyse and to determine the impact of the dredging and dumping activities on the turbidity and suspended sediment levels during construction of the artificial island, a 3D numerical model has been developed. Two scenarios representing dredging-dumping by only one TSHD of 10.000 m³ (Scenario 1) and by two TSHD of 5.000 m³ (Scenario 2) have been investigated respectively. The overflow in dredging is shown to have a larger impact than the dumping. Although a higher SSC could be observed during the overflow, the overflow and dumping are both able to produce SSC larger than the background level of 4 mg/l. The effects of draghead losses in dredging seem to be invisible and can be neglected in practice.

A flood event is considered to be the worst case for both scenarios in terms of lateral extent beyond the project zone. The worst case of both scenarios shows that the sediment plume can move ca. 2.500 m for Scenario 1 and ca. 1.400 m for Scenario 2 in the periods between occurrence of the first 4 mg/l contour line and disappearance of the 4 mg/l contour line for the sediment plume produced by overflow. During the dredging-dumping cycle (1h35min) of the worst case, the turbidity values exceed the background level of 4 mg/l for about 1h15min in Scenario 1 and for about 40min in Scenario 2. During slack water, the sediment plume with 4 mg/l moves ca. 2.000 m within 1h35min. The plume diameter where turbidity exceeds the background level is not larger than 1.300 m.

In addition, the probability of exceedance over 4 mg/l and 10 mg/l during the time of construction is calculated for both scenarios. The contour of this exceedance is orientated in the direction of the main tidal currents, centred around the dredging and dumping sites. For both scenarios the SSC around the dredging and dumping sites stays below 4 mg/l for more than 70% of the time within the project zone (8.7h and 13.2h above the limit for resp. Scenario 1 and 2 on a total time of approximately 42 hrs). Scenario 2 shows more intensive but smaller plume with probability of exceedance over 4 mg/l than Scenario 1. The probability of exceedance over 10 mg/l, i.e. the upper clear water limit, is limited to much smaller areas around the dredging and dumping sites in both scenarios (ca. 1.400 m vs. ca. 4.500 long at the dredging site in Scenario 1, and ca. 900 m vs. 3.200 m long at the dredging site in Scenario 2), and even invisible at the dumping site in Scenario 2.

5. REFERENCES

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6. APPENDIX — FULL DREDGING AND DUMPING CYLCE

6.1 SCENARIO 1 (ONE TSHD OF 10.000 M³)

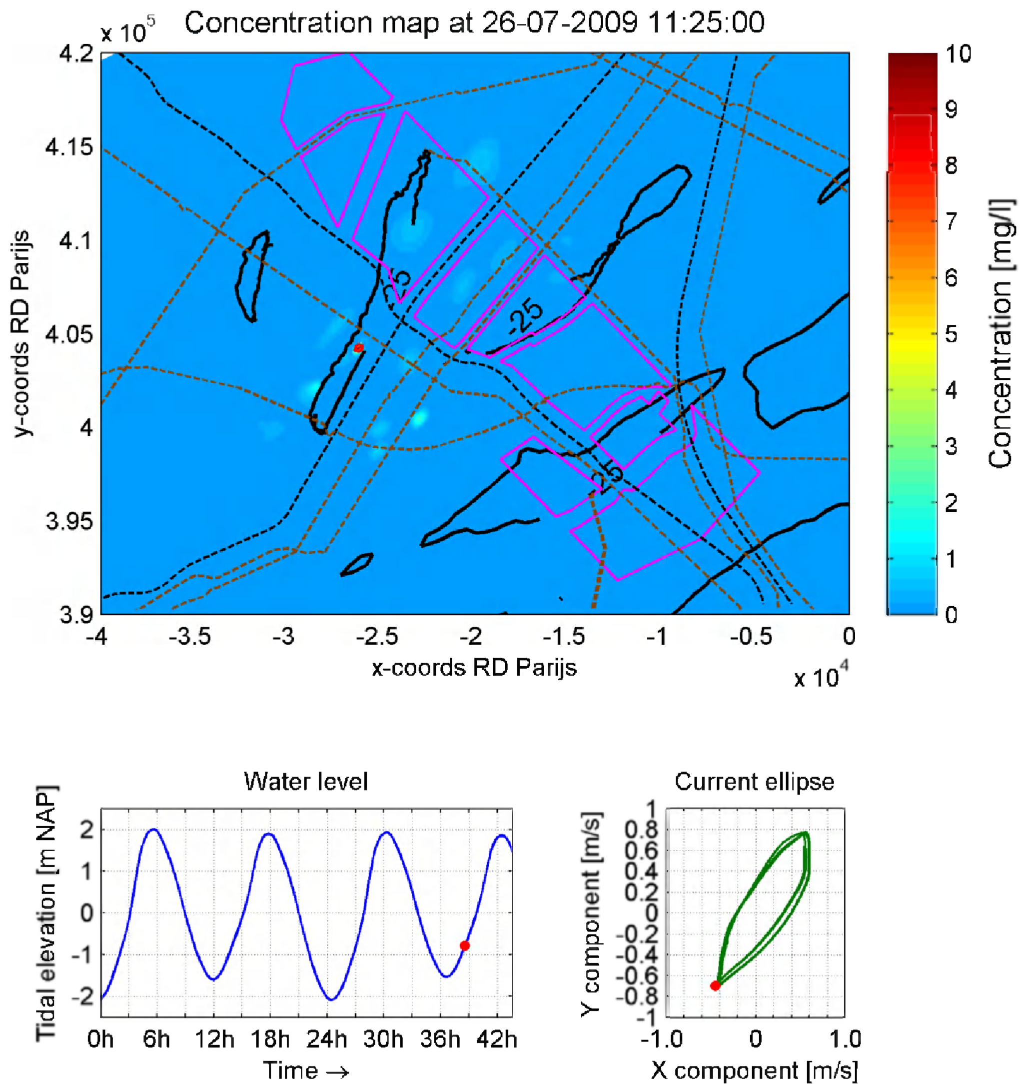

Figure 6-1: Evolution of a sediment plume for a full dredging-dumping cycle 5min after overflow in cycle 25 (11:20) during an ebb event in Scenario 1.

