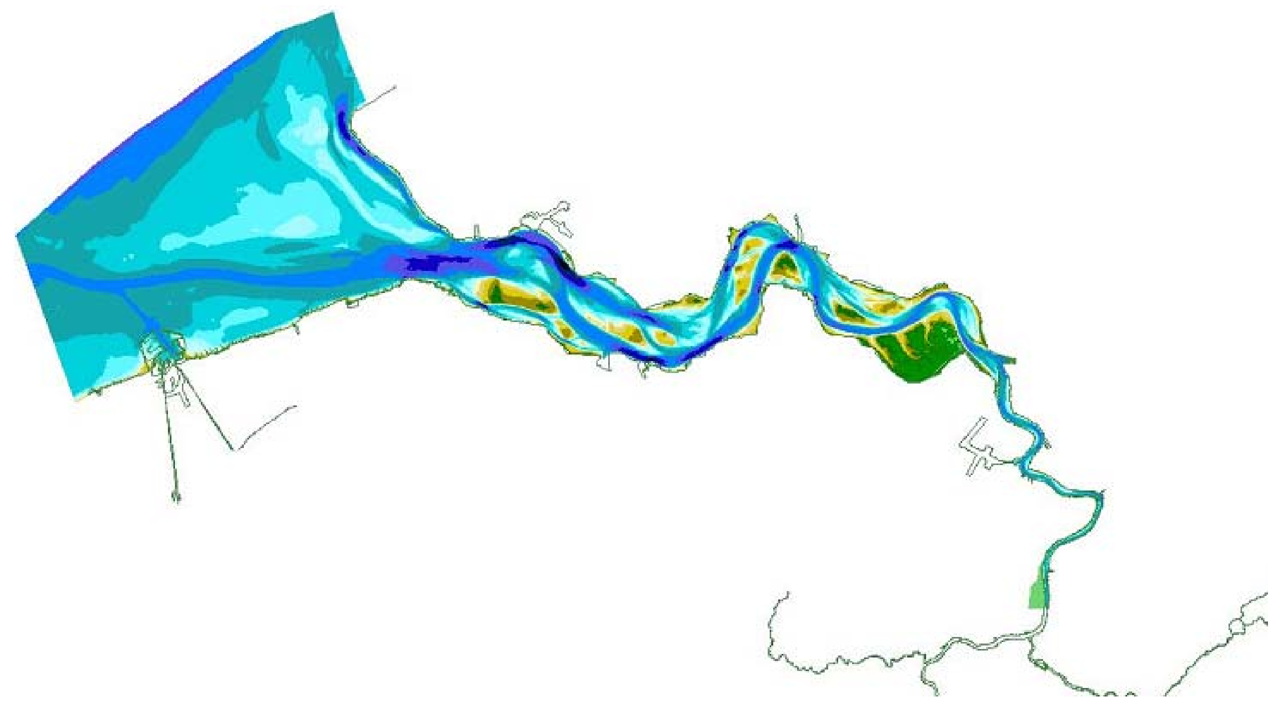
Vlaamse Overheid
Departement Mobiliteit en Openbare Werken
Afdeling Waterbouwkundig Laboratorium

LTV O&M Actieplan 2004 voor morfologisch onderzoek, Modelinstrumentarium MIKE11

Bestek nr.16EB/04/16

Scheldt estuary



Report 1: hydrodynamic model

June 2006

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1. INTRODUCTION

The MER commission "*Strategische milieueffectrapport ontwikkelingsschets 2010 Schelde-estuarium",* has recommended the development of a set of operational morphological models in order to provide technical assessment during the deepening of the Western Scheldt. Based on this recommendation, the Technical Scheldt Commission (TSC) has established an action plan for the morphological modelling of the Western Scheldt.

As part of the Dutch and Flemish Long Term Vision project, and within this "action plan 2004 for morphological research", it was concluded that the current set of models could no longer consist only of Delft- 3D and therefore should be extended. IMDC was invited to present an offer in order to develop a morphological model of the Western Scheldt and Lower Sea Scheldt based in the existing MIKE 11 SIGMA-model.

The terms of reference for this study were prepared by the "Administratie Waterwegen en Zeewezen, Afdeling Waterbouwkundig Laboratorium en Hydrologisch Onderzoek" (16EB/04/16).

1.1. Objective of the study

The objective of the present study is to transform the existing MIKE 11 1D model of the Western Scheldt and Sea Scheldt, built as part of the "actualization of the SIGMA Plan", into a 1D morphological model comparable to the SOBEK model developed by WL/Delft Hydraulics. This 1D model should be able to perform morphological simulations in order to evaluate different scenarios for the deepening of the navigation channel to the port of Antwerp.

To achieve this goal the existing MIKE 11 1D hydrodynamic numerical model has first to be adapted. This modified 1D model should be able to reproduce the water levels and discharges along the estuary, as well as the distribution patterns of the discharges in such a way that the residual discharges along the different branches (ebb and flood channels) are properly reproduced.

1.2. Overview of the study

The present report is the first of two reports describing the results of the study:

- Report 1: Hydrodynamic model (I/RA/11278/06.014/FPE).
- Report 2: Morphological model (I/RA/11278/06.015/FPE).

1.3. Structure of the report

This report gives a general description of the development of the 1D hydrodynamic model of the tidal reach of the Scheldt, from Ghent to the mouth in the North Sea. The report is divided into 5 sections:

Section 2 presents a general characterization of the study area, and in addition a short description of the available data for the development of the numerical model is given. A description of the hydrodynamic model is given in section 3, and in section 4 the results of the calibration are presented.

Section 5 shows the results of simulations performed to evaluate the effects of the new schematization compared to the original SIGMA model. Finally, in section 6 the general conclusions and recommendations are presented.

2. THE SCHELDT ESTUARY

2.1. General description

The Scheldt originates in the north of France near Saint-Quentin at an altitude of 100 m above sea level and discharges into the North Sea approximately 350 km downstream. During its trajectory, the Scheldt receives different names:

- Upper Scheldt, from its origin down to Ghent.
- Sea Scheldt, from Ghent to the Dutch border.
- Western Scheldt, from the Belgian/Dutch border to the mouth in the North Sea.

The Upper Scheldt is a non-tidal river connected to the Sea Scheldt by means of the control structures of Zwijnarde and Merelbeke, which avoid the tidal waves to propagate up-stream and at the same time regulate the water levels in the ring-channel around Ghent.

The Sea Scheldt and Western Scheldt form together the Scheldt estuary, which constitutes the study area of the present project. Along the estuary 4 zones are distinguished for their geometry as well as for the local physical processes (De Kramer, 2002):

- The Upper-Sea Scheldt, which corresponds to the reach between Ghent and the Rupel: In this reach the tidal effects are still noticeable but the influence of upstream discharges dominates the behavior of the river. The width of the estuary increases from 50 m in Ghent to 300 m at the confluence with the Rupel. This fresh water reach receives most of the major tributaries of the Scheldt in the study area.
- The so-called Lower-Sea Scheldt, which stretches from the confluence with the Rupel to the Belgian/Dutch border: In this zone, the width of the estuary increases to nearly 2 km. This reach constitutes a transition area from slightly to highly brackish water.
- The Western Scheldt: This reach has a funnel shape, the width of which increases from 2 km at the border to over 5 km at the mouth in the North Sea. The salt concentration increases in the direction of the sea.
- Finally the mouth area in the North Sea corresponds to the delta-area situated between Vlissingen and Westkapelle, Zeebrugge/Oostende.

The most important area related to morphological changes is the Western Scheldt, which can be described as a typical multiple flood and ebb channel network. The ebb channels are deeper and have a sill at the seaward end where they join the flood channels. The flood channels are shallower and have a sill at the landward side (Peters, 2004).

2.2. Water levels

The tide is the driving force behind all the dynamics in the estuary, and determines the high and low waters. Semidiurnal and fortnightly tidal cycles play the most important role in the hydrodynamic condition, the water quality and the morphological processes. During the fortnightly neap-spring cycle the tidal prism varies considerably.

In order to calibrate the, model measured time series for different stations have been used. Most of the time series were already available as part of the "actualization of the SIGMA Plan". Within that project time series have been received, for the period from 1986 to 2002, with a time step of 10 minutes and from most of the tidal gages. For the period before 1986, time series of high water and low water were also available for the following tidal-stations:

- Vlissingen, from 1931.
- Prosperpolder, from 1971.
- Antwerp, from 1971.
- Dendermonde, from 1971.

Rijkwaterstaat (RIKZ) provided the time series from the Netherlands and the time series from Belgium were provided by AWZ. Figure 2 shows the location of the available stations. For the morphological simulations a neap-spring tide cycle of September 2002 will be applied. These time series were provided by WL/Delft Hydraulics, and correspond to the generated water levels with a DELFT 3D simulation for the boundary points of the SOBEK model.

As can be observed in Table 1, the tidal range varies from location to location: from a mean tidal range of 3.8 m at Vlissingen, to 5.2 m at Antwerp and 4 m at Ghent. Therefore, the estuary can be classified as meso-tidal to macro-tidal. A very important characteristic is the asymmetry of the vertical tide, and therefore higher flow velocities are observed during flood than during ebb.

Table 1: General tidal characteristics, SIGMA IMDC 2003

	Vlissingen	Prosperpolder	Antwerp	Dendermonde
Average values				
Avg. HW [m TAW]	4.35	5.03	5.24	5.2
Avg. LW [m TAW]	0.55	0.09	0.05	1.24
Avg. tidal range [m]	3.80	4.94	5.19	3.96
Avg. duration Flood (h:mm)	5:57	5:41	5:22	4:48
Avg. duration Ebb (h:mm)	6:28	6:45	7:03	7:37
Average values for spring tide				
Avg. HW [m TAW]	4.77	5.5	5.7	5.53
Avg. LW [m TAW]	0.31	-0.14	-0.17	1.29
Avg. tidal range [m]	4.46	5.64	5.87	4.24
Avg. duration Flood (h:mm)	5:52	5:27	5:00	4:40
Avg. duration Ebb (h:mm)	6:28	6:53	7:20	7:40
Average values for neap tide				
Avg. HW [m TAW]	3.84	4.45	4.69	4.78

	Vlissingen	Prosperpolder	Antwerp	Dendermonde
Avg. LW [m TAW]	0.87	0.43	0.38	1.23
Avg. tidal range [m]	2.97	4.02	4.31	3.55
Avg. duration Flood (h:mm)	6:08	6:03	5:54	5:05
Avg. duration Ebb (h:mm)	6:33	6:39	6:48	7:37

The historical analysis of measured water levels (IMDC, 2003) shows an increasing trend of mean tidal range during the last years. Figure 1 gives the results of the 10-year average of the high and low waters for Antwerp.

