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KPP Ems-Dollard Effect Chain Model

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1204394-000

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Title
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Client	**Project**	**Reference**	**Pages**
Waterdienst	1204394-000	1204394-000-ZKS-0001	86

Keywords
Ems Dollard effect chain model

Summary
This report describes the activities carried out during 2011 in the framework of the project KPP Eems-Dollard on effect chain modelling of the Ems-Dollard estuary. It consists of the three following parts:

1 Hydrodynanmics and sediment transport;
2 Water quality and primary production;
3 Habitat suitability assessment.

The ongoing model development and testing is discussed. The model is also applied for the testcase of releasing dredged material near Eemshaven.

References
-

Version	Date	Author	Initials	Review	Initials	Approval	Initials
	Apr. 2012	dr. ir. T. van Kessel	TvK	dr. D.S. van Maren		ir. T. Schilperoort	
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		dr. W. Stolte					
		ir. J.T. Dijkstra					

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final

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Appendices

1 Introduction

The present report describes the progress during 2011 of the project ‘KPP Ems-Dollard Effect Chain Modelling’. According to the project plan for 2011, the following activities were foreseen with regard to the effect chain consisting of hydrodynamics, mud transport, primary production and ecology:

Hydrodynamics: temperature model, update bathymetry, simulations for a full year.

Mud transport: combination of strong points of both model variants (possibly by parameterization residual transport Ems), check SPM concentrations Huibersgat and fluvial mud flux Ems, year simulations with validation, scenarios dredging- and dumping strategy, compare with results BAW (Unter-Ems Model).

Primary production: application of year simulations mud, improvement phosphate modelling, detritus, benthic production and grazing, further validation, year and scenario simulations. Moreover, carrying capacity computations on mussels will be started, but results will not be available before 2012. Further calibration can take place in the Water Framework Directive (WFD) project started in 2011.

Ecology (Habitat): 1. Final choice species and determination response curves 2. validation (f.i. using German fish data) 3. year simulations for establishment of baseline and 4. scenario simulations.

These activities are discussed in the next chapters. Apart from ongoing model development and validation, also the application of the model for the testcase of releasing dredged material near Eemshaven is discussed.

2 Hydrodynamics and mud transport

2.1 Hydrodynamics

From an operational model for water level prediction the boundary conditions were generated for the Ems-model for the year 2001. For this purpose the Ems model was nested in the Kuststrook model, a SIMONA model maintained by RWS. The existing Ems-model was extended with temperature and was re-run with the 2001 boundary conditions. Figures 2.1 – 2.3 show the results with regard to water level, salinity and temperature. Figure 2.4 shows the variation of the freshwater discharge over the year. Although the performance of the hydrodynamic model could still be improved, results are judged suitable for further application in the mud transport and water quality models for the purpose of system understanding and sensitivity studies. Note that the largest deviations between modelled (black) and observed (red) water levels is caused by the boundary conditions (blue = Kuststrook model). For quantitative impact assessment of water levels, temperature and notably salinity further calibration is recommended. Apparently, the freshwater discharge into the Dollard (at Nieuw Statenzijl) is too low during periods of high discharge, explaining the too weak model response and overprediction of salinity at Groote Gat Noord. A simulation with improved and variable discharge at Nieuw-Statenzijl, Delfzijl and Lauwersmeer shows an increased seasonal trend at Groote Gat Noord (lower panel of Fig. 2.2), but overall still overestimates salinity with a few ppt. Further improvement may be obtained by including the discharge of other small streams or by a reduction of the mixing of freshwater in the Ems-Dollard. Apparently, the mixing is overestimated and as a result, the residence time is underestimated.

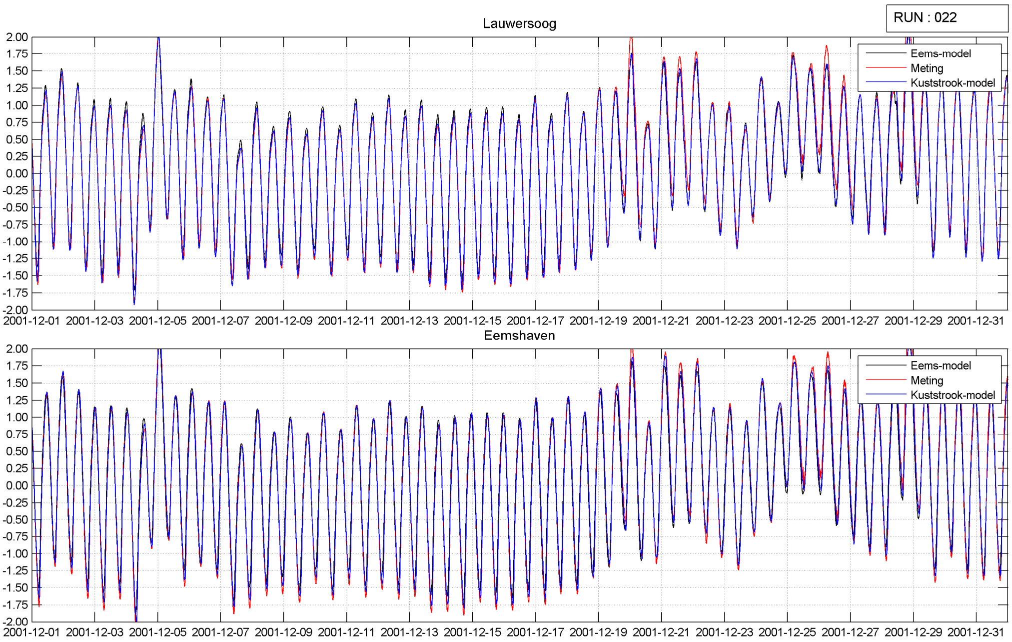


Figure 2.1: Measured and modelled water level at Lauwersoog and Eemshaven in December, 2001.

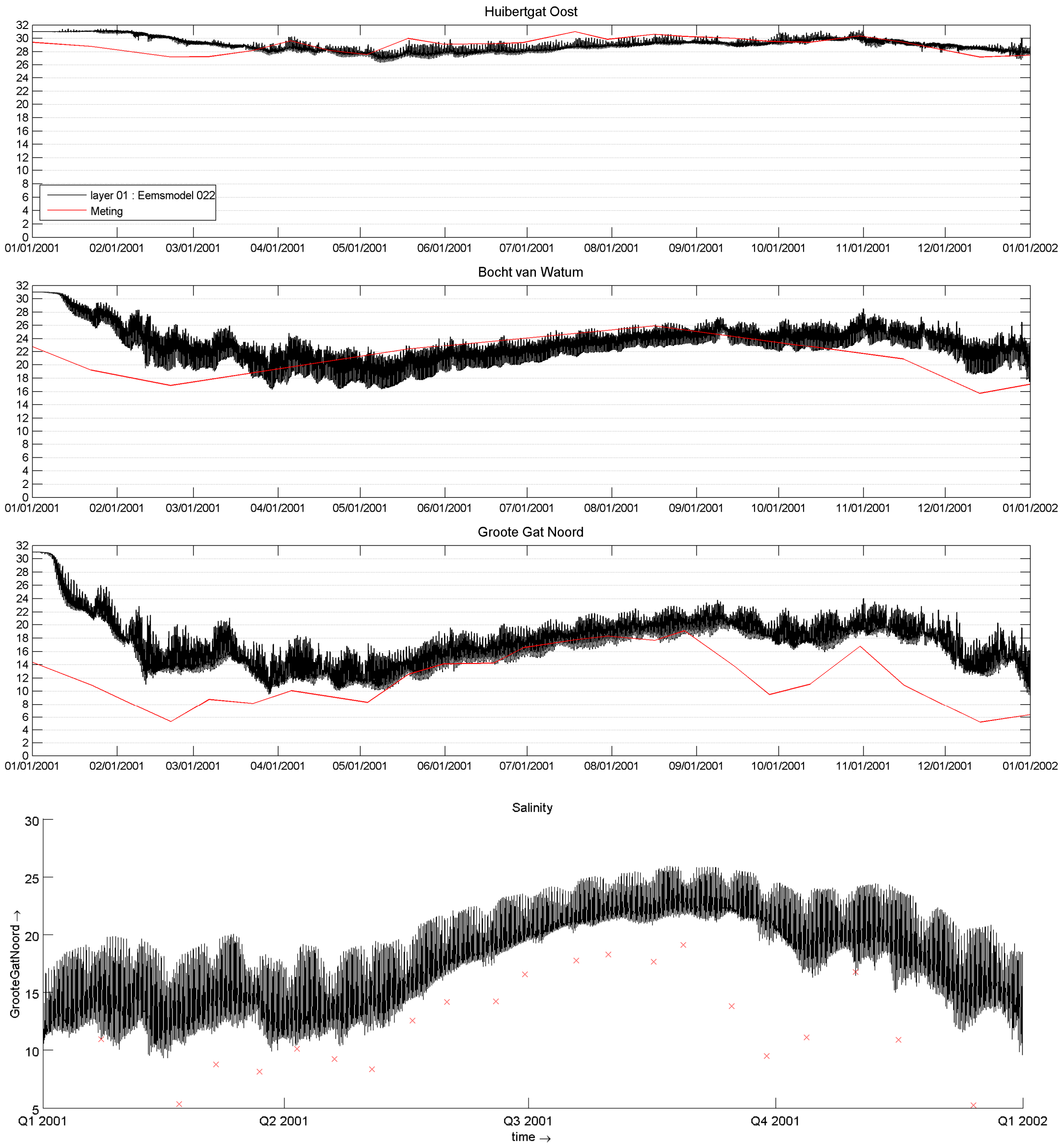


Figure 2.2: Measured and modelled salinity at Huibertgat Oost, Bocht van Watum en Groote Gat Noord in 2001. The first 3 months show spin-up effects from the initial uniform salinity of 31 ppt (disappears after restart, shown in lowest panel for Groote Gat Noord).

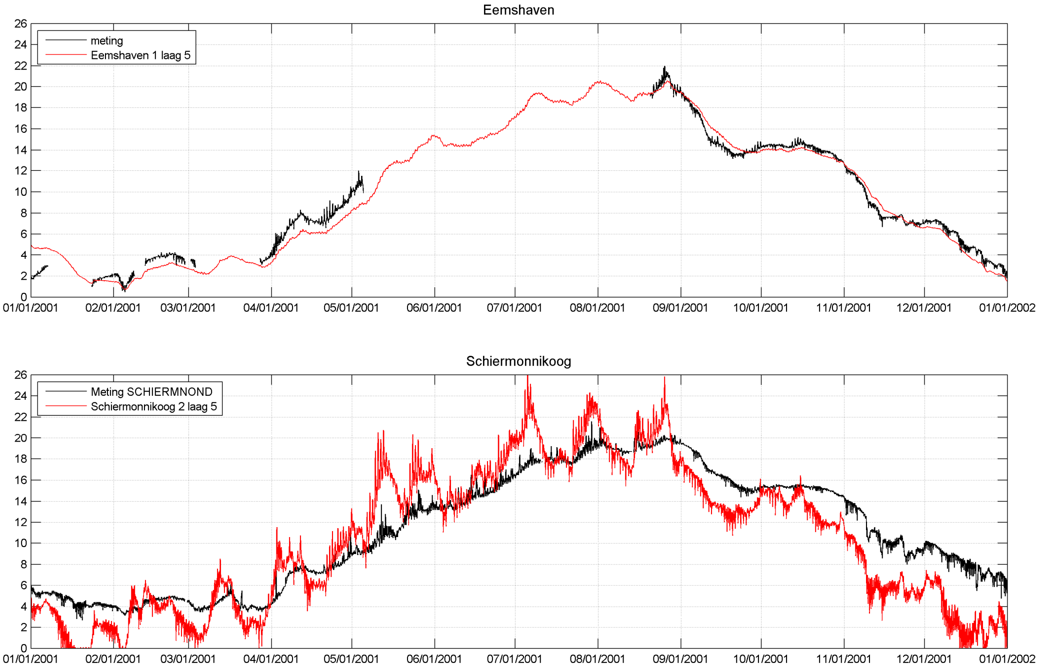


Figure 2.3: *Measured and modelled temperature at Eemshaven and Schiermonnikoog in 2001.*

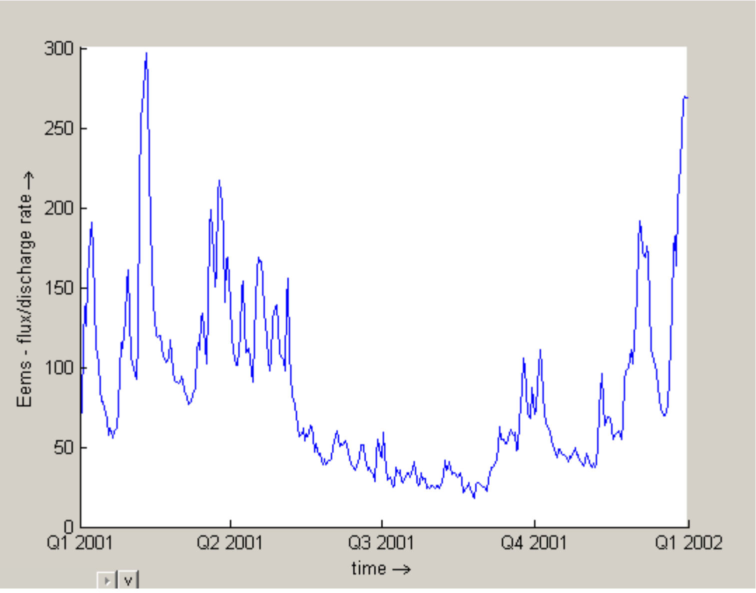


Figure 2.4: Applied Ems discharge (m^3/s) in 2001.

2.2 Mud transport

2.2.1 Natural background concentration

The mud computations carried out in 2010 (Dijkstra *et al.*, 2011) were based on a one-month hydrodynamics repeated 12× to obtain a full year period. In 2011, these computations have been repeated, but now based on a hydrodynamic database covering the full year. Apart from the hydrodynamic forcing, the model settings described in Dijkstra *et al.* (2011) have not been changed. A comparison between the results of these simulations is shown in Fig. 2.5 regarding time series and in Fig. 2.6 regarding spatial distribution of the suspended sediment concentration. Although differences are limited, the simulation based on the full year hydrodynamics shows more variability (induced by changes in freshwater discharge and wave climate) and, on average, somewhat lower concentration levels.

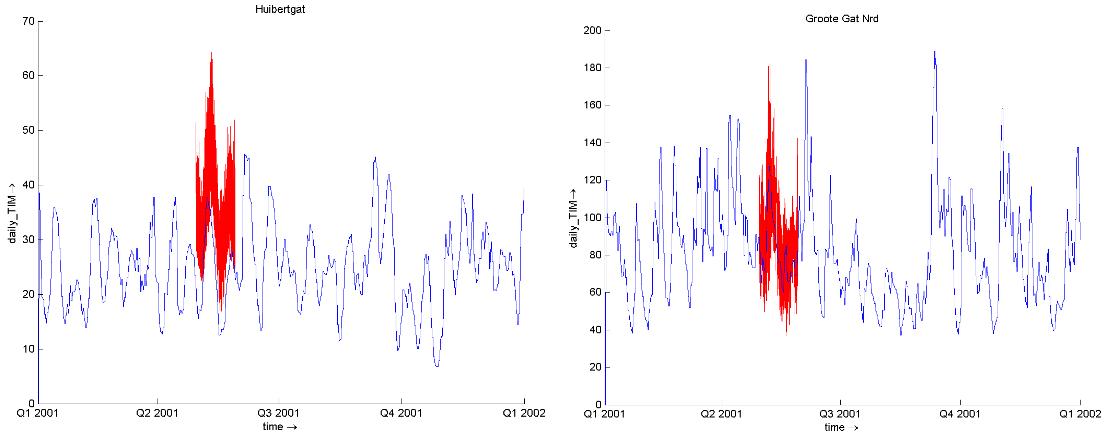


Figure 2.5: Modelled daily-average near-surface SPM concentration (mg/l) at Huibertgat Oost (left) and Groote Gat Noord (right). Blue lines: concentration for the year simulation, red lines: concentration for the one-month simulation.

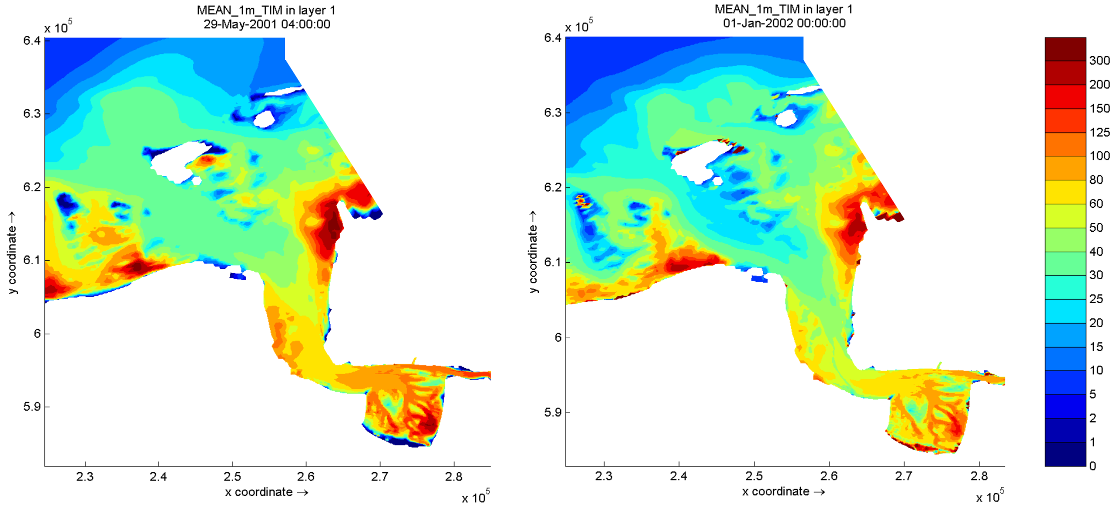


Figure 2.6: Modelled near-surface SPM concentration (mg/l). Left: averaged over May 2001. Right: averaged over entire 2001.

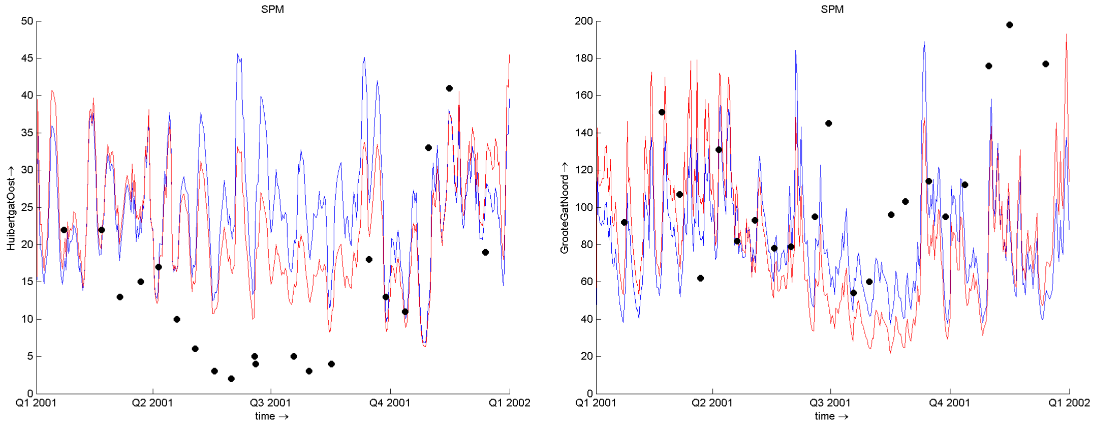


Figure 2.7a: Modelled (lines) and observed (black dots) near-surface SPM concentration (mg/l) at Huibertgat Oost (left) and Groote Gat Noord (right). The blue lines represent a simulation with constant settling velocity; the red lines represent a simulation with temperature varying settling velocity. Year = 2001. Model = Ems-model.

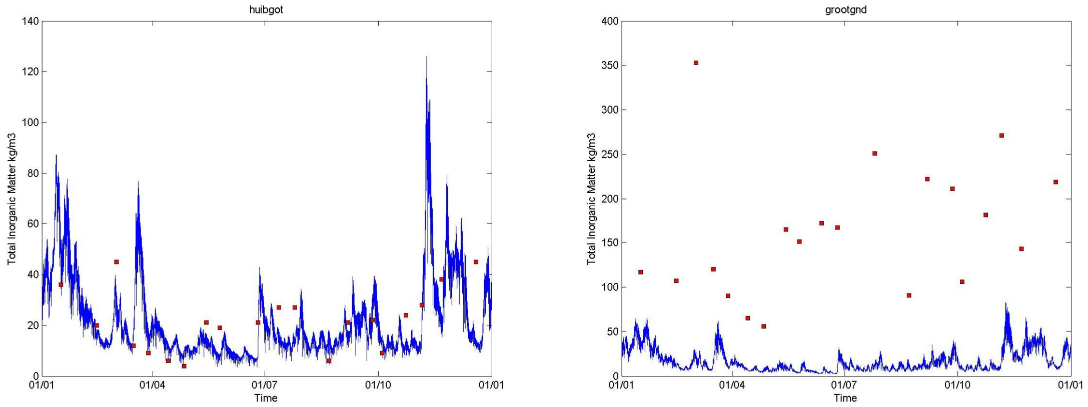


Figure 2.7b: Modelled (lines) and observed (red dots) near-surface SPM concentration (mg/l) at Huibertgat Oost (left) and Groote Gat Noord (right). The blue lines represent a simulation with constant settling. Year = 2007. Model = ZUNO-DD model.

Fig. 2.7a shows the modelled and observed concentrations at Huibertgat Oost (at the inlet between the North Sea and Wadden Sea) and Groote Gat Noord (at the entrance between the Dollard) for the entire year 2001 in order to analyse the seasonal dynamics. For both stations, typical winter concentration levels are well reproduced. At Groote Gat Noord, also summer concentrations are reproduced reasonably well. However, the observed summer concentration levels at Huibertgat Oost are strongly overpredicted by the model. The observations show a strong seasonal trend that does not occur in the model (nor in the observations at Groote Gat Noord). However, Remark the number of measuring points is relatively small.

Probably salinity variations due to variations in freshwater discharge (see Fig. 2.4) are not the cause for this seasonal trend, as in that case a much stronger trend is expected at Groote Gat Noord than at Huibertgat Oost. In fact, the reverse occurs.

Another cause may be the wave climate at the North Sea, which is not well represented in the present model. A fetch length approach has been adopted, which works well for locally generated waves inside the Ems estuary and Wadden Sea, but which is less suited for the (small) North Sea domain of the model grid. As a result, storm waves at the North Sea are strongly underestimated. As a result, the seabed at the North Sea contains more mud in the model than according to observations. This implies that under calm conditions, more tide-induced resuspension may occur (as more mud is available in the seabed), whereas under rough conditions less wave-induced resuspension occurs (as the wave-induced bed shear stress is underestimated). This results in more constant (tide-dominated) SPM levels. A better representation of wave forcing at the North Sea is recommended to overcome this limitation and will therefore be implemented in 2012. This may improve the modelling of chlorophyll-a, see Section 3.

A third cause may be due to variations of settling velocity or sediment stability. These may have a physical (e.g. temperature) or biological origin. This has been investigated by making the settling velocity temperature-dependent. As a result, the settling velocity is lower in winter than in summer (lower viscosity of water in summer and possibly more flocculation of organic matter. The result of this sensitivity study is shown in Fig. 2.7a. The red lines represent the simulation with temperature-dependent settling velocity. This indeed enhanced the seasonal variation of SPM, but not up to the desired level for 2001. However, the long-term average inter-annual SPM variation is about a factor 2, which is reasonably close to the temperature-induced inter-annual variation. A further increase of the seasonal variation of settling velocity (e.g. by assuming more flocculation in summer than in winter) would improve matters at Huibertgat Oost, but would worsen the model performance at Groote Gat Noord.

The results presented in Fig. 2.7b suggest that with more appropriate wave forcing the model quality would improve at Huibertgat Oost. Fig. 2.7b shows results for a ZUNO-DD model of the North Sea in which realistic wave forcing is applied based on 2007 wave data from the North Sea. At Huibertgat Oost, SPM levels are reasonably well reproduced by the ZUNO-DD model. Realistic wave forcing at the North Sea results in a significant computed seasonal trend in SPM levels at Huibertgat Oost. However, note that the strong seasonal trend observed in 2001 does not occur in 2007. As the ZUNO-DD is unsuitable for application in the Ems because of insufficient resolution, the computed concentration at Groote Gat Noord is understandably much too low.

2.2.2 Parametrization of the mud flux towards the Ems

In earlier studies (Boon *et al.* 2002) two approaches were adopted to parameterize the mud flux towards the Ems:

4. a local increase of the critical shear stress for resuspension to parameterize fluid mud trapping;
5. a local increase of the near-bed residual velocity to parameterize fluid mud transport towards the Ems.

The first approach enhances the net flux towards the Ems by enhancing the trapping efficiency and, as a result, reducing the return flux. It will result in a decreased suspended sediment concentration in the Ems because all sediment settles on the bed. The second approach enhances the net flux by enhancing sediment import and reducing sediment export. It will result in an increased suspended sediment concentration in the Ems.

The first approach is easy to implement, no changes are required in the software. It is recommended to adopt this approach only in combination with dredging and dumping in the Ems. In this way trapped sediments are remobilized, which also occurs in reality. Without such remobilization, the computed suspended sediment concentration in the Ems may become unrealistically low.

The second approach is difficult to implement, as changes to the software are required. Also, it is not obvious where and when the residual transport should be enhanced. Simulations with the Delft3D sediment-online system, in which sediment-induced density currents can be computed, may provide guidelines.

The effect of tidal asymmetry is in itself insufficient to fully control the net sediment flux. Although a stronger tidal asymmetry enhances up-estuary transport, the area suitable for permanent deposition also influences net import (linked to net deposition) and local concentration levels.

As model application was prioritized over further model improvement, these approached have not yet been further investigated. Depending on the questions to be answered, this may be done in the framework of the WFD-project.

2.2.3 Effect of sediment dumping

The model has been applied to investigate the effect of sediment dumping on concentration levels in the Ems estuary. Several simulations have been made:

0. No release (background only)
1. Release at dumping location P5 west of Eemshaven
2. Release at dumping location P6 in front of Eemshaven
3. Release at location P5 in the period 10-15 March instead of 10-15 January
4. Release at location P5 assuming a 30× higher buffer capacity of the seabed.

For all simulations, 120 kton of material is released within a period of 5 days between 10 and 15 January 2001 (except for simulation 3). This mass and release rate is identical to a scenario previously computed by Alkyon (2008) in the framework of an EIA. All material is released continuously (so without tidal window) in or near the bed: 50% in the lowest water layer and 50% in the upper bed layer. A different distribution between water and bed would affect the short-term impact, but hardly the long-term impact. The positions of the release locations is shown in Fig. 2.8.

These simulations are made to investigate the relative impact of several dumping scenarios. They are not yet meant to investigate the absolute impact of sediment release originating from harbour maintenance on the turbidity level in the Ems estuary. For a proper assessment of the impact of harbour maintenance on turbidity, the sediment mass released at the dumping location(s) should be well matched with the deposited (and subsequently dredged and released) sediment mass in the harbour. These terms go hand-in-hand: if no harbour siltation occurs, no maintenance dredging is required. Whereas the released mass has a concentration enhancing effect, the deposited mass has a concentration reducing effect. Integrated over time, both terms are equal, but as deposition and release occurs at different locations and in different periods, the integral effect is non-zero. Prior to such assessment, the model needs further calibration with regard to harbour siltation.

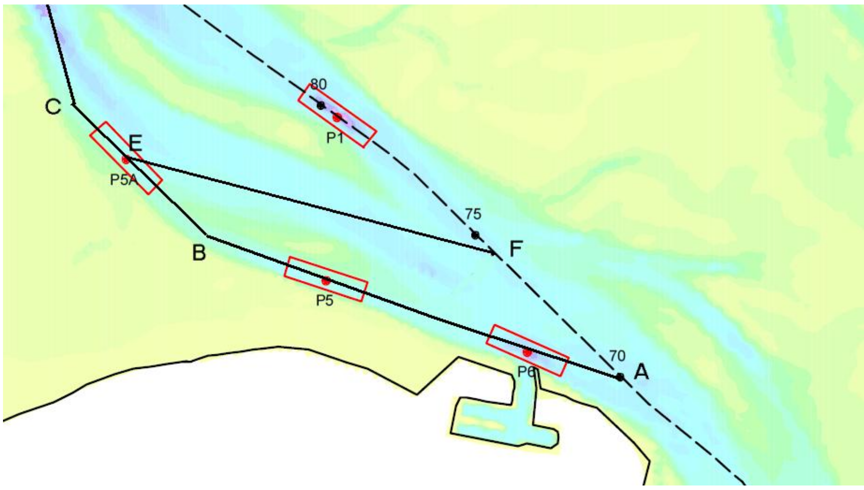


Figure 2.8: Positions of release locations P5 and P6 near Eemshaven. Black dots '70', '75' and '80' are distances in km along the thalweg from the weir at Papenburg.

2.2.3.1 Scenario 1: location P5

Fig. 2.9 shows the relative concentration increase (%) averaged over the second-last day and the last day of dumping and the fourth and tenth day after the end of dumping. The (fine) sediment spreads rather quickly over a large part of the estuary. As a result, the excess concentration is much diluted. Initially and locally, the concentration increase is about double the natural background level. Within ten days, the relative increase diminishes below 50%, but a significant part of the estuary is affected. After two months, the relative increase is still about 5% (see Fig. 2.15). Compared with earlier computations with a model with simpler process formulations but higher horizontal resolution and different calibration, results are quite similar (see Fig. 2.10).

Although fine sediment spread quickly through the estuary, most excess deposition is concentrated at the channel edges of Oude Westereems and in the Eems harbour itself. It is concluded that a substantial return current occurs (see Fig. 2.11). This is further discussed in §2.2.2.2. Figure 2.12 shows the absolute suspended sediment concentration (including the natural background) for scenarios 0 to 3. Figure 2.13 shows the absolute and relative excess concentration of scenarios 1 to 4 (respectively $S_i - S_0$ and S_i/S_0, with i = 1, 2, 3 or 4).

It is concluded that the initial impact is large: near the release location, the excess concentration is of the same order as the natural background concentration (50 mg/l). However, the impact diminishes quickly after ending the sediment release. Within two month after sediment release, the impact becomes less than 10% of the natural background level (< 5 mg/l excess concentration). However, after two months the area experiencing a 10% increase has grown substantially, covering an important part of the estuary (see Fig. 2.15).

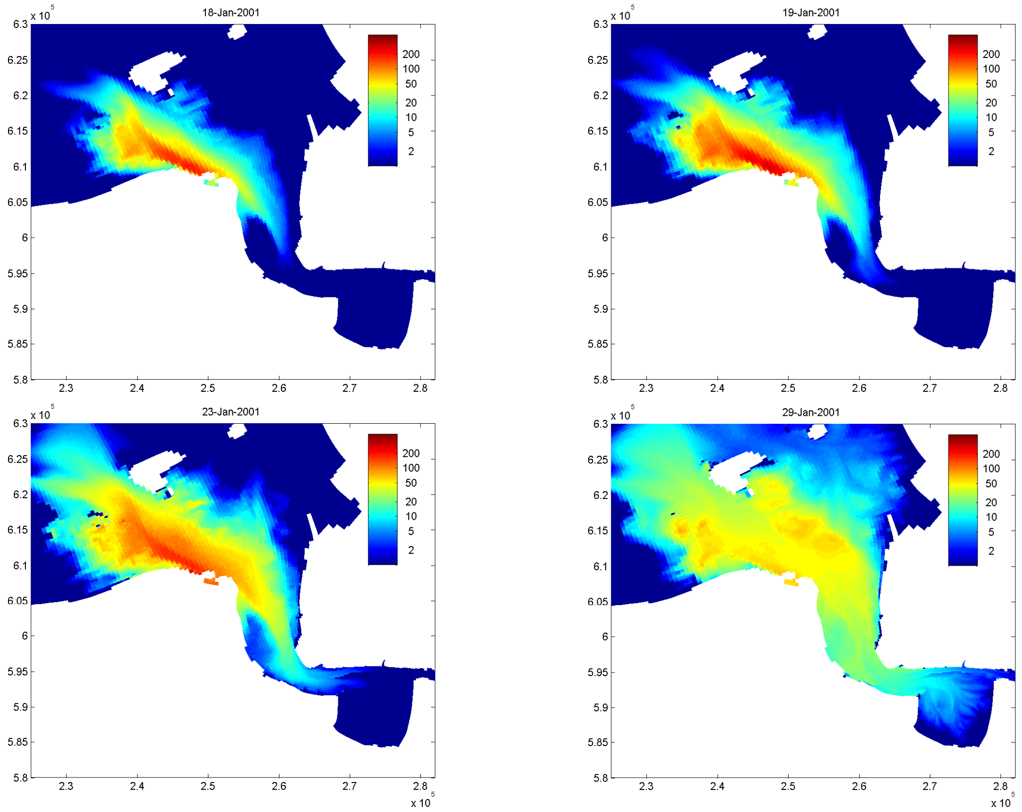


Figure 2.9: Daily-average SPM concentration increase (%) in the surface layer on 18, 19, 23 and 29 January 2001 due to sediment dispersion of 120 kton at location P5 in the period of 15 to 20 January, 2001.