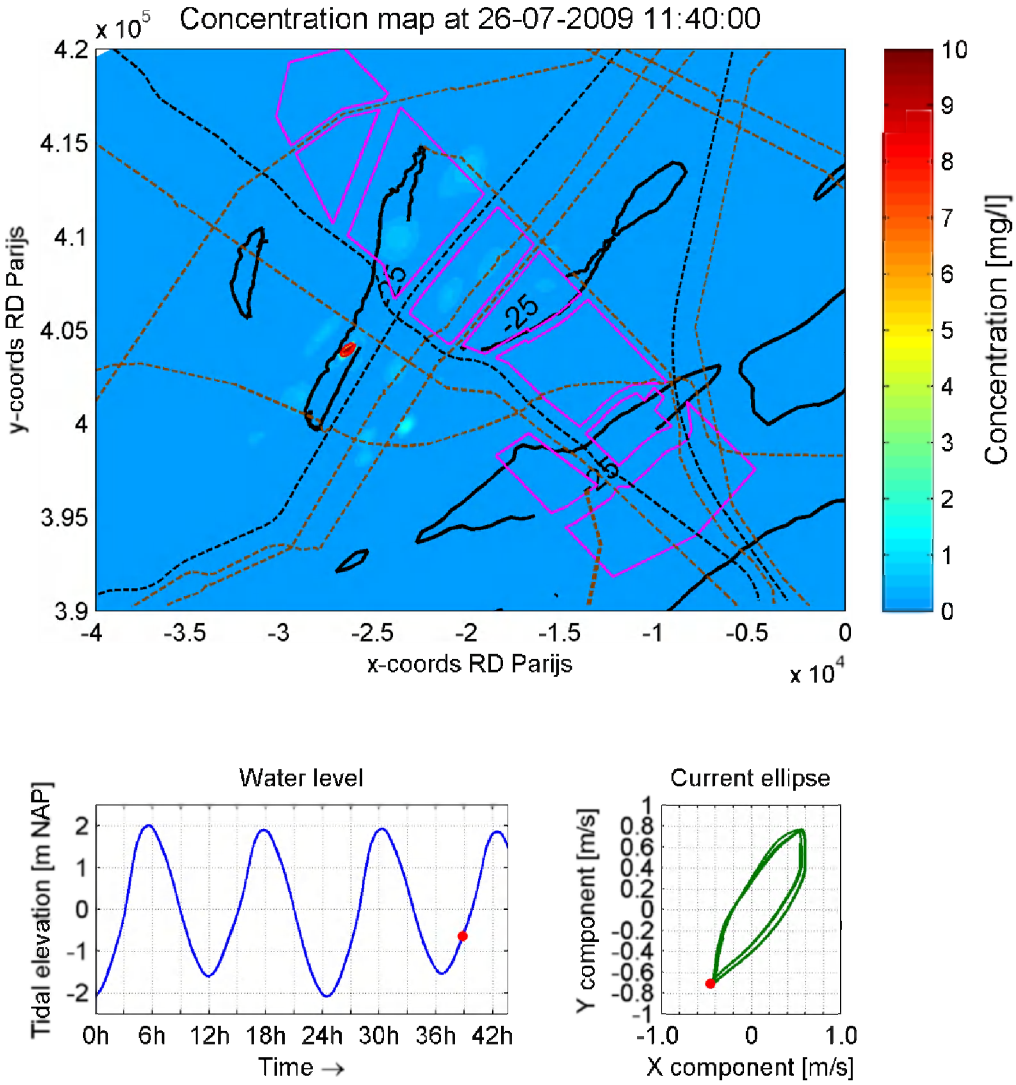

Figure 6-2: Evolution of a sediment plume for a full dredging-dumping cycle 20min after overflow in cycle 25 (11:20) during an ebb event in Scenario 1.

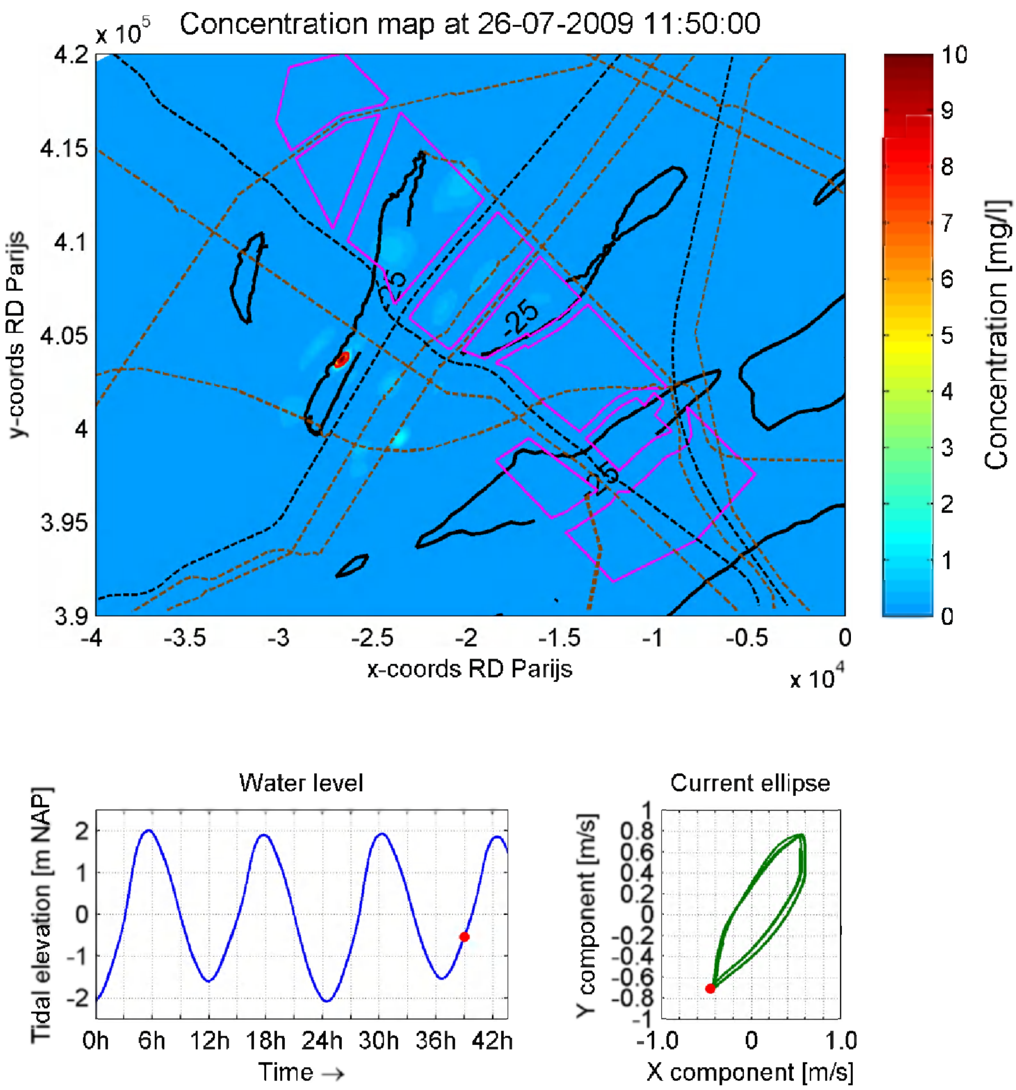

Figure 6-3: Evolution of a sediment plume for a full dredging-dumping cycle 30min after overflow in cycle 25 (11:20) during an ebb event in Scenario 1.