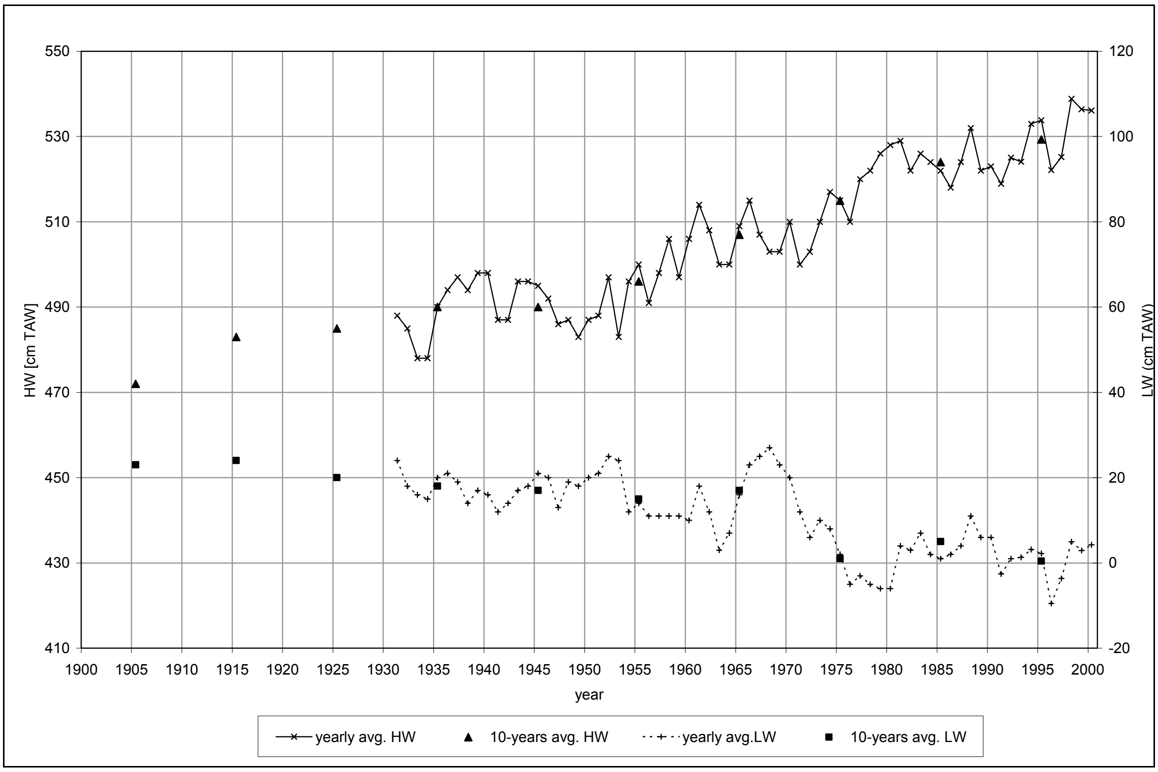

Figure 1: Evolution of water levels of the Scheldt at Antwerp

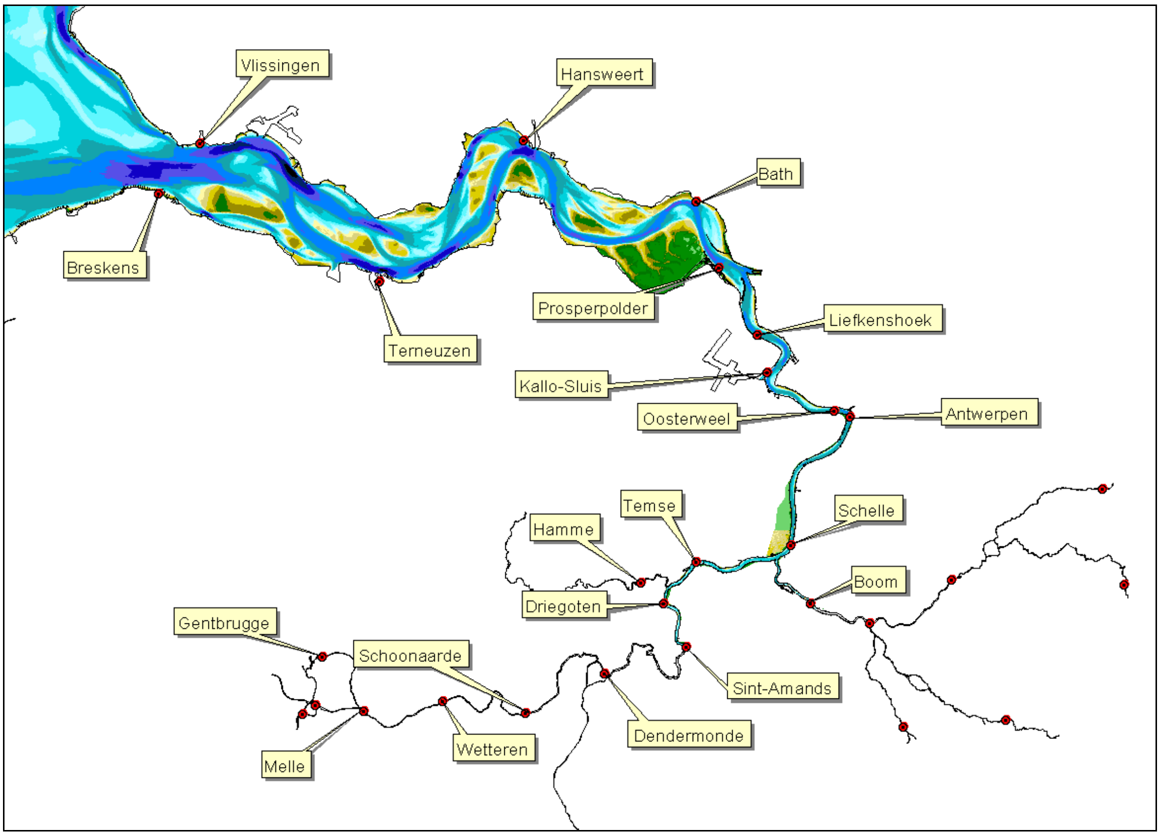

Figure 2: Tidal measuring stations for water levels at the Scheldt estuary.

2.3. Discharges

2.3.1. Flow discharges in the Scheldt estuary

Although the system is dominated by the tidal cycles, the fresh water inflow into the estuary plays an important role in the ecology of the system. The average daily discharge of the Scheldt at Schelle is 125 m³/s. Figure 3 presents the average discharge per decade and shows that the winter months (Dec-Feb) have higher discharges (in average 191 m³/s) than the summer months, with an average around 76 m³/s.

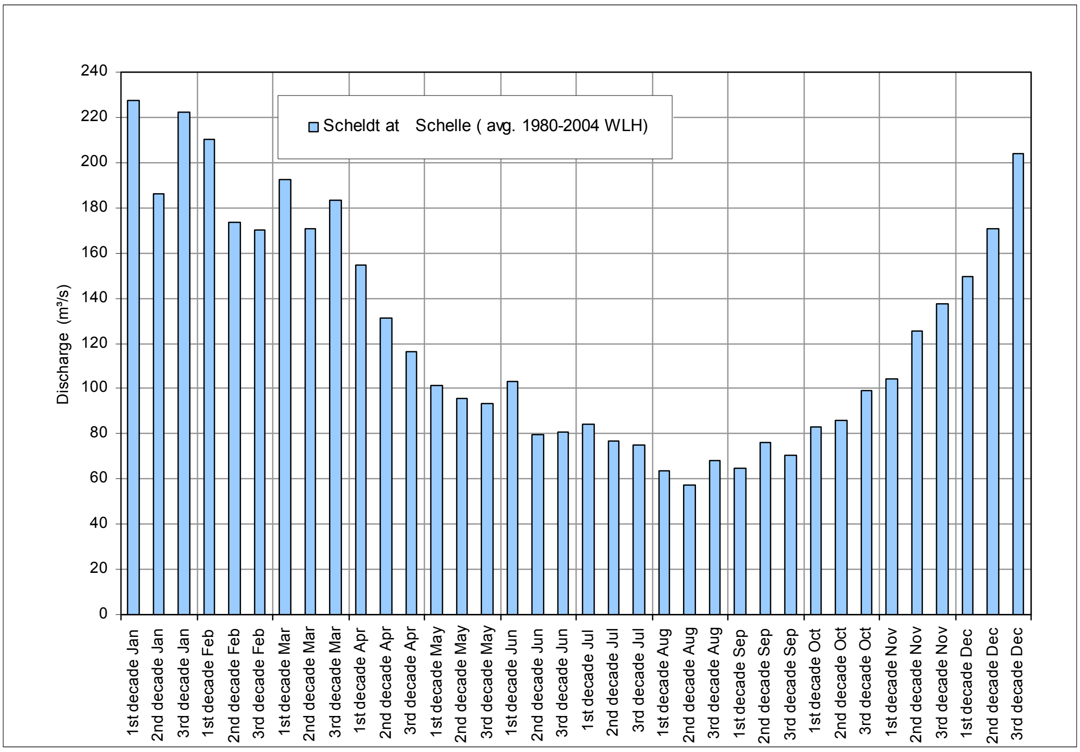

Figure 3: Decade average discharges form the Scheldt at Schelle (information source: WLH).