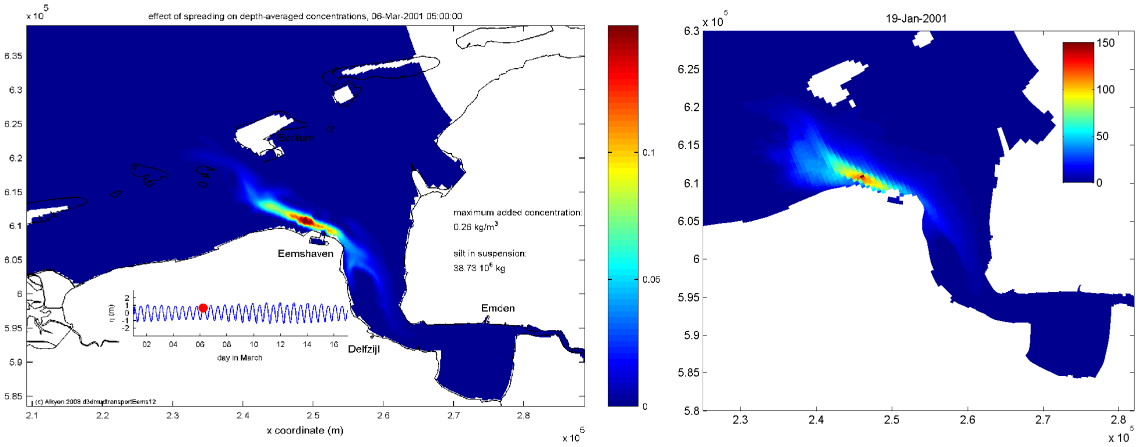


Figure 2.10: Excess SPM concentration due to sediment dispersion of 120 kton at location P5 after 5 days of spreading. Left simulation by Alkyon, 2008 (scale in g/l). Right: present simulation (scale in mg/l).

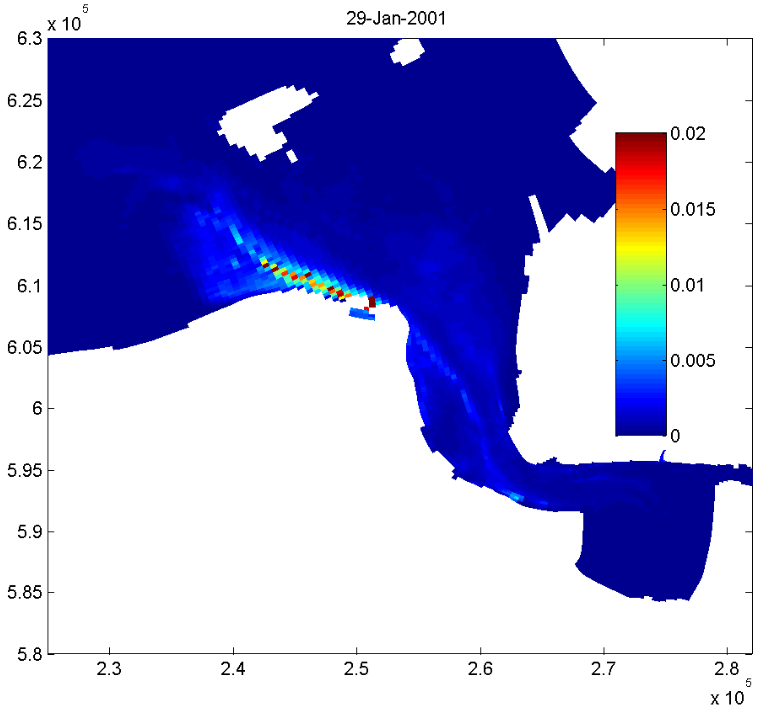


Figure 2.11: Excess sedimentation (m) due to sediment dispersion of 120 kton at location P5 in the period of 15 to 20 January, 2001.

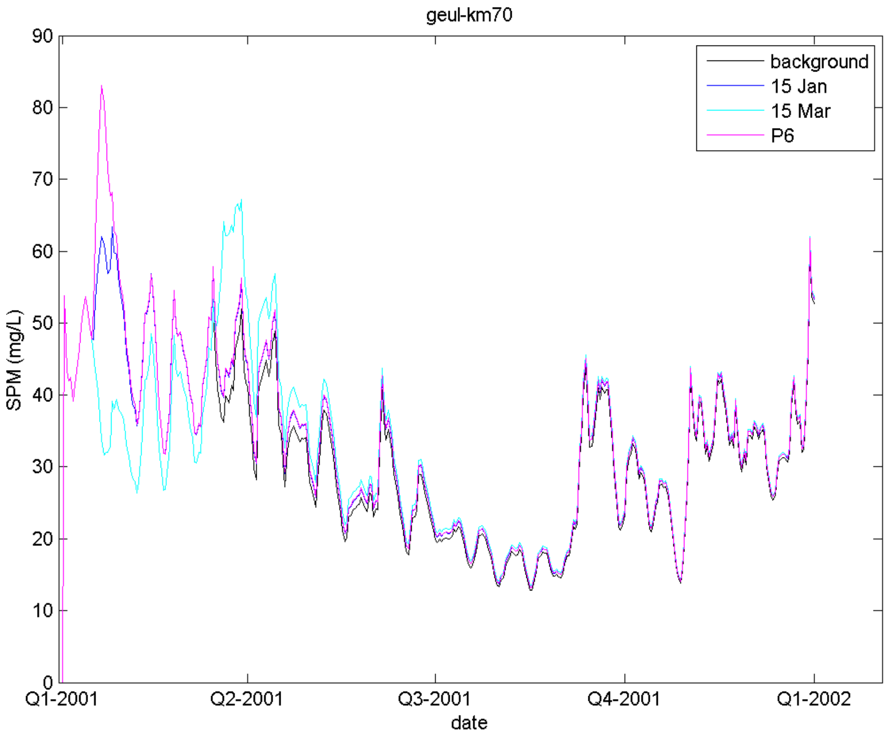


Figure 2.12: Daily-average near-surface suspended sediment concentration at location 70 km in year 2001 for scenarios 0 (background without release), 1 (release at P5 from 15 Jan), 2 (release at P6) and 3 (release at P5 from 15 Mar). The black curve overlaps with the light blue curve prior to 15 March.

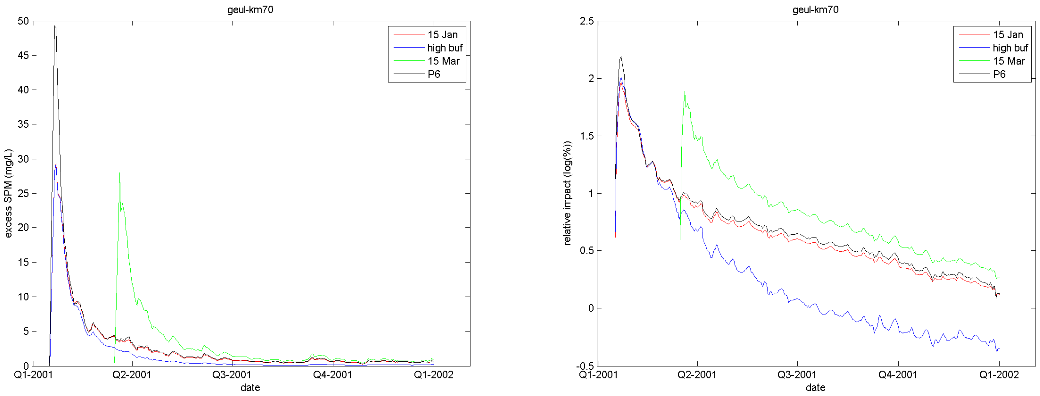


Figure 2.13: Absolute (left, mg/l) and relative (right, log(%)) near-surface excess concentration due to sediment dispersion of 120 kton at location 70 km in year 2001.

These results are input for the nutrient and algae model to assess ecological impact of human sediment dispersal (see Chapter 3).

2.2.3.2 *Scenario 2: location P6*

The only difference between Scenario 2 and 1 is the release location. Figures 2.12 and 2.13 show that during and just after sediment release, computed impacts significantly differ close to the release locations (as expected). At larger spatial and temporal scales, differences become insignificant. For the large-scale impact and ultimate fate of released sediment the exact release location is therefore of minor importance.

For equal environmental impact, economic benefits will be an important evaluation criterion to determine the optimal release locations. An optimal balance between sailing distance and return flux should be established. A small distance between dredging and release locations is beneficial in terms of cycle time, but unfavourable in terms of enhanced harbour siltation. Table 2.1 shows the relative impact of release in P5 or P6 on harbour siltation. The near-bed suspended sediment concentration in Eemshaven has been used as a proxy for harbour siltation (neglecting the possible contribution of fluid mud dynamics). Location P6, which is closer to the harbour mouth, results in more additional siltation than location P5. However, results from the dispersion model alone are insufficient to determine the optimal location, for this also data on dredging costs would be required.

Table 2.1: Relative increase (%) in harbour siltation in Eemshaven due to sediment release at locations P5 or P6.

Period	**P5**	**P6**
15-30 January	53	81
15 Jan. – 15 Feb.	34	45
15 Jan. – 15 Apr.	19	23
complete year	9	11

2.2.3.3 Scenario 3: 10-15 March

The only difference between Scenario 3 and 1 is the release period. Dispersion behaviour is very similar, small differences originate from differences in meteo and tidal forcing. By shifting the release period, periods that are most sensitive with respect to ecology may be spared. Figure 2.14 shows the excess concentration on April 1 for Scenarios 3 and 1. It is obvious that if the period around April 1 is a sensitive period (for the water system and ecology), sediment release between Jan 10-15 is much preferred over sediment release between March 10-15.

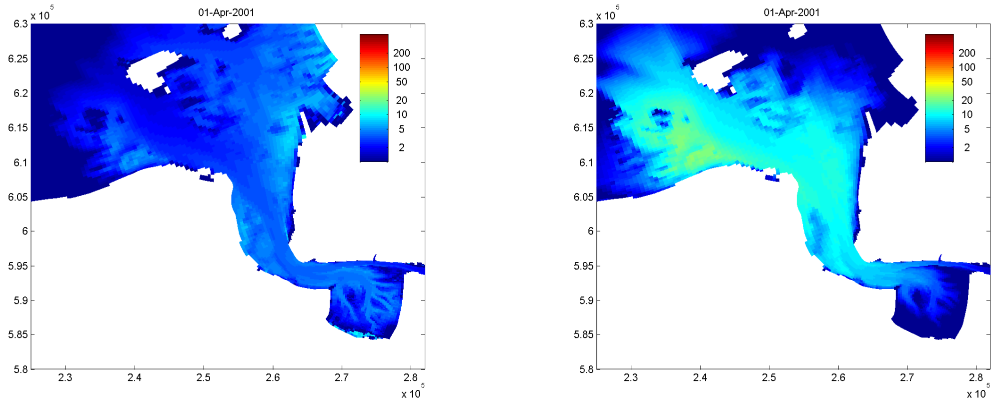


Figure 2.14: Excess daily-averaged near-surface concentration (mg/l) at location km 70 on April 1 due to sediment release in P5. Left: release between Jan. 10-15 (scenario 1). Right: between March 10-15 (scenario 3).

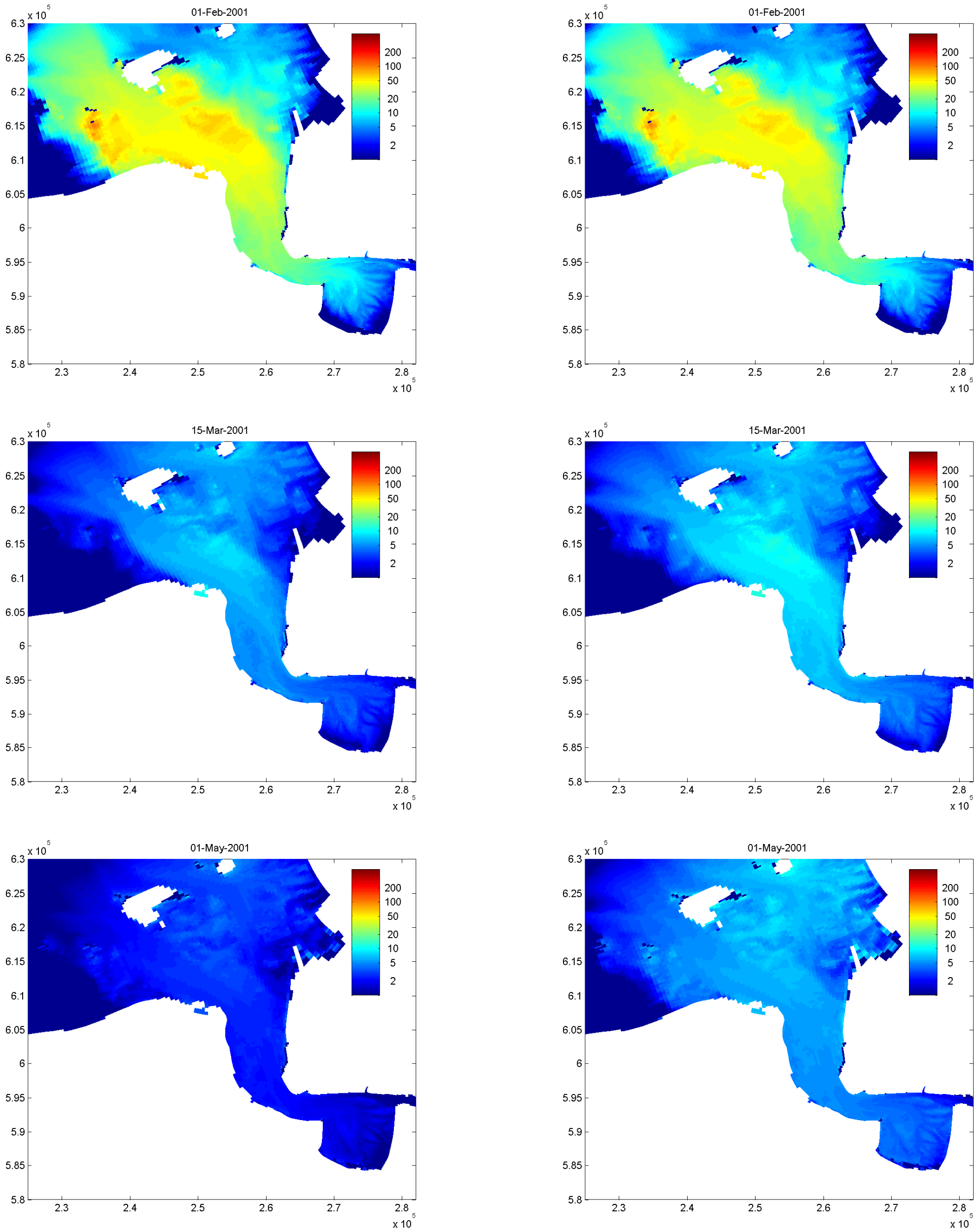
2.2.3.4 Scenario 4: higher buffer capacity

The only difference between Scenario 4 and 1 is the assumed buffer capacity, i.e. the amount of sediment that can be (temporarily) stored in the active part of the seabed. A low buffer capacity implies a thin SPM layer and therefore faster resuspension and dispersion. For Scenario 1 the thickness h of the buffer layer is only 1 cm, which implies that at most $h\ \rho_{bed}\ (1\text{-}n_{por}) = 15.6\ \text{kg/m}^2$ can be stored. For Scenario 4 the buffer layer thickness is 30 cm, which implies a buffer capacity of at most 468 kg/m^2. Based on experience from North Sea models, a buffer layer thickness of 30 cm appears to be more realistic. However, as the wave forcing is the Ems estuary is less than at the North Sea, also the active layer thickness may be less.

Figures 2.13 and 2.15 show that during and shortly after sediment release, the computed impact is insensitive to the assumed buffer capacity. However, at a longer timescale the difference becomes significant: with a higher buffer capacity, a lot of released fines are trapped within the seabed and no longer contribute to turbidity. This results in an approximately threefold reduction of the excess concentration after three months. Increasing the amount of net deposition in the model will have a similar effect: the more sediment is permanently deposited, the less is available to affect turbidity.

2.2.3.5 Conclusions

Insight into the dispersion behaviour of released fine sediments has been obtained. The sensitivity to release location, release period and buffer capacity has been investigated. Results have been compared with previous sediment dispersion studies. It is anticipated to extend this comparison to German dispersion studies carried out with BAW's Unter-Ems Model, but for this more exchange of model results is still required.



01-Feb-2001

01-Feb-2001

15-Mar-2001

15-Mar-2001

01-May-2001

01-May-2001

Figure 2.15: Relative effect (%) of sediment release in P5 on 1 Feb, 15 Mar and 1 May 2001. Left: high buffer capacity (scenario 4). Right: low buffer capacity (scenario 1).

3 Water quality and primary production modelling

3.1 Introduction

The water quality model provides a building block in the “effect chain” modeling approach, linking the hydrodynamic (Delft3D-FLOW) and sediment transport (Delft3D-SED) to the ecological assessment in HABITAT. The primary objective of the water quality/ecological model is to get a better understanding of those factors that determine the biogeochemical and ecological dynamics in the Ems-Dollard estuary. As already described in Dijkstra et al., 2011, the model will be used to provide insight in the factors controlling primary production, namely to determine whether primary production is nutrient-limited or light-limited. Considering the high nutrient concentrations and the reduced light climate due to suspended sediments in an estuary, primary production is expected to be predominantly controlled by light availability. The availability of light to primary producers is determined by: (a) the amount of incident light, (b) the bathymetry, (c) vertical mixing, (d) the presence of inorganic particles and (e) the concentration of pelagic algae themselves. Consequently, the water quality/primary production model should accurately describe these factors.

The second major issue concerns oxygen levels and the occurrence of oxygen-depleted zones. Oxygen can be considered as a key variable, meaning that its concentration is determined by the complex interaction of physical (advection and diffusion, governed by hydrodynamic circulation), chemical (re-oxidation of reduced species) and biological (primary production vs organic matter degradation) processes. The interaction of these processes forms the basis of the water quality/primary production model described in the following sections.

In this section, details on setting-up, development and the improvements made to the water quality/primary production model in 2011 are presented. Starting from the model set-up available at the end of 2010 (see Dijkstra, 2011) and the issues that required further development and/or improvement identified therein, the following objectives have been formulated for 2011:

1) Improve the physical descriptions and boundary conditions by coupling a full-year of hydrodynamics with realistic discharge to the water quality and primary production model.
2) Test the improved suspended sediment simulations based on the same hydrodynamic model and evaluate its usefulness for the estimation of light climate and primary production.
3) Test the addition of extra water quality processes, more specifically, the sediment-water flux of dissolved phosphate, and benthic primary production. Where possible, evaluate their usefulness of an adequate description of primary production along the estuary.
4) Where necessary, fine-tuning of the model by varying some of the parameters that determine primary production by algae. The latter depends on the satisfactory implementation of the above objectives.

The established goals for 2011 contribute towards the ultimate aim of developing a robust and quantitative assessment modeling tool to support management decision related to site-specific issues, such as the effect of nutrient inputs and dredging activities on water quality and habitat suitability. This will enhance the understanding of cause-effect relationships between the physical, natural environment and system stressors.

3.2 Model Setup

3.2.1 Hydrodynamic model

The water quality model set up in Delft3D-WAQ is coupled to the results of the flow model (implemented in Delft3D-FLOW) used to simulate hydrodynamic circulation, water velocities and salinity. These results are the basis for the further modeling activities related to suspended matter, nutrients and phytoplankton productivity and hence also to the ecosystem. In line with Objective (1), the water quality model is coupled to a full-year hydrodynamic flow-field, simulating the conditions for the year 2001. This presents a significant improvement as compared to the set-up in Dijkstra (2011), in which the water quality model was coupled to a one-month hydrodynamic simulation rewound 12 times to reconstruct the period of a full year. The full-year hydrodynamic simulation also accounts for daily discharge measurements of the Ems river (Figure 3.1). As expected, the results show an improvement in the simulated salinity gradients within the estuary and a better match with the simulated salinity in the hydrodynamic model and measured values (Figure 3.2). Moreover, more realistic time series for nutrient loading from the Ems River is now available based on daily riverine discharge and nutrient concentrations at the mouth of Ems river (Section 3.3).

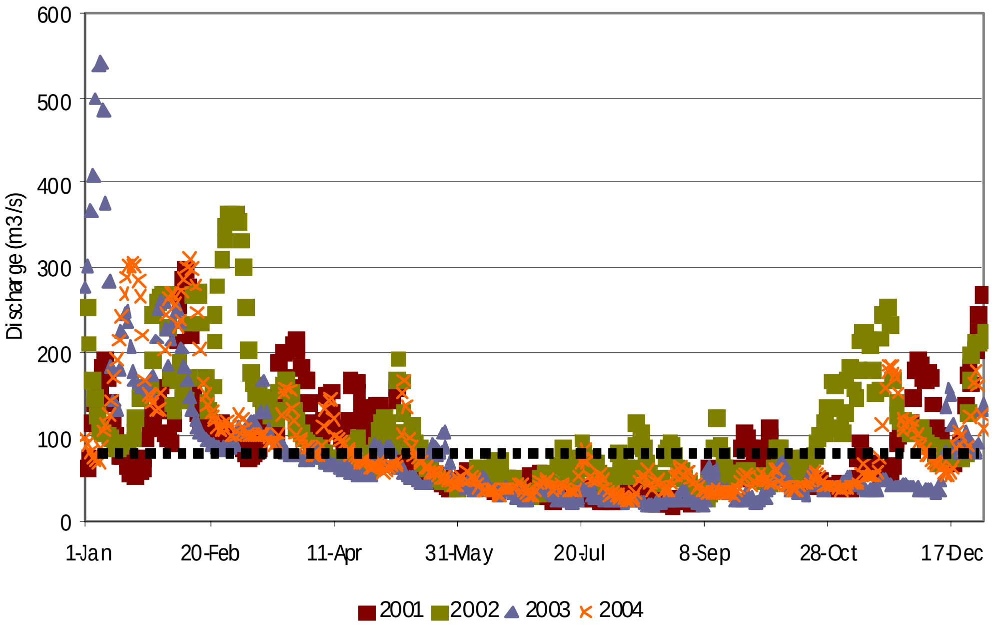


Figure 3.1 Time series for discharge (m3/s) in the Ems River. The 2001 daily discharge values are used in 2011 water quality model.

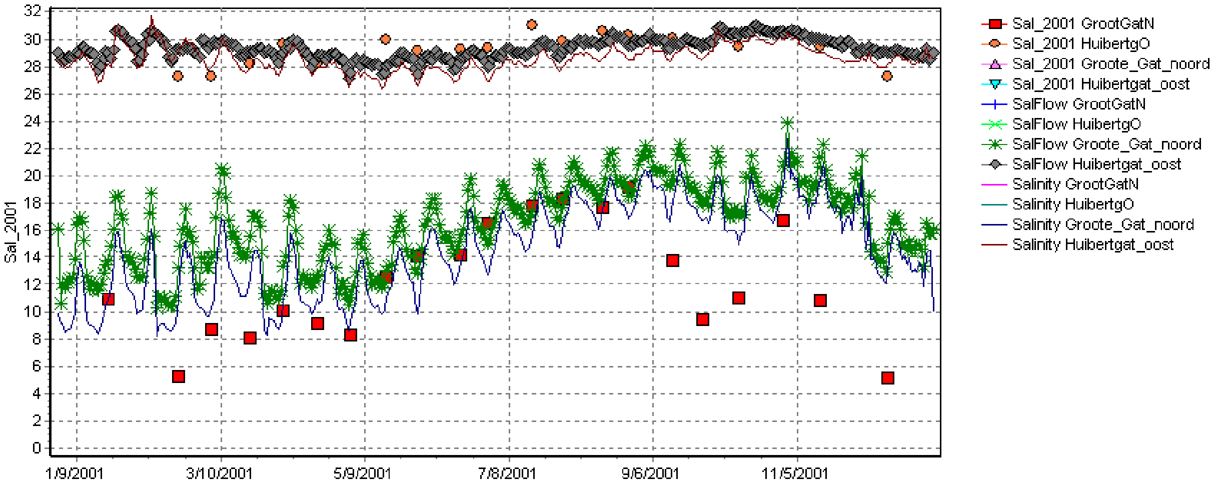


Figure 3.2 Comparison between the salinity from the full-year hydrodynamic model (SalFlow), the recalculated salinity from the water quality model (Salinity) and salinity measurements (Sal_2001) at Groot Gat Noord and Huibertgat Oost monitoring locations.

Boundary conditions - Changes have been made in the hydrodynamic boundary conditions as compared to the model setup reported in 2010 (Dijkstra et al., 2011). These changes were necessary to overcome technical problems due to numerical problems related to drying and flooding emerging from running a full-year hydrodynamic simulation. There are now four boundaries defined in the current model set-up as compared to six boundaries in the 2010 model set-up. The former right-hand side boundary between the Wadden Island Juist and the mainland has been removed, whereas the Ems River is now represented as a discharge source rather than a boundary (Section 2.3). Moreover, the western Wadden Sea boundary between the island Ameland and mainland has been shortened. The location of the monitoring locations considered in the different boundaries is given in Table 3.1 and Figure 3.3 whereas the nutrient concentration time series at the monitoring locations are given in Dijkstra (2011).

Table 3.1 Monitoring locations used for defining nutrient concentrations in boundary conditions

Boundary name	Monitoring station used as boundary conditions
Left-right 1	Rottum3
Top-bottom 1	Rottum3
Top-bottom 2	NZR9TS010 (Terschelling 10)
Top-bottom 3	WZ480 (Zoutkamperlaag)

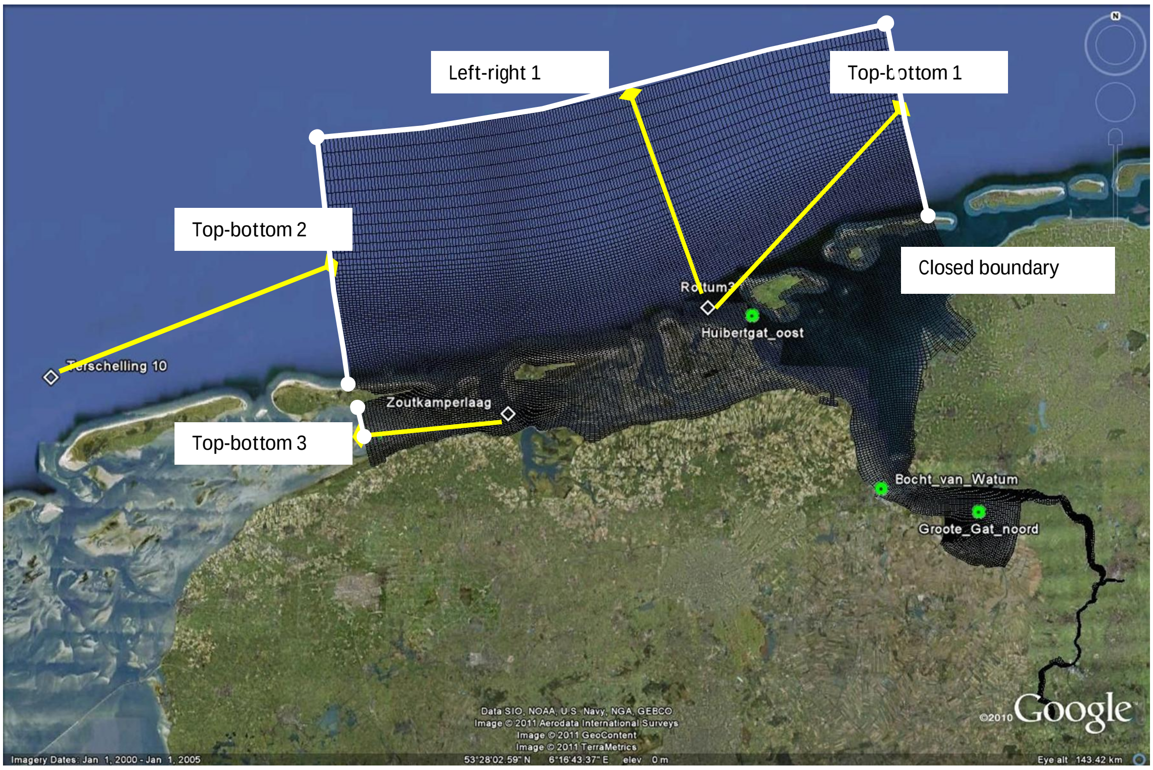


Figure 3.3 Location of boundaries, measurement stations for boundary conditions (squares) and monitoring stations for validation (green circles)

3.2.2 Coupling to sediment transport model

Variations in inorganic suspended matter, and hence in the underwater light regime, are considerable both in time and space. For this reason, significant effort has been put in obtaining a realistic spatial and temporal suspended sediment field, as defined by objective 2) and described in Chapter 2. Two approaches are followed in coupling to the results of the sediment transport model. In the first approach, the seasonal variation in suspended sediments over one year are represented by means of a cosine function. This represents an idealized spatial and temporal distribution of suspended sediment with relatively high values in winter and low values in summer, based on the model output of the sediment transport model (Los et al. 2008). Starting from an average suspended sediment distribution, the amplitude is based upon the level of variation in the measurements. This approach has been already applied and described in Dijkstra (2011). Figure 3.4 shows a comparison of the sediment function composed of two sediment fractions (IM1 and IM2) based on the latest sediment simulations and the measured sediment concentrations in the three reference monitoring locations. For the water quality modeling in this report, the cosine function approach has not been used.

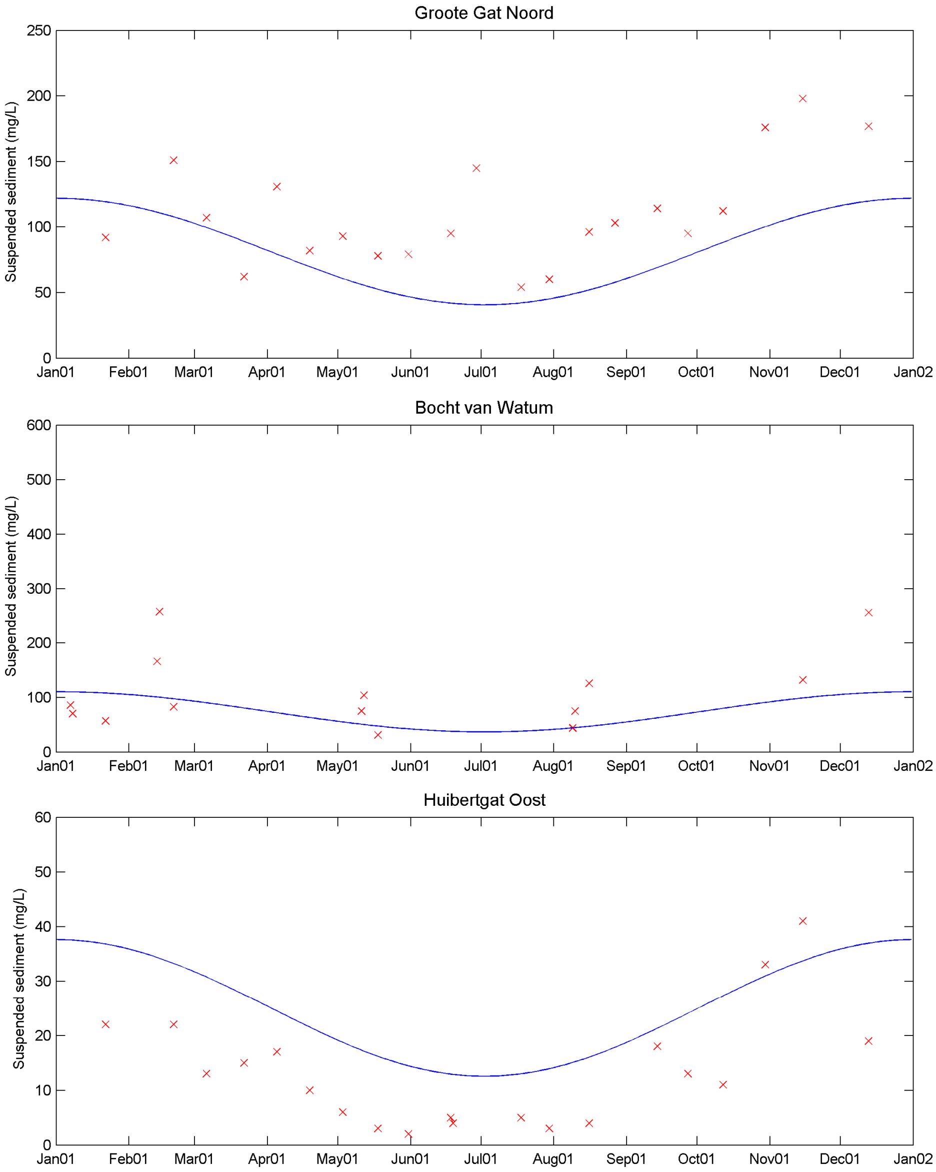


Figure 3.4: Measured suspended sediment concentration and a cosine distribution of average sediment concentration from the sediment model output used as forcing in the model set-up.