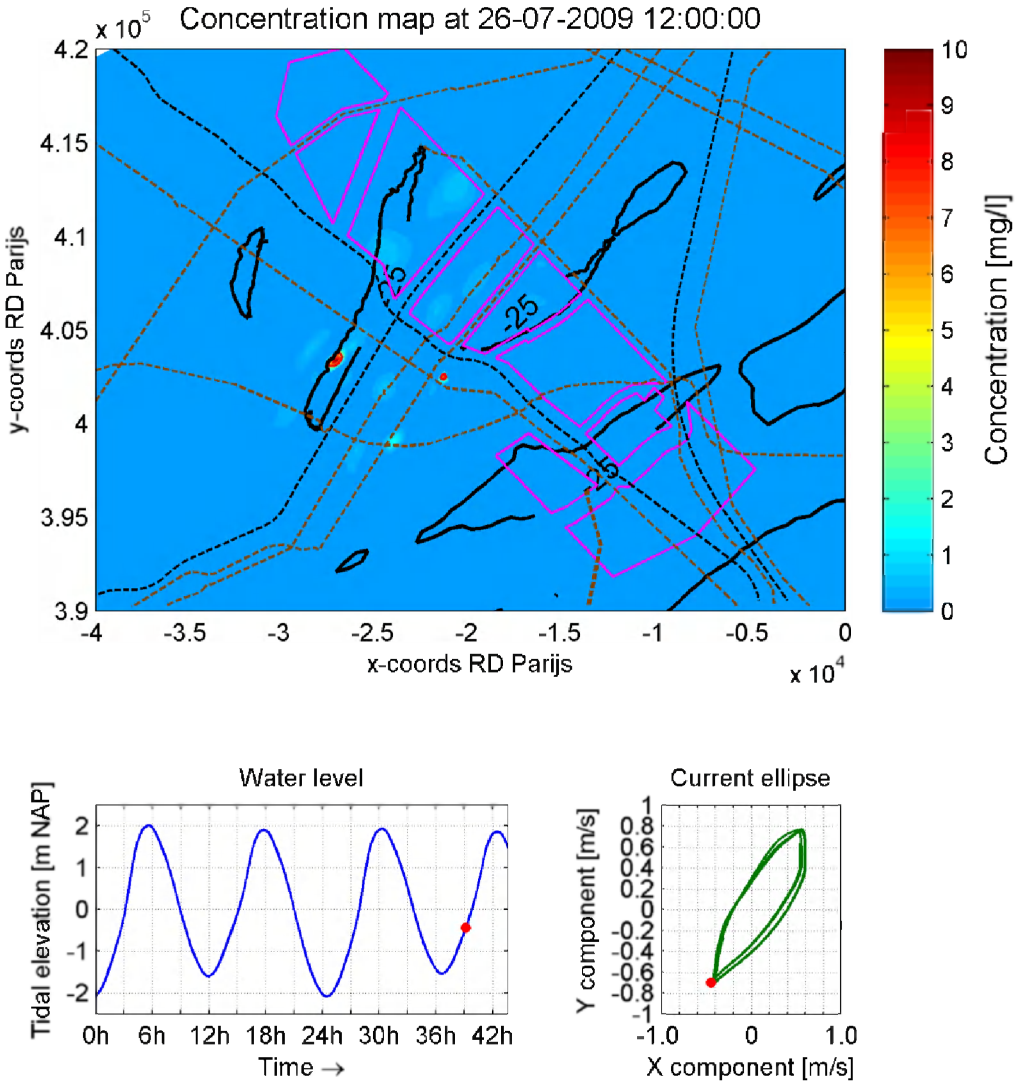

Figure 6-4: Evolution of a sediment plume for a full dredging-dumping cycle 40min after overflow in cycle 25 (11:20) during an ebb event in Scenario 1. First observation of plume due to dumping in cycle 25, 5min after start (11:55).

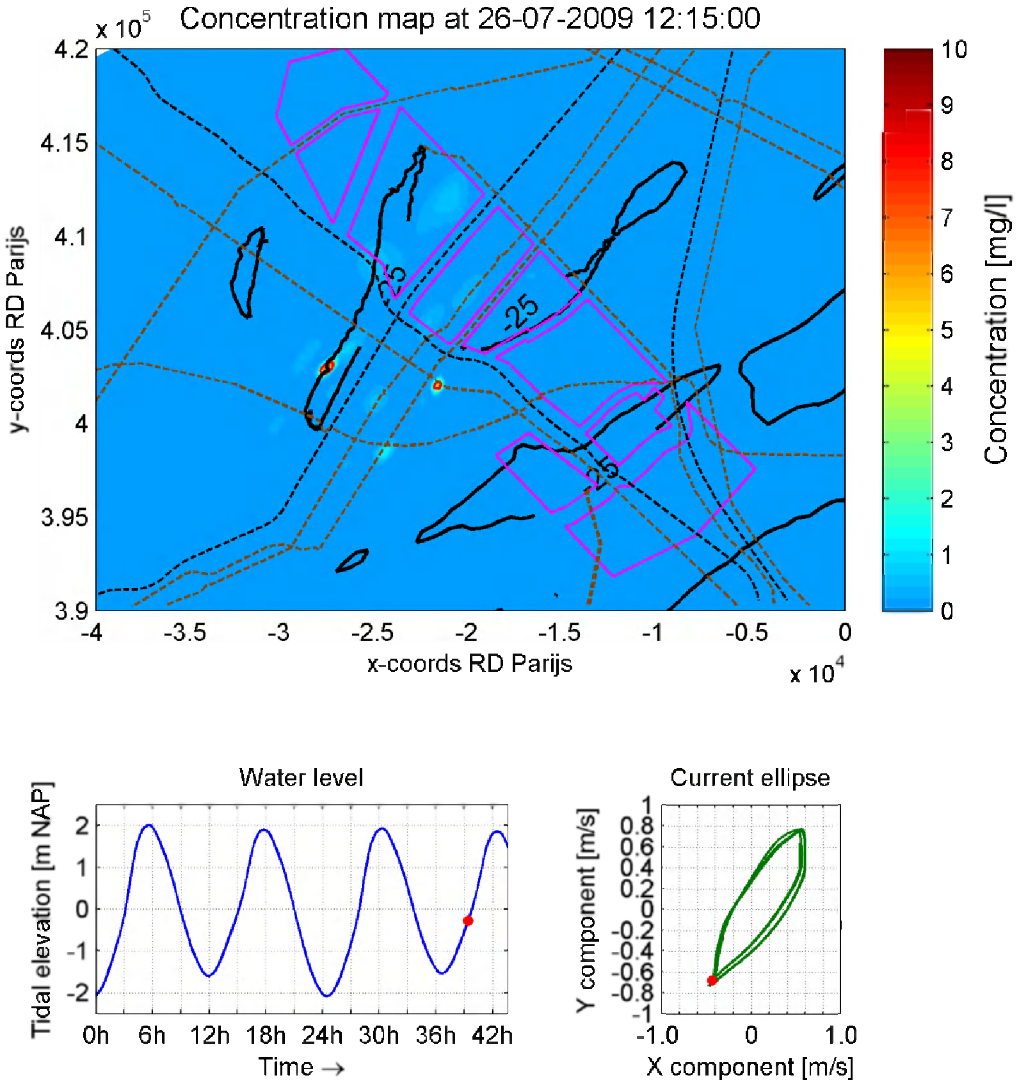

Figure 6-5: Evolution of a sediment plume for a full dredging-dumping cycle 55min after overflow in cycle 25 (11:20) during an ebb event in Scenario 1.