Tidal currents determine the morphological changes in the estuary, while river discharge has a negligible impact. Therefore, it was decided to impose a fixed average discharge at the upstream boundaries representing the different tributaries:

- Durme, 3 m³/s
- Scheldt in Ghent and the Dender, 33 m³/s
- Zenne, 14 m³/s
- Dijle, 28 m³/s
- Nete, 17 m³/s

Rijkswaterstaat performs measuring campaigns of discharges at specified measurement tracks (“raaien “ in Dutch) on a regular basis. For the current study, measuring campaigns during the period 2000-2002 have been made available. The results of the measuring campaigns, carried out by IMDC in 2002 as part of the study “density currents at the lower Scheldt” at several locations of the Sea Scheldt (IMDC, 2003), were also available. In Figure 4 the location of the official locations of Rijkwaterstaat as well as the measurement tracks of the IMDC campaigns are indicated. Table 2 gives a summary of the available campaigns.

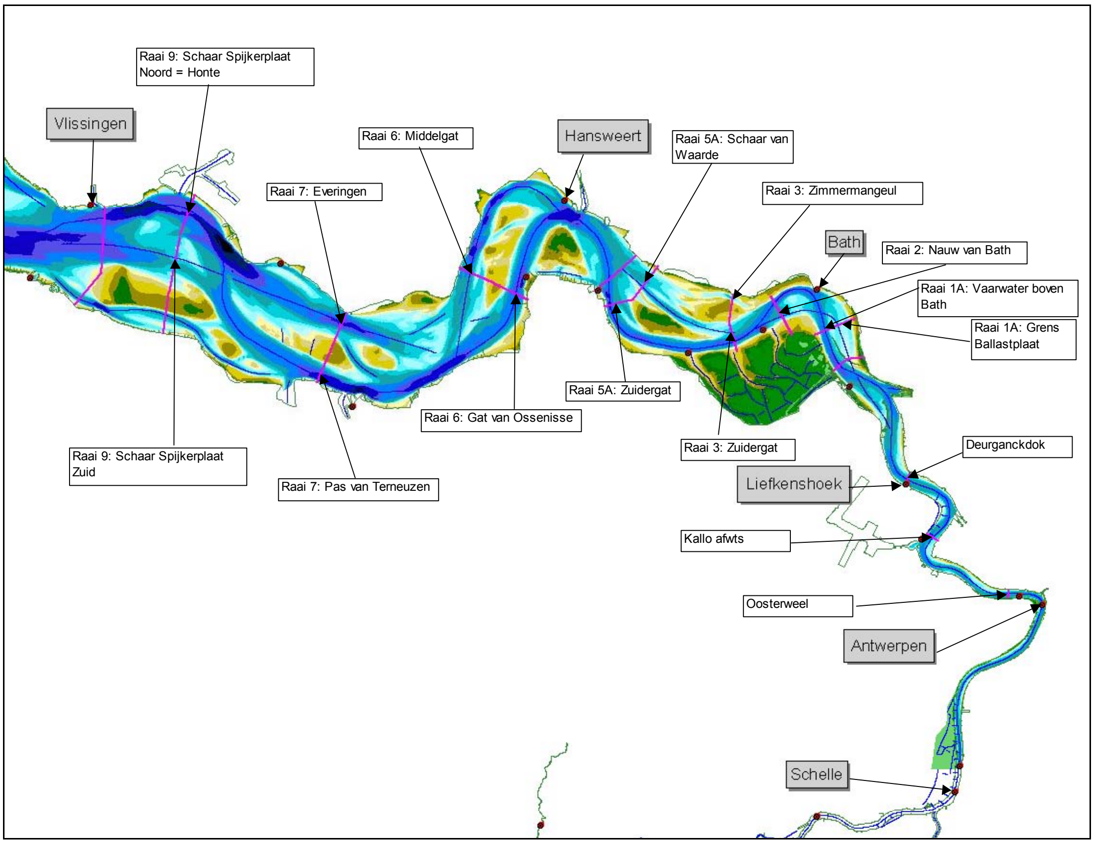

Figure 4: Location of the measurement tracks at the estuary.

Table 2: Available discharge measurements.

Nr.	channel	date
Raai 9	Honte	13-mar-2001
	Spijkerplaat	13-mar-2001
Raai 7	Pas v Terneuzen	25-apr-2002
	Everingen	25-sep-2002
Raai 6	Gat van Ossenisse	20-sep-2001
	Middelgat	24-sep-2001
Raai 5A	Zuidergat	27-mar-2002
	Schaar van Waarde	27-mar-2002
Raai-3	Overloop Valkenisse	16-oct-2001
	Zimmermangeul	16-oct-2001
Raai-1A	Vaarwater boven Bath	22-feb-2000
	Grens Ballastplaat	21-feb-2000
	Deurgankdock	12-jun-2002
IMDC	Kallo	12-jun-2002
	Oosterweel	12-jun-2002
IMDC	Kallo	05-jun-2002
	Oosterweel	05-jun-2002

2.3.2. Residual discharges and circulations

The so-called ebb channels convey larger volumes of water during ebb than during flood, while in the flood channels large volumes are conveyed during flood. This results in a residual discharge (discharge during ebb – discharge during flood). These residual discharges characterize the circulations observed in the system. Therefore special attention was given to reproducing the measured discharge patterns.

Measured average ebb and flood volumes at different locations have been used, in order to confirm the behavior of the residual volumes and residual discharges along the different reaches. These ebb and flood volumes have been provided by RIKZ. Details about this information are given in annex 1. These circulation patterns, along the ebb and flood channels, are shown in Figure 5.

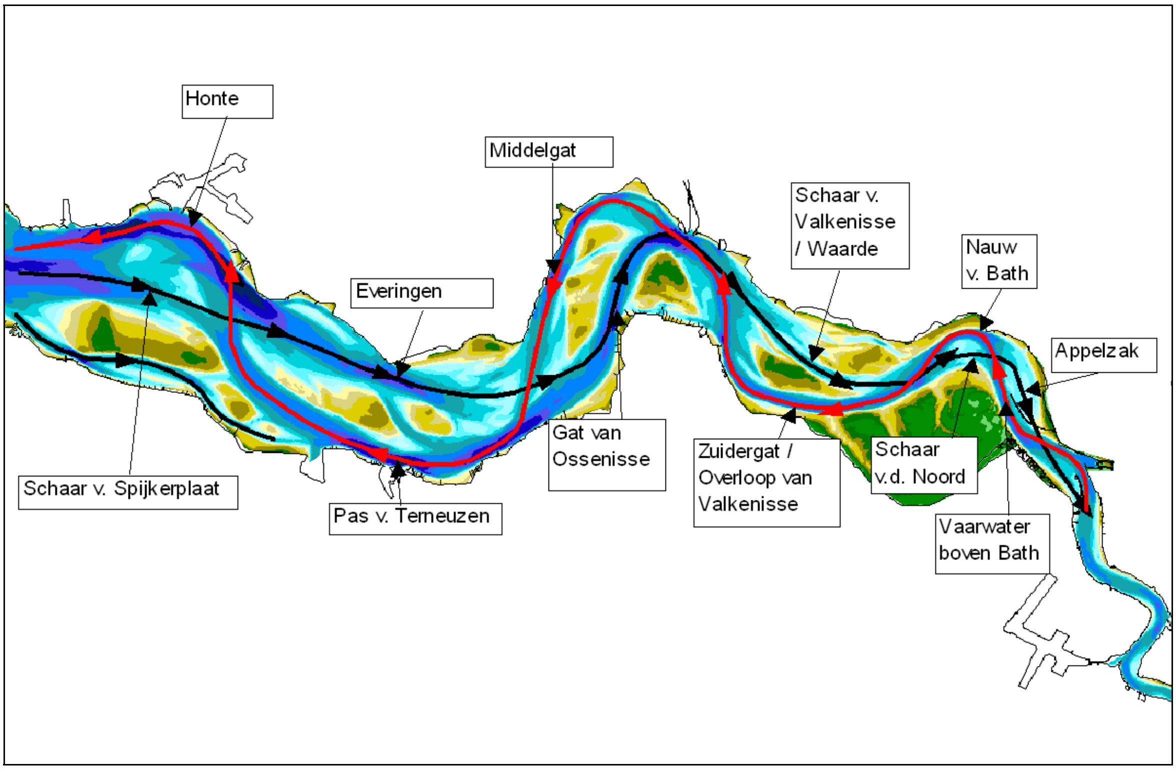

Figure 5: Circulation patterns along the Western Scheldt

Winterwerp (2000) has schematized the channel system by means of a so-called macro and meso-cells, this schematization have been adopted during the modelling with the SOBEK and DELFT 3D models. In order to compare results, about the circulation patterns, the same macro-cells have been adopted in this study.

2.4. Sediment measurements

No information about in-situ transport measurements was available, as part of the basic information provided by WLH. However the following reports of measurement campaigns have been used:

- ZLMD-91.N.061. Measurements of flow and sediment discharges. Raai: 1 Vaarwater boven Bath. 11th July 1991 (RIKZ, 1991).

- ZLM-89.n.118 I and II. Measurements of flow and sediment discharges. Raai: 6 Gat van Osssenisse/Middelgat. 3th October 1989 (RIKZ, 1989).
- ZLMD-89.N.069 I and II. Measurements of flow and sediment discharges. Raai: 7 Pas van Terneuzen. 6th April 1989 (RIKZ, 1989).

These reports give the results of measuring campaigns of flow discharges and suspended sediment transport. The discharges were calculated based upon flow velocity measurements performed with an Ott -propeller. The direction of the flow has been determined with an Elmar-Flow direction meter.

The sand transport was measured with an AZTM (acoustic sand transport meter). Detailed information about the measuring campaigns can be found in the respective reports. Figure 6 gives the total transport of sand for the ebb channel (Pas van Terneuzen) and the Flood channel (Everingen) at Raai-7.