In the second approach, the full-year model output of the sediment transport model is directly used as input to the water quality model in the form of a segment function, i.e. spatially and temporally-variable (Figure 3.5). In this case, the light regime in the water quality model is subject to the daily local variations in both sediment fractions IM1 and IM2. However, the temporal and spatial distribution of suspended sediment is notoriously difficult to model. Especially at the seaward station Huibertgat Oost, suspended sediment concentrations are overestimated during summer. For details, see Section 2.2. Despite the shortcomings with respect to a correct description of seasonal variation, the latter method is the preferred option, because variations due to tide and wind are captured more realistically, and scenarios with respect to changing sediment dynamics and dredging/dumping strategies could be directly compared to the reference simulation.

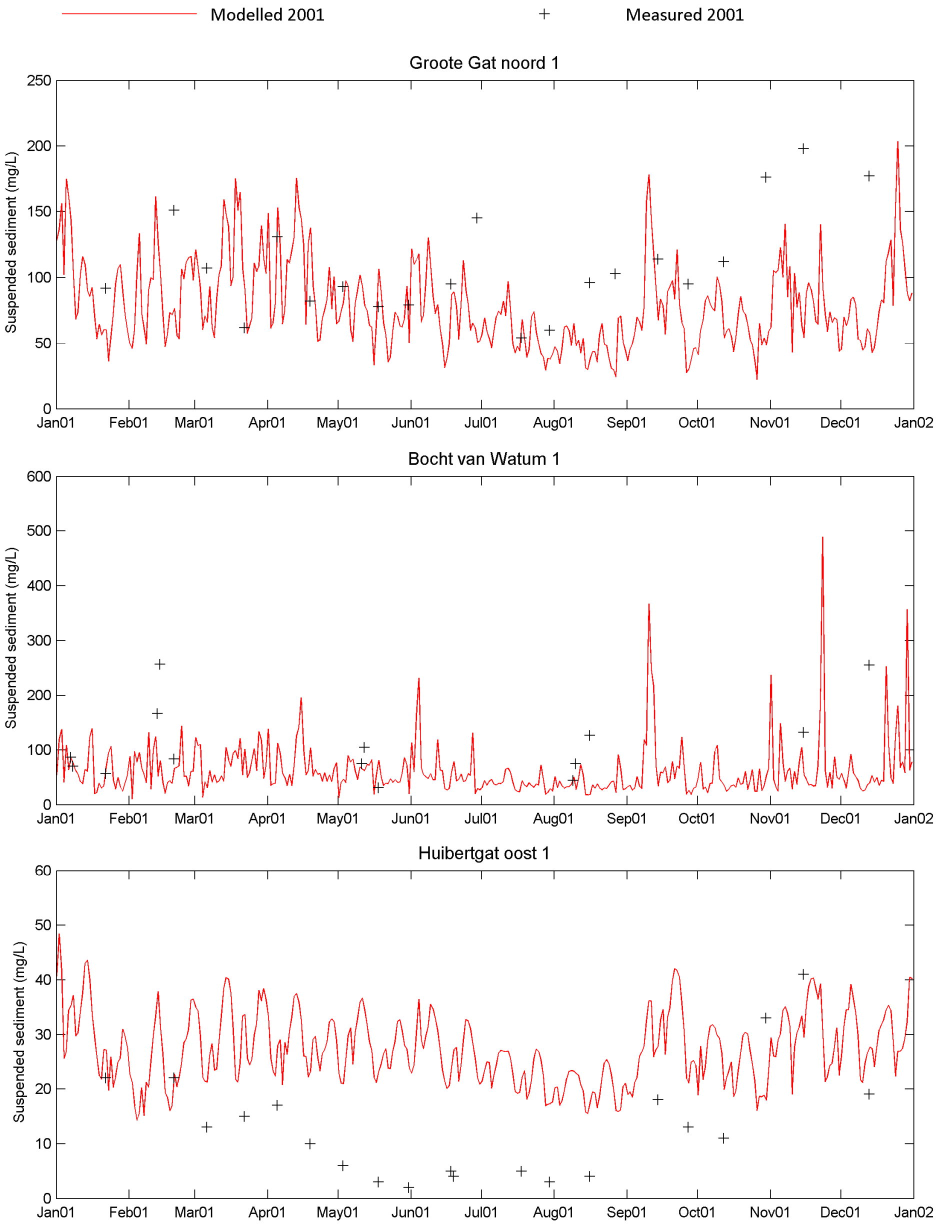


Figure 3.5 Measured suspended sediment concentration and simulated sediment concentrations (sum of IM1 & IM2 fractions) from the sediment model output used as segment function in the water quality model.

The direct coupling to the sediment model output requires modification of the sediment output files in a way that they can be imported as a so called segment function (containing concentrations for all time steps and all model segments) in the water quality model. This includes, for example, spatial aggregation to match the 2x2 aggregated model domain used in the water quality simulations. In the current report, only results are included that make use of the second approach of forcing suspended sediment. The main reason for this is to facilitate a better comparison of the scenario results with the reference conditions.

3.2.3 Water quality/ecological model

As described in more detail in Dijkstra (2011), the setting up of the water quality/primary production model is planned to take place in steps. As a first step, the water quality model includes the main processes of the Generic Ecological Model (GEM) in combination with the phytoplankton module BLOOM models the competition between species and the adaptation by species to limiting factors such as nutrients and light. (Los et al. 2008, Blauw et al. 2008). The model set-up described in Dijkstra (2011) contained the main reactions that determine nutrient dynamics, including the effect of light availability and primary production processes (Table 3.2). However, as specified in Objective 3) above, the model improvements envisaged for 2011 also include the addition of other water quality processes, such as the sediment-water flux of dissolved phosphate and benthic primary production. Field measurements (see for example Figure 3.14) suggest that phosphate is not limiting in large parts of the estuary and therefore should not have a drastic effect on primary production. This is confirmed by other studies, e.g. Colijn & Cadée (2003). For this reason, the main focus in 2011 was on the implementation of benthic production by microphytobenthos.

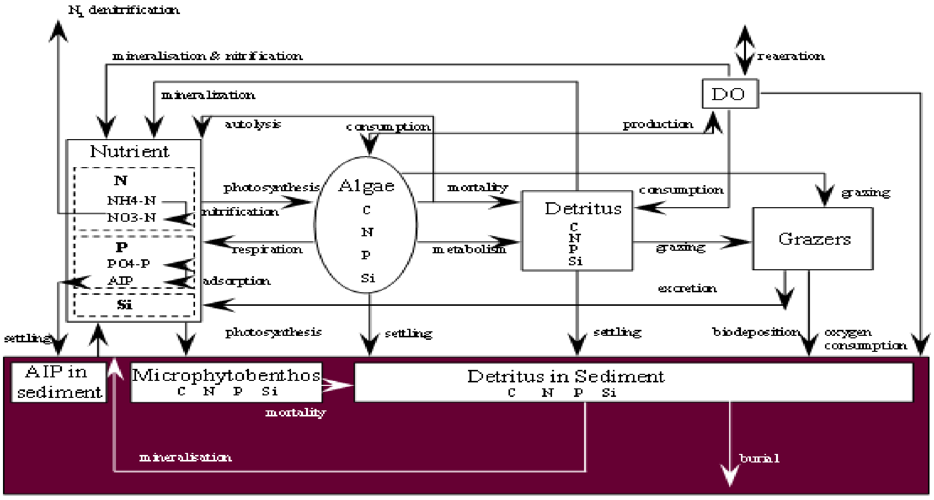


Figure 3.6 Schematic overview of the main DELWAQ processes and variables

Benthic primary production - The inclusion of benthic diatoms/ microphytobenthos is formulated as a competing algal species in the ecological BLOOM model through the variable *Ulva* (named after the species it originally was developed for). As for microphytobenthos, *Ulva* can occur in two forms, fixed or suspended. Under certain conditions determined primarily by the computed critical shear stress, the sediment is eroded and the microphytobenthos are released to the water column. In the water column, these microphytobenthos are regarded as “regular” phytoplankton types and therefore integrated in the BLOOM computation. The settling of the suspended microphytobenthos into deep areas will lead to their death. However, if they settle in shallow areas with sufficient light, they are converted back to the fixed microphytobenthos type. As a first step in the process of introducing microphytobenthos, the threshold shear stress for the erosion of microphytobenthos was set to a very high level, effectively blocking the process of resuspension. Therefore, no pelagic microphytobenthos occurs at this moment in the model. A next step is to alter threshold shear stress to a realistic level, and analyse the contribution of microphytobenthos in the water column.

Table 3.2 Overview of the main processes included in the water quality model. Note that an additional process, benthic production by microhpytobenthos was implemented in 2011. Grey processes are not yet active in the current set-up.

Process	**GEM**	**BLOOM**	**CONSBL**	**S1/S2**	**DELWAQ-G**
sedimentation and resuspension	**x**			x	x
Re-aeration of oxygen	**x**				
aerobic decomposition of organic substances	**x**				x
denitrification	**x**				x
nitrification	**x**				x
phosphorus sorption/desorption	x				x
light extinction	**x**				
phytoplankton growth/respiration/mortality		**X**			
atmospheric deposition	**x**				
microphytobenthos		**X**			
grazing			x		
sediment diagenesis					x

Table 3.3 An overview of the state variables in the model.

State variable	Name used in the model
Water column	
Salinity	Salinity
Pelagic phytoplankton community	5 species/15 types [1]: Dinoflagellates (DIN_E,N,P) Marine Diatoms (MDI_E,N,P) Marine flagellates (MFL_E,N,P) Phaeocystis sp. (PHA_E,N,P) Benthic diatoms (ULF_E,N,P)
detritus fraction of organic carbon, nitrogen, silica and phosphorus	DetC, DetN, DetSi, DetP
inorganic nitrogen (ammonia, nitrate)	NH4, NO3
inorganic dissolved silica	Si
inorganic phosphorus (dissolved ortho-phosphate)	PO4
dissolved oxygen	OXY
Sediment	
organic fraction of organic carbon, nitrogen, silica and phosphorus	DetCS1, DetNS1, DetSiS1, DetPS1

[1] Each phytoplankton species is composed of 3 types: N-type representing the ecophysiological condition of a species under nitrogen limitation, a P-type for phosphorus limitation and an E-type representing the state of a species under light limitation

It was assumed that microphytobenthos in the Ems/Dollard consists of diatoms. Therefore, as a first try, growth and mortality parameters also used for Marine Diatoms were implemented for the microphytobenthos. There is one difference however consisting of a substantially better tolerance for low salinity water. Since microphytobenthos is fixed with the sediment and is normally not transported with the surrounding water, it is facing larger variations in salinities and have adapted a higher tolerance towards this factor.

The updated list of state variables including microphytobenthos is given in Table 3.3. The list of processes is given in Appendix A. Parameters that have been added related to benthic primary production are similar to the parameter for the other algae.

Algal mortality is caused by temperature dependent natural mortality, grazing by consumers, as well as salinity stress mortality. Salinity driven mortality is described with a sigmoidal function of chlorinity, governed by two parameters Mort0ALG and Mort2ALG. For marine algae, Mort2ALG is larger than Mort0ALG and mortality rate increases with decreasing chloride concentration. The fresh water algae mortality rate increases with increasing chloride concentration and Mort0ALG is larger than Mort2ALG. At first instance, only marine algae are included since a very small part of the estuary contains fresh water. The list of algae may be reconsidered and extended with freshwater species when it is clear that freshwater primary production is underestimated.

For already incorporated species, some mortality-related parameters were adjusted.
The parameter for salinity-dependent mortality rate for all algae (Mort2ALG has been altered from 0 to more positive values of 0.84 (light-limited algae) and 1.28 (nutrient-limited algae). Since this is the mortality at zero salinity a positive value is necessary. Above mentioned values are the default values.

(MrtB2MDI) has been decreased for marine diatoms, in order to increase the tolerance of marine diatoms to lower salinities. The rationale behind this is that the diatom species composition most likely is adapted to estuarine conditions, and species will be selected for lower salinities.

Water temperature – Until 2010, *t*he water temperature was assumed to be spatially constant based on the 2001 field measurements. In the current version, the simulated water temperature from the hydrodynamic model is used as a forcing function in the water quality model, resulting in spatially and temporally varying temperature fields (Figure 3.7). The model results of water temperature have improved substantially with this step.

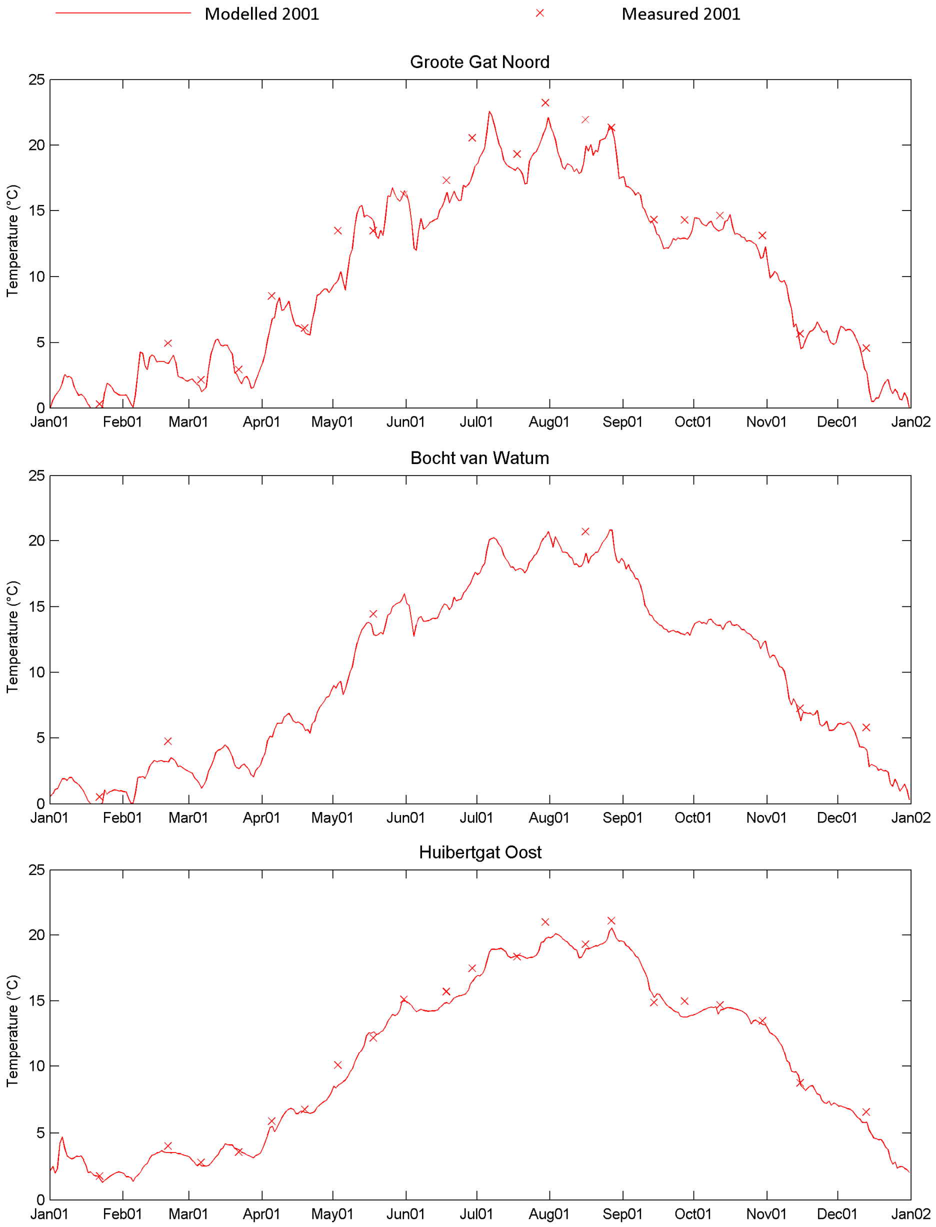
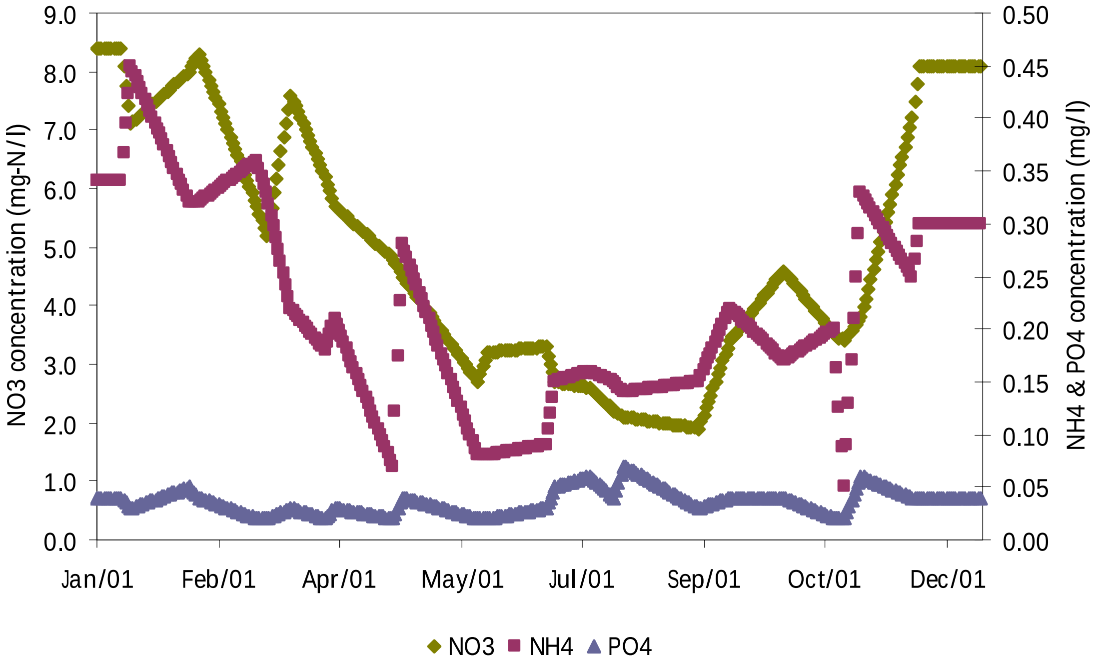


Figure 3.7 Measured water temperature and modelled results from the hydrodynamic model, used as a forcing for the water quality model at the three reference monitoring stations.

Nutrient sources - In the current model setup, the Ems River is no longer considered as a boundary (Top-bottom 5 in Dijkstra, 2011) but rather as a point source. Once again, this change was made to overcome technical problems that resulted when running the full-year hydrodynamic simulation. The time series concentration for NO3, NH4 and PO4 used is obtained from OSPAR compilation of field measurements (Figure 3.8), resulting in the nutrient loading shown in Figure 3.8. The discharge rates and nutrient concentrations of the other four point sources, Eems/Leda, NW-Stratenzijl, Delfzijl and Lauwersmeer are assumed to be the same as those reported in Dijkstra (2011).



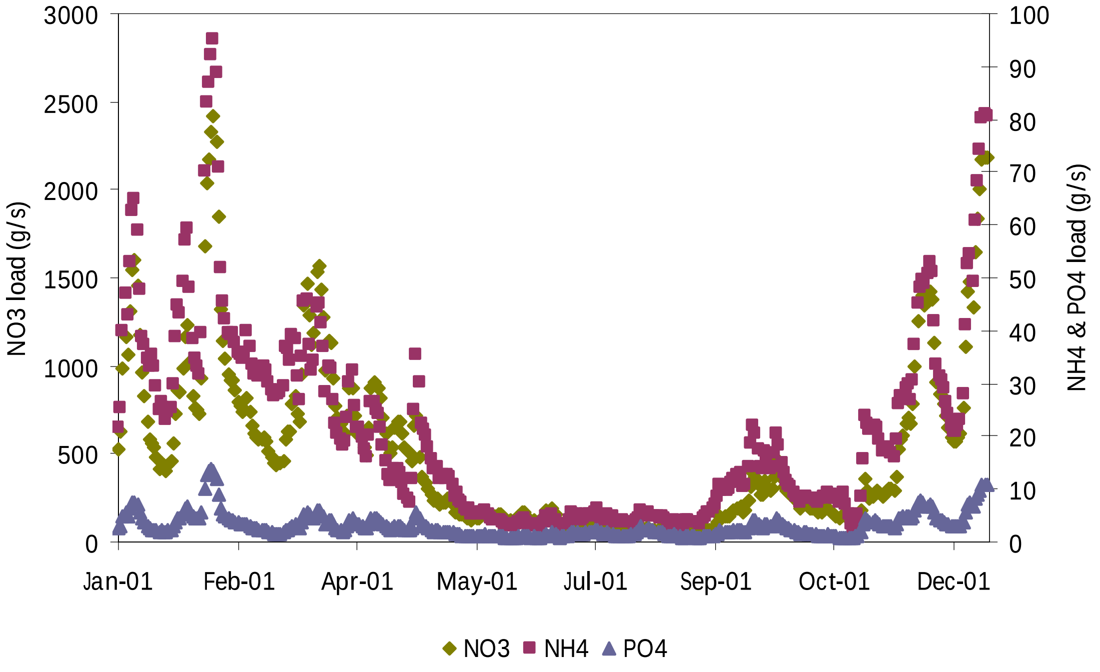


Figure 3.8 Time series of nutrient concentrations and loads at the Ems river

3.2.4 Coupling and numerical aspects

The coupling between the full-year hydrodynamic model and the water quality model was carried out following a 2x2 aggregation of the model domain in the horizontal. The vertical resolution was maintained at 8 layers. The aggregated model was tested for consistency of the model performance. No further testing was done with respect to the aggregation level since the outcome of the performance tests on level of aggregation, size of time step and numerical scheme presented in Dijkstra (2011) are considered to be still valid for the current model set-up.

3.2.5 Overview of changes in model setup

In summary, the main changes in the water quality model set-up that took place in 2011 are:

- Coupling of the water quality model to a full-year hydrodynamic model that accounts for daily variable Ems discharge and therefore more realistic nutrient loading
- Direct coupling to the output of the sediment transport model
- Inclusion of benthic production by microphytobenthos
- Inclusion of spatially- and temporally- variable temperature as segment function

All other forcings and parameters, such as meteorological forcings, wind velocity, irradiance, etc. are as reported in Dijkstra (2011).

3.2.6 Scenarios

The effect of dumping scenarios on primary production and chlorophyll a was studied for two scenarios, P5 and P6 (for details see section SPM). SPM data from the sediment model were directly used to force SPM concentrations in the water quality model.

3.3 Results

3.3.1 Consistency checks: conservation of mass

The model has been run for the year 2001. A conservative state variable called “continuity” has been simulated. This variable is initialised at a value of 1.0 and is given boundary conditions equal to 1.0. If the hydrodynamical forcing (water volumes and water fluxes) are consistent, the resulting concentration consistently should be 1.0 in space and time. Deviations from this results could indicate errors due to differences in numerical schemes for the hydrodynamic model and the water quality model, or inconsistent boundary conditions. This demonstrates the conservation of water in the hydrodynamic forcing, which ensures conservation of mass in the water quality model. Figure 3.9 illustrates that the model is consistent in this respect.

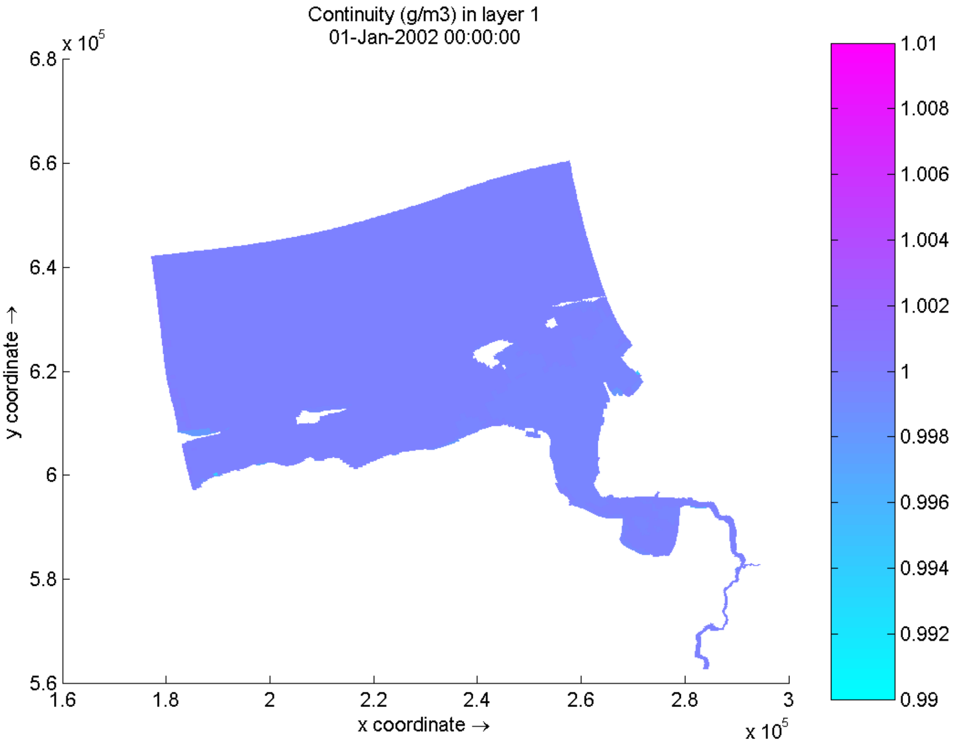


Figure 3.9 Distribution of continuity at the end of a one year simulation. Only at some intertidal areas (close to the coast, there are some light-blue spots), the value deviates slightly from 1. It was concluded that these model results are fully acceptable (deviations < 1 %).

3.3.2 Model validation

The following main water quality parameters are inlcuded in the model validation:

1. Salinity
2. Oxygen
3. Chlorophyll a
4. Nutrients:
    a. Total nitrogen, NH4, NO3
    b. Total Phosphorus, PO4
5. Light extinction - this parameter could only be compared to measurements for other years, since no extinction measurements for 2001 were available.

For each substance, time series of model results and field measurements (when available) are shown for the three reference locations, Groote Gat Noord, Bocht van Watum and Huibertgat Oost. A short description of the validation results follow below. The results are further interpreted in section 3.4.

Salinity (*Figure 3.10*) is reproduced well by the current model. The seasonal variation at the upstream stations is reproduced well, with a slight overestimation at the end of the year.

Total nitrogen (Figure 3.11**)**, **nitrate (**Figure 3.12**)** and **ammonium** (Figure 3.13) concentrations all compare well to the measurements. Roughly, seasonal dynamics is also covered well. This is an indication that the nitrogen loads as well as the transformation and mixing processes are estimated well. A slight an underestimation of total nitrogen occurs at the end of the year, which is also reflected in underestimated nitrate concentration. For ammonium, measurments

The average **total phosphorus (**Figure 3.14**)**, and **phosphate** (Figure 3.15) concentrations are also in the right order of magnitude. The typical increase of especially phophate during summer is not reproduced in the current model.

The modelled light **extinction coefficient** (Figure 3.16) can only be compared with measurements (Figure 3.17) from other years. The modelled values are on average well within the range of the measurements. The variation on a shorter time scale is most likely related to the variation in suspended matter. This short term variation in extinction can not be validated, due to the relatively low frequency of measurements.

The average concentrations of dissolved oxygen is comparable to the measured values (**Error! Reference source not found.**). Also seasonal variation is covered roughly reasonable well. In detail, oxygen concentrations is overestimated at the upstream station, and underestimated in the more seaward station.

Despite relatively good descriptions of nutrient concentrations and extinction coefficients, still seasonal patterns of phytoplankton biomass in chlorophyll a is not very well described yet (Figure 3.19). Especially the timing of the observed spring bloom at the upstream station is not very well reproduced. For completeness, also net primary production is shown (Figure 3.20). This gives an impression whether observed biomasses are locally produced or fed by transported production elsewhere. At Huibertgat, for example almost no net primary production is modelled during the whole year.
Section 0.