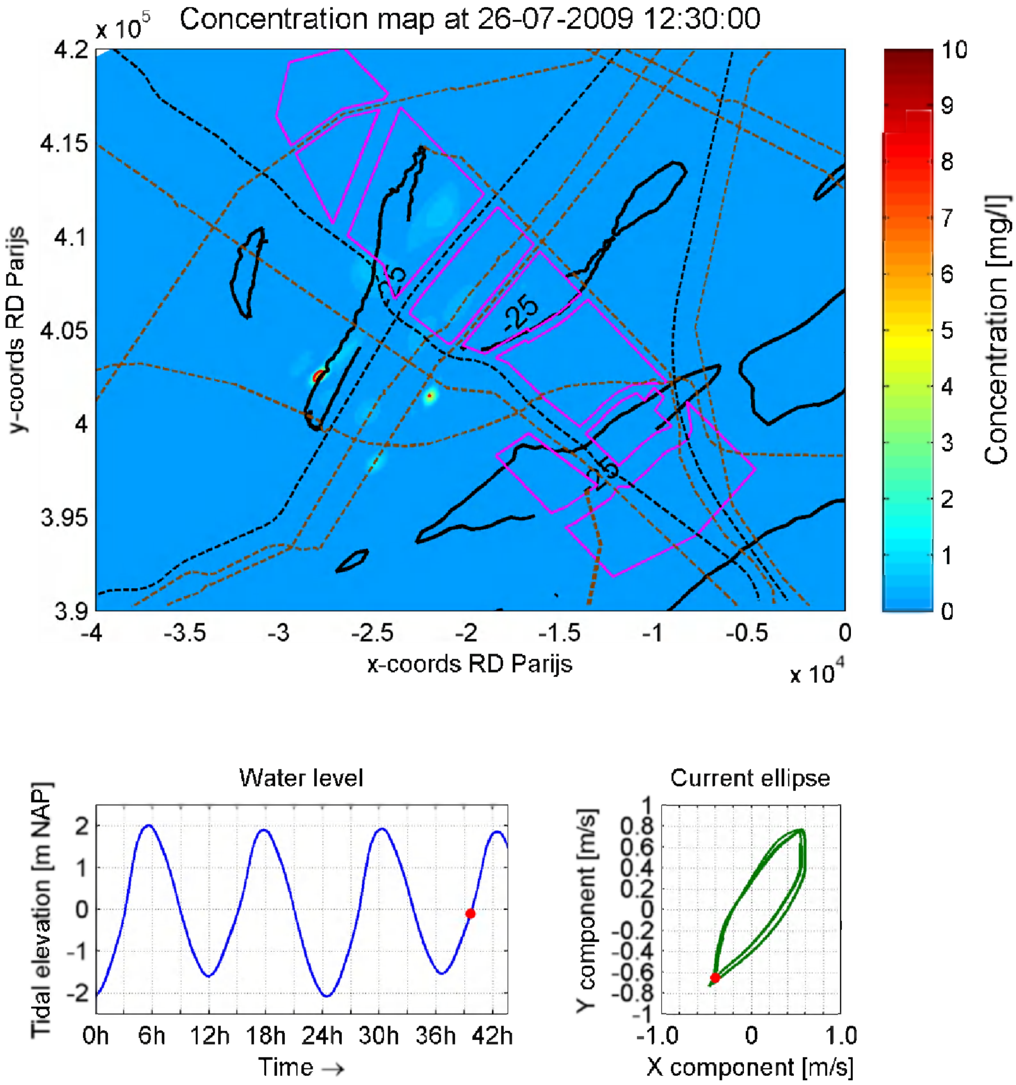

Figure 6-6: Evolution of a sediment plume for a full dredging-dumping cycle 1h10min after overflow in cycle 25 (11:20) during an ebb event in Scenario 1.

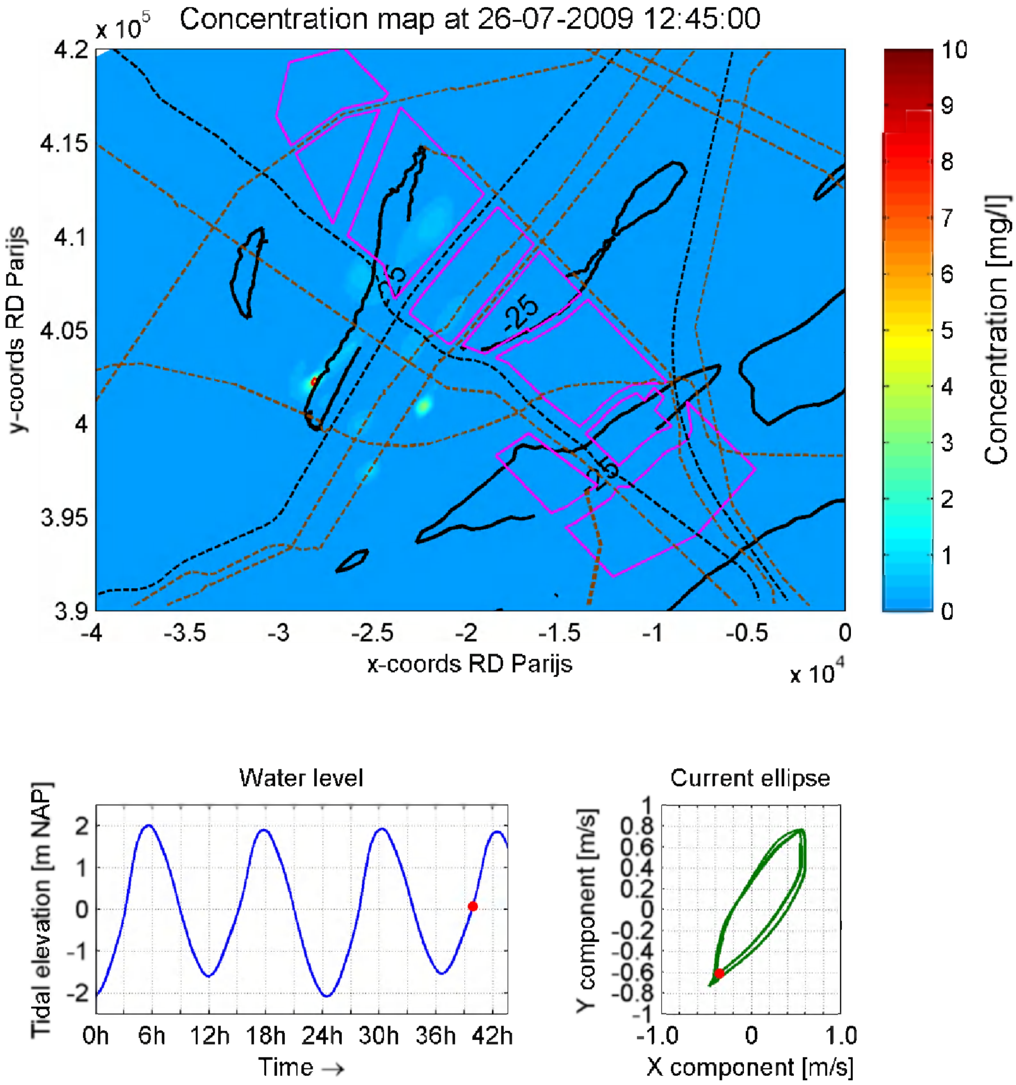

Figure 6-7: Evolution of a sediment plume for a full dredging-dumping cycle 1h25min after overflow in cycle 25 (11:20) during an ebb event in Scenario 1.

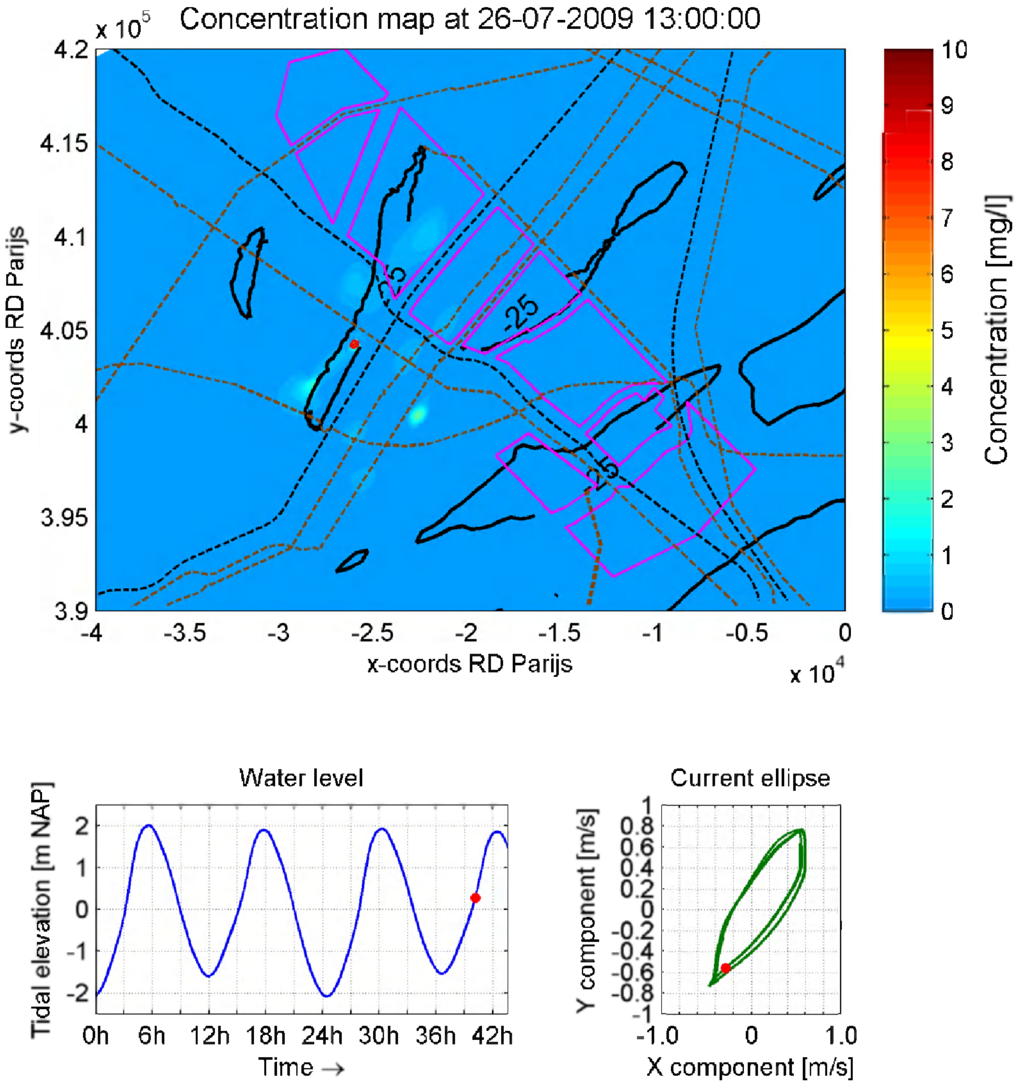

Figure 6-8: Evolution of a sediment plume for a full dredging-dumping cycle 1h40min after overflow in cycle 25 (11:20) during an ebb event in Scenario 1. First observation of plume due to overflow in cycle 26, 5min after start (12:55).