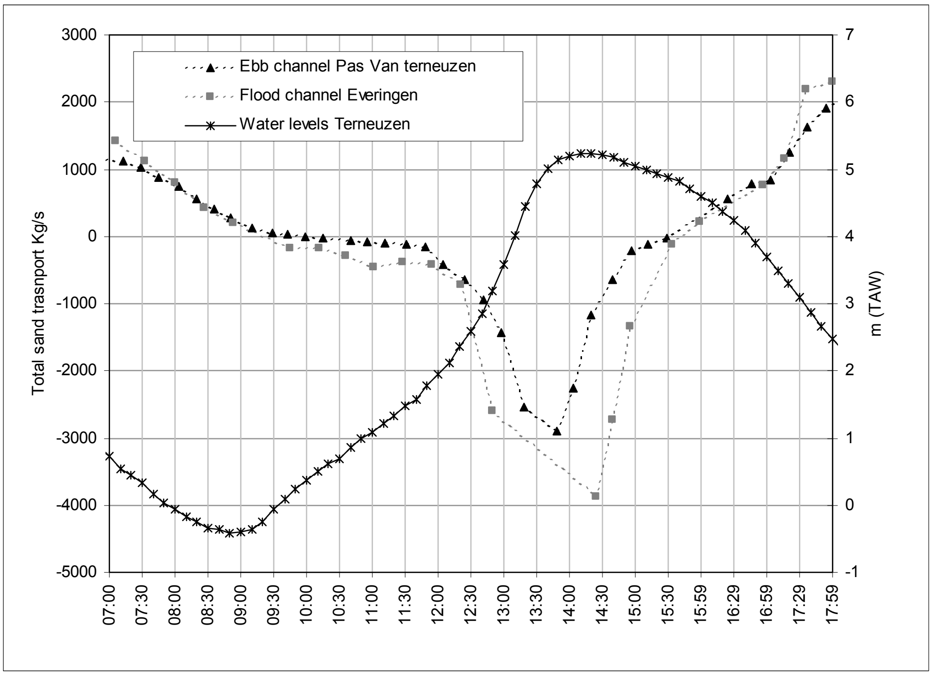

Figure 6: Total sand transport at raai: 7. (RIKZ 1989)

2.5. Bathymetry

2.5.1. Available bathymetries

Three sources of bathymetric information have been used during the project:

- The bathymetric information of 2001, on which the existing SIGMA-model (IMDC, 2003) is based; which consists of:
    - o Bathymetric survey of the Western Scheldt.
    - o Topographic survey of the Sea Scheldt.
    - o Digital elevation maps of the Netherlands including the dikes along the Western Scheldt.

    - Shape files with the elevation and characteristics of the dikes along the Sea Scheldt.
- 49 grid files with bathymetric information of the Western Scheldt covering different years from 1931 to 2003, provided by RIKZ.
- 4 grid files with bathymetric information of the Sea Scheldt (1970, 1980, 1990, 2002), provided by RIKZ.

For the calibration and validation of the model the bathymetries of 1968 and 1994 have been used respectively.

Based on the different grid files the change in bathymetry was estimated. However some shifting in the basic data was detected at the time, which led to inaccurate values. Given that the results of the morphological model were to be compared to the results generated with the SOBEK model, it was requested to use the same set of information of changes in the bathymetry.

The provided information about volume changes in the estuary was calculated for RIKZ. This information was distributed in the different compartments (micro-cellls) analyzed by the SOBEK model.

2.5.2. Morphological changes

According to Peters (2001), as result of the rising in the sea level between the Holocene and the Pleistocene, the Atlantic Ocean invaded the area between Europe and England. An inner sea, where the Scheldt discharged its waters, was formed. This lagoon was separated from the open sea by a sand barrier, which was later breached during storms.

The interaction of the tidal currents and the flow discharge of the Scheldt with little and silty sediment loads allowed the progressively penetration of the tidal action. This initiated the development of sea branches that later became the estuary of the Scheldt River. Till the 11th century, morphological evolutions were significant and entirely natural (Meersschaut et al 2004).

From 1800 on the influence of man becomes more important, with land reclamation activities and from 1970 on with dredging activities. One of the major changes in the last decades is the change of the behavior at Middelgat and the Gat van Ossenisse, where the flood-ebb channel behavior has been exchanged between the two branches. However since 1970 the Gat van Ossenisse has remained as flood channel. Figure 7 taken from Kramer (2002), illustrates the cyclical changes in this area.

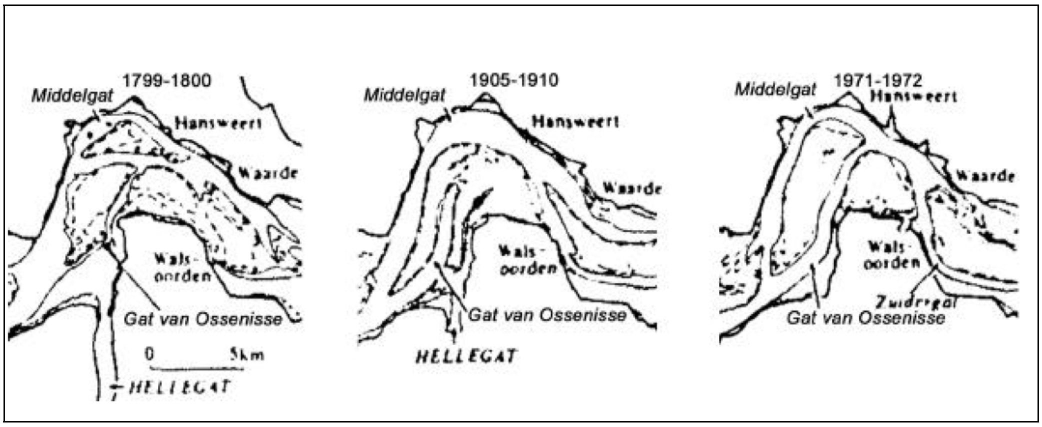

Figure 7: Cyclical changes in the position of the main channel close to Hansweert (Kramer, 2002 after Coen, 1988)

2.5.3. Bed composition

According to Kuijper. (2004) the sediment in the Western Scheldt consists mainly of sand with less than 10% mud in the channels and on the shoals (Dutch: platen).(see van Eck, 1999). Characteristic values for the median diameter (d50), as given by (van Eck, 1999) are:

- Channels: d50 > 150 µm;
- Shoals: d50 = 50 to 150 µm;
- Estuarine margin (intertidal areas and salt marshes): d50 < 125 µm.

In the upstream estuarine sections the grain size diameter in the channels is somewhat smaller than in the downstream sections, with values ranging from 90 to 120 µm in the Sea Scheldt.

2.6. Dredging, dumping and sand mining

According to Kramer (Kramer, 2002), the first dredging works occurred at the sill of Bath and took place around 1905. Since 1925 a yearly program for deepening the navigational route of the Sea Scheldt has taken place. According to Meersschaut (Meersschaut et al., 2004), till 1970 dredging was restricted to maintaining depths on crossings in the navigation channel, formed by the main ebb channels. Traditionally, the sediments were disposed in the flood channels, with the assumption that it would take a rather long time before coming back into the main ebb channel.

With the demand for increased navigation depth, a first deepening was carried out between 1970 and 1976. At this time, the dredged sediments were still disposed in the flood channels. A second deepening took place in the 90's of the 20th century. In Figure 8 the yearly distribution of the dredging, dumping and also sand mining activities are shown.

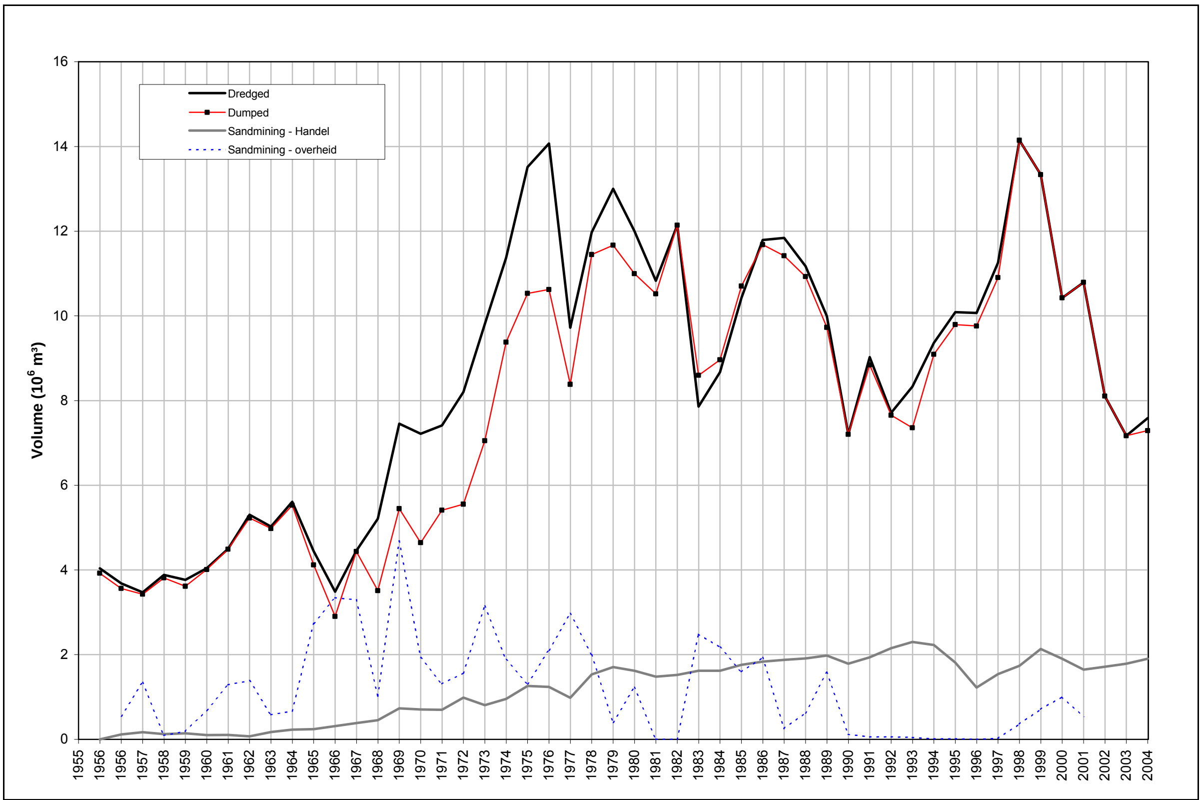

Figure 8: Yearly distribution of dredging, dumping and sand mining activities at the Western Scheldt and Sea Scheldt.