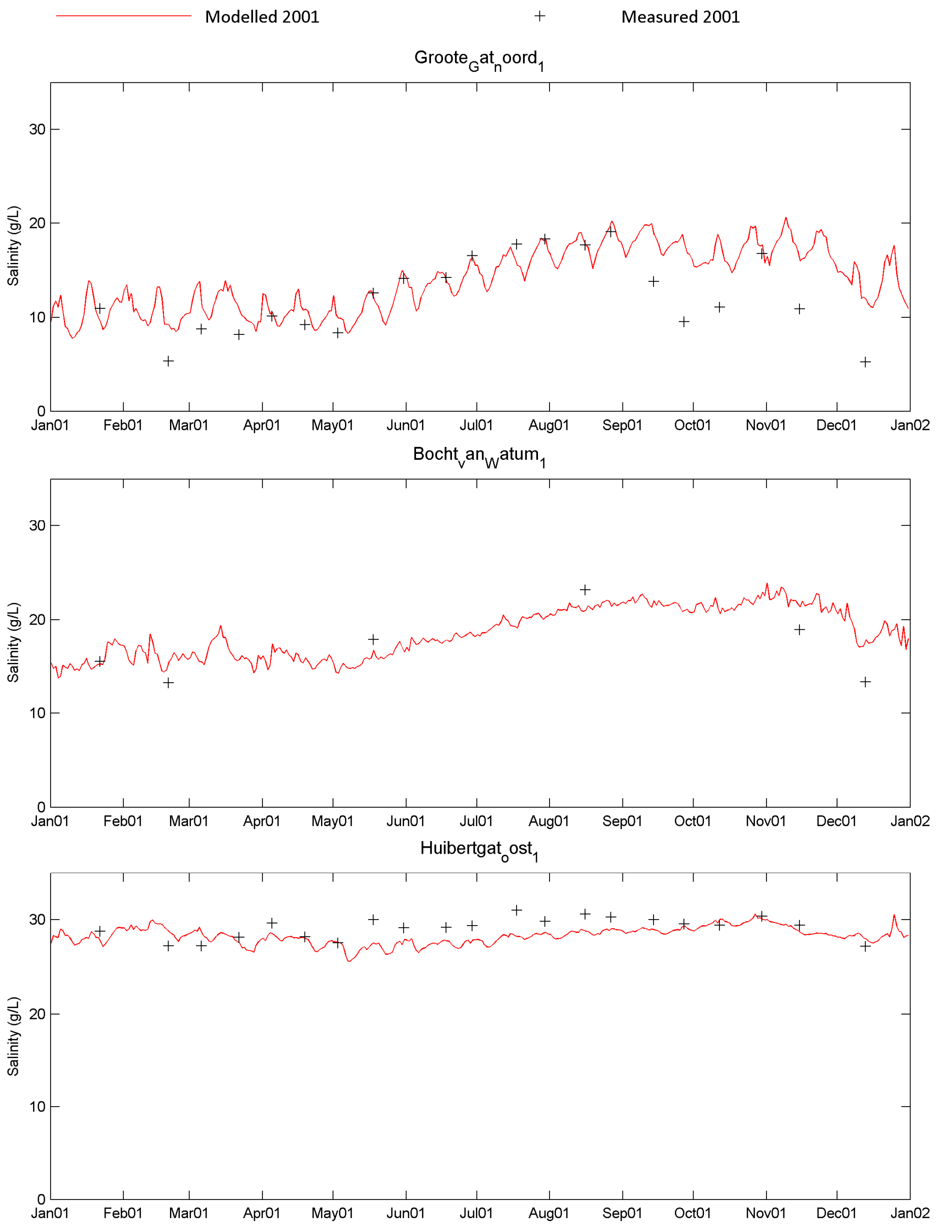


Figure 3.10 *Measured and modelled salinity at the reference stations*

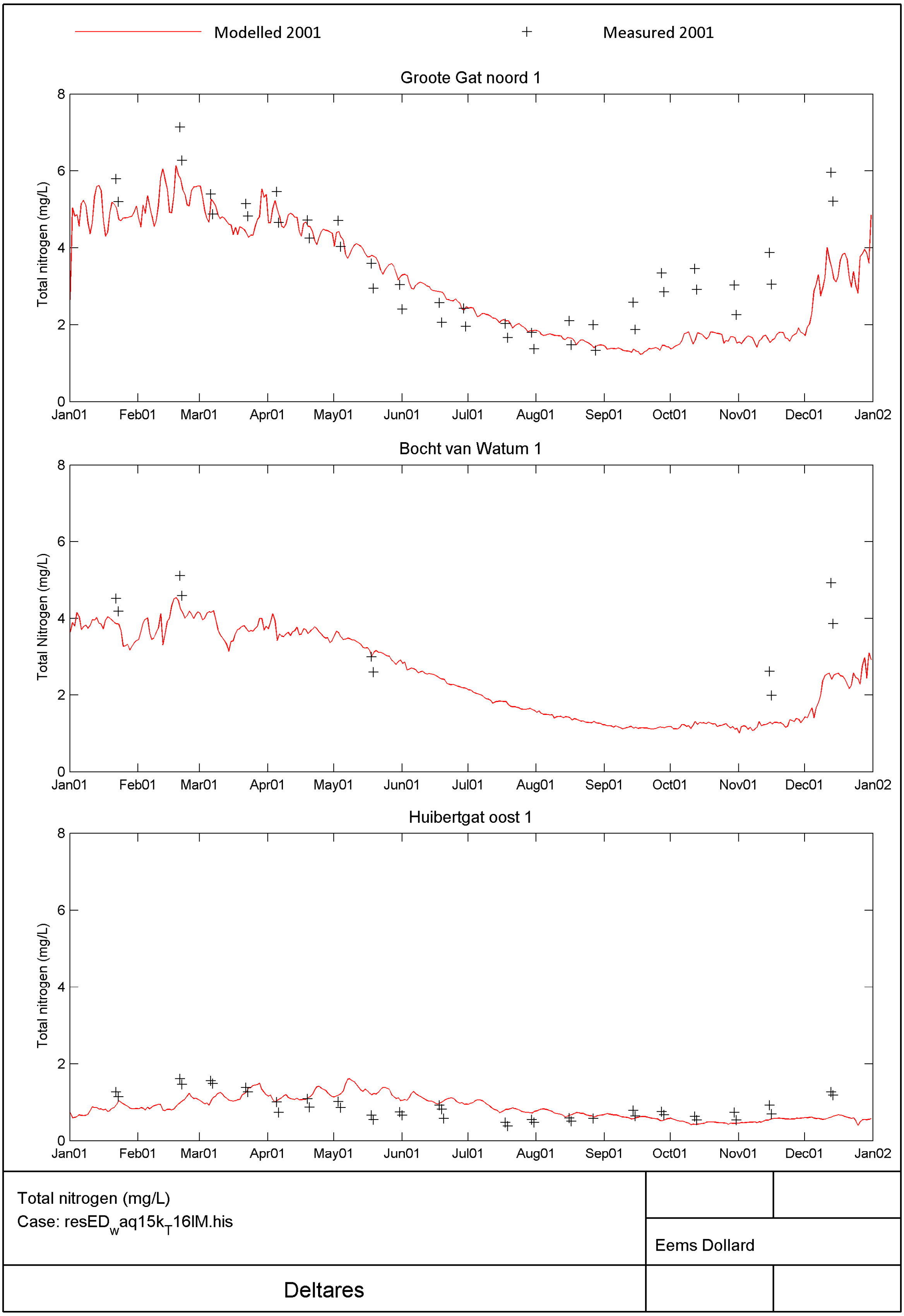


Figure 3.11 Measured and modelled total nitrogen concentration at the reference stations

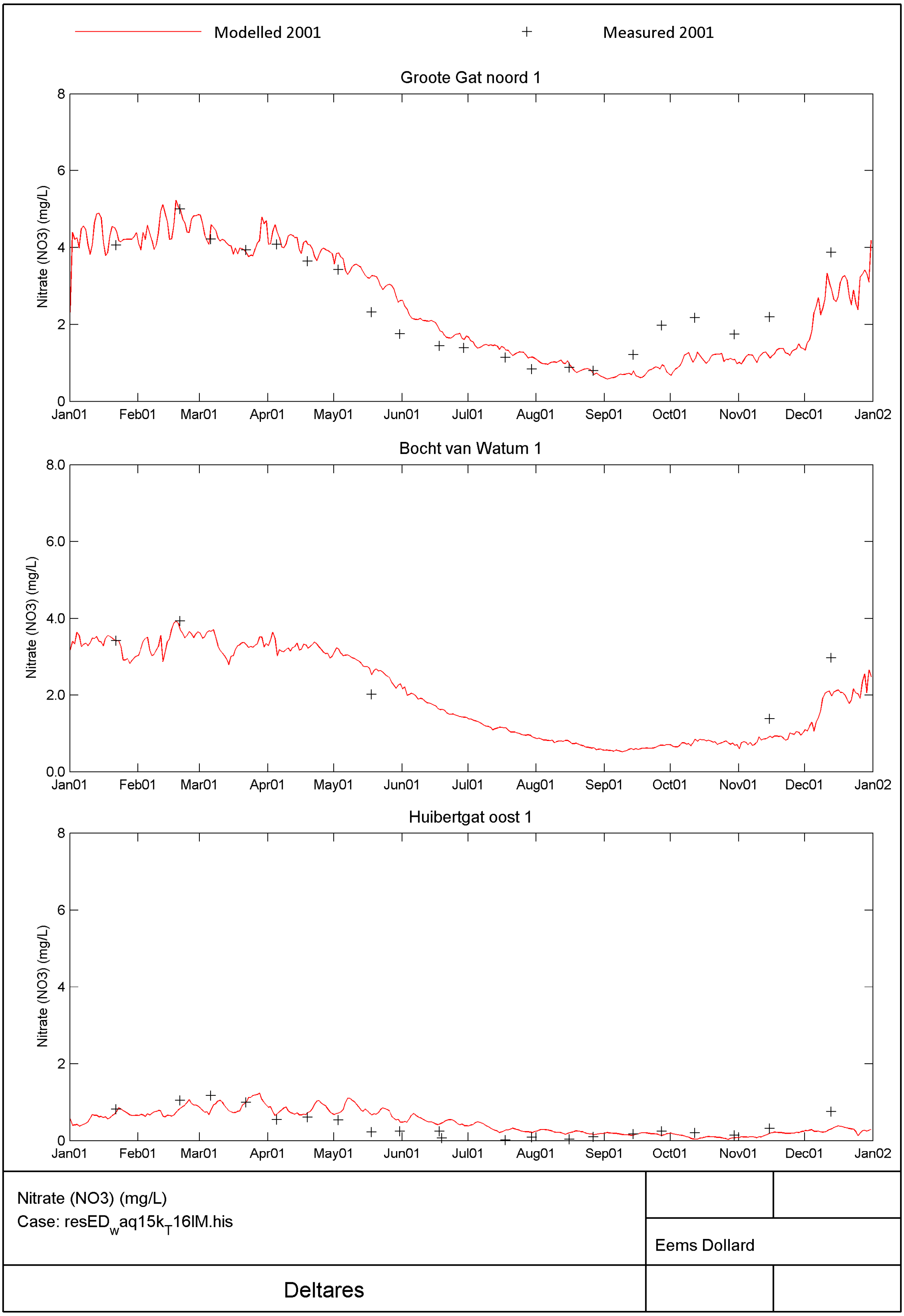


Figure 3.12 *Measured and modelled nitrate concentration at the reference stations*

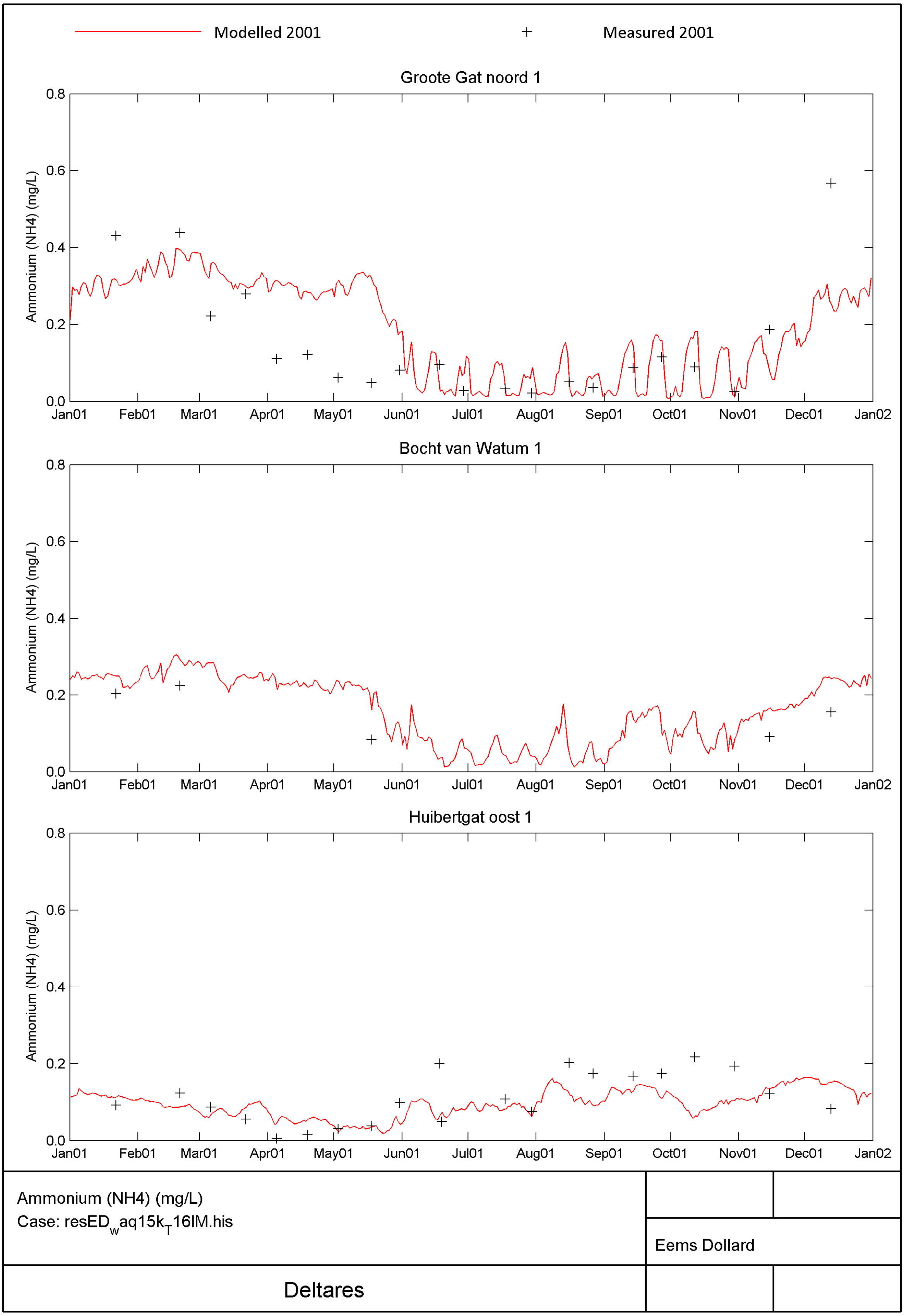
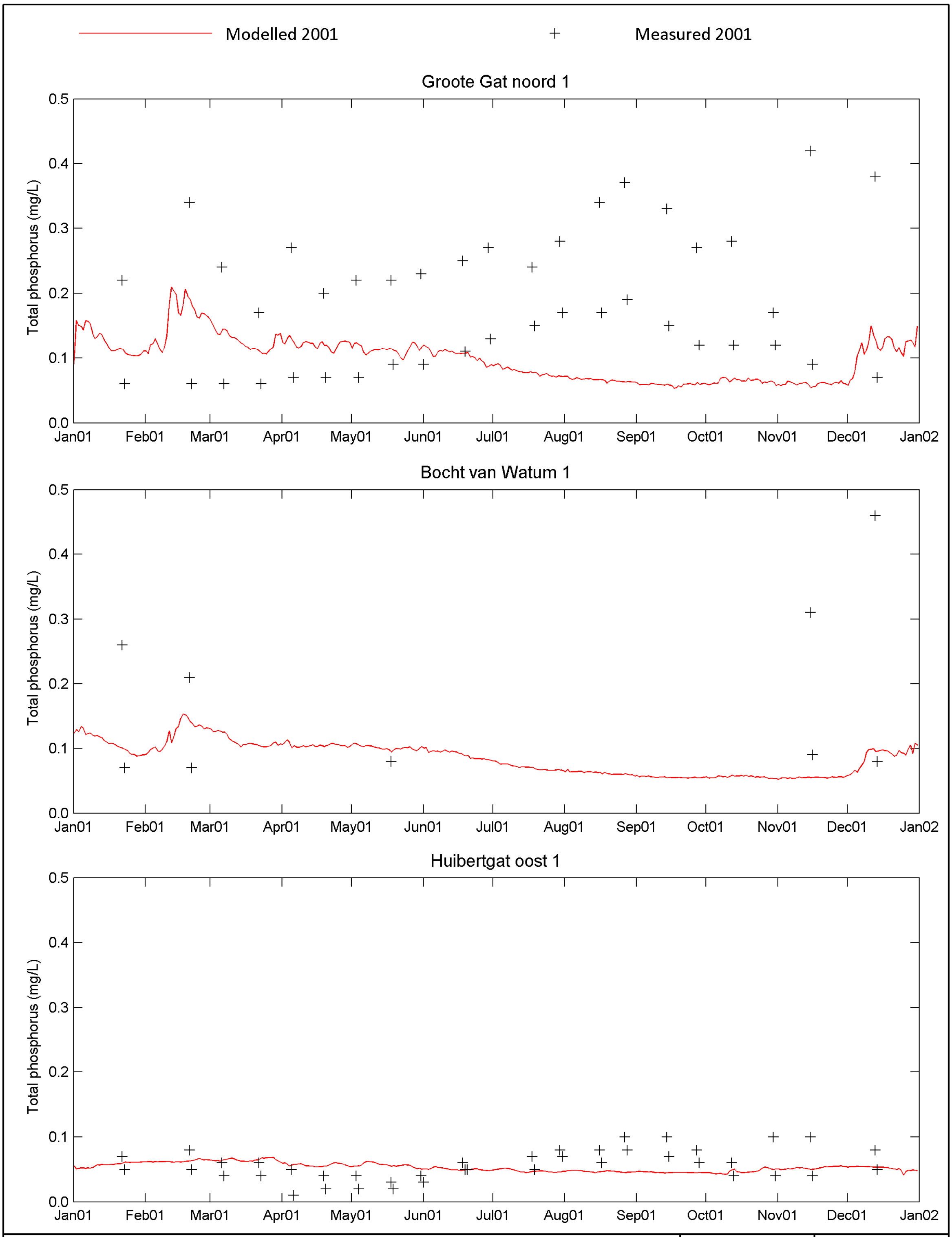


Figure 3.13 Measured and modelled ammonium concentration at the reference stations



Total phosphorus (mg/L)
Case: resED$_w$aq15k$_T$16IM.his

Eems Dollard

Deltares

Figure 3.14 Measured and modelled dissolved total phosphorus at the reference stations

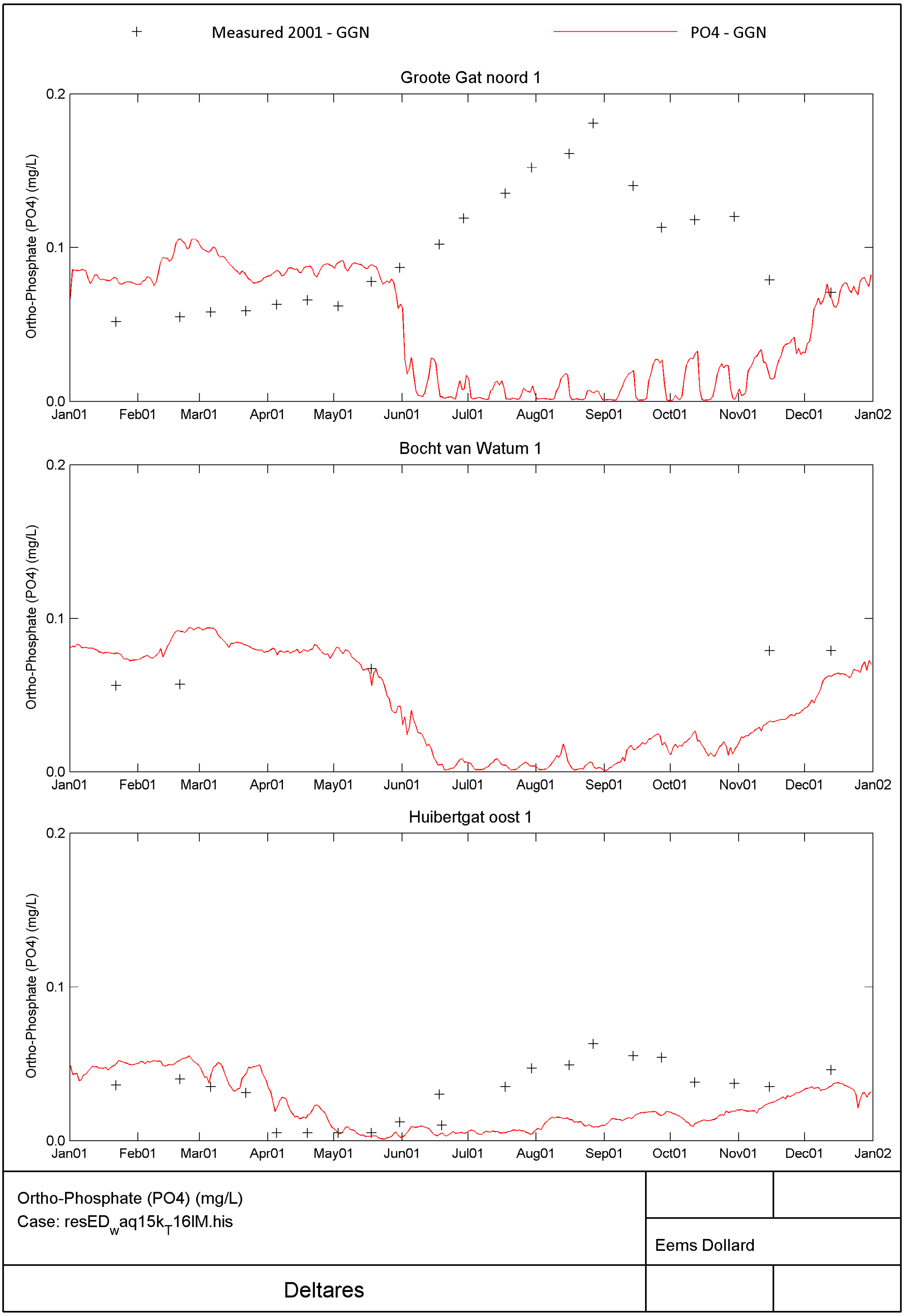
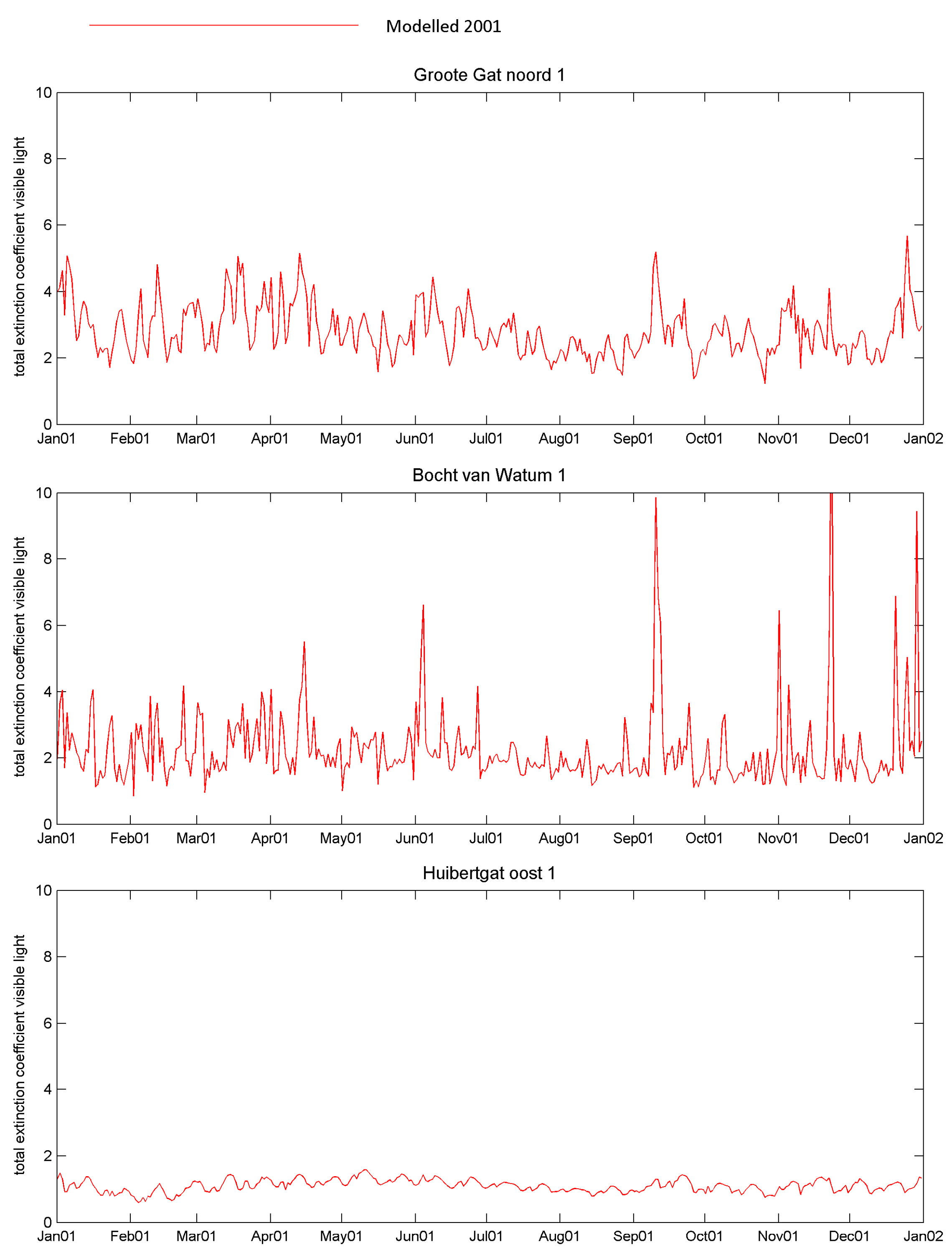


Figure 3.15 *Measured and modelled dissolved inorganic phosphate concentration at the reference stations*



total extinction coefficient visible light
Case: resED$_w$aq15k$_T$16IM.his

Eems Dollard

Deltares

Figure 3.16 Modelled total extinction coefficient at the reference stations

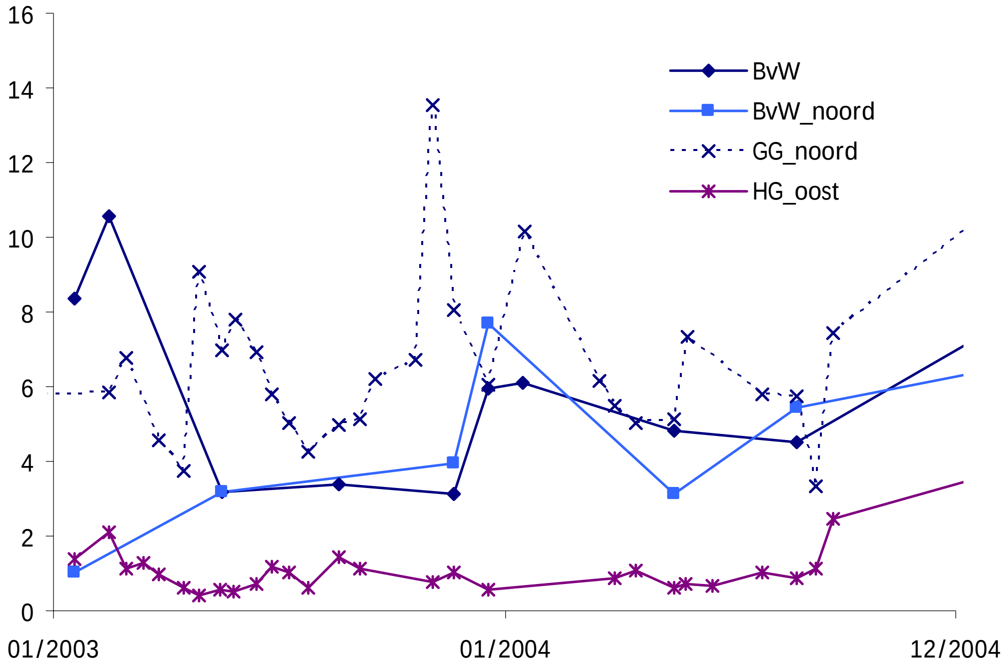


Figure 3.17 Total extinction coefficient for the reference stations for the years 2003 and 2004. Data for 2001 were not available.

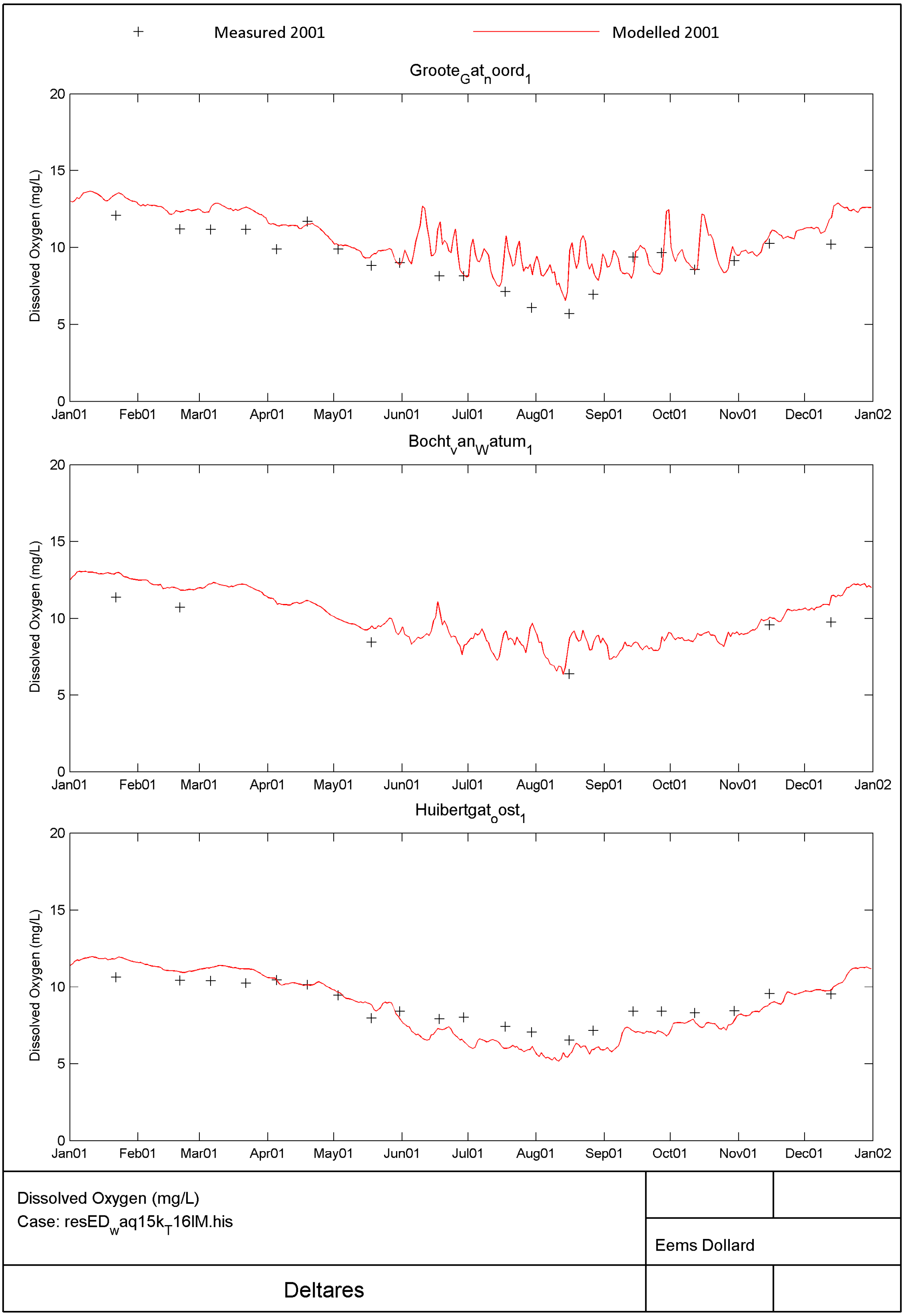


Figure 3.18 Measured and modelled dissolved oxygen concentration at the reference stations

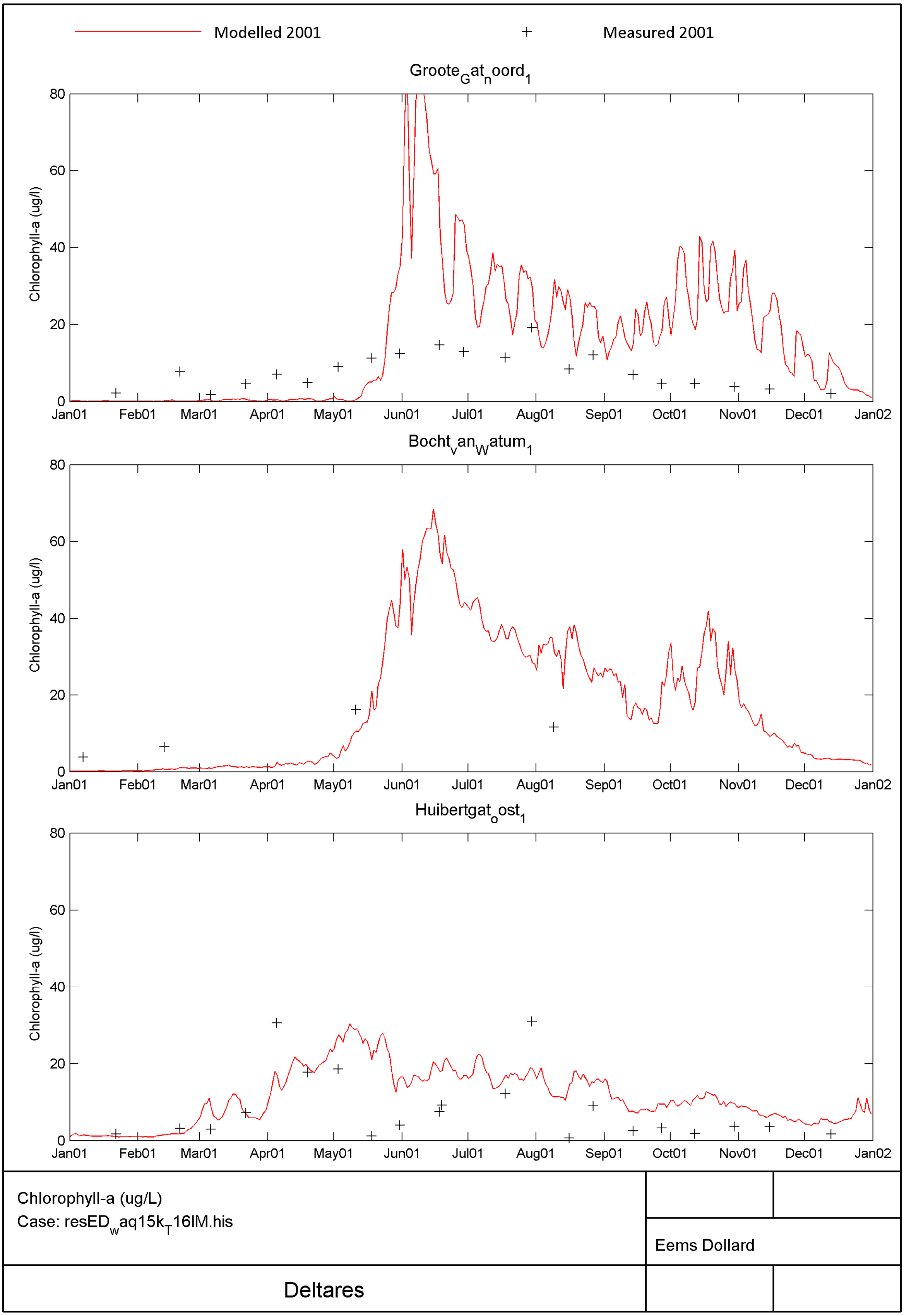


Figure 3.19 *Measured and modelled chlorophyll a concentration at the reference stations*

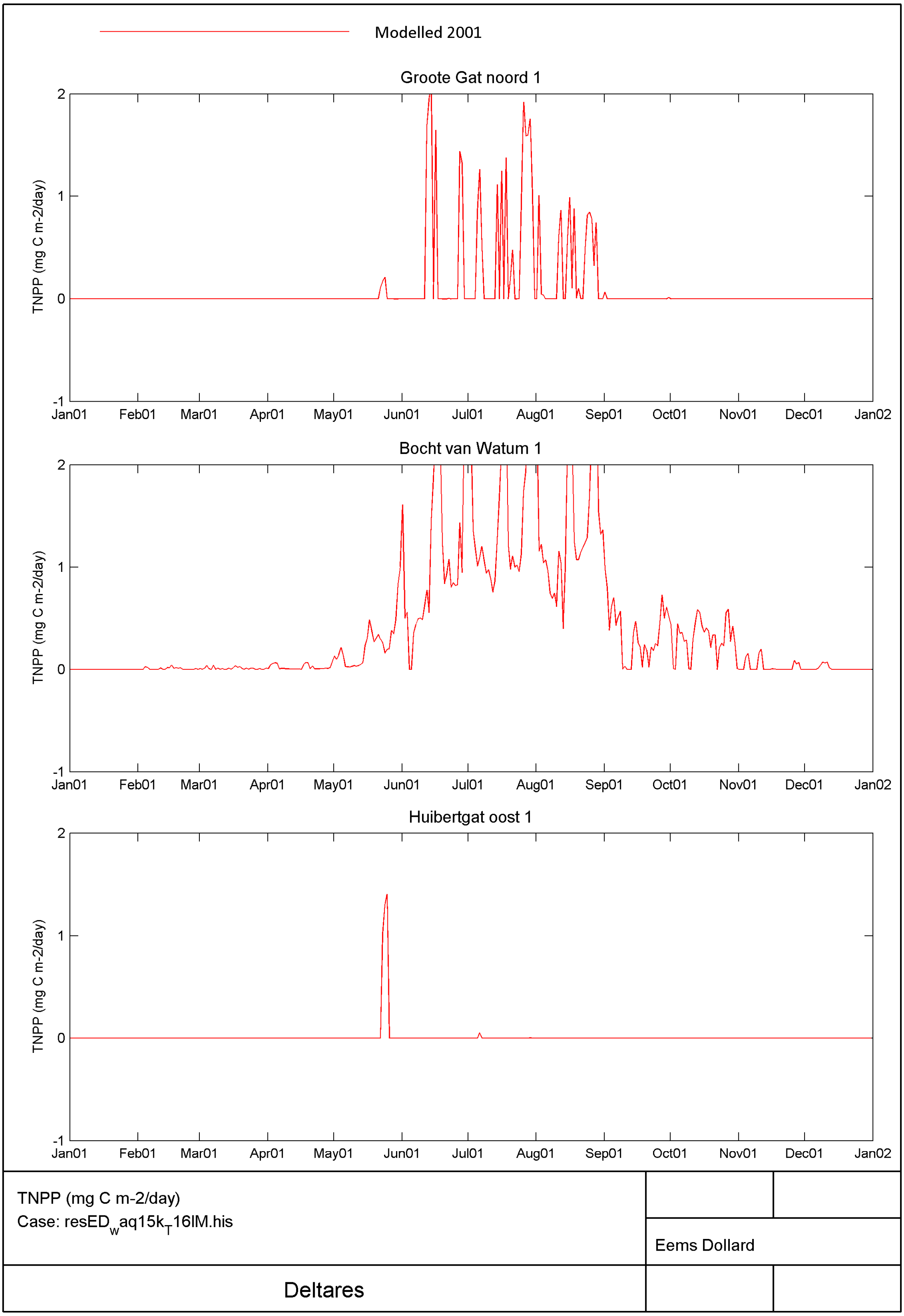


Figure 3.20 Total Net Primary production at the three reference stations.