6.2 SCENARIO 2 (TWO TSHDS OF 5.000 M³)

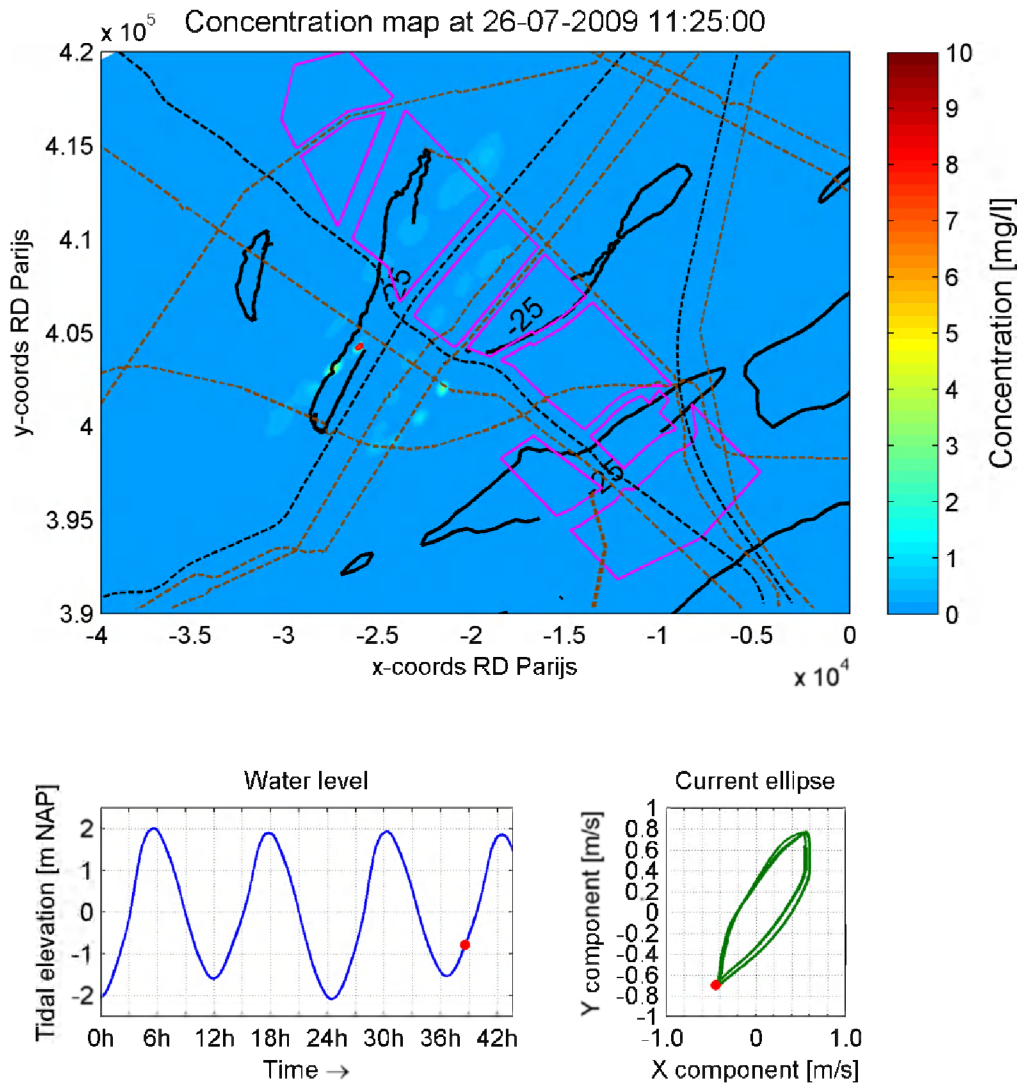

Figure 6-9: Evolution of a sediment plume for a full dredging-dumping cycle 5min after overflow of TSHD A in cycle 25 (11:20) during an ebb event in Scenario 2.

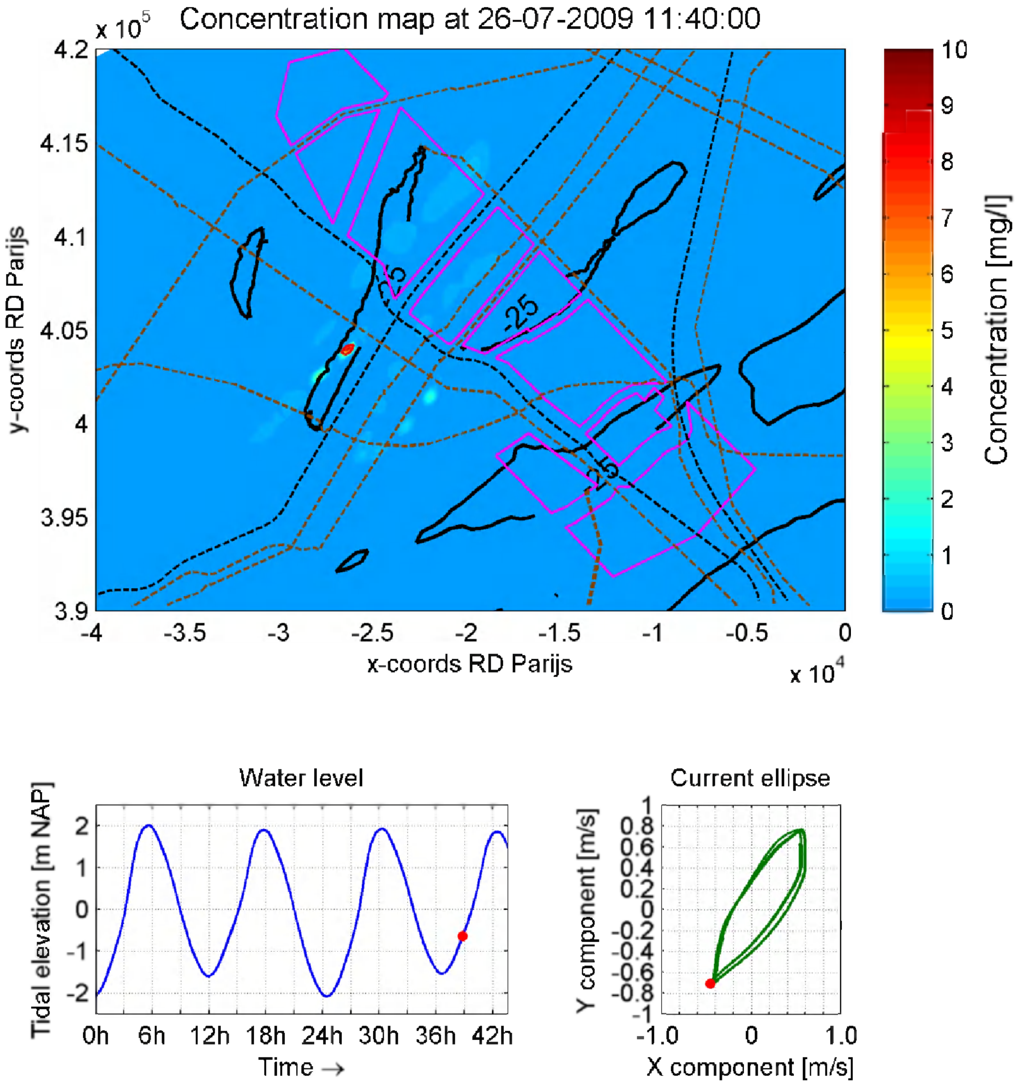

Figure 6-10: Evolution of a sediment plume for a full dredging-dumping cycle 20min after overflow of TSHD A in cycle 25 (11:20) during an ebb event in Scenario 2.