The location of dredging, dumping and sand mining areas in the Western Scheldt has changed. Before the 2nd deepening, sand mining activities were focused in the western part of the estuary, while dumping occurred in the flood channels at the eastern part (See Figure 9). After the second deepening, the dumping activities are focused in the western part of the Western Scheldt, while sand mining occurs mainly at the eastern part (Figure 10).

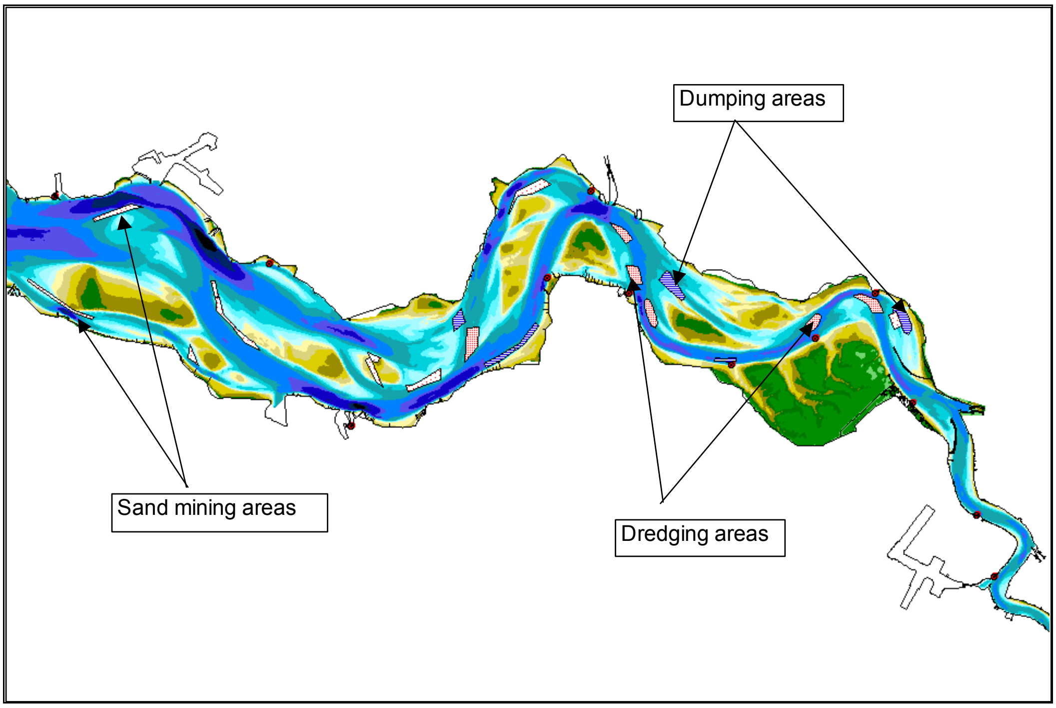

Figure 9: Location of the dredging and dumping areas at the Western Scheldt, 1971.

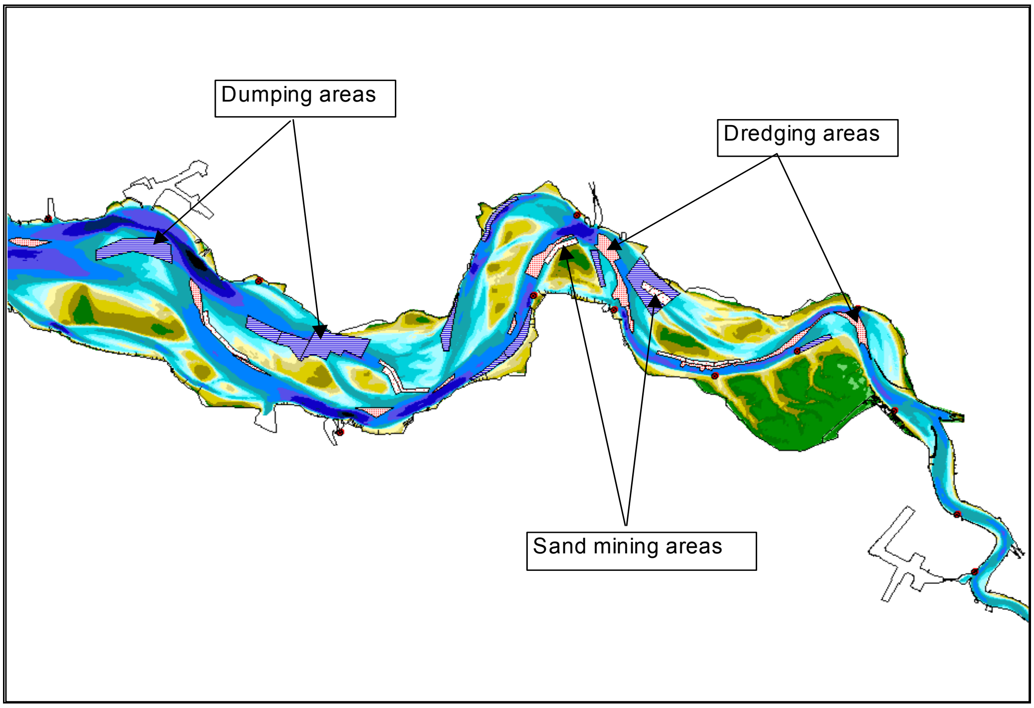

Figure 10: Location of the dredging and dumping areas at the Western Scheldt, 2000.

As part of the basic information, the different volumes of dredging, dumping and sand mining as well as their geographical location have been provided. Nevertheless not all the information was geographically referenced in a consistent way. Information about dredging, dumping and part of the sand mining ("Handel") at the Western Scheldt was given in the form of polygons, while other part of the information about sand mining ("Overheid") was given as points (see Figure 11). "Handel" covers sand mining activities assigned to private companies, while "Overheid" are the ones assigned to the public administration.

The different dredging, dumping and sand mining activities in the Sea Scheldt are related to a particular location, however no coordinates were available for this reach. Therefore a system of geo-referenced points, based on the available cartographical information, has been developed to link these activities to the respective areas (see Figure 11).

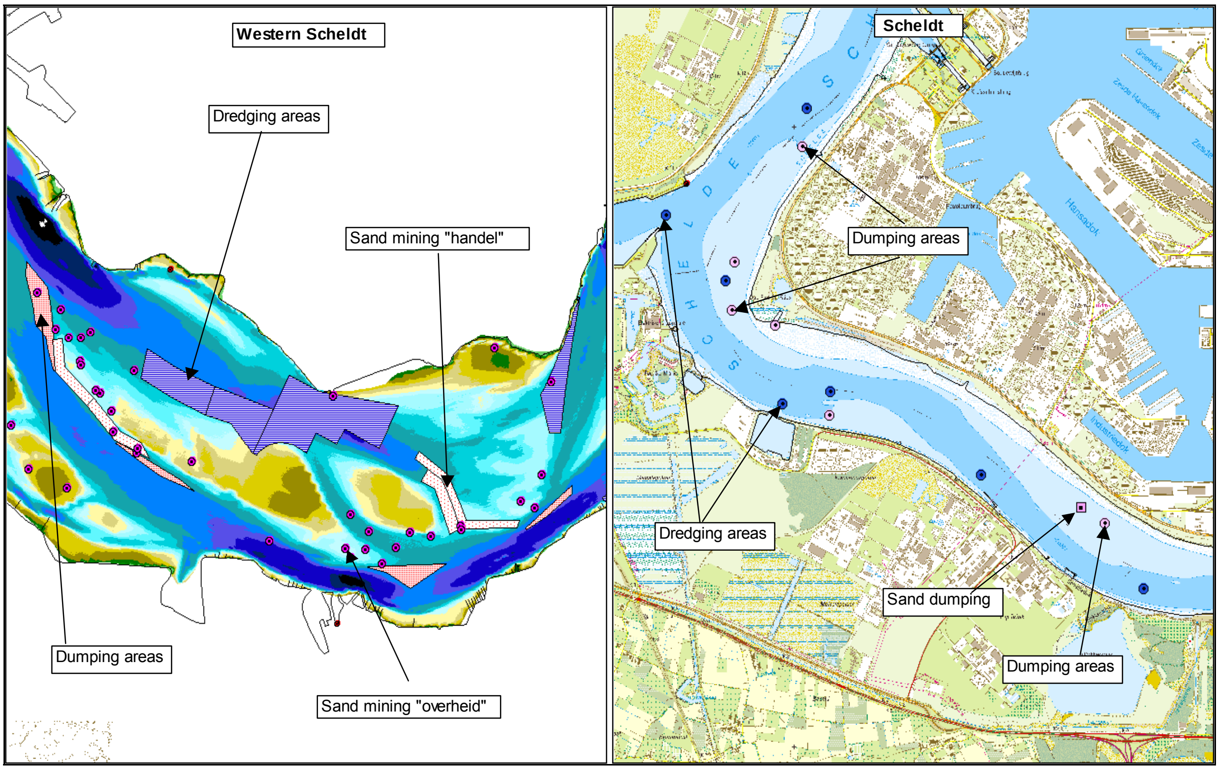

Figure 11: Example of the geographical referencing of dredging, dumping and sand mining.

3. SET-UP OF THE HYDRODYNAMIC MODEL

One-dimensional modelling is appropriate for long-term simulations with well-defined channels and confined flow in one (or opposite) direction. In an estuary with a network of inter-connected channels like the Western Scheldt, precaution has to be taken to ensure validity of the 1D approach. Therefore for the long-term sediment transport modelling with the 1D model, three conditions need to be fulfilled:

- The location of the main channels must remain the same, i.e. the discretisation of the main branches is valid throughout the studied period
- The ebb and flood channels are adequately described in the 1D model, i.e. the horizontal circulation patterns must be reproduced
- The shape of the cross-sections can be assumed to be the same throughout the study period, as a 1D model cannot by definition predict changes in width/depth ratios.

In order to have a useful prediction tool with the inherent limitations of the 1D model, it is imperative to have a model, which is exhibiting close to dynamic morphological equilibrium as observed in the field. This means, that the horizontal circulation patterns around the main intertidal flats are properly reproduced.