3.3.3 Benthic primary production

Benthic primary producers in the model are restricted to the deepest water layer and are not transported. Therefore, they only occur in very shallow areas and tidal flats, where enough light is available averaged over the tidal cycle (see Figure 3.21 and Figure 3.22 for a snapshot view). Area-specific biomass of benthic diatoms was in the order of magnitude of 0.5 – 5 g m^2.

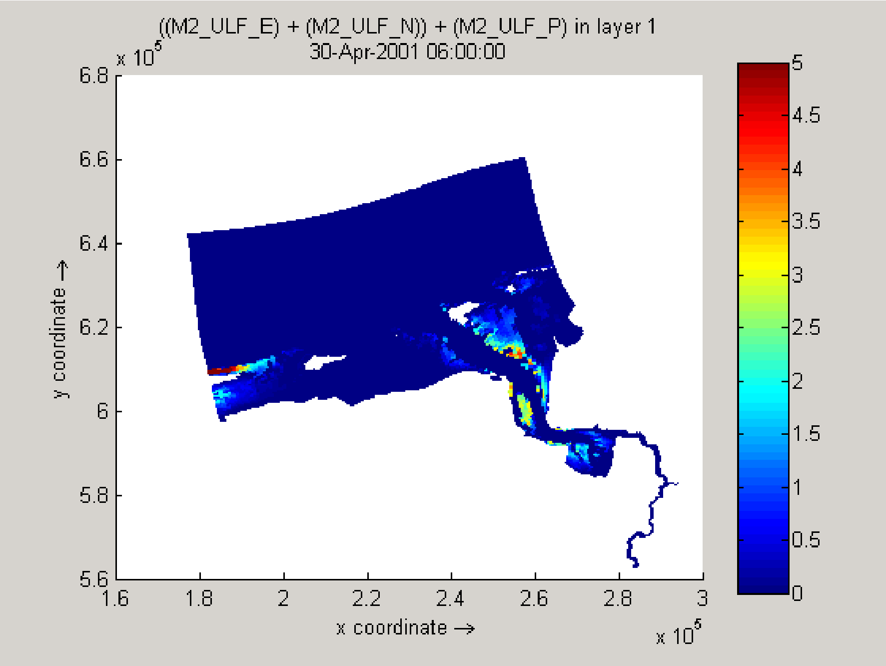


Figure 3.21 Snapshot of benthic diatoms biomass (in mgC/m2) in the Dollard area modeled with Delwaq BLOOM. Growth is restricted to shallow areas due to light limitation.

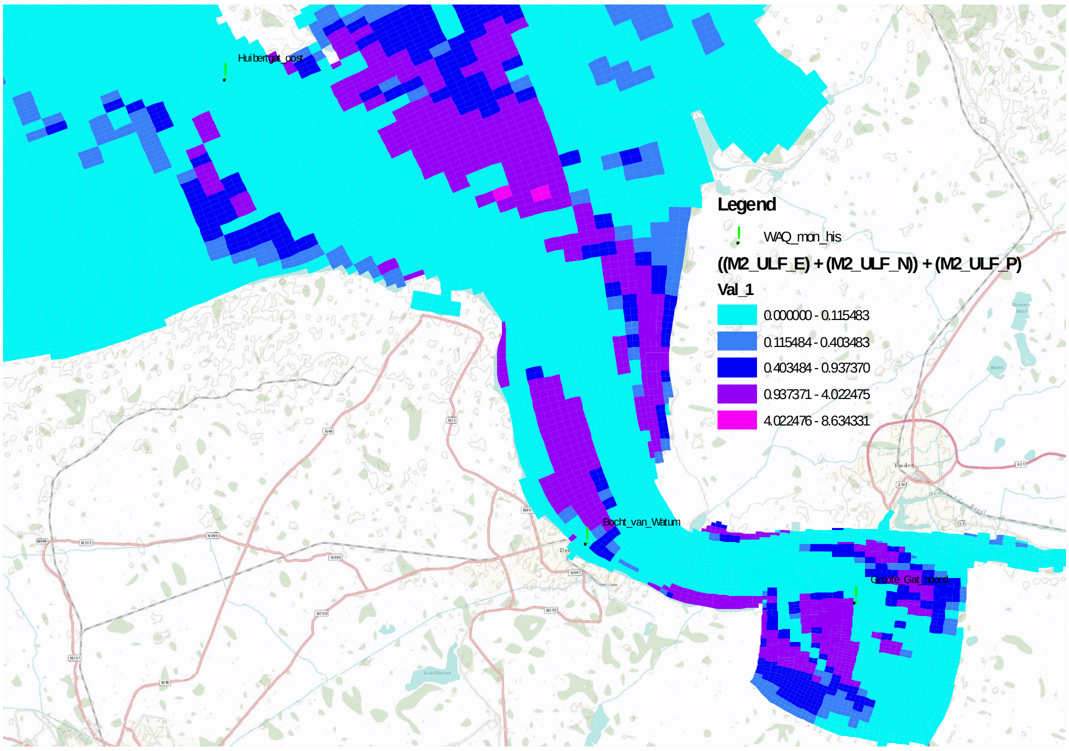


Figure 3.22 Detailed map of benthic diatoms (mg C m-2 day-1) in the estuary at 30th April, when biomasses were relatively high. The MWTL validation stations for water quality and phytoplankton are indicated with green circles.

3.3.4 Effects of dredging and dumping scenarios

The effect of two different dumping scenarios were studied. Suspended sediment concentrations were recalculated using the sediment model (see Section 2.2.3) and the resulting SPM concentrations were used as an input for the water quality and ecology model. For the three reference stations, SPM concentrations were mostly influenced at Huibertgat Oost, with a higher effect at the P5 scenario than the P6 scenario (Figure 3.23). Chlorophyll concentrations were reduced in may and the beginning of June, and were slightly enhanced later on in the season (Figure 3.24). Chlorophyll a and Total Net Primary Production were influenced over a large area (Figure 3.25 and Figure 3.26) but the effect was often relatively small.

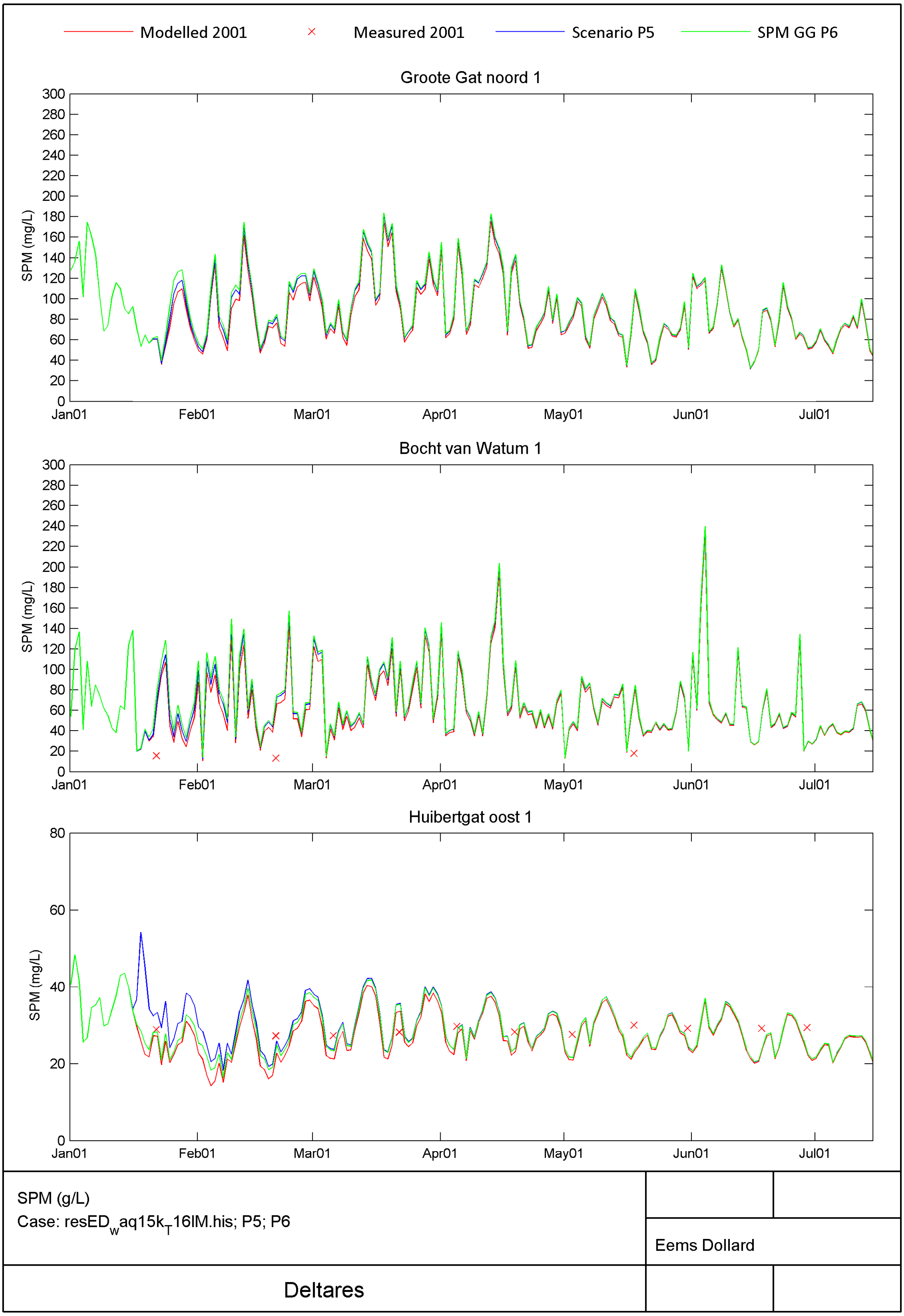


Figure 3.23 SPM concentration at the three reference stations. Reference run (red) and the two scenarios P5 (blue) and P6 (green)

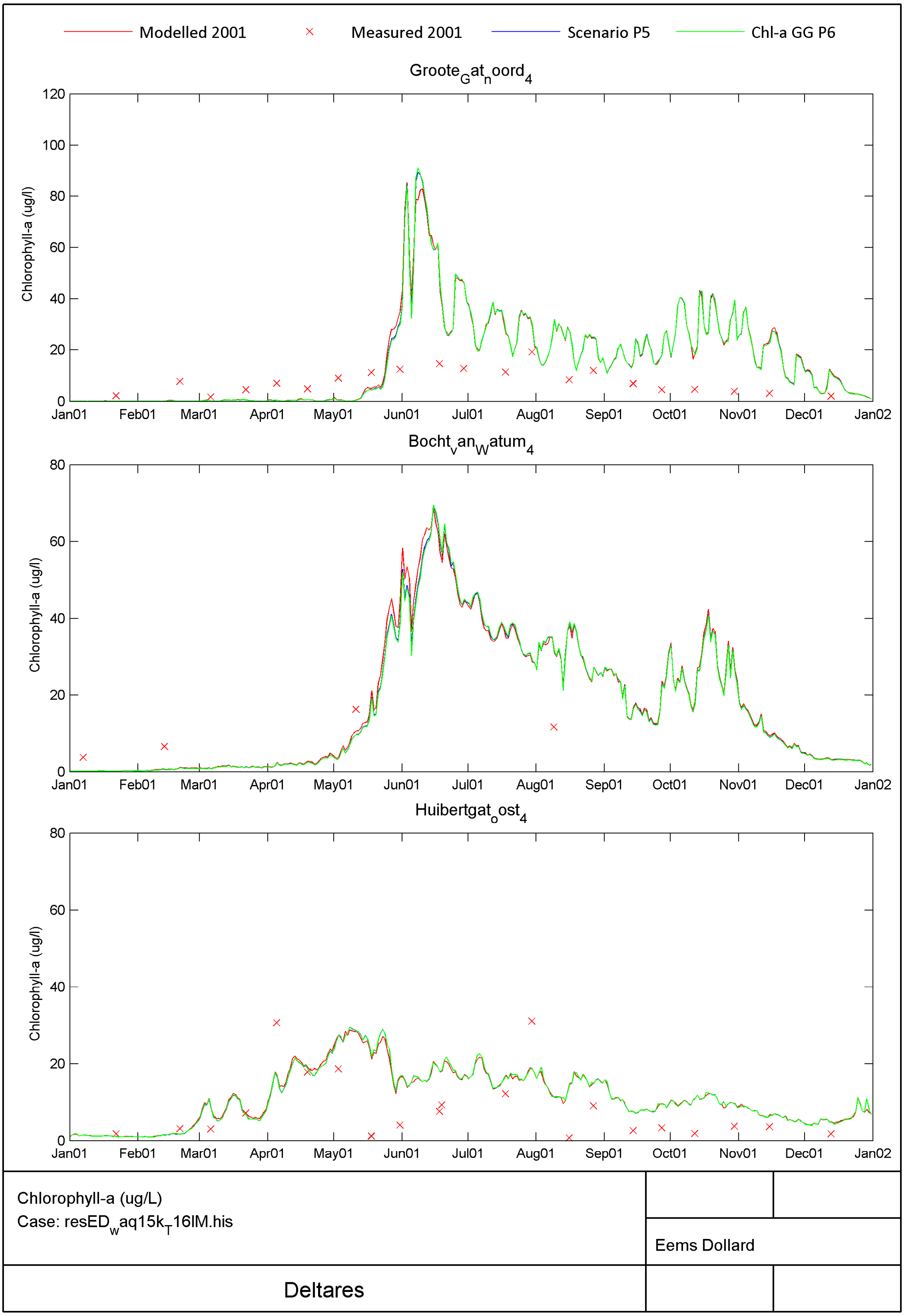


Figure 3.24 Chlorophyll concentration in the surface layer at the three reference stations. Reference run (red) and the two scenarios P5 (blue) and P6 (green).

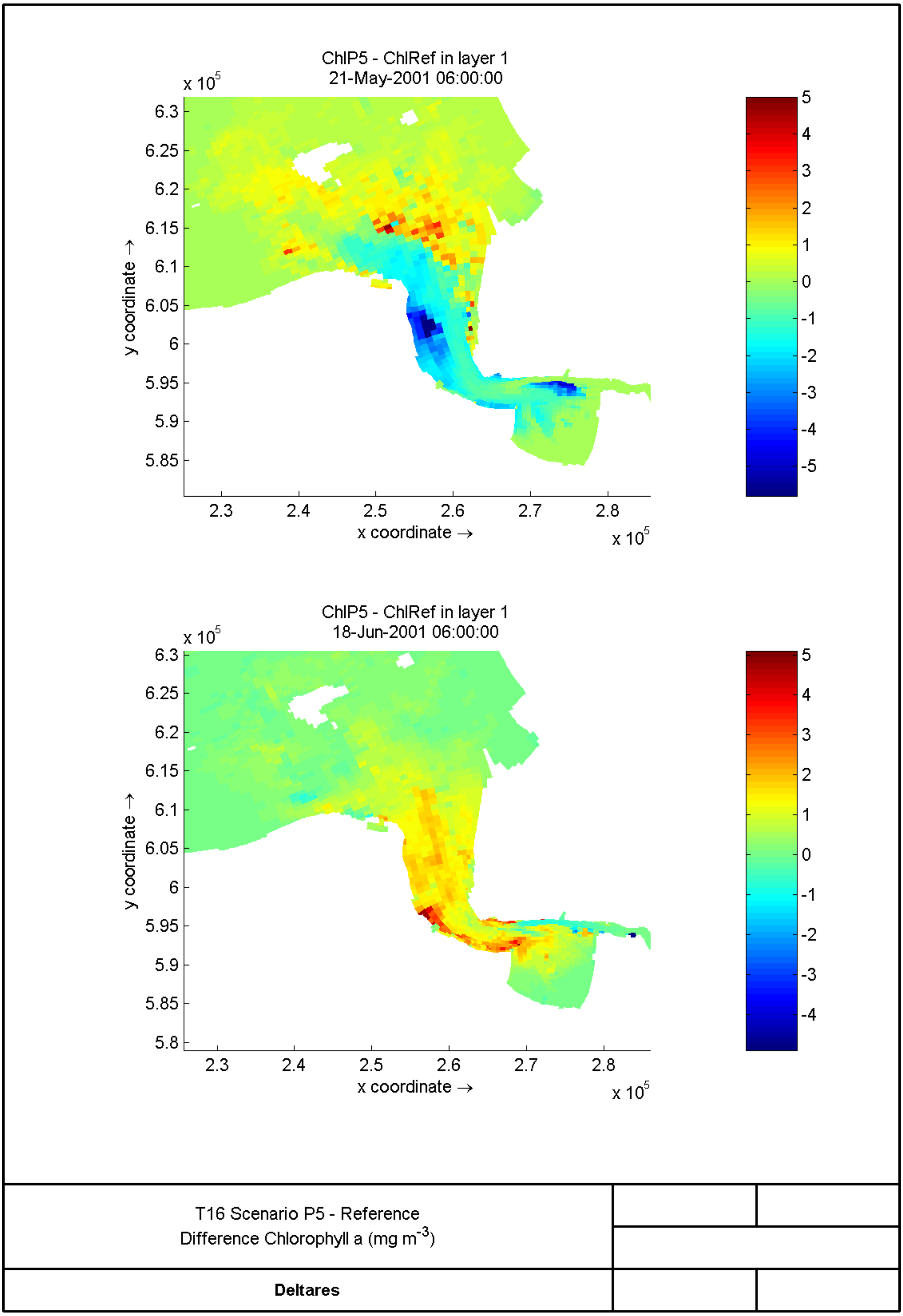


Figure 3.25 Difference maps of the Chlorophyll concentration in µg/L in the surface layer (Scenarios P5 – Reference) at 21st May (upper panel) and 18th June (lower panel)

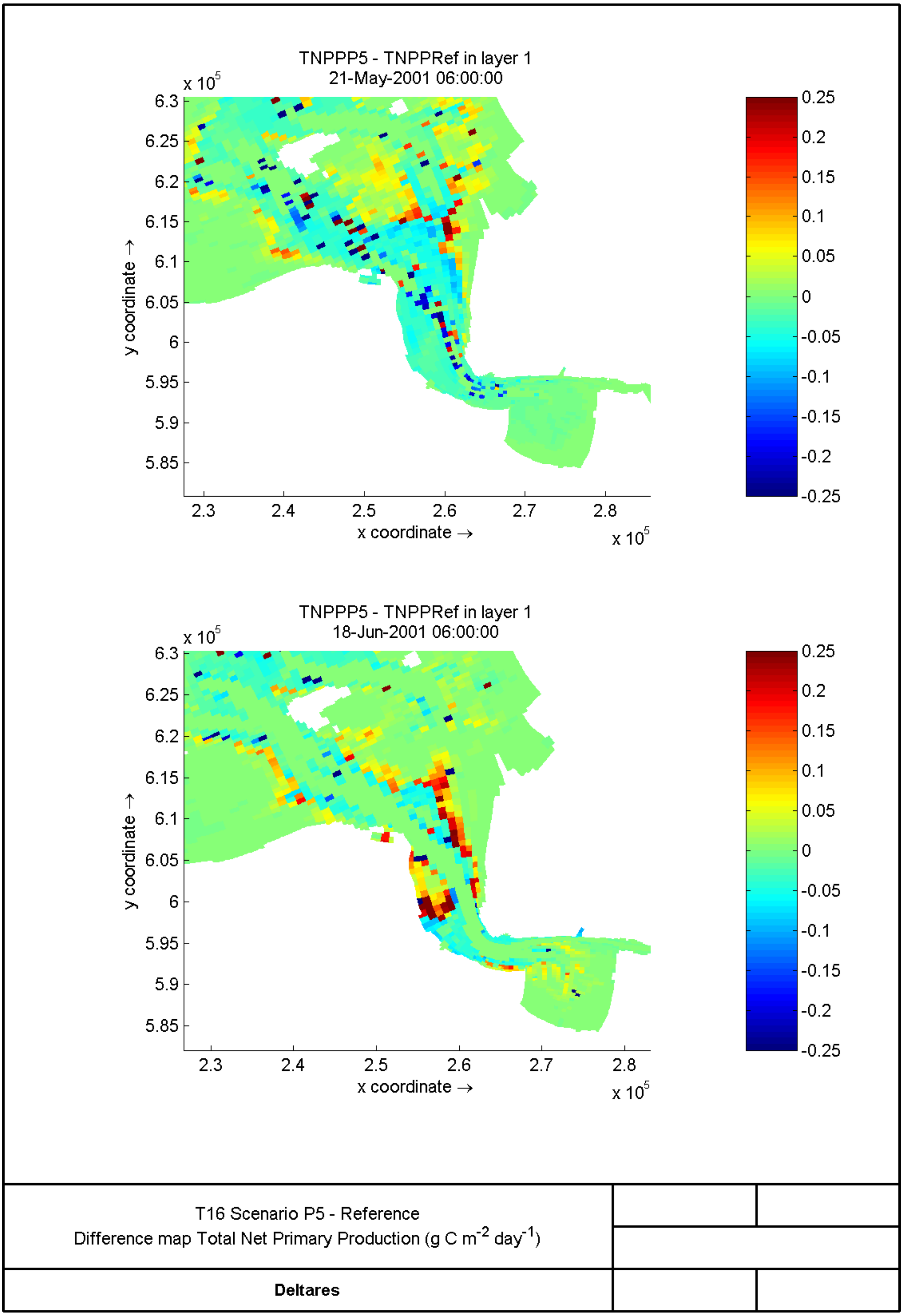


Figure 3.26 Difference maps of the Total Net Primary Production in gC.m^{-2}/day in the surface layer (Scenarios P5 – Reference) at 21st May (upper panel) and 18th June (lower panel).

3.4 Discussion of the results

As compared to the results from last year, the current set-up of the model produces realistic simulation of salinity. This is mainly due to the complete year of hydrodynamic modelling, and a better seasonal description of the Ems discharge.

The absolute concentration of SPM at the inner stations Grootegat Noord and Bocht van Watum have also improved and are now not far from the measured values. However, especially further off to the North Sea, at Huibertgat, SPM is overestimated during large parts of the year. Especially, the typical seasonal variation of SPM with high values in winter and lower values during summer is not correctly reproduced yet. Consequently, modelled light availability in spring and summer in the outer parts of the estuary are likely to be underestimated. It is reasonable to assume that for this reason, the pattern of Chlorophyll a is not correctly reproduced. Using the modelled SPM concentrations, Chlorophyll a is kept at low values during the spring, and starts to increase at a later moment in time than is indicated by the measurements. Most likely, due to the late growth start of phytoplankton in the model, nutrients have accumulated for a longer time, and the maximum concentration of chlorophyll a that is finally reached is much higher than expected on the basis of the measurements. However, this conclusion is at the moment very preliminary. A sensitivity analysis with respect to SPM is planned for 2012. This may give better indications of the causes of the current deviations from measured chlorophyll a.

Total Net Primary Production (TNPP) is dependent on light and nutrient availability. Light availability in turn is dependent on irradiance, sediment concentration, and mixing depth. At Groote Gat Noord, TNPP is zero for almost the whole year, due to high suspended sediment concentrations. At Huibertgat Oost, also TNPP is zero, but suspended sediment concentrations are much lower. Here, the mixing depth is higher, causing the algae to experience too low average light levels for a positive net production. Chlorophyll concentration at these two stations are therefore solely determined by production elsewhere, and physical transport. Therefore, a mismatch of SPM in the outer estuary may also explain mismatches of chlorophyll a in the inner estuary.

Because the growth of algae is deviating rather a lot from the observed values, it can not be expected that nutrient concentrations are well-described at the moment. Modelled total nitrogen is indeed slightly overestimated during the growth season. This seems mainly due to an overestimation of the ammonium concentration. The underestimation of phosphate during late summer is caused by the fact that there is no phosphate return flux from the sediment in the model at this moment.

Benthic primary producers have been introduced into the model. As a first approach, the characteristics have been adopted from (pelagic) marine diatoms. The modelled biomass of benthic diatoms can at the moment not be compared to measured values for the same year (2011). For 1977, average sediment chlorophyll a concentrations varied from 20 – 200 mg.m-2 at 6 stations in the Ems estuary. This compares well with the modelled biomass of 0-4 mgC.m^{-2}, assuming a chla/C ratio of 0.01 as used in the model (de Jonge & Colijn 1994). The spatial distribution of benthic diatom biomass coincides with shallow areas, and is highest at mud flats that run dry part of the day. Concluding, the modelled biomass of benthic diatoms is in the right order of magnitude as expected from historic measurements. The spatial distribution and the temporal trends need to be analysed further. In the future, model results can be compared with new measurements as planned in a coming project can be used for validation (van Maren et al., 2011).

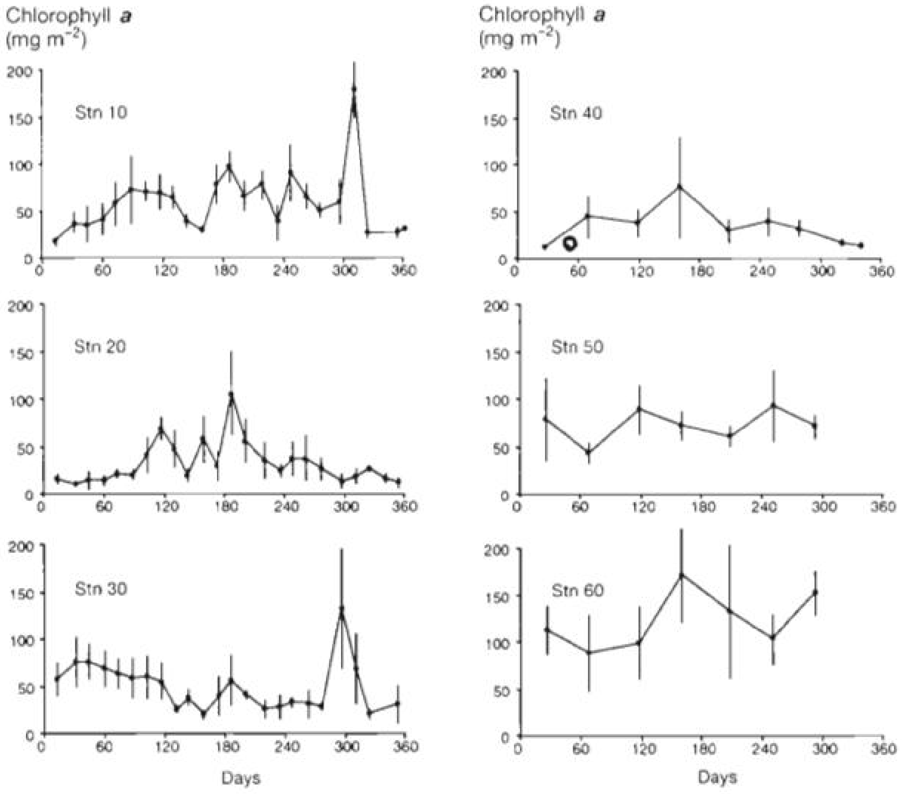


Fig. 3. Mean chl *a* concentrations (± SD) in the upper 0.5 cm sediment layer of the 6 stations in 1977

Figure 3.27 Mean chlorophyll a concentrations in the sediment at 6 intertidal locations in the Ems-Dollard estuary (de Jonge & Colijn 1994).

The effect of dumping of dredging material on the water quality and phytoplankton production was investigated by implementing the recalculated suspended sediment concentrations from the dumping scenario sediment model runs. At first sight, the differences are not very noticeable. Changes in suspended sediment concentrations, chlorophyll a concentrations and total net primary production due to the dumping are limited to approximately 10 % of instantaneous values and are limited to part of the estuary. However, since the reference run has not been optimized yet to fit the measured values of chlorophyll a and nutrients, no further conclusions can be drawn yet. Also, further spatial analyses will have to be done in order to asses the effect on total primary production (including benthic primary production) in the estuary.

For primary production, some segments show relatively high differences between the scenario and reference conditions (Figure 3.26). This may be caused by the occasional switch between the different types of algae within one species (E-, N-, and P-types) which is a much faster process than the succession of species. Since the different types differ by their N/C and P/C quota. The effect of these switches on total primary production can be expected to be small.

3.5 Conclusions and recommendations

The current model for water quality and phytoplankton growth is performing technically well and includes both phytoplankton and phytobenthos. It uses the new full-year hydrodynamics and suspended sediment concentrations and 2 alternative dumpingscenarios have been implemented. The first tests give hopeful results, but it is clear that some improvements are required to produce results that better fit the available measurements.

Sensitivity analyses of the model with respect to SMP will have to further indicate to what extent the deviating primary production and chlorophyll a model results can be improved by more accurate SPM model input. Depending on these results, improvements of the model may have to start with improved description of the SPM concentrations, especially in the outer estuary. Once this has been achieved, other processes and parameters can be adjusted for a better fit of the model to the observations. Also, two processes that still have to be added are

- modelling the return flux of phosphate from the sediment to the water
- Including grazing by zooplankton and optionally benthic grazers

The addition of a process that returns phosphate from the sediment to the water phase may improve the description of dissolved phosphate in the water column. However, it is not evident that the addition of this process will also lead to improved primary production and phytoplankton biomass description, since phosphate is most likely not a limiting factor for phytoplankton growth. It can therefore be questioned whether it is useful at this stage to include such a process.

Grazing by zooplankton will definitely affect phytoplankton biomass and production. It can be anticipated that the highest phytoplankton values will be reduced when grazers are introduced in the model, and therefore lead to better descriptions at especially the inner estuary stations.

Further adaptation of the model will include the adjustment of some of the algal physiological parameters, for an earlier onset of growth in the season. Currently, the algal growth parameters have been adopted from the ones used in the North Sea model in order to keep the model as generic as possible. However, for estuarine algal species the light response may differ from typical North Sea species, reflecting their adaptation to areas with notoriously lower light availability. Therefore, alterations in the growth parameters are justified and perhaps required.

4 Habitat suitability

4.1 Introduction

The two previous reports on ecology in the Ems-Dollard focussed on an inventory of the system with all biota and stressors, and on the set-up of the ‘Habitat’ modelling tool, respectively. The latter report also discussed an identification of possible key species and the response curves that characterise their habitat suitability, as well as an assessment on the model’s sensitivity for grid size and input values.

The purpose of this year’s report was to describe the final choice of key species, a validation of the Habitat-results with observations in the year 2001 or close to that year, a baseline- or reference scenario that covers the entire year 2001 and the effect of the dredging & dumping scenarios. Not all of these goals have been met, partly due to problems with the sediment and water quality models, partly due to the amount of work involved in assessing all species, all year in full detail. Therefore, the report also provides some suggestions regarding the development and application of the model in the final year of this Ems-Dollard study.