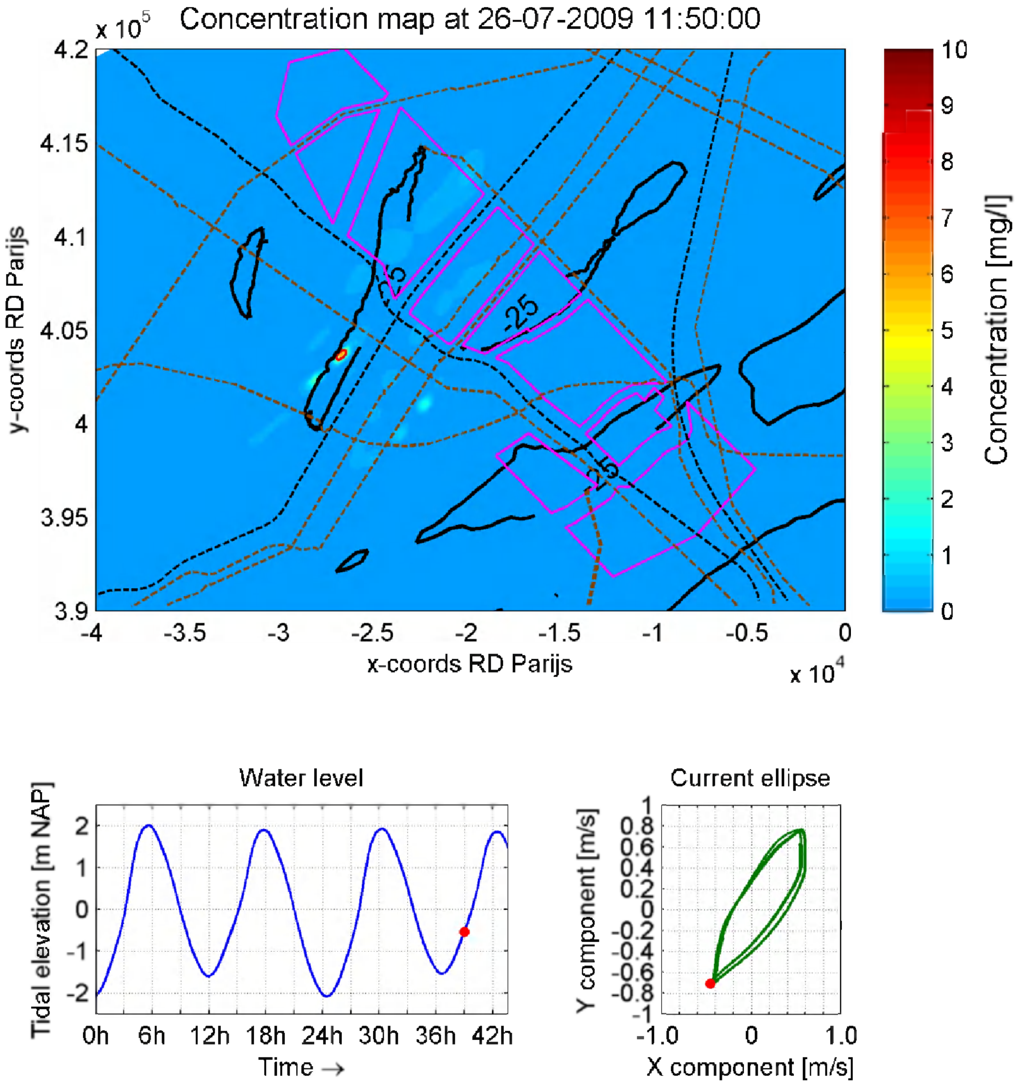

Figure 6-11: Evolution of a sediment plume for a full dredging-dumping cycle 30min after overflow of TSHD A in cycle 25 (11:20) during an ebb event in Scenario 2.

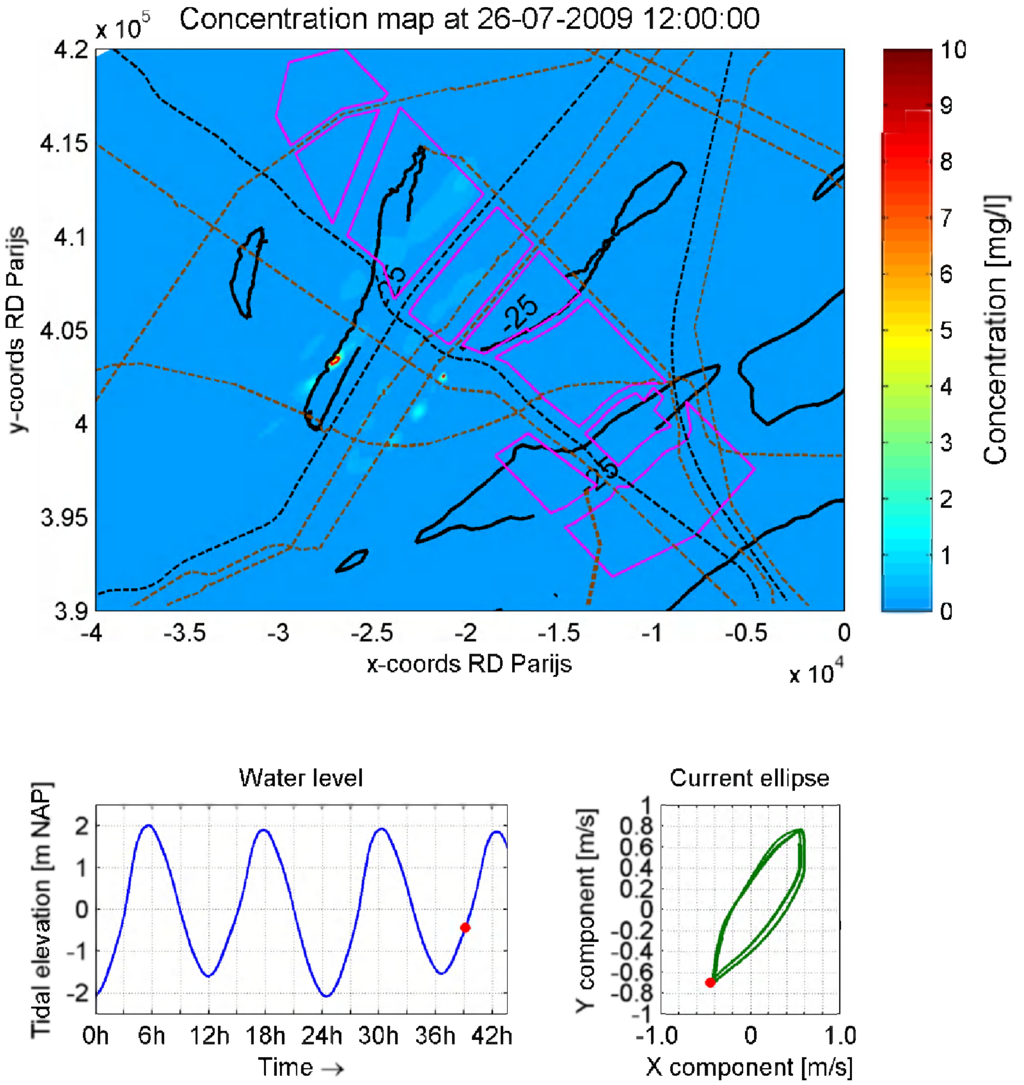

Figure 6-12: Evolution of a sediment plume for a full dredging-dumping cycle 40min after overflow of TSHD A in cycle 25 (11:20) during an ebb event in Scenario 2. First observation of plume due to dumping of TSHD A in cycle 25, 5min after start (11:55).