The Existing-SIGMA-HD model was adapted to be used as basis for a morphological model. To do so, the followings steps have been taken:

- Simplification of flood plains of the Existing-SIGMA-HD model.
- Decrease of the number of computational points and discarding less relevant structures in the upper tributaries.
- Optimization of the channel network set-up.
- Recalibration based on bathymetry 2001.
- Extension in the North Sea.
- Set up of the 1D model with the bathymetries of 1968 and 1994

Given that different network schematizations have been modelled during the study, it is important to give a short overview from these set-ups:

- **“Existing-SIGMA- HD”**: The original SIGMA model with all flood plains, based on the bathymetry 2001.
- **“Reduced-SIGMA-HD”**: The original SIGMA without flood plains, but where the wetlands of “Verdronken land van Saeftinge” and the harbours of the Western Scheldt are included
- **“Modified-SIGMA-HD”**l: A simplified version of the “SIGMA-reduced-HD” with less computational points, where the Western Scheldt is re-schematized. This model uses the measured water levels at Vlissingen, as downstream boundary condition, and has been used to calibrate the discharges and circulations.
- **“Extended-SIGMA-HD”**l: The former one but with extension in the North Sea.
- **“Reduced-Modified-SIGMA-HD”**: A reduced version of the “Modified -SIGMA-HD” model, where only the Rupel and the Durme are modelled as tributaries. The wetlands of “Verdronken land van Saeftinge” are simplified, and uses the bathymetry of 1968.

- **“SIGMA-Morphological-reduced”**: The former configuration, but when the Non-Cohesive Sediment Transport (NST) module is applied.
- **“SIGMA-Morphological”**: The same as before but where the study area has been extended in the North Sea.

3.1. General description of the Existing-SIGMA-HD model

The Existing-SIGMA-HD model was built to study the actual situation with respect to flood risk and to assess different strategies to improve the flood protection plan for the Scheldt. Special attention was given to the inclusion of all potential flood areas and the modelling of current inundation areas.

It is important to note that the1D hydrodynamic model does not take into account the effect of salinity and any kind of secondary currents due to density gradients. The 1D hydrodynamic Existing-SIGMA-HD model is composed of:

- The following rivers:
  - Western Scheldt, from Vlissingen to the Belgium border.
  - Sea Scheldt, from the Belgium border up to Ghent
  - Durme downstream Lokeren.
  - Rupel and Beneden-Nete.
  - Kleine Nete, downstream the gauge station of Grobbendonk
  - Grote Nete, downstream the siphon under the Albert Channel
  - Dijle, downstream the gauge station of Wilsele-Wijmaal
  - Zenne, downstream the gauge station of Vilvoorde
  - Demer, downstream the gauge station of Aarschot
- Relevant structures.
- Existing controlled inundation areas, including KBR (Kruibeke-Bazel-Rupelmonde).
- Potential flood areas.
- Natural flood areas.

These different flooding areas have been derived from the available digital terrain model of Flanders. A more detailed description of the Existing-SIGMA-HD model can be found in the report: “Deelopdracht 3: hydrologische en hydraulische modellen Scheldebekken, volume 2a: Hydraulica Scheldebekken” (IMDC, 2003). Figure 12 shows the model and Table 3 gives a description of the computational points of the Existing-SIGMA-HD model built with MIKE 11.

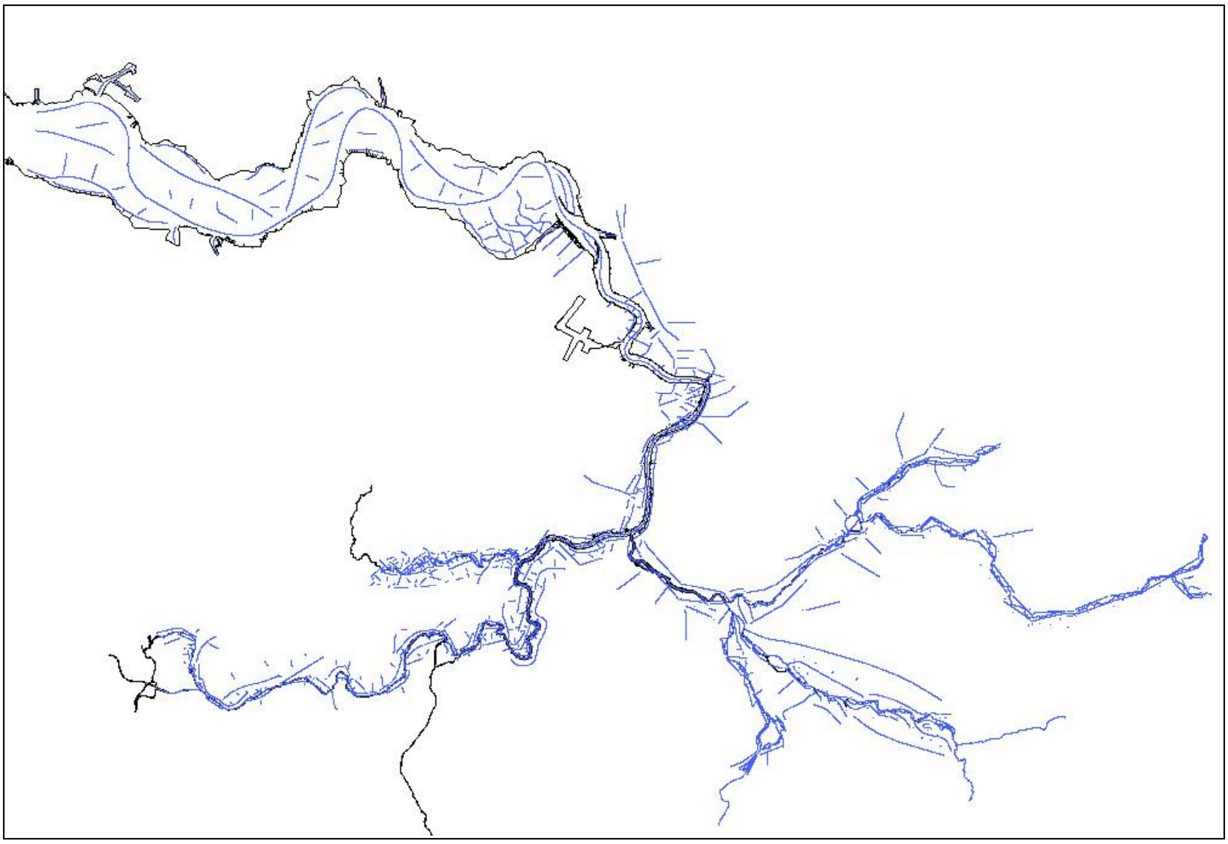

Figure 12: General schematization the Existing-SIGMA-HD Model

Table 3:Summary and computational points of the Existing-SIGMA-HD model

Existing-SIGMA-HD model	
Branches	1.822
Culverts	513
Weirs	8
Pumps	54
Dam break units	104
Run-off	198
H points	11.197
Q points	7.431
Computational points	18.628

The Existing-SIGMA-HD model is conceived to evaluate the hydrodynamic behavior of flood areas, with a large number of computational points. The upstream boundary conditions of the model correspond to the measured discharge at the different gauging stations. The flow coming from non-gagged catchments was estimated by means of rainfall-run-off models and introduced through the network file. Tidal measurements have been applied as downstream boundary condition, and the measured wind at the same location, was applied in the Western Scheldt from Vlissingen up to Bath.

3.2. Network schematization

In order to perform a correct morphological modelling, it was necessary to make some modifications in the schematization of the branches of the Western Scheldt.

3.2.1. Model simplification

In order to simplify the model, the first step was to exclude flood areas along the Sea Scheldt and its tributaries (see Figure 12). Only the main channels have remained, this generates higher water levels during river-flood events in the upper reaches of the tributaries (Demer, Grote Nete, etc). However for an average tide or even for storm tide events, no significant difference can be noted.

Furthermore, many cross-sections have been eliminated, particularly in the tributaries where a cross section was defined every 25 m. Many bridges have also been removed. The reduction of bridges and sections was performed in an iterative way; after removing bridges and cross-sections in a given reach; a verifying simulation was performed in order to compare the results of the Reduced-SIGMA-HD model, with the Existing-SIGMA-HD model without flood areas.

The reduced main channel model has 42 bridges instead of 95. A reduction of 26% in the computational points from (4.467 to 3.311) has been achieved by means of reducing the number of cross sections.

Figure 13 shows a longitudinal profile of the maximum water levels simulated by the two models, the Reduced-SIGMA-HD model and the Existing-SIGMA-HD model without inundation areas. Given that no significant differences are observed between the two models, the difference of the simulated water levels is plotted in centimeters at the secondary “y” axis of the same figure.

The simulation was performed with a storm tide with a high-water level of 7.52 m TAW in Vlissingen. The general schematization of the Reduced-SIGMA-HD model is presented in Figure 14.