4.2 Additional response curves

In addition to the species discussed in last year’s report, it was considered useful to include juvenile herring too.

(Juvenile) Herring – *Clupea harengus*
Shallow areas such as Ems-Dollard are more suitable for juveline herring than for adults, which prefer more open waters. Herring feeds on zooplankton, shrimp, fish eggs, worms and jellyfish (Brevé, 2007), but also phytoplankton. They can deal with euryhaline conditions. Due to sensitive hearing system possibly disturbed by (shipping) noise. Swims in schools, from just below the surface (during night) to 200 m deep (100 m for young herring; during day).

Spawning near the bed, on coarse sands, gravel, shells, small stones, red algae and seagrasses; oxygen and water temperature are important, so sufficient water motion (turbulence, waves) is required. The use of an area as a spawning area not only depends on habitat suitability, but also on whether adults know to find these areas or not. The incubation time of the eggs ranges between 105-136 daydegrees; 40 days at 3 °C, 11 days at 10°C. Above 19°C the eggs die. Minimum temperature for adults is 2-5°C, maximum 25°C; spawning occurs between 3-12°C. Light is important, as they hunt visually. A quantification of light requirements was not found in literature however, so this is estimated (Fig. 4.1).

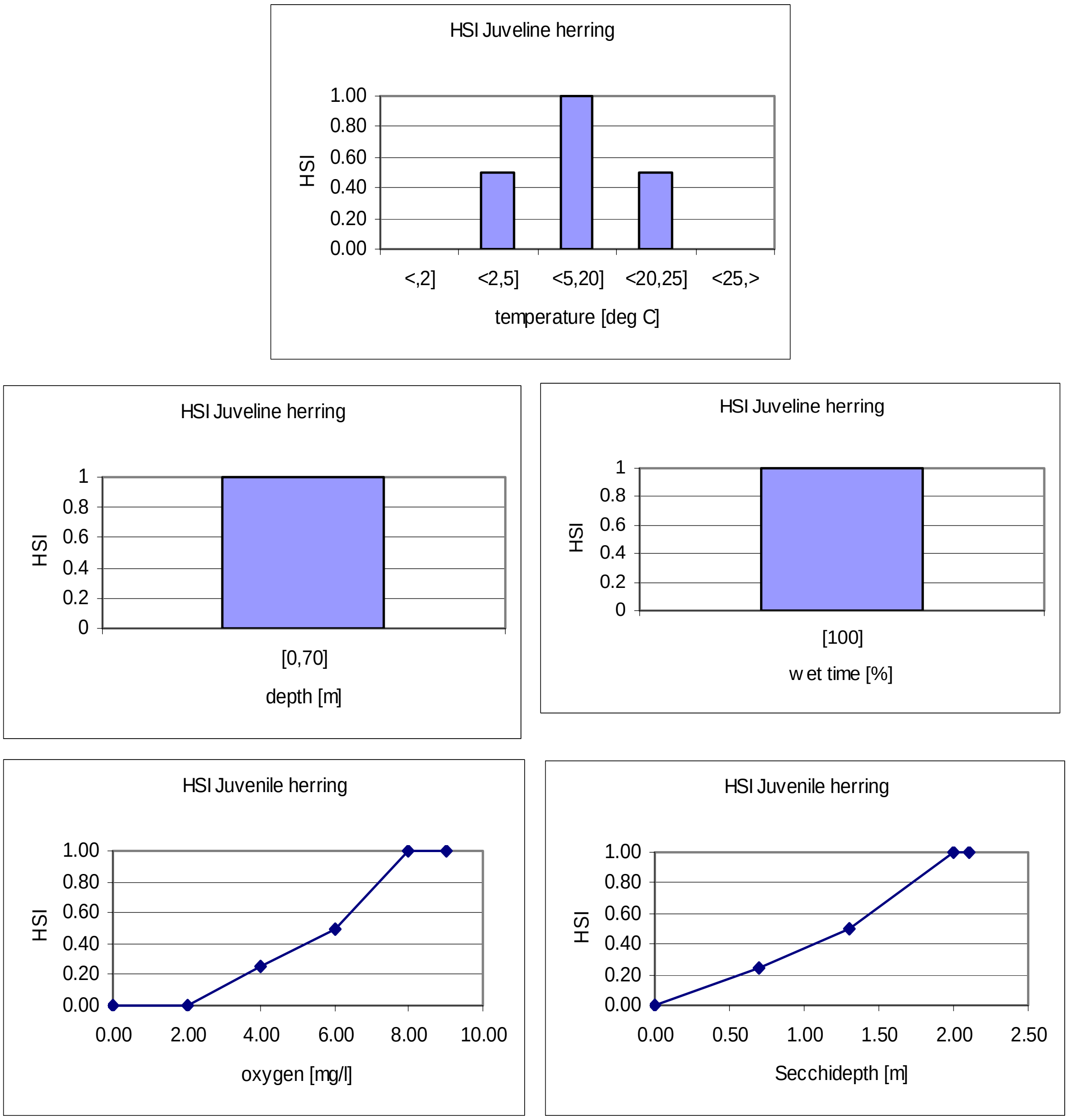


Figure 4.1. Response curves of juvenile herring Clupea harengus.

4.3 Species inventory around 2001

In this chapter, the abundance of the key species around the year 2001 is summarized, to serve as validation data for the Habitat-model. Because 2001 is the year used for the hydrodynamic boundary conditions and the bathymetry, the data on ecology should ideally be from the same year. However, as not all ecological surveys are performed yearly, sometimes data from nearby years has been used. Where possible and relevant, i.e. for migratory birds and fish, seasonal data is listed as well.

4.3.1 Eelgrass

The Hond-Paap was covered by 190 hectares of eelgrass (*Zostera marina*) in 2001 (Erftemeijer & Wijsman, 2004; Fig. 4.2). This population had an average density of 20% at an elevation of -20 to +20 cm NAP, which is dry for 40-60% of the time. Reproduction mainly occurs by means of seeds that survive the winter and germinate in spring; some reproduction occurred through rhizomes. German monitoring in 2001/2002 (Adolph et al., 2003) indicated small meadows of *Z. noltii* and incidental occurrence of *Z. marina* near Randzel and Norddeich. During an earlier mapping (1993/1994) meadows in stead of incidental plants were reported near Randzel. The years before 2001 showed a steady increase in cover, whereas in recent years the population on Hond-Paap has diminished (Fig 4.3).

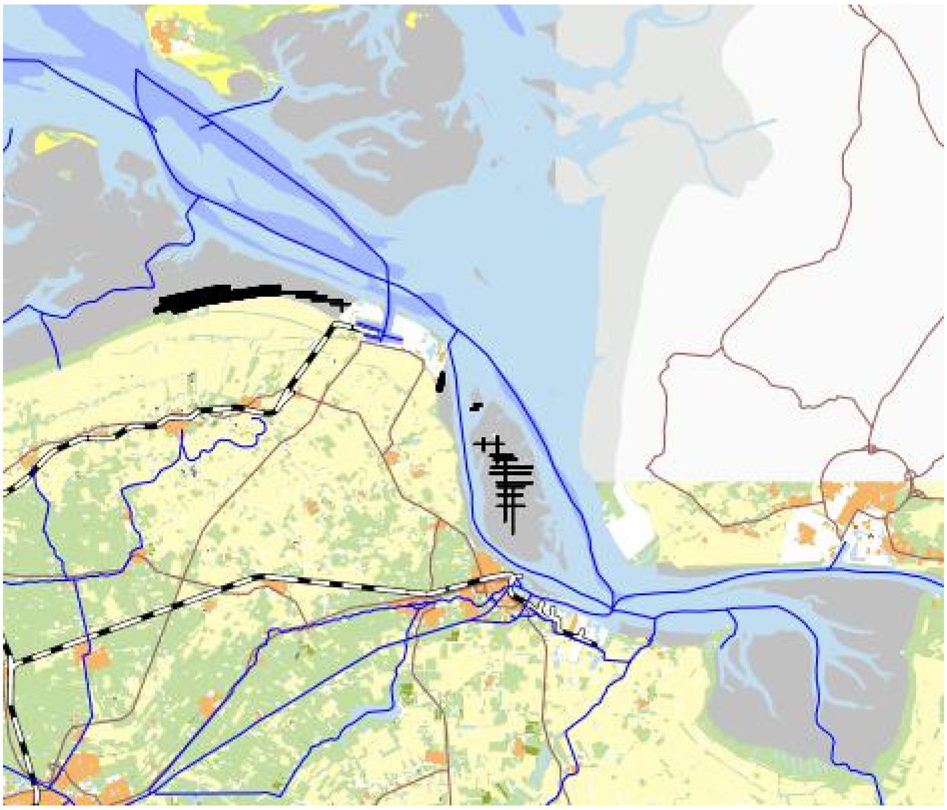


Figure 4.2. Approximate locations of Zostera marina on Hond-Paap and Zostera noltii at other locations. Other areas Year unknown. Source: Watlas 2011.

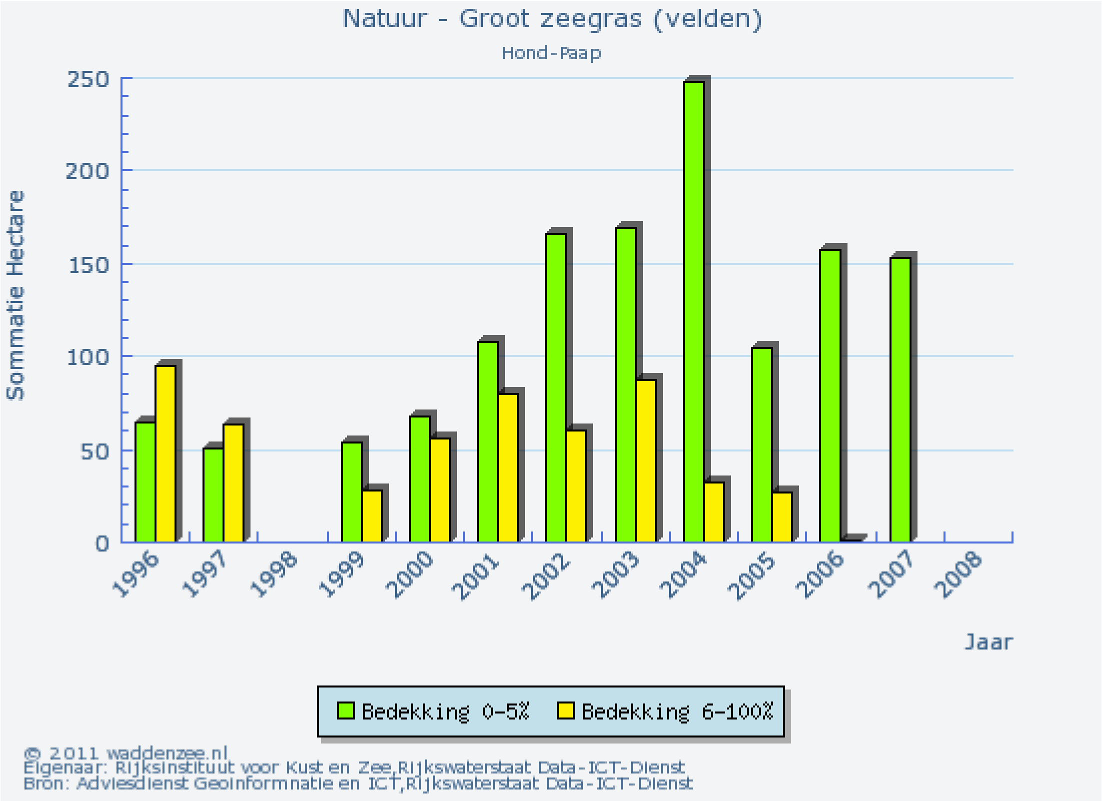


Figure 4.3. Eelgrass cover on the Hond-Paap, 1996-2008. Source: Watlas, 2011.

In 2003, the first plants germinated early March but these suffered from frost. At the end of April / early May many young plants were reported. The density varied throughout the year and per location: The population at the Northern plot grew from 3.7 ± 0.1 shoots per m^2 in April, via 34.8 ± 1.4 per m^2 in August, to decrease in September (25.2 ± 19.9 per m^2). At the Southern location, densities were lower: 1.7 ± 0.3 in April, 20.6 ± 5.7 in August and 20.0 ± 9.4 per m^2 in September. The sediment at the two sites differed: the North was muddier (D_{50}=53µm; mud content 46.2 ± 6.9 %), the South was sandier (D_{50}=82µm; mud content 35.6 ± 3.9 %). On both locations, the sediment composition varied considerably throughout the year, possibly as a consequence of nearby dredging activities.

4.3.2 Salt marshes, pioneer zones and Spartina swards

The different types indentified by the European Habitat directive –H1310 Salicornia, H1320 Spartina and H1330 Atlantic salt meadows- differ from most mapping programs, which usually identify the first two as the pioneer zone and subdivide salt meadows into low marsh, high marsh, sandy green beach and brackish marsh (QSR, 2004).

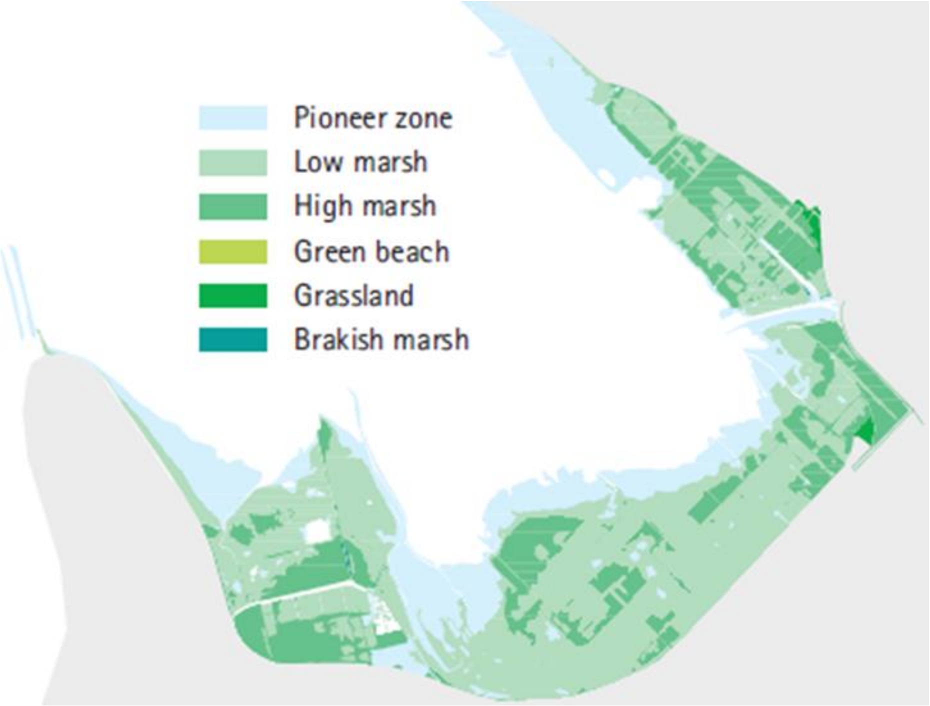


Figure 4.4 Salt marsh zones at Leybucht. Source: QDR 2004

4.3.3 Blue mussel

In the Ems-Dollard area, wild as well as cultivated mussels predominantly occur in the sheltered areas behind the islands of Rottumeroog, Borkum and Juist (Figs. 4.5 & 4.6). Some banks occur on Hond-Paap and near Voolhok. No banks are found in the Dollard, but this area is not part of the regular monitoring program.

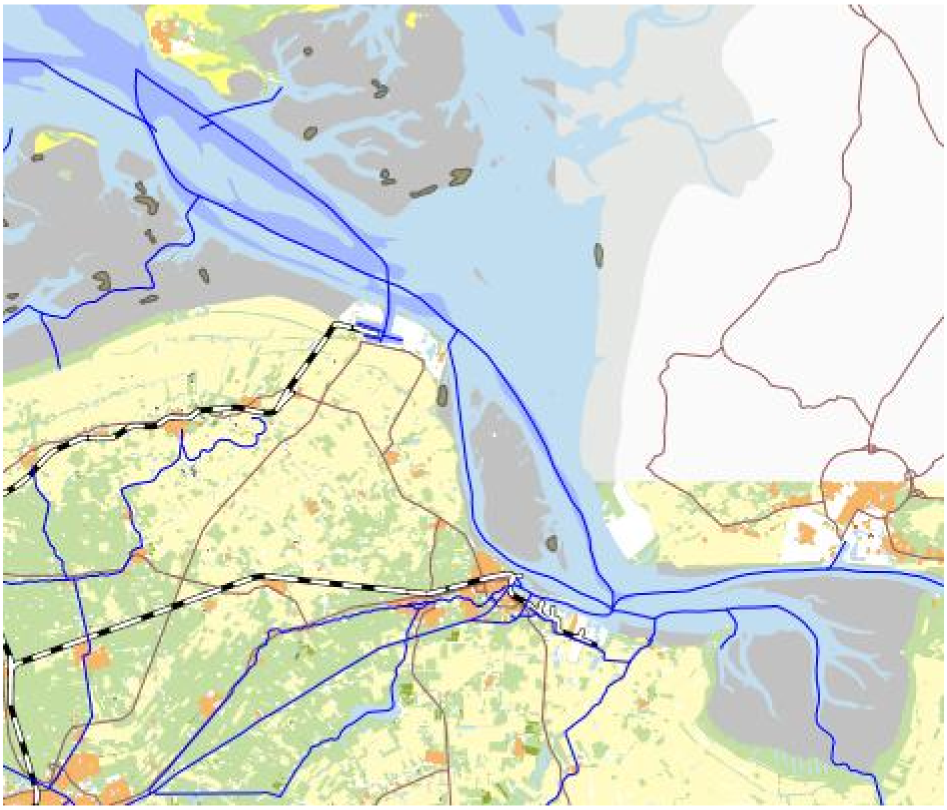


Figure 4.5. Natural mussel banks in Ems-Dollard. Year unknown. Source: Watlas 2011

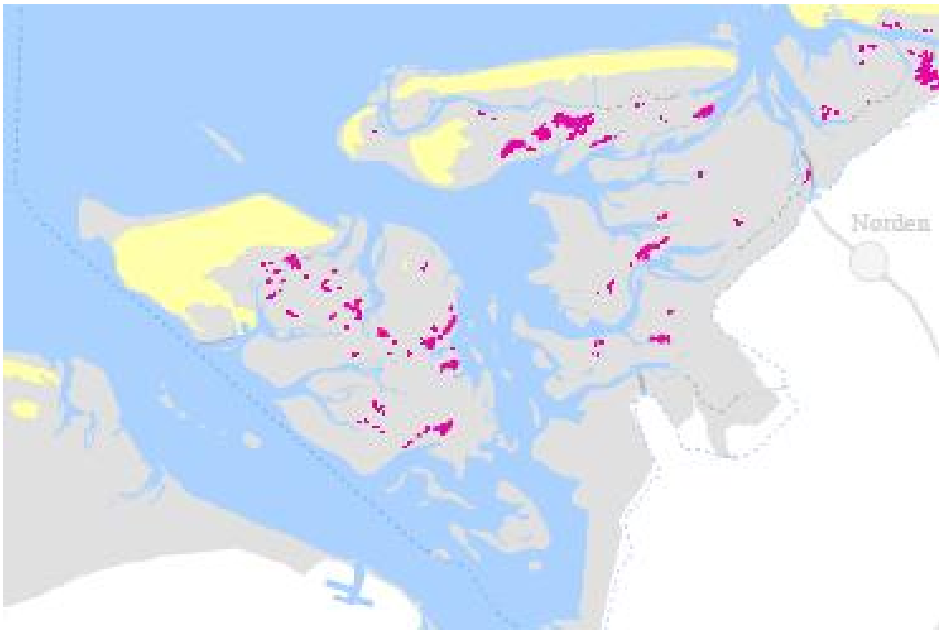


Figure 4.6. Locations of natural mussel banks in 2007 in Germany. Source: Nationalpark Wattenmeer, 2007.

Mussels are the most abundant bivalve species on the Hond-Paap in 2002: 2.26 million kg, or 151 ha, corresponding to a bank density (cover) between 239 and 523 mussels –or 74 g dry weight- per m^2. In 2001, about 1 million kg mussels was fished away; just two of the four mussel banks remained (Dankers, 2001). These banks occur between -35 and -50 cm NAP and are under water for 50-60 % of the time. In 2003, the density is higher for the northern bank (not visible in Fig. 4.4, but slightly South of Voolhok), and varies more during the year: 780 ± 250 individuals per m^2 halfway May, 580 ± 100 at the end of June, 400 ± 70 halfway July, 360 ± 90 halfway August and 490 ± 320 per m^2 medium September. Fort the South location (in front of Delfzijl in Fig. 4.5), these values were 350 ± 160, 300 ± 120, 250 ± 50, 210 ± 50 and 250 ± 80 per m^2 at the same periods. Early April, the density at the South location was 180 ± 180 per m^2. The increase in numbers at the end of the season is the result of new spat.

4.3.4 Cockle

The occurrence of cockles in the Ems-Dollard seems to be limited to the Voolhok and the area west of the Eemshaven (Fig. 4.7), although this cannot be said with certainty as areas further into Ems-Dollard are not part of the monitoring program. Over the entire Dutch Wadden Sea, the year 2001 is characterized by an average number of cockles, though the period 1998-2003 shows a clear negative trend (Fig. 4.8). No information could be found about cockle beds in Germany.

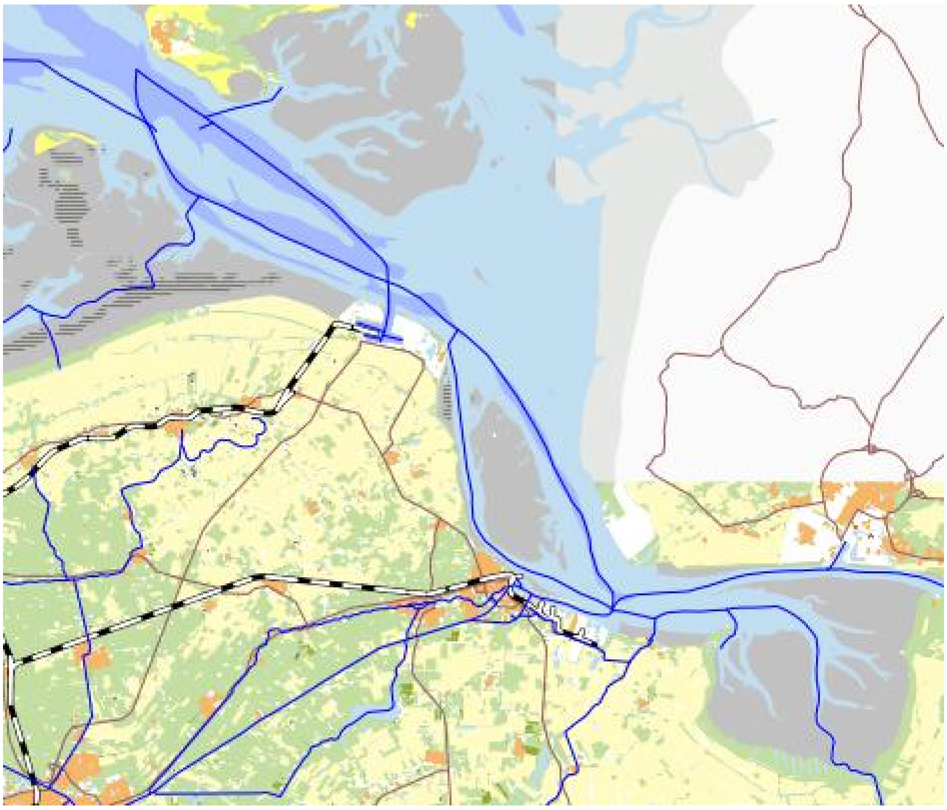


Figure 4.7. Cockle beds in the Dutch part of Ems-Dollard. Year unknown. Source: Watlas 2011.

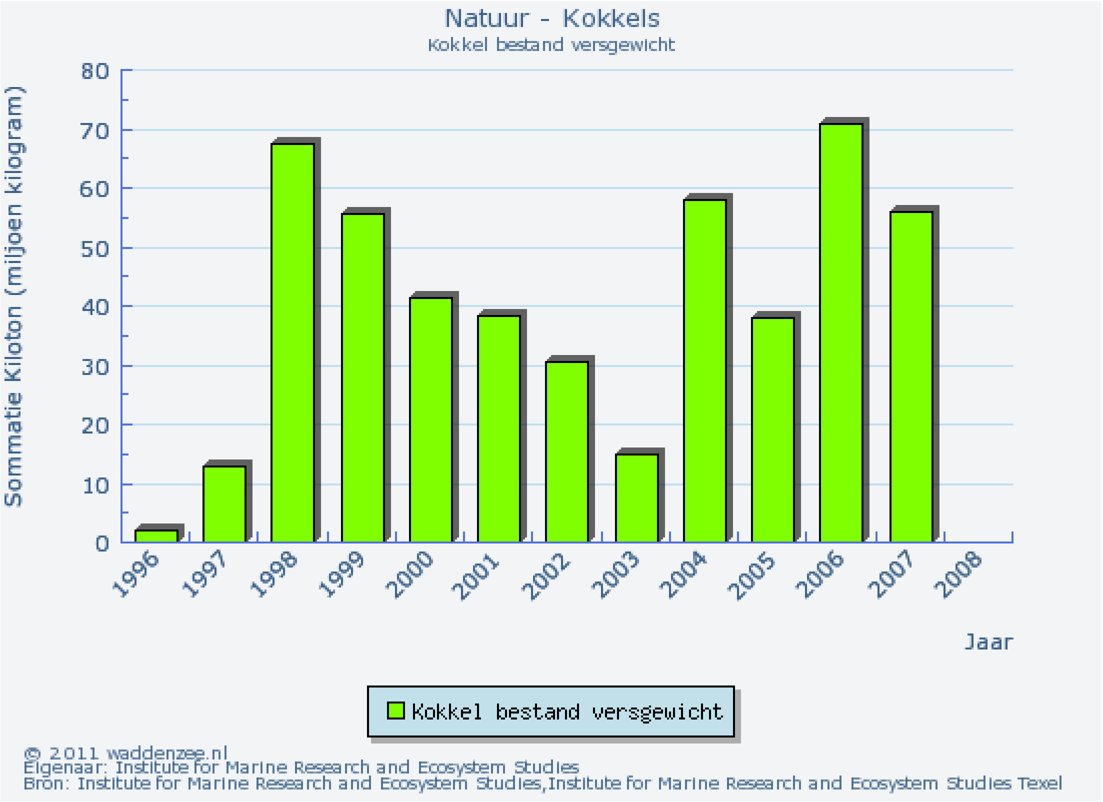


Figure 4.8. Cockle stock in the Dutch Wadden Sea, 1996-2008. Source: Watlas, 2011.

4.3.5 Lugworm

The information on the spatial occurrence of macrozoobenthos other than bivalves in the Ems-Dollard is rather limited, but the inventories that are performed twice a year by NIOZ (Dekker & Waasdorp, 2002) provide detailed information on three transects at the Heringsplaat (Dollard). Transect 1110 is the most Northern one, situated between -0.2 +0.6 m NAP, 1111 lies more to the South between -0.1 and +0.7 m and the southernmost transect 1112 has an elevation of +0.3 and +0.9m NAP. Compared to other sampling locations in the Wadden Sea, the sediment on these sites was rather fine, with a high mud and organic content: D_{50}=103-137 µm, mud (<16 µm) 4.79-8.65%, 0.59-1.07% organic material.

In general, they report average winter temperatures for 2001, a limited die-off of macrozoobenthos. Regarding the Dollard they report good breeding success of *Macoma balthica*, an increase of *Mya arenaria* biomass as a result of somatic growth, a slightly higher total winter biomass than the previous year and a 50% higher total biomass in summer.
In March/April 2001, Dekker & Waasdorp (2002) found hardly any lugworms on the Heringsplaat: none at 1110, and one at 1111 and 1112 in March-April, one at 1110 and 1111 vs. none at 1112 in August, with a biomass between 0.175 and 0.334 g/m^2. Other worms, especially *Nereis diversicolor* and *Marenzelleria wireni* were present in much higher numbers (161-718 ind./m^2) and biomass (0.719-3.039 g/m^2), especially in summer.

4.3.6 Mudshrimp

In March/April 2001, Dekker & Waasdorp (2002) found 5678 resp. 6000 ind./m^2 on the lowest transects (1110 and 1111) and 1778 ind./m^2 on the higher transect (1112). This corresponded to biomasses of 2.007, 3.449 and 1.276 g/m^2. In August, these numbers had increased to 18633, 11794 and 5933 ind./m^2, or 5.113, 3.548 and 2.434 g/m^2. In both seasons, *Corophium volutator* is one of the most abundant species (between 18-40% of total biomass). Other main contributors to total biomass are *Marenzelleria wireni, Nereis diversicolor, Macoma balthica* and *Mya arenaria*.

4.3.7 Sparling/Smelt

The spawning of *Osmerus eperlanus* in Ems-Dollard is initiated at temperatures between 4-9°C and extends from January/February to the end of March (Scholle et al., 2007; Jager & Bettels, 1999). Scholle et al. (2007) assessed the spatial and temporal distribution of smelt larvae in the lower Ems (upstream of Emden) between the end of April and mid- June 2007, using a Bongo-net. In the same year, the structure of the smelt stock were evaluated with anchor nets on ten locations (Fig. 4.9). Additionally, they interviewed five (out of nine) fishermen in the area.

No smelt larvae nor twaite shad (*Alosa fallax*) larvae were found; larvae of flounder (*Platichtys flesus;* mean 1.34 individuals per m^2), gobies (0.03 per m^2), herring (*Clupea harengus*) and sprat (*Sprattus sprattus;* 0.1 per m^2) as well as fresh water species were present. Adult smelt was present at Emden and the two stations closer to the coast (19-29 individuals per hour per 80 m^2), whereas juvenile smelt was also found upstream of Emden, albeit in small numbers (1-10 h^{-1}80m^{-2}). Smelt landings were very variable in between 1945 and 1990, but after 2000 the landings have dropped to just 1000 kg/year with minor interannual variability. The data of the Demersal Fish Study by Imares (Bolle et al., 2009) show more variability throughout the years (0.5-1.5 individuals per 1000 m^2), but it is uncertain how representative beam trawl data are for a pelagic fish species.

Hadderingh & Jager (2002) caught on average 15 individual smelts per 10 000 m^3 in 1992-1993 and 4.4 in 1996-1997 in the Doekegat channel, at flow velocities of 0.75-0.97 ms^{-1} using an anchornet between 10-14 m deep. Using a beam trawl at the same location, they found densities of 14.8 individuals per 15 000 m^2 in 1992-1993 and 6.9 in 1996-1997. For both methods the variation throughout the year was low, but only samples between October and April were taken.

The study of Kleef & Jager (2002) assessed the presence of diadromic species over the years 1999-2001 in the Groote Gat (Dollard) using standing nets (‘staande kuil’) and near Oterdum, using anchor nets. They found sparling and herring on all locations, in all samples.