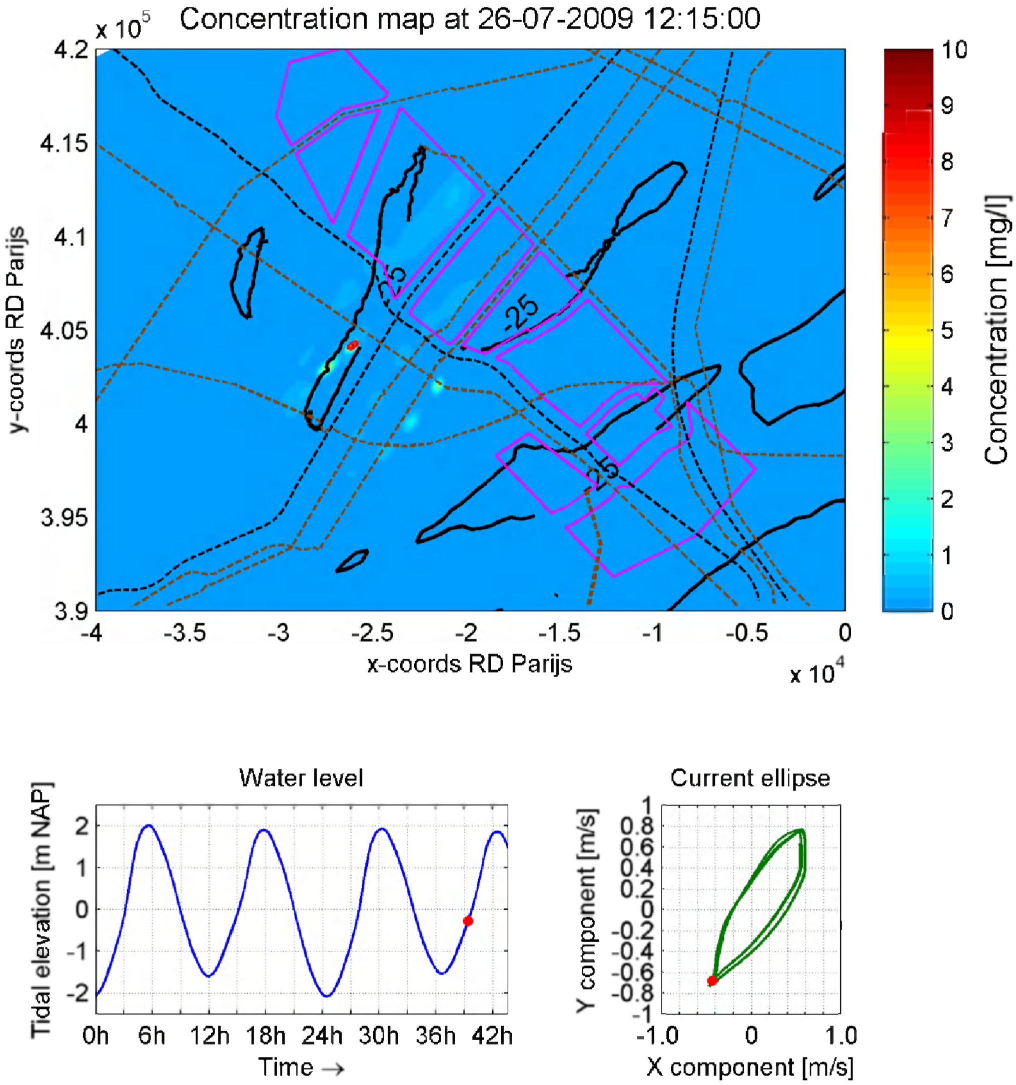

Figure 6-13: Evolution of a sediment plume for a full dredging-dumping cycle 55min after overflow of TSHD A in cycle 25 (11:20) during an ebb event in Scenario 2. First observation of plume due to overflow of TSHD B in cycle 25, 10min after start (12:05).

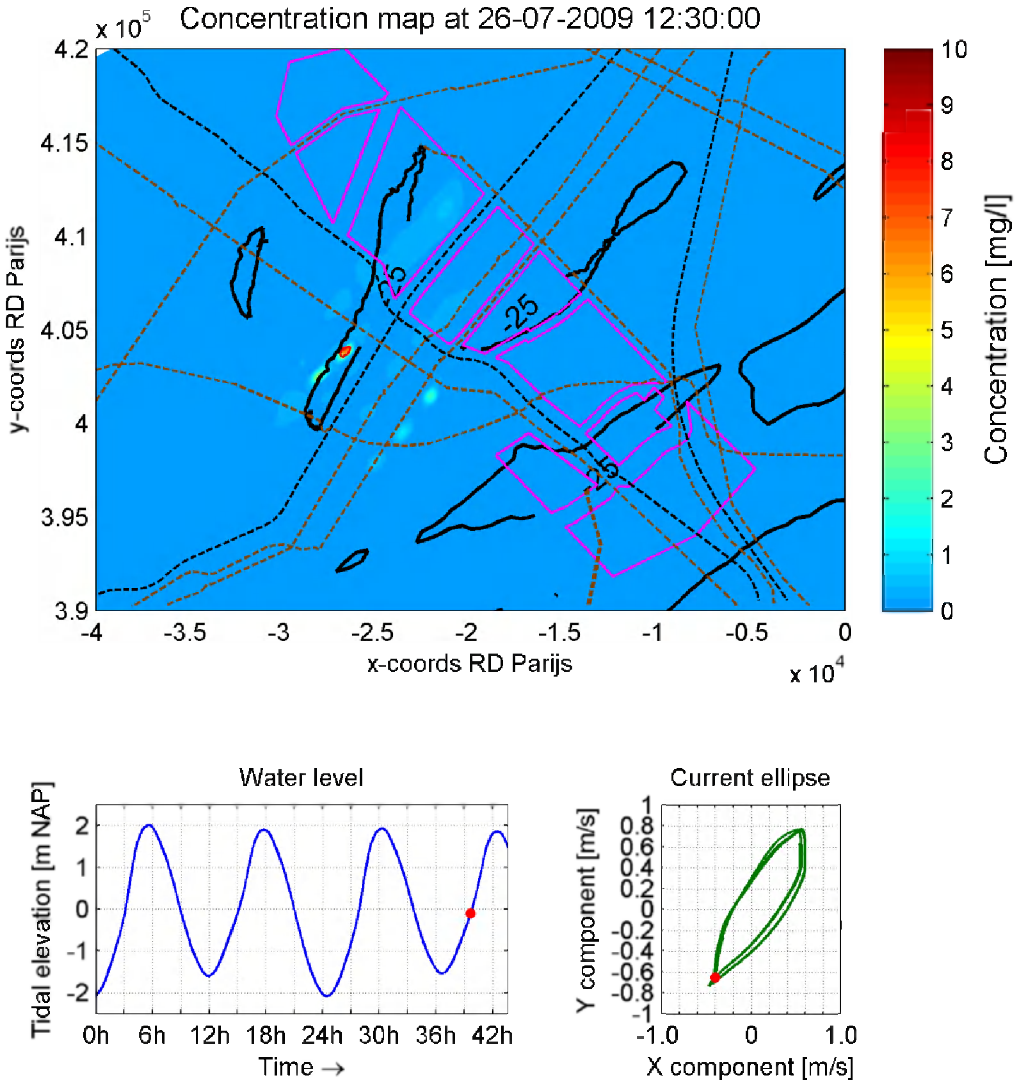

Figure 6-14: Evolution of a sediment plume for a full dredging-dumping cycle 1h10min after overflow of TSHD A in cycle 25 (11:20) during an ebb event in Scenario 2. Evolution of a sediment plume due to dumping of TSHD B in cycle 25, 25min after start (12:05).