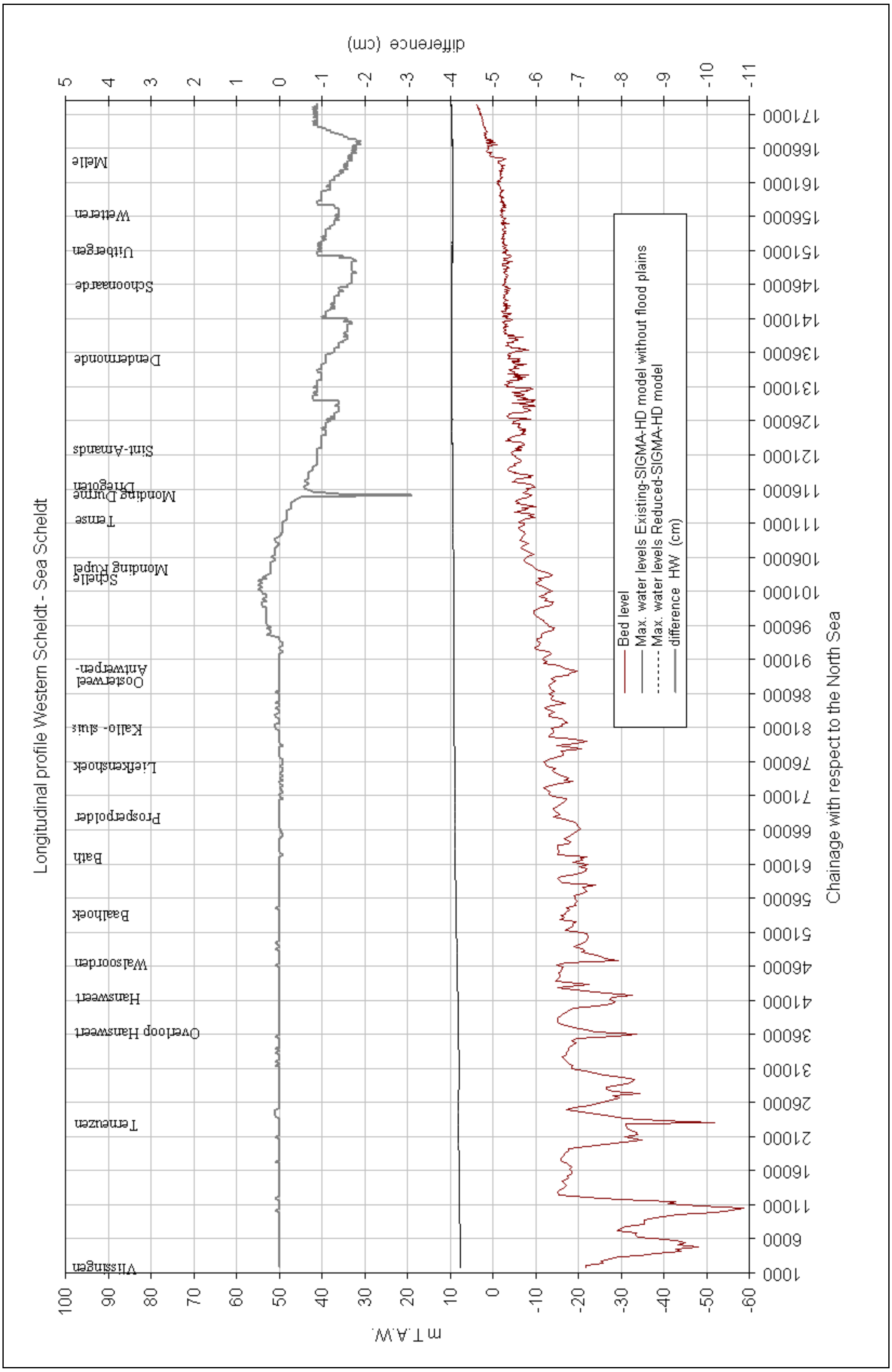

Figure 13: Longitudinal profile of simulated water levels SIGMA and SIGMA–reduced models.

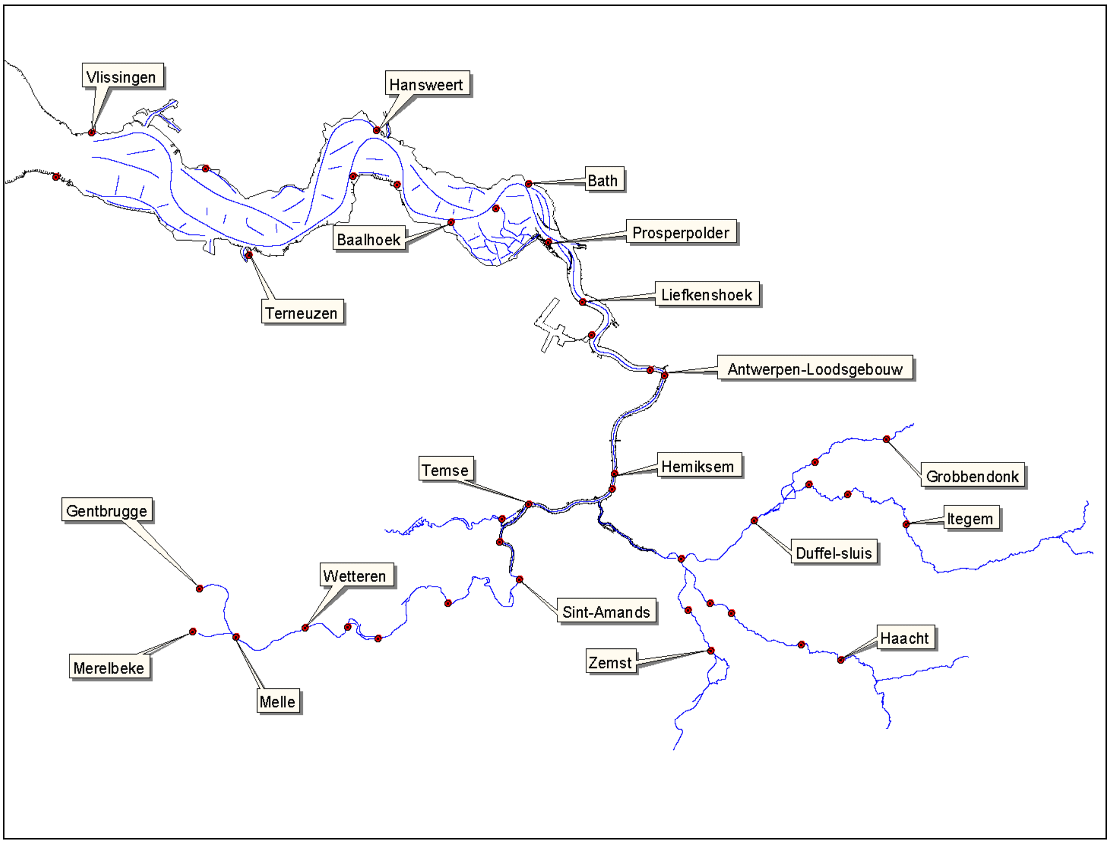

Figure 14: General schematization of the reduced SIGMA model

3.2.2. Schematization changes in the Western Scheldt

The Western Scheldt had to be re-schematized in order to comply to the requirements of a morphological model. Therefore some link-channels, which represent the flow over the intertidal flats, have been removed. Some areas that could produce shortcuts of discharges have also been modified.

Special attention was given to the bifurcation of branches. In the new schematization a confluence of 4 branches is represented by one single bifurcation point, in this way it is possible to have control of the discharge distribution between the branches. As a result of these modifications the number of branches in the Western Scheldt is reduced. Although most of the changes in the ma in ebb and flood channels can be considered as minor changes, the schematization of some specific areas was significantly modified.

One of the most affected areas is the one around the Plaat van Valkenisse (see Figure 15). In the new schematization the intertidal flats are no longer modelled as link channels, and the Zimmermangeul is no longer modelled as an independent branch. As a result of these changes it is not longer possible to compare directly the measured discharges (raai: 3) to the simulated ones. Therefore, it is important that the results of the discharges at this measurement track are correctly interpreted.

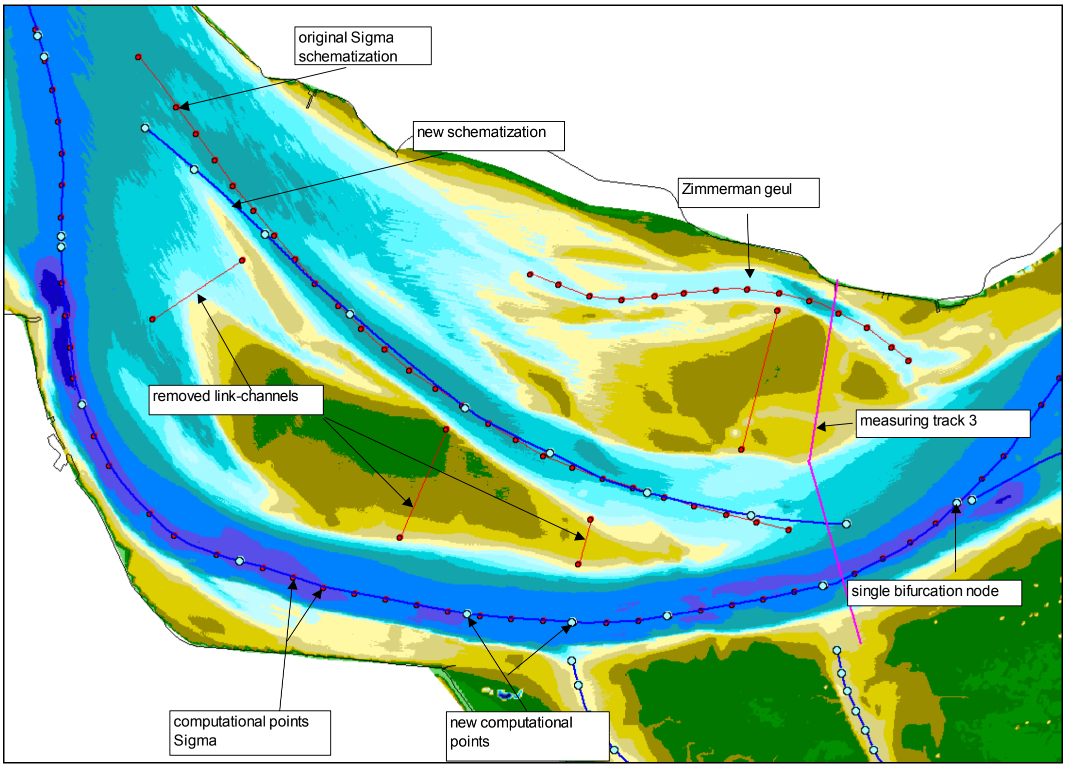

Figure 15: Changes in the schematization near the Plaat van Valkenisse

3.3. Bathymetry and cross sections

A cross section database was built based on the bathymetric information received as part of this study. The Existing-SIGMA- HD model is a very detailed model in which at least one cross-section was inserted every 300 m in all the reaches from the Western Scheldt. Moving further upstream, the Sea Scheldt was built with one cross-section every 100 m and upper tributaries with one section every 25 m.

The number of cross sections in the upper tributaries was reduced, in order to decrease the number of computational points (see §3.2.1). Reducing the number of sections in the Western Scheldt was achieved by selecting representative sections, which determine the flow at each branch and can properly characterize the behavior of each (ebb-flood) channel.