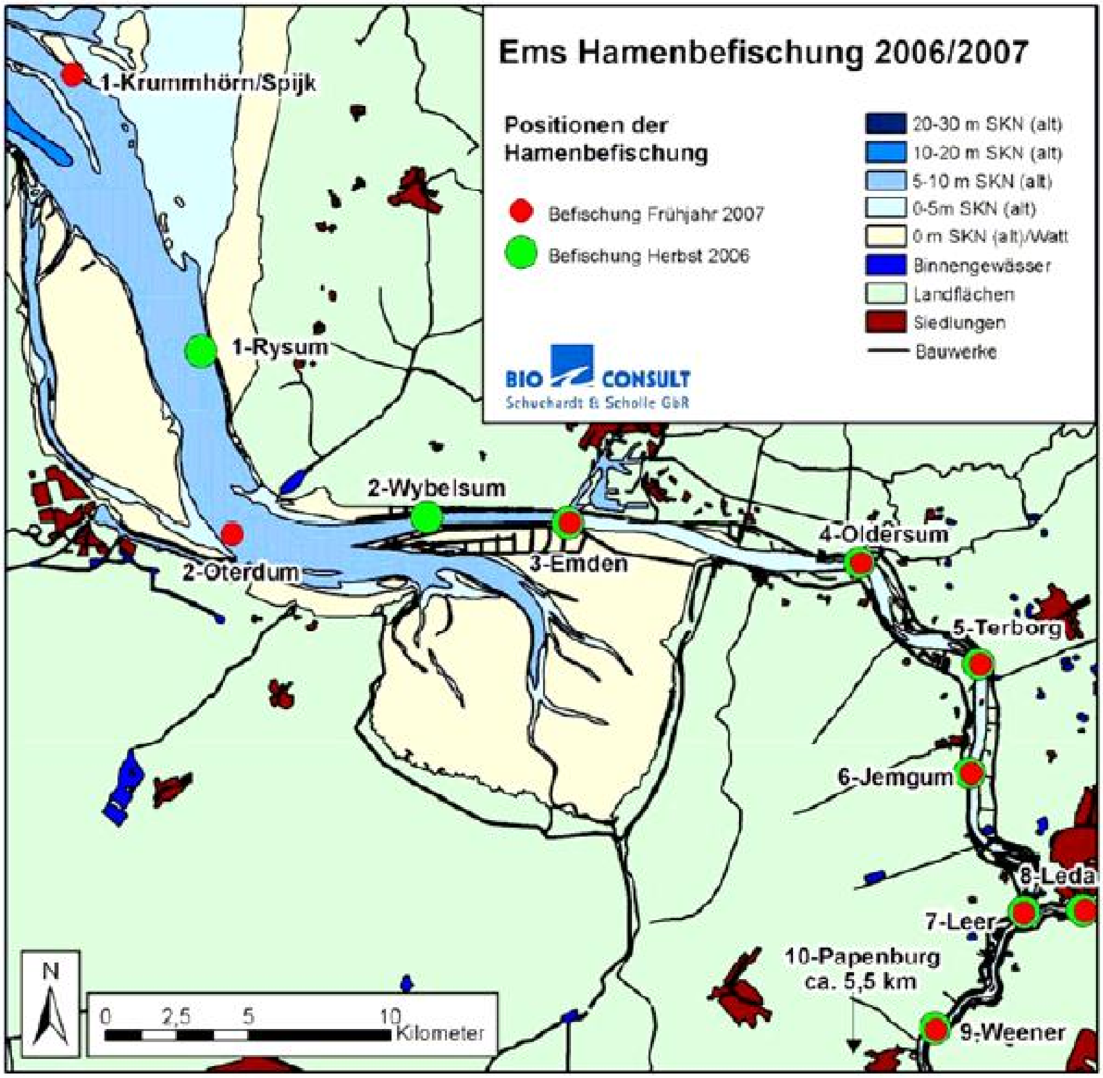


Figure 4.9 Sample sites for smelt study of Scholle et al. (2007).

4.3.8 Juvenile herring

The study of Hadderingh & Jager (2002) in Doekegat does not distinguish between the clupeid species *Clupea harengus* and *Sprattus sprattus* due to damaged specimen. They used an anchor net and a beam trawl. The densities in the two nets did not always correlate (Table 4.1).

Table 4.1 Clupeids reported by Hadderingh & Jager (2002)

	Unit	Oct 1992	Nov 1992	Feb 1993	Apr 1993	Nov 1996	Feb 1997	Mar 1997
Anchor net	per 10000 m^3	21.9	121.0	516.0	597.0	522.0	455.0	313.0
Beam trawl	per 15000 m^2	11.6	68.0	98.0	12.0	113.0	81.0	15.5

4.3.9 Avocet

The polder Breebaart is a very important nesting area for Avocets (*Recurvirostra avosetta*) since the partial opening of the polder to the tide in 2000 (Fig. 4.10). The numbers in 2004 (559) and later (143 in 2005) are lower than in 2003 as a result of predation and a decrease in food (*Nereis, Corophium*) availability (Willems et al. 2005), but the birds were not absent. In the Dutch Wadden Sea, the number of Avocets in 2001 was somewhat larger than in earlier years, but on a declining trend (Fig 4.11)

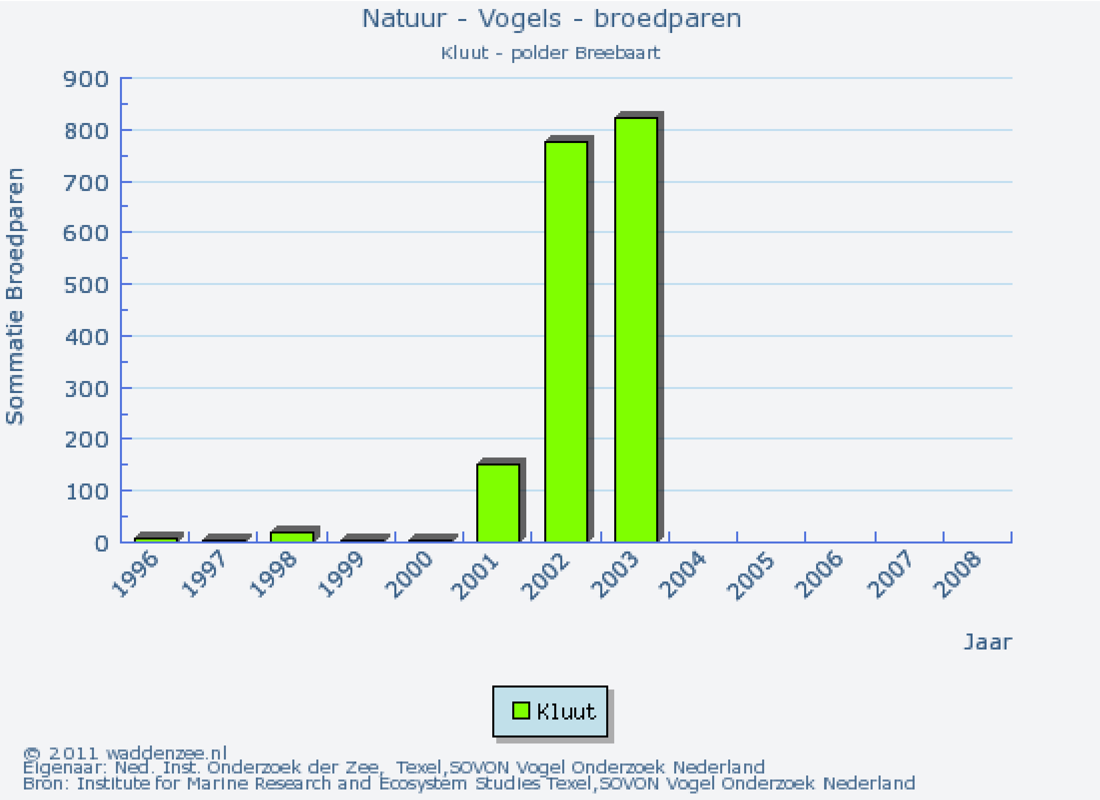


Figure 4.10 Number of Avocet breeding pairs at polder Breebaart between 1996-2008. Source: Watlas 2011.

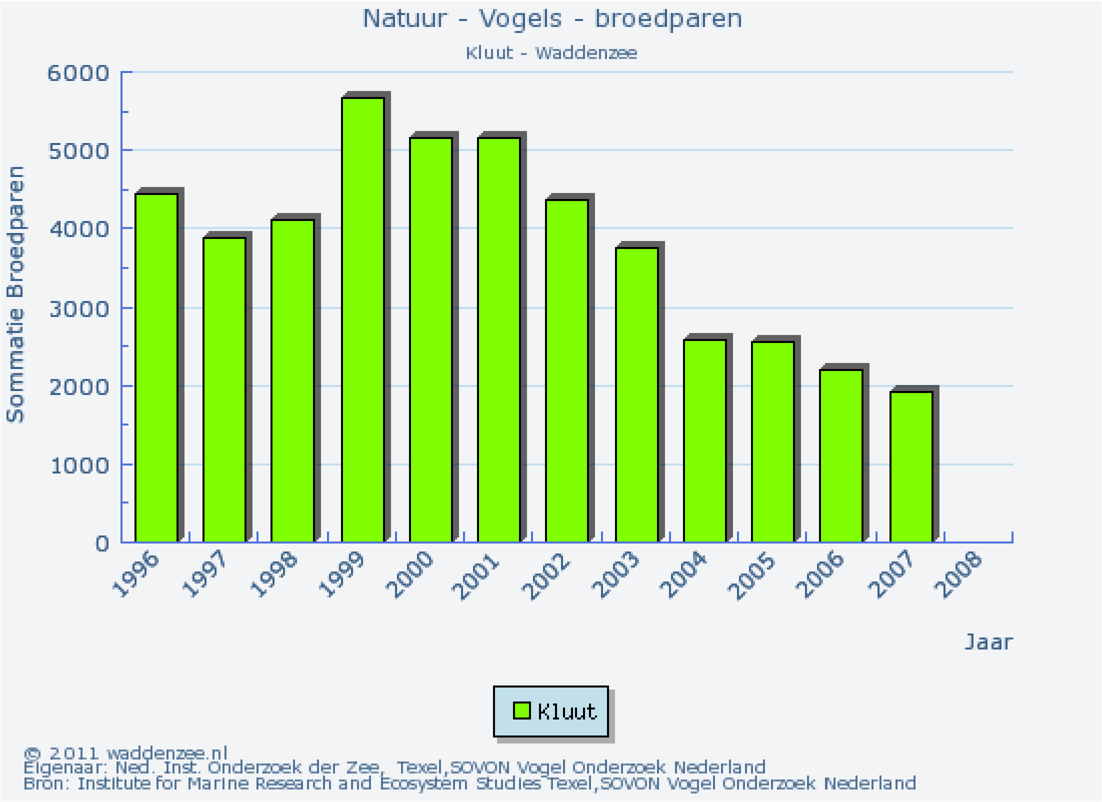


Figure 4.11 Number of Avocet breeding pairs in the Dutch Wadden Sea. Source: Watlas 2011.

4.3.10 Eurasian widgeon

The Eurasian widgeon mainly occurs in the Wadden Sea between September and March; it does not breed here. Most counts consider the Wadden Sea without the Ems-Dollard region. A specific study on birds on the Hond-Paap (De Boer et al., 2002), performed to assess the effects of construction works, provides detailed information on the spatial and temporal occurrence of *Anas Penelope* in this region. This study started in July 2002; the first birds were observed halfway August in small numbers (up to 150), whereas higher numbers (>1000) were found from the 2nd week of September to the end of the study in the first week of November. The highest densities were found along the coast of the Bocht van Watum and on the western part of the Paap; they were absent on the North part.

According to Laursen et al. (2010), the numbers of Eurasian widgeon in the Wadden Sea as a whole have been quite stable. Within Ems-Dollard, they distinguish three areas: the Dollard, the German part seaward of the Dollard, well past Borkum and the Dutch part, extending West of Rottumerplaat. For all these areas, the number of birds decreases from September to April. The highest numbers occur in the Dollard; around 8000 in September-November, 4000 from December to February and 2000 in March-April. In the Dutch Ems estuary, the numbers are lower: 3000, 2500 and 1000 in the respective periods. The German part has the lowest numbers, with just a couple of hundreds of birds in all periods.

4.3.11 Common tern

The harbour of Delfzijl is home to a large breeding colony of terns (934 pairs; Willems et al. 2005). Smaller colonies were found (in 2005) at Rottumerplaat (217), Eemshaven (31), polder Breebaart (10) and Punt van Reide (100). The locations in harbour areas are favourable due to the presence of fences that keep predators (foxes) away, but do have the risk of increased mortality of young birds due to collisions with cars. The number of birds throughout the Wadden Sea was quite stable during the study period (Figure 4.12). The South part of Hond-Paap and the cooling water outlet of the Eemscentrale are popular feeding areas for Terns according to the study of de Boer et al. (2002). Here, the highest numbers were observed in July and August; after September all Terns were absent.

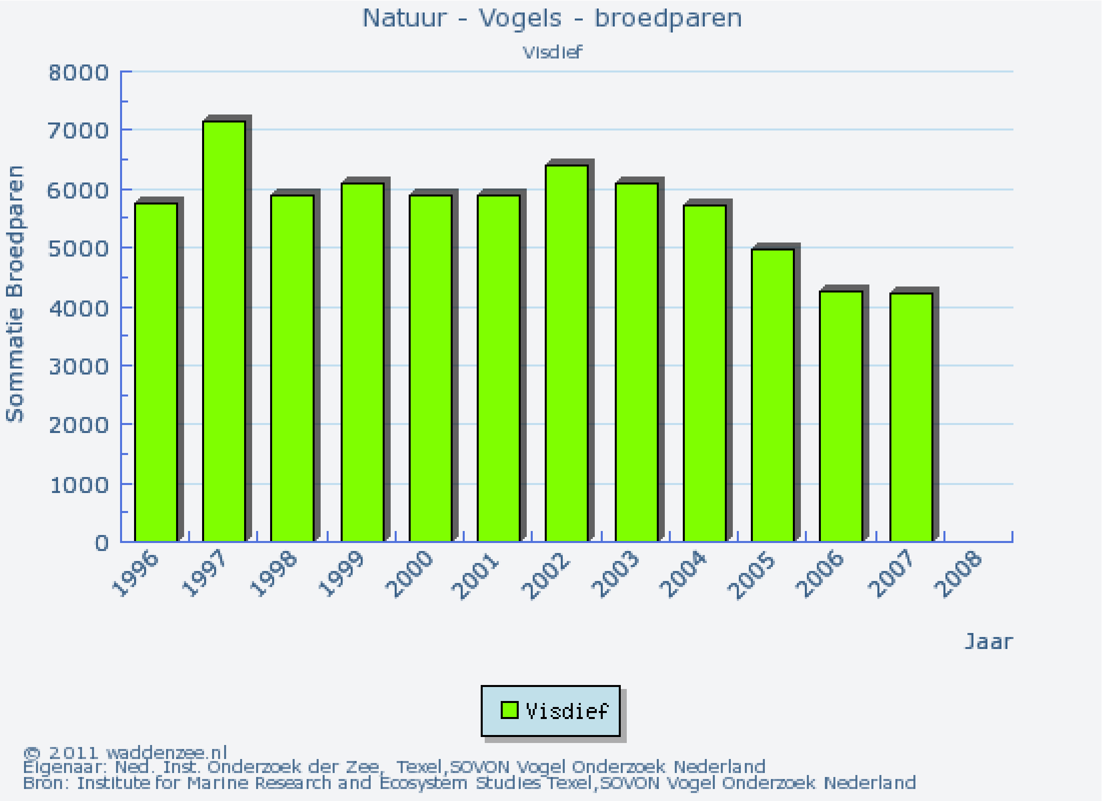


Figure 4.12 The number of Common Tern breeding pairs in the Dutch Wadden Sea. Source: Watlas 2011.

4.3.12 Red-breasted merganser

The red-breasted merganser (*Mergus serrator*) does not breed in the Wadden Sea, but occurs from October to April. Over the years 2000-2005, it occurred in relatively low numbers (1-10 per count) along the coastline seaward of Delfzijl (Fig. 4.13). No birds were reported in the Dollard, and no information was found on occurrence in Germany.

Figure 4.13 Average numbers of Red-breasted merganser per census (October to April, 2001-2005). Source: Sovon, via Rijkswaterstaat WD

4.3.13 Grey seal

No reports on systematic observations of the grey seal in Ems-Dollard were found. Reports on other mammals occasionally mention the presence of the grey seal in areas suitable to the common seal, as well as an increase in numbers since the beginning of the 21st century. The number of grey seals in the western Wadden Sea has increased steadily since the 1980's (~20% per year; Fig. 4.14), probably as a result of an influx from animals from the British isles. The grey seal was hardly affected by the phocine distemper virus outbreaks in 1988 and 2002. Grey seal pups are born in winter.

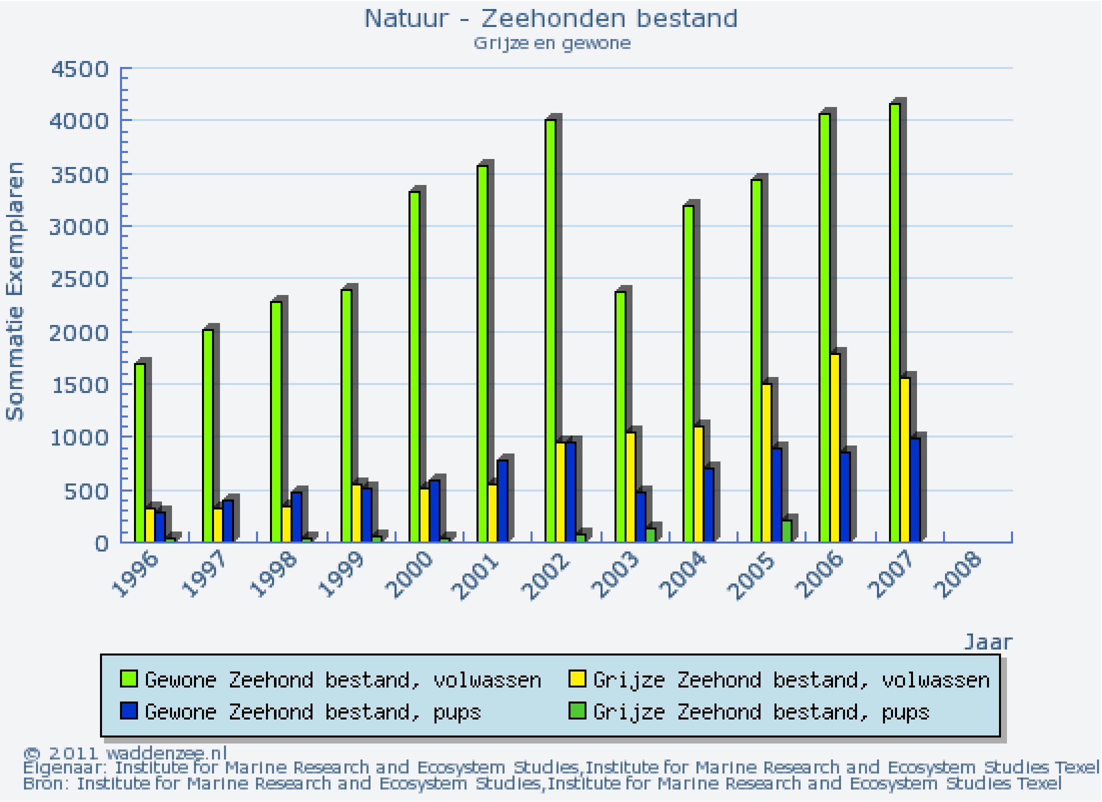


Figure 4.14. Common and grey seals (incl. pups) in the Dutch Wadden Sea, between 1996-2008. Source: Watlas 2011.

4.3.14 Common seal

Common seals in Ems-Dollard are systematically counted during low water by Imares five times a year (Figs. 4.15-4.17). The maximum numbers are observed in June/July, when pups are born, and in August, when the animals moult.

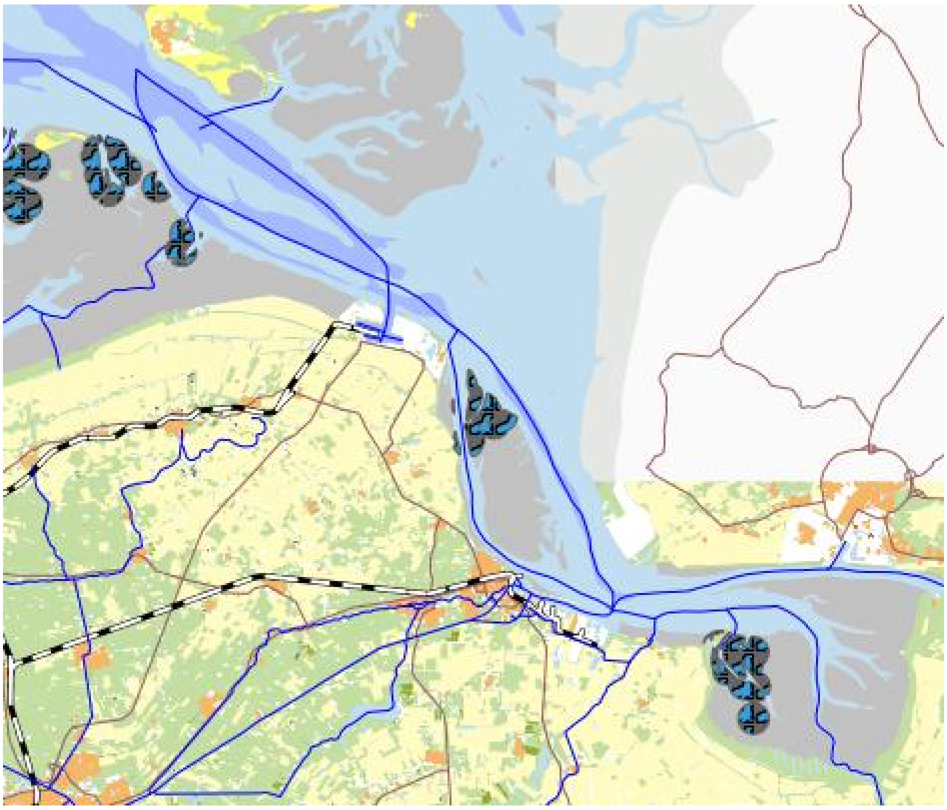


Figure 4.15. Resting places of the Common seal. Source: Watlas 2011.

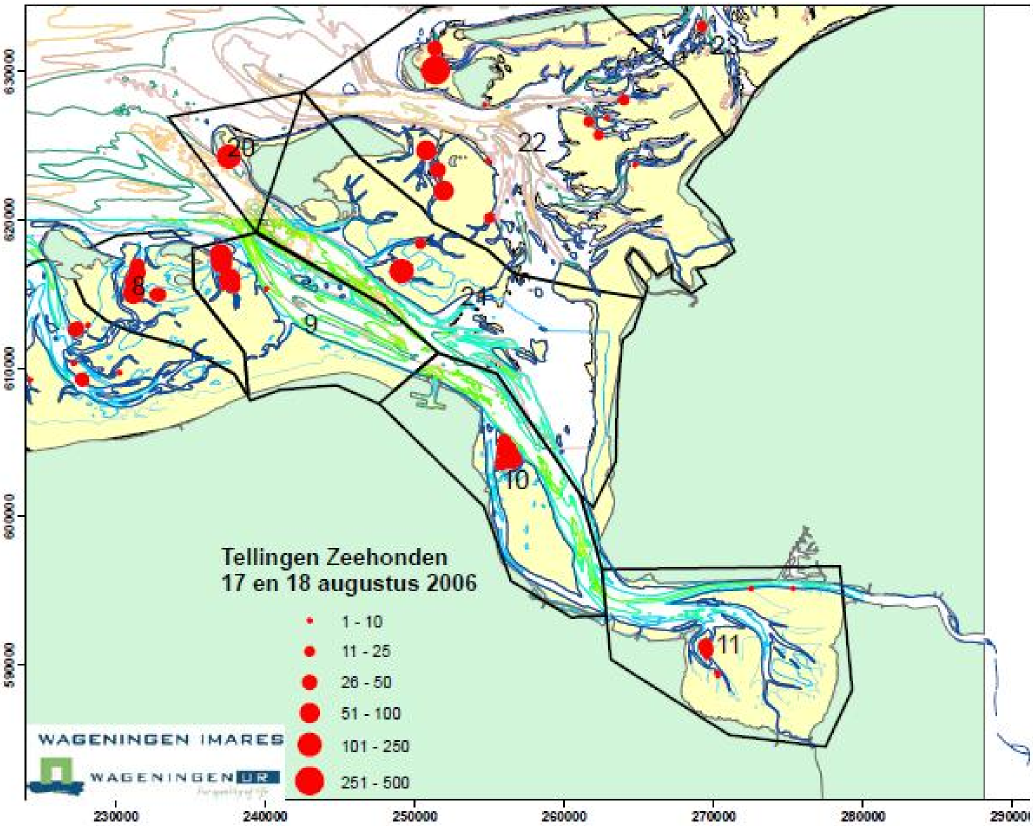


Figure 4.16. Spatial occurrence of the Common seal, August 17th and 18th 2006. Source: Brasseur, 2007.

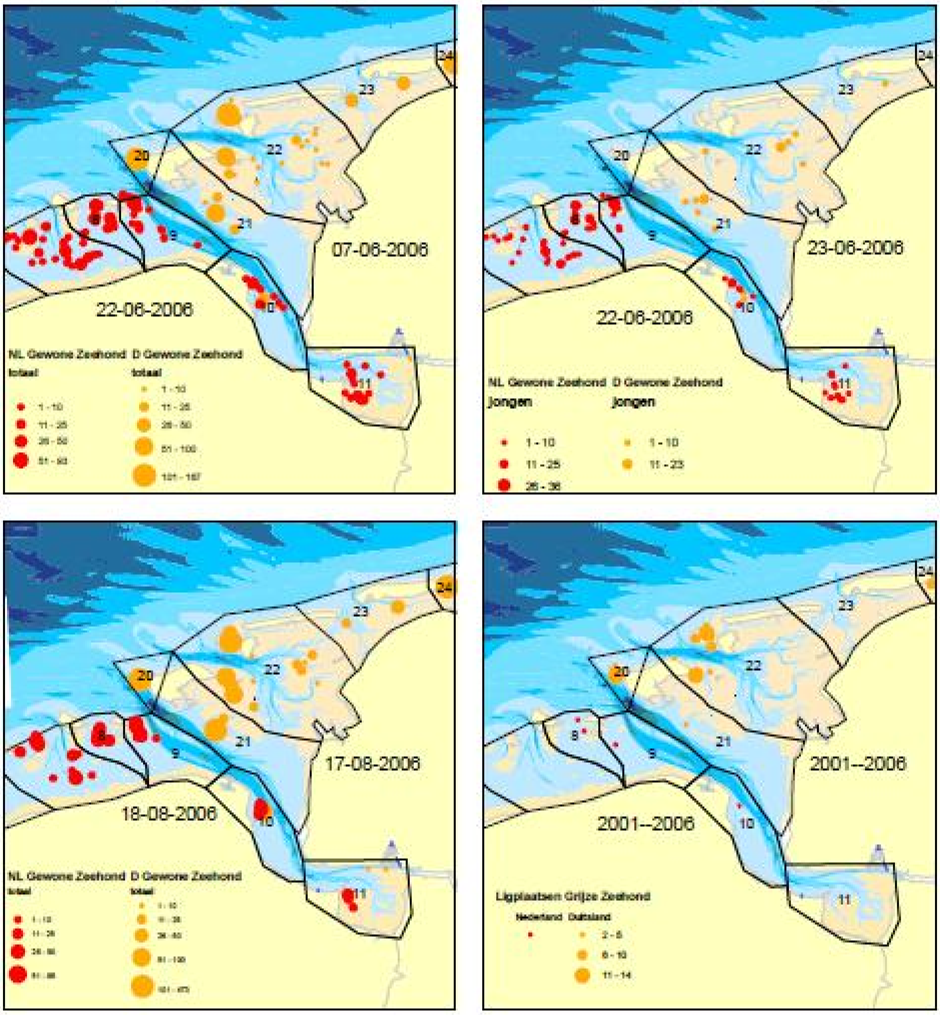


Figure 4.17. Occurrence of common and grey seals in the Ems-Dollard. Above, left: maximum numbers during birth. Above, right: pups. Below, left: during moulting. Below, right: grey seals. Soucre: Brasseur, 2007.

4.3.15 Porpoise

After a period of nearly complete absence in the seventies and eighties, the harbour porpoise returned to the Wadden Sea in the 1990's. This return partly coincides with a southward shift of the porpoise population in the North Sea (Brasseur, 2007; SCANS II, 2006). Around the year of interest (2001), there was no structural monitoring program for porpoise occurrence, therefore observations are incidental or part of other monitoring programs such as seabird counts. Since several years, a passive monitoring program exists that uses buoy-deployed acoustic sensors (so-called CPODS) to record 'clicks'. The incidental observations show a substantial increase in numbers since the beginning of this century (Figs. 4.18 and 4.19). During the year, the highest numbers of animals are observed during winter to early spring. In Ems-Dollard, the peak in observations seems to be about one month later (i.e., early April) than along the rest of the Dutch coast. German monitoring by aeroplane in April and May 2008 only showed porpoises at the seaside of the islands (Gilles & Siebert, 2008), whereas incidental observations between 2001-2008 reported the presence of porpoise in the shipping lane up to Emden and between Borkum and Juist (Nationalpark Wattenmeer, 2008).

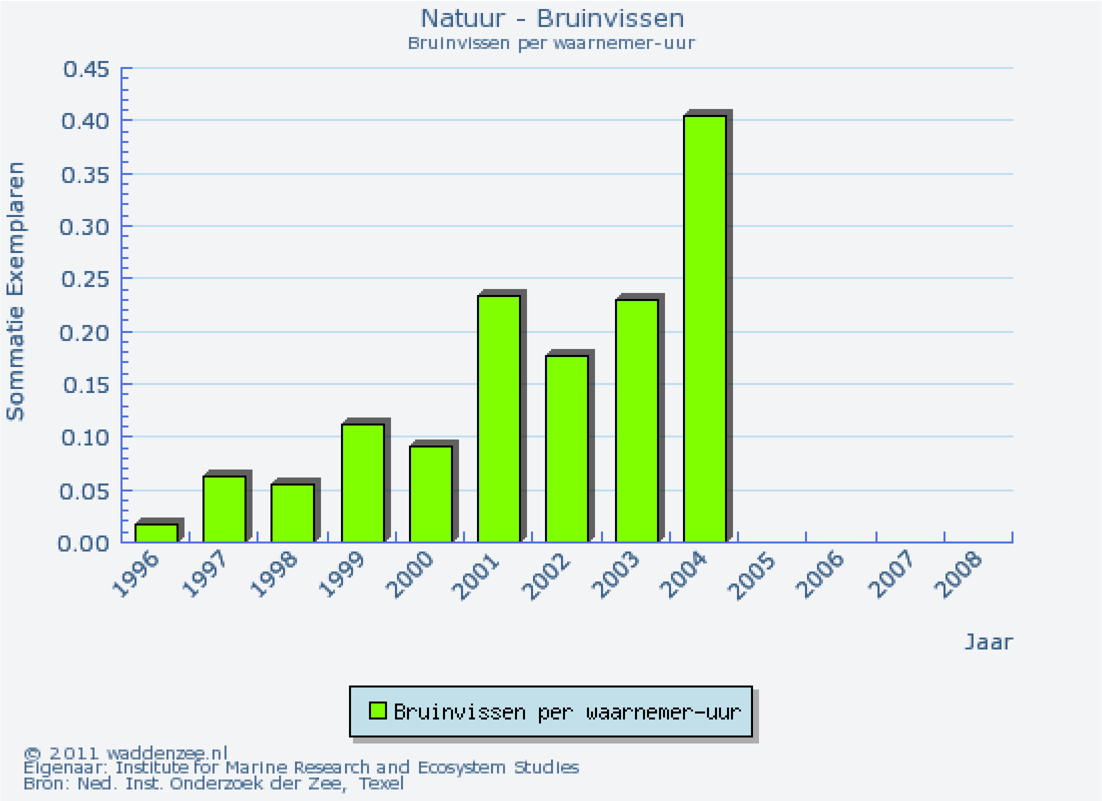
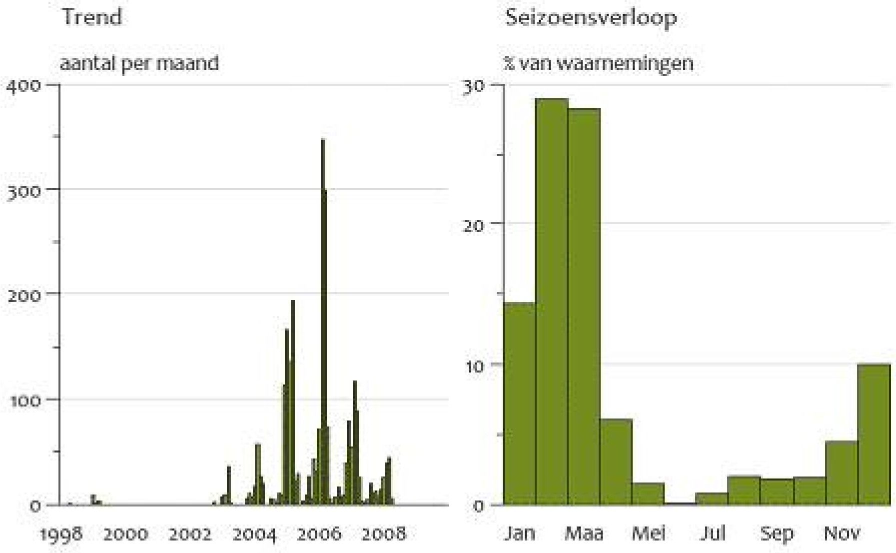


Figure 4.18. Porpoise observations along the Dutch coast 1996-2008. Source: Watlas 2011.



Figuur 2: De trend (aantal per maand) en seizoensverloop (% van het aantal waarnemingen) van bruinvissen in de Nederlandse kustwateren (
Bron: Trektellen.nl in PLB 2010

Figure 4.19. Incidental seasonal observations of porpoise along the Dutch coast. Source: PLB 2010, based on data from waarneming.nl

4.4 Habitat suitability determination

The Habitat Suitability Index (HSI) for each key species is determined using response curves and results of the hydro/morphodynamic- and water quality models. The response curves were predominantly discussed in last year's report (Dijkstra et al., 2011), and are not repeated here. Additional rules, for additional species such as juvenile herring, are discussed at the beginning of this year's section on ecology.