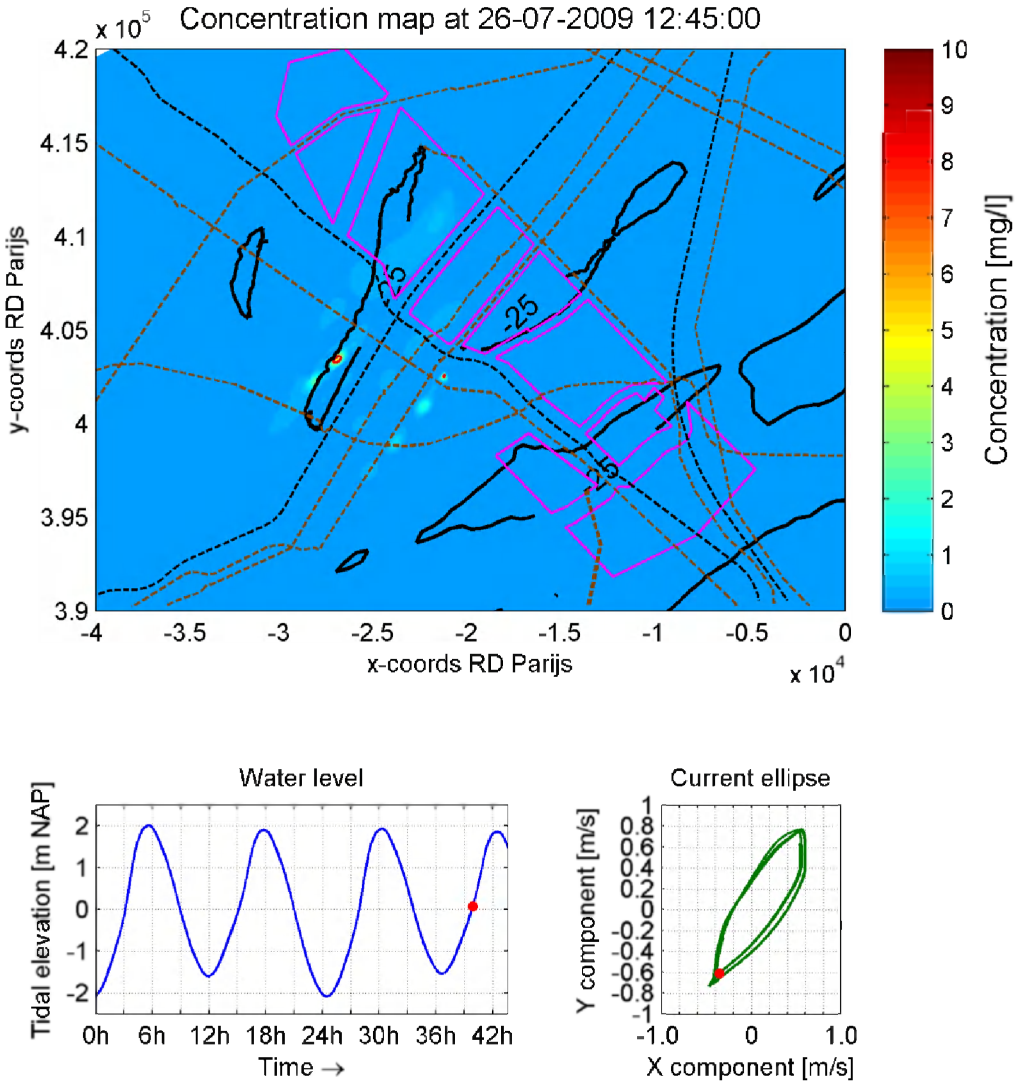

Figure 6-15: Evolution of a sediment plume for a full dredging-dumping cycle 1h25min after overflow of TSHD A in cycle 25 (11:20) during an ebb event in Scenario 2. Evolution of a sediment plume due to dumping of TSHD B in cycle 25, 40min after start (12:05).

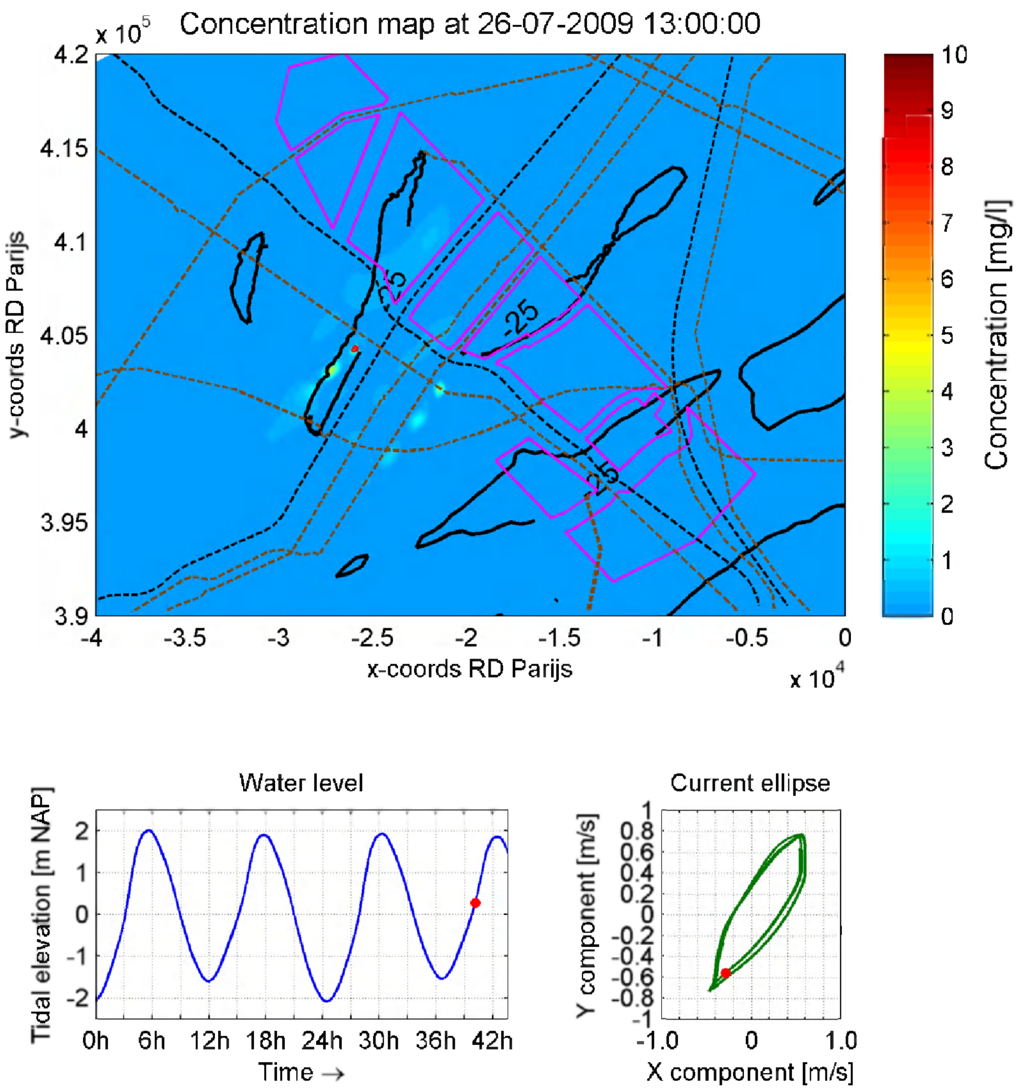

Figure 6-16: Evolution of a sediment plume for a full dredging-dumping cycle 1h40min after overflow of TSHD A in cycle 25 (11:20) during an ebb event in Scenario 2. Evolution of a sediment plume due to dumping of TSHD B in cycle 25, 55min after start (12:05). First observation of plume due to overflow of TSHD A in cycle 26, 5min after start (12:55).