To represent the variation of environmental parameters throughout the year, four 'seasons' are used. Each of these seasons summarizes the conditions during two spring-neap cycles – i.e. one month: January corresponds to 'Winter', April to 'Spring', July to 'Summer' and October to 'Fall'. Depending on the parameter and the species of interest, the normative value is the average over this period, or an extreme (minimum or maximum) that occurred. Likewise, the normative value can be either a depth-averaged one, or one that occurs near the water surface or near the bed. Which values are used to determine the HSI is mentioned in the treatment of every species.

During this suitability assessment phase of this study, not all water quality results were considered to be correct yet. Similarly, not all response curves have been validated. Therefore, the HSI is not determined for every key species for every season: This would require 26 (key species and groups) times 4 (seasons) habitat suitability maps per area (3; a total of 312 maps). Instead, the effort is aimed towards validation of the response curves and parameter maps using the observations from the previous section. For the same reason, habitat suitability will be principally assessed for the seasons and areas for which validation data exists. In addition, for some species an entire year will be analyzed, to see how important variations throughout the year are.

All water quality data are based on the run 'ED_waq11_sub7benth_edit'. Given the results of the grid size sensitivity study in the previous year, a Habitat grid size of 50 by 50 m is used while Delwaq used an aggregation of 2 by 2 hydrodynamic cells. Per species, the relevant environmental parameters are listed, along with a specification of spatial and temporal averaging options that are also used in file-naming conventions. For the extraction of information from computational layers, 'BL' means bottom layer, 'SL' surface layer and 'DA' depth-averaged. 'WN' means winter, 'SP' signifies spring, 'SM' summer and 'FL' fall. The temporal averaging options are 'MN' for the minimum during the period of interest, 'MX' for the maximum and 'AV' for the average. In the filenames of habitat suitability per species, the initials of their scientific names are used as an identifier, i.e. 'ME' for *Mytilus edulis.*

The lines in italic are parameters that cannot be used yet; the reason for this is mentioned in the 'Remarks' column. Note that because of the missing and incorrect parameters, habitat suitability cannot be assessed realistically at the moment: in most cases the HSI will be overestimated. Instead, the results presented here aim to give an idea of variations between the three sub-areas of Dollard, Ems estuary and Outer area, between the seasons and between species.

4.4.1 Conditions in Dollard, Ems estuary and outer area in spring

To give an impression of how the physical conditions differ per study area, the six most common parameters are shown per area in Figures 4.20-4.22. All three figures have the same legend, but not the same spatial scale.

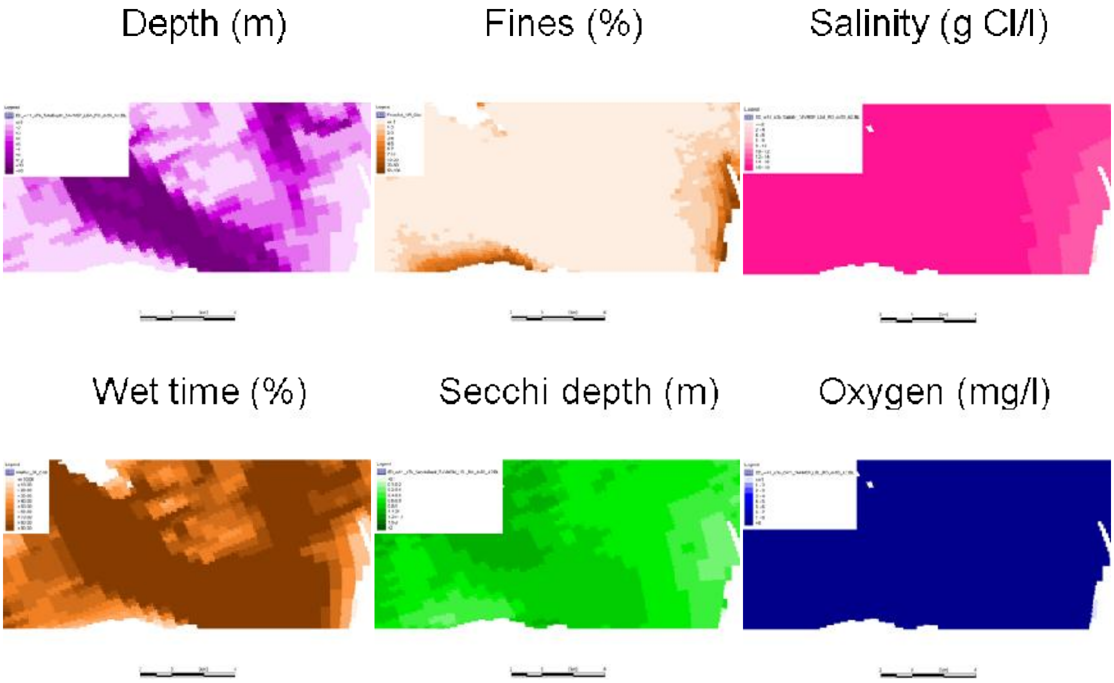


Figure 4.20. Environmental parameters in the Outer area during Spring 2001.

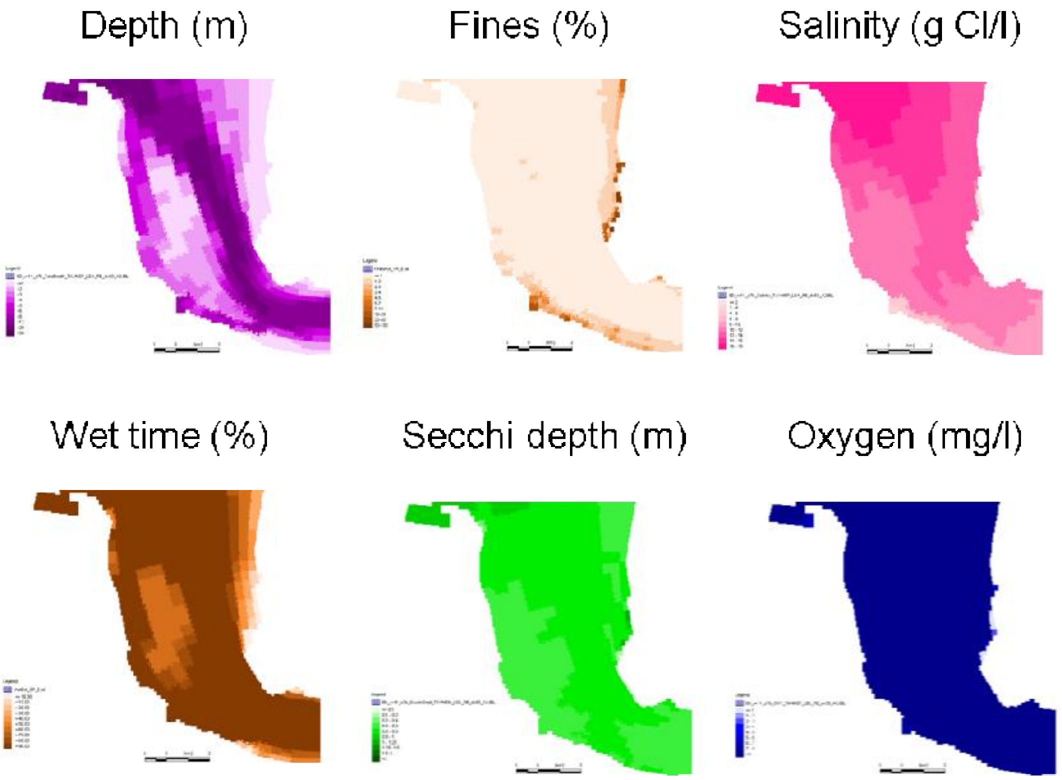


Figure 4.21. Environmental parameters in the Ems estuary during Spring 2001.

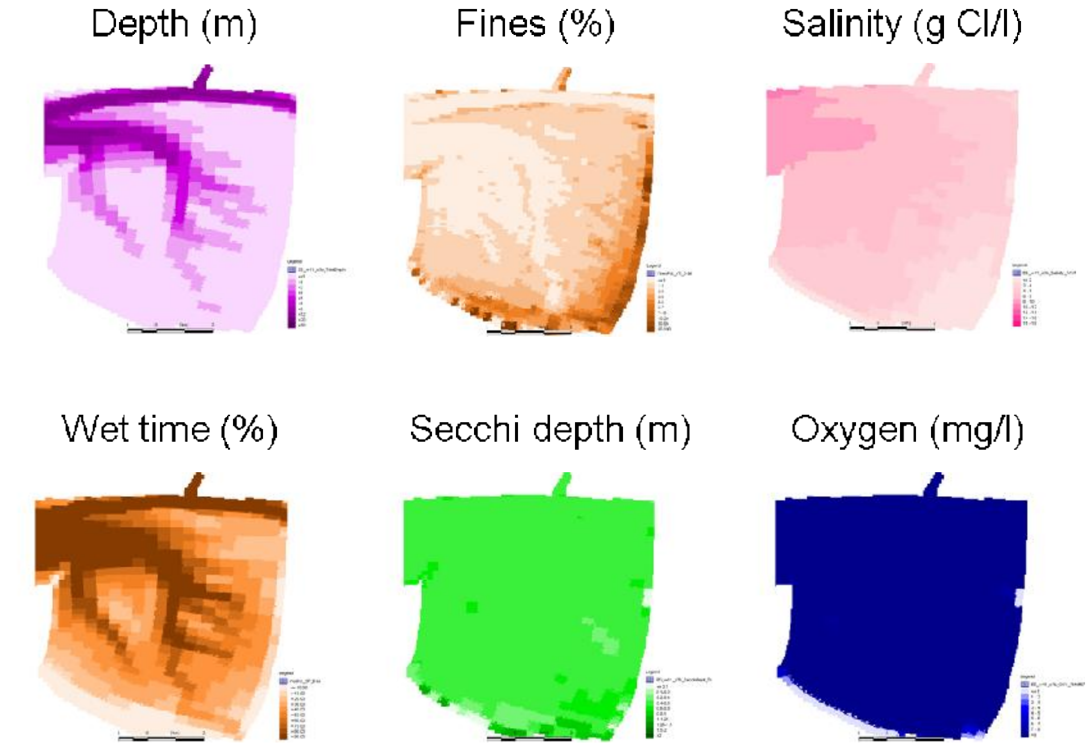


Figure 4.22. Environmental parameters in the Dollard during Spring 2001.

4.4.2 Determination of Habitat Suitability Index per species

Table 4.2 Parameterisation for suitability for Eelgrass (ZM)

Parameter	Layer	Season	Temporal	Remark
Salinity	AV	SP	AV	
Dry time	n.a.	SP	AV	
Flow velocity	*AV*	*SP*	*MX*	*(requires new input files)**
Fines in bed	Bed	SP	AV	

**Parameters that are just related to hydrodynamics and not to water quality are not passed on by the water quality model, which generates the input results for the Habitat model. Thus, hydrodynamic parameters require a different input file.*

Table 4.3 Parameterisation for suitability for salt marshes (H1330), pioneer zones (H1310) and Spartina swards (H1320)

Parameter	Layer	Season	Temporal	Remark
Salinity	AV	SP	AV	
Depth	n.a.	SP	AV, MN, MX	
Dynamics	*n.a*	*SP*	*MX*	*Requires definition of dynamics*

Table 4.4 Parameterisation for suitability for Blue mussel (ME)

Parameter	Layer	Season	Temporal	Remark
Oxygen	BL	SP	MN	
Salinity	AV	SP	AV	
Temperature	AV	SP	MX	Not used; irrelevant in spring
Depth	n.a.	SP	AV	
Wet time	n.a.	SP	AV	
Flow velocity	*AV*	*SP*	*MX*	*(requires new input files)*
Orbital velocity	*AV*	*SP*	*MX*	*(requires new input files)*

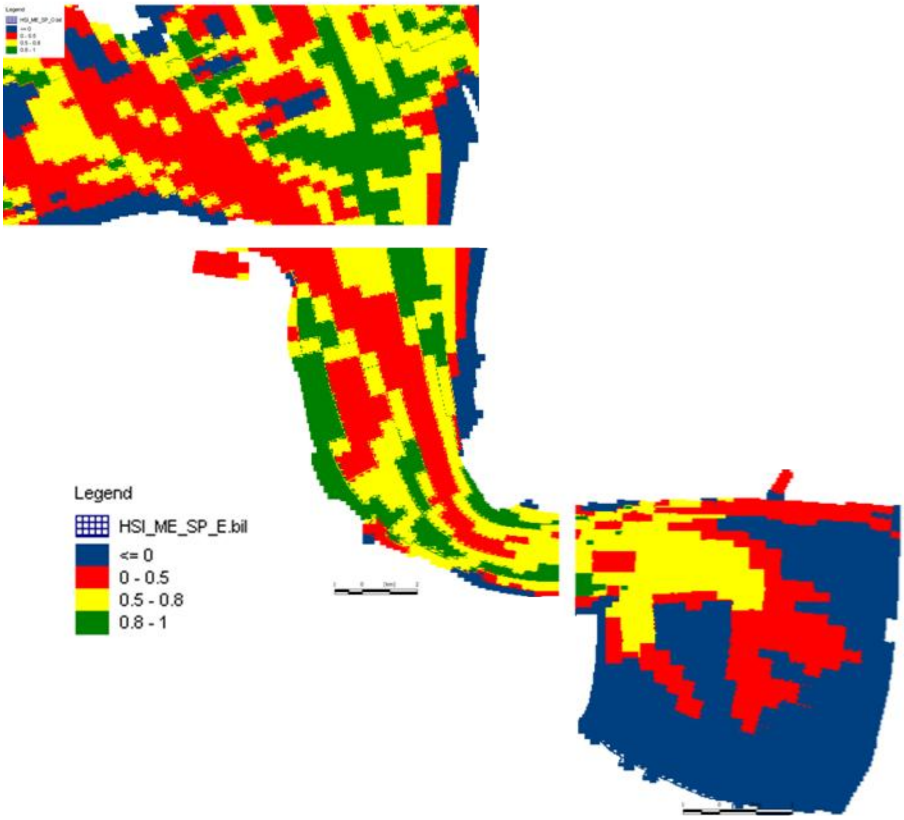


Figure 4.23. Habitat suitability index for Blue Mussel in all areas, Spring 2001. Flow dynamics not yet included. Blue (0) =unsuitable, red (0-0.5) =moderately suitable, yellow (0.5-0.8) =sufficiently suitable, green (0.8-1) =very suitable.

Table 4.5 Parameterisation for suitability for Cockle (CE)

Parameter	Layer	Season	Temporal	Remark
Oxygen	BL	SP	MN	
Salinity	AV	SP	AV	
Temperature	AV	SP	MX	Not used; irrelevant in spring
Depth	n.a.	SP	AV	
Dry time	n.a.	SP	AV	
Flow velocity	*AV*	*SP*	*MX*	*(requires new input files)*
Grain size	*Bed*	*SP*	*AV*	*(requires new input files)*
Sediment concentration	Bed	SP	AV	

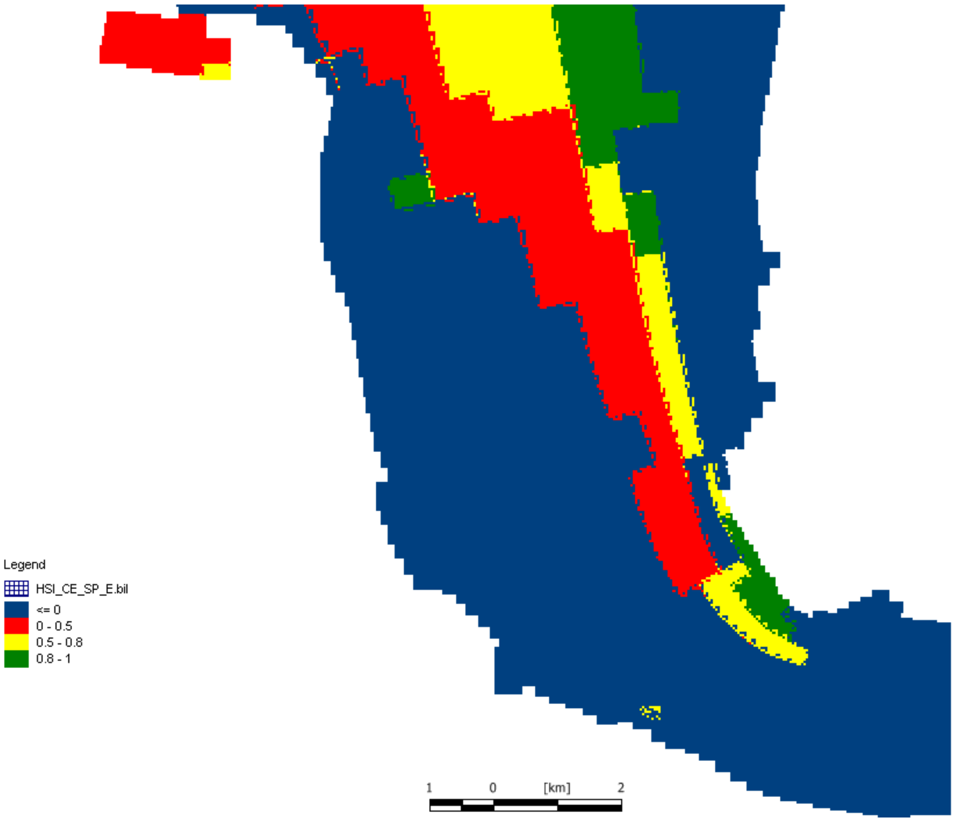


Figure 4.24. Habitat suitability index for Cockle in Ems estuary, Spring 2001. Flow velocity and grain size not yet included.

Table 4.6 Parameterisation for suitability for Lugworm (AM)

Parameter	Layer	Season	Temporal	Remark
Oxygen	BL	SP	MN	
Salinity	AV	SP	AV	
Temperature	AV	SP	MX	Not used; irrelevant in spring
Depth	n.a.	SP	AV	
Dry time	n.a.	SP	AV	
Fines in bed	n.a.	SP	AV	

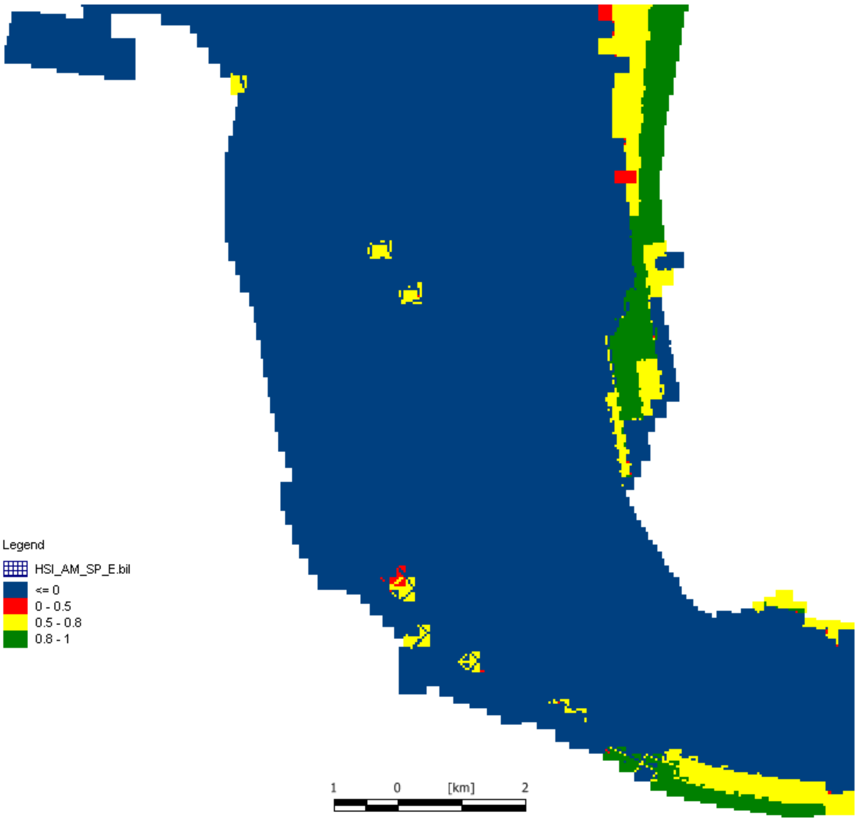


Figure 4.25. Habitat suitability index for Lugworm in Ems estuary, Spring 2001. Grain size not yet included.

Table 4.7 Parameterisation for suitability for Mudshrimp (CV)

Parameter	Layer	Season	Temporal	Remark
Salinity	AV	SP	AV	
Dry time	n.a.	SP	AV	
Phytoplankton	*n.a.*	*SP*	*AV*	*(requires good phytoplankton calculation)*

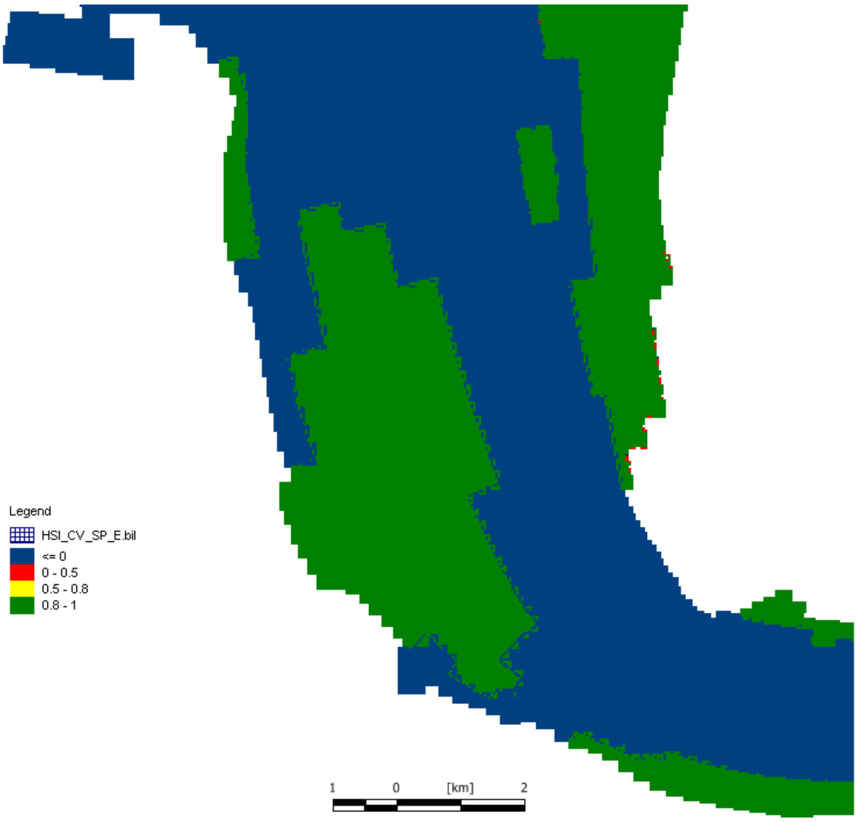


Figure 4.26. Habitat suitability index for Mudshrimp in Ems estuary, Spring 2001. Phytoplankton not yet included.

Table 4.8 Parameterisation for suitability for juvenile Herring (CH)

Parameter	Layer	Season	Temporal	Remark
Oxygen	BL	SP	MN	
Turbidity	AV	SP	AV	
Temperature	AV	SP	MX	Not used; irrelevant in spring
Depth	n.a.	SP	MN	

Table 4.9 Parameterisation for suitability for Sparling (OE)

Parameter	Layer	Season	Temporal	Remark
Oxygen	BL	SP	MN	
Turbidity	AV	SP	AV	
Temperature	AV	SP	MX	Not used; irrelevant in spring
Depth	n.a.	SP	MN	

Table 4.10 Parameterisation for suitability for Avocet (RA)

Parameter	Layer	Season	Temporal	Remark
Depth	n.a.	SP	AV	
Fines in bed	n.a.	SP	AV	
Food	*n.a.*	*SP*	*AV*	*Requires macrofauna abundance*

Table 4.11 Parameterisation for suitability for Eurasian widgeon (AP)

Parameter	Layer	Season	Temporal	Remark
Depth	n.a.	SP	AV	
Dynamics	*n.a.*	*SP*	*AV*	*Requires definition of dynamics*
Food	*n.a.*	*SP*	*AV*	*Requires macrophyte abundance*

Table 4.12 Parameterisation for suitability for Common tern (SH)

Parameter	Layer	Season	Temporal	Remark
Depth	n.a.	SP	AV	
Turbidity	SL	SP	AV	
Flow velocity	*AV*	*SP*	*AV*	*(requires new input files)*
Colony distance	*n.a.*	*n.a.*		*Requires locations of colonies*

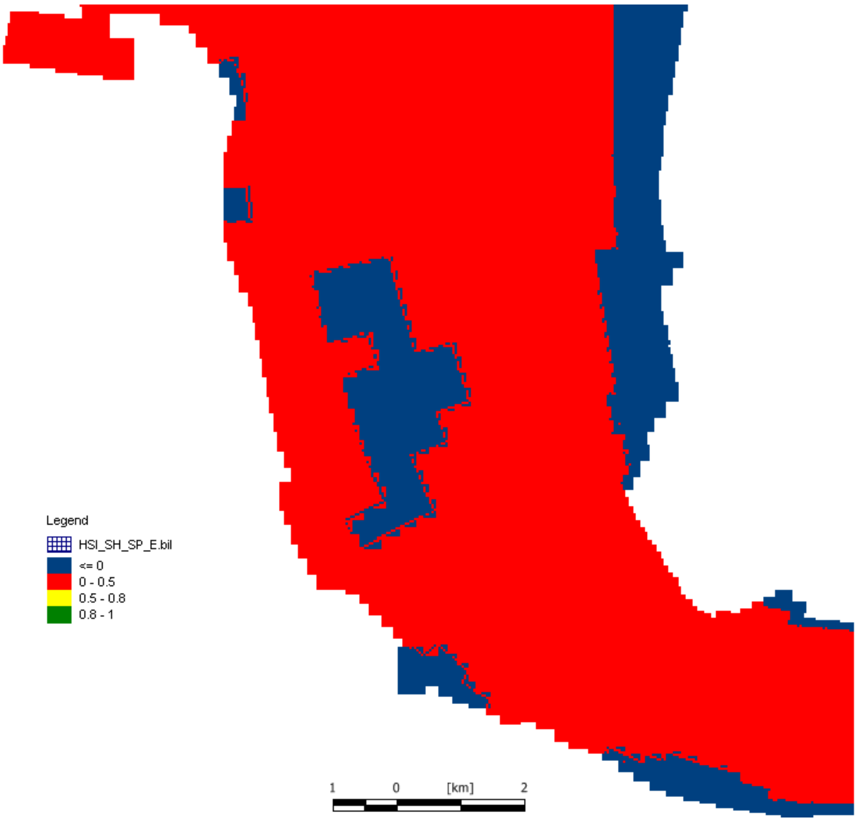


Figure 4.27. Habitat suitability index for Common Tern in Ems estuary, Spring 2001. Flow velocity and distance to colony not yet included.

Table 4.13 Parameterisation for suitability for Red-breasted merganser (MS)

Parameter	Layer	Season	Temporal	Remark
Depth	n.a.	SP	AV	
Turbidity	SL	SP	AV	

Table 4.14 Parameterisation for suitability for Common seal (PV)

Parameter	Layer	Season	Temporal	Remark
Depth	n.a.	SP	AV	Birth early summer, moult early fall
Shipping distance	*n.a.*	*n.a.*	*n.a.*	*Requires distance calculation*
Resting area	*n.a*	*n.a.*	*n.a.*	*Requires substrate of area*

Table 4.15 Parameterisation for suitability for Grey seal (HG)

Parameter	Layer	Season	Temporal	Remark
Depth	n.a.	SP	AV	Birth December
Shipping distance	*n.a.*	*n.a.*	*n.a.*	*Requires distance calculation*
Resting area	*n.a*	*n.a.*	*n.a.*	*Requires substrate of area*

Table 4.16 Parameterisation for suitability for Porpoise (PP)

Parameter	Layer	Season	Temporal	Remark
Depth	n.a.	SP	AV	
Temperature	AV	SP	AV	

4.5 Discussion and possible improvements

The bed topography or depth is taken from the aggregated DelWaq water quality results, thereby giving a very coarse picture. Where possible, the finer resolution of the sediment model should be used, also for other parameters like sediment composition and flow velocity.

Some parameters still require quantification: ‘dynamics’ for salt marshes and other vegetation, and distances to shipping lanes or colonies.

Most parameters vary little throughout the year; only temperature and turbidity show substantial fluctuations.

An elaborate treatise per species, containing a comparison with measurements, an analysis of limiting factors and a discussion of model performance will follow in 2012. To limit the amount of data presented to the reader, the representation of habitat suitability will be limited to one map per species for the entire year, unless crucial differences per season are found. More information will be presented in tables, and the colours of the HSI-maps will be changed to an easier-to-understand colour scheme.

Not every scenario will be assessed for Habitat suitability in 2012: Since the dumping location P5 or P6 does not make much difference to the distribution of sediment after a couple of days, only P5 will be studied. The different dumping periods can be very relevant for ecology, so these will be compared. The effect of a 30x bed buffer capacity, i.e. a reduction of sediment concentration, may be better assessed by implying a reduced turbidity.

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A List of processes

List of processes used in the current Delft3D-WAQ model

Technical identification	Description
BLOOM_P	BLOOM II algae module
WM_DetC	Mineralisation detritus carbon
SedDetC	Sedimentation detritus carbon
Res_DetC	Resuspension detritus carbon
Secchi	Extinction of visible-light (370-680nm)
BMS1_DetC	Mineralisation detritus carbon in sediment S1
SedPhBlo_P	Sum sedimentation of algae - Bloom
BurS1_DetC	Burial detritus carbon from sediment S1
WM_DetN	Mineralisation detritus nitrogen
SedN_Det	Sedim. nutrients in detritus
ResN_Det	Resuspension nutrients in detritus
BMS1_DetN	Mineralisation detritus nitrogen in sediment S1
BurS1N_Det	Burial nutrients in detritus from sediment S1
WM_DetP	Mineralisation detritus phosphorus
BMS1_DetP	Mineralisation detritus phosphorus in sediment S1
WM_DetSi	Mineralisation detritus silicium
BMS1_DetSi	Mineralisation detritus silica in sediment S1
Nitrif_NH4	Nitrification of ammonium
DenSed_NO3	Denitrification in sediment
DenWat_NO3	Denitrification in water column
AdsPO4AAP	Ad(De)Sorption ortho phosphorus to inorg. matter
SEDALG	Sedimentation of algae species
RearOXY	Reaeration of oxygen
BODCOD	Mineralisation BOD and COD
PosOXY	Positive oxygen concentration
Chloride	calculation of chloride from salinity
Extinc_VL	Extinction of visible-light (370-680nm)
EXTINABVLP	Extinction of light by algae (Bloom)
CalcRad	Radiation at segment upper and lower boundaries
DynDepth	dynamic calculation of the depth
DepAve	Average depth for Bloom step
Daylength	Daylength calculation
vtrans	vertical mixing distribution over a period
VertDisp	vertical dispersion
Res_DM	Resuspension total bottom material (dry mass)
S1_Comp	Composition sediment layer S1
Bur_DM	Burial total bottom mass (dry matter)
Veloc	horizontal flow velocity
SaturOXY	Saturation concentration oxygen
TotDepth	depth water column
POC_Dyn	Composition of POC (Dynamo & Bloom)
ExtPODVL	Extinction of light by POC (Dynamo & Bloom)
Sum_Sedim	Total of all sedimenting substances
Sed_IM1	Sedimentation IM1
SedPODyn	Sum sedimentation of POC (Dynamo & Bloom)
CalVS_IM1	Sedimentation velocity IM1 = f (Temp SS Sal)
Compos	Composition
CalVS_DetC	CalVS_DetC
CalVSAlg	generic for all algae

SedAlg	sedimentation of all algae
AtmDep NH4	Atmospheric deposition of NH4
AtmDep NO3	Atmospheric deposition of NO3
Grd_Rho	Calculation of gradient in space of density
Grd_Vel	Calculation of gradient in space of horizontal velocity
CalVSDIN_E	CalVSDIN_E
CalVSDIN_N	CalVSDIN_N
CalVSDIN_P	CalVSDIN_P
CalVSMDI_E	CalVSMDI_E
CalVSMDI_N	CalVSMDI_N
CalVSMDI_P	CalVSMDI_P
CalVSMFL_E	CalVSMFL_E
CalVSMFL_N	CalVSMFL_N
CalVSMFL_P	CalVSMFL_P
CalVSPHA_E	CalVSPHA_E
CalVSPHA_N	CalVSPHA_N
CalVSPHA_P	CalVSPHA_P
EXTINABVL	EXTINABVL
SEDDIN_E	SEDDIN_E
SEDDIN_N	SEDDIN_N
SEDDIN_P	SEDDIN_P
SEDMDI_E	SEDMDI_E
SEDMDI_N	SEDMDI_N
SEDMDI_P	SEDMDI_P
SEDMFL_E	SEDMFL_E
SEDMFL_N	SEDMFL_N
SEDMFL_P	SEDMFL_P
SEDPHA_E	SEDPHA_E
SEDPHA_N	SEDPHA_N
SEDPHA_P	SEDPHA_P