The visualization tools of MIKE 11 were used to identify these representative sections. By comparing, branch per branch and cross section per cross section, different characteristics like the conveyance, hydraulic radius and flow; was possible to identify the representative sections. Figure 16 gives an example of the sections along Everingen, where it is possible to identify the limiting section for the flow. In Figure 17 the general schematization of the Modified-SIGMA-HD model is presented.

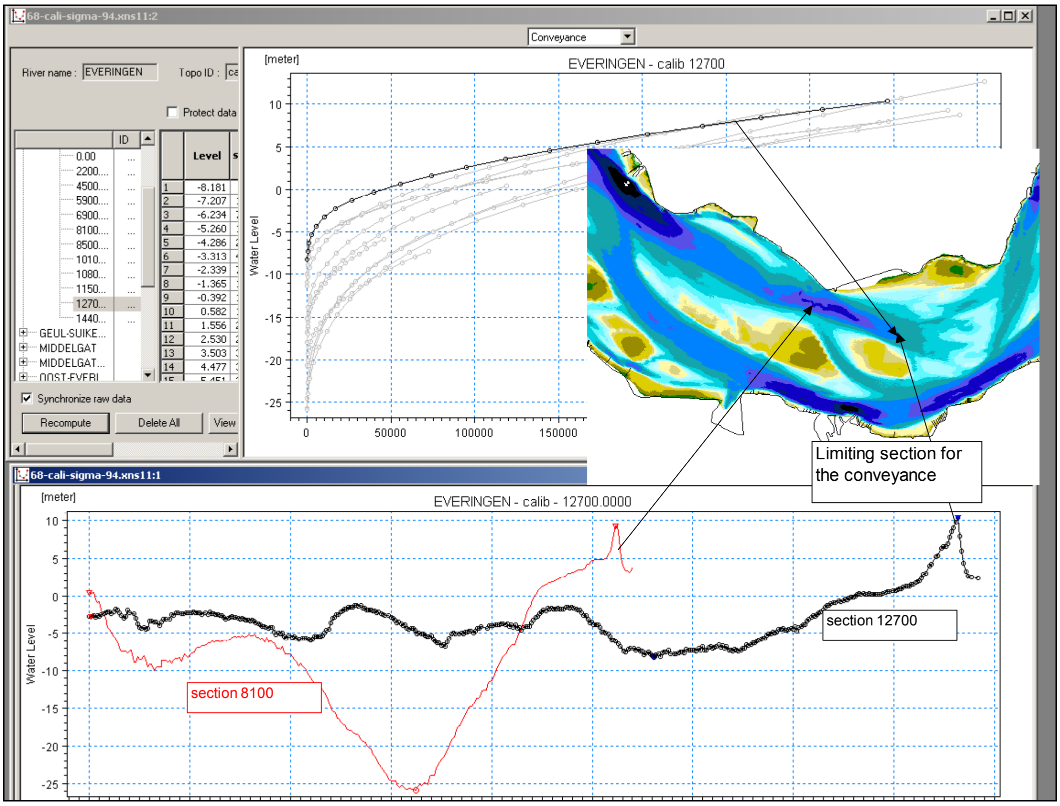

Figure 16: Cross sections in Everingen, cross section database in MIKE 11.

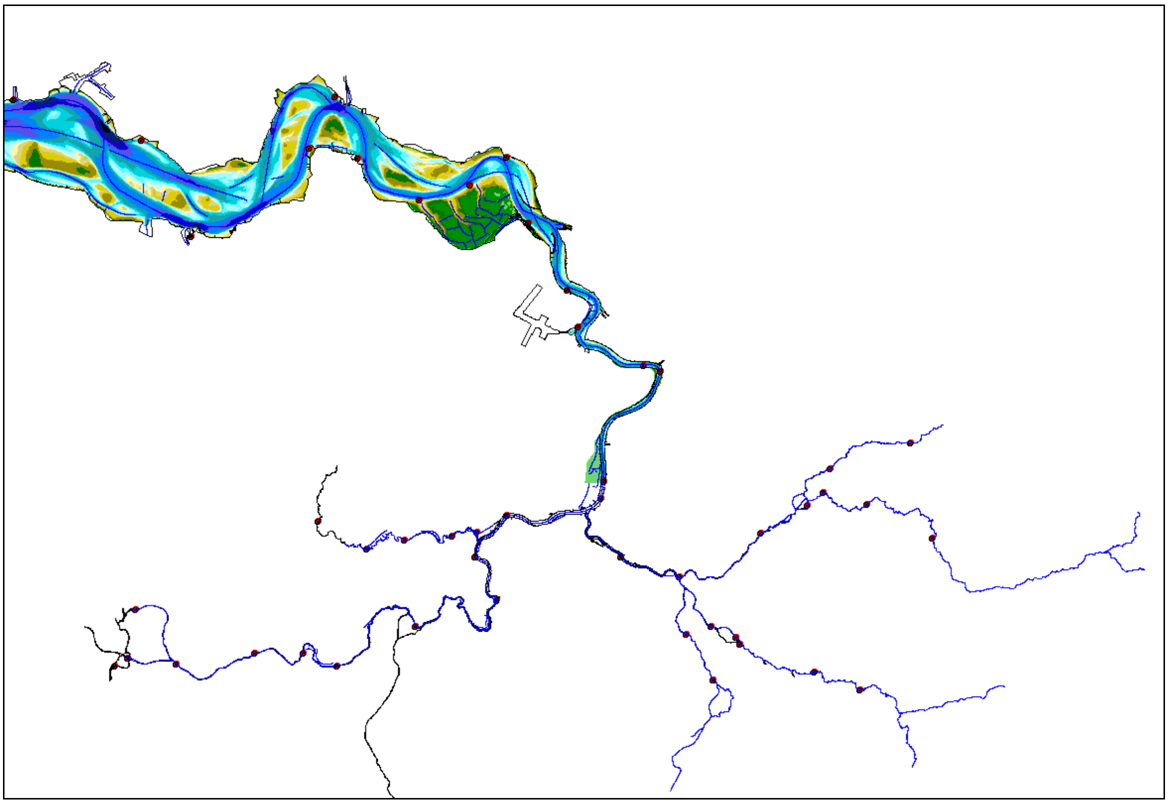

Figure 17: General schematization of the Modified-SIGMA-HD Model

3.4. Extension into the North Sea (Delta-area)

Information about the SOBEK model was used to extend the model into the North Sea, and therefore the study area could be comparable to this model. Based on the information provided by WL\Delft Hydraulics, a new configuration of the model, which includes the delta-area of the estuary, was built. Furthermore, the boundary conditions in the North Sea were assumed to be in the same position as the schematization of the SOBEK model.

In Figure 18 the Existing-SIGMA-HD model is represented together with the SOBEK schematization; later in Figure 19 the full-extended model of MIKE 11 (Extended-SIGMA-HD) is shown. The extension in the North Sea occurs by including 11 new branches; as a result the number of computational points increases.

Table 4 gives a general summary of the extended model. By comparing the information of this table with the one of the Existing-SIGMA-HD model one can observe that a reduction of 81 % of the computational points has been achieved.

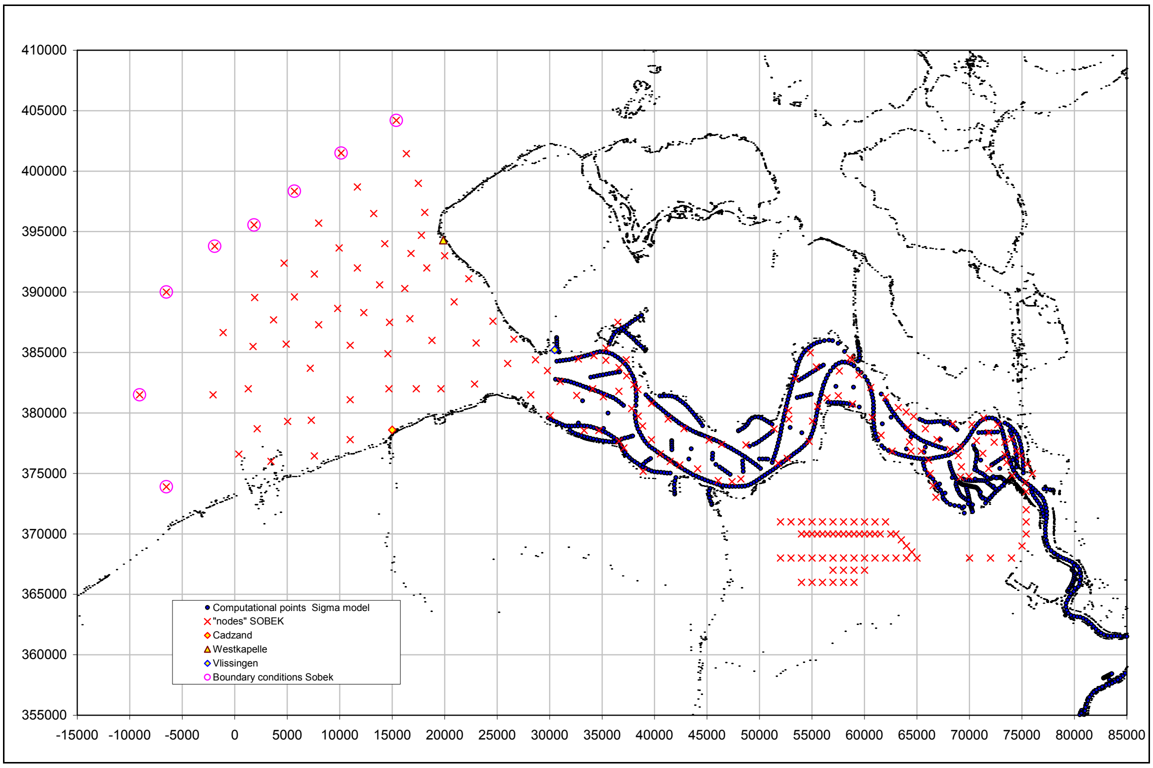

Figure 18:Schematization of the SOBEK model and location of the downstream boundary conditions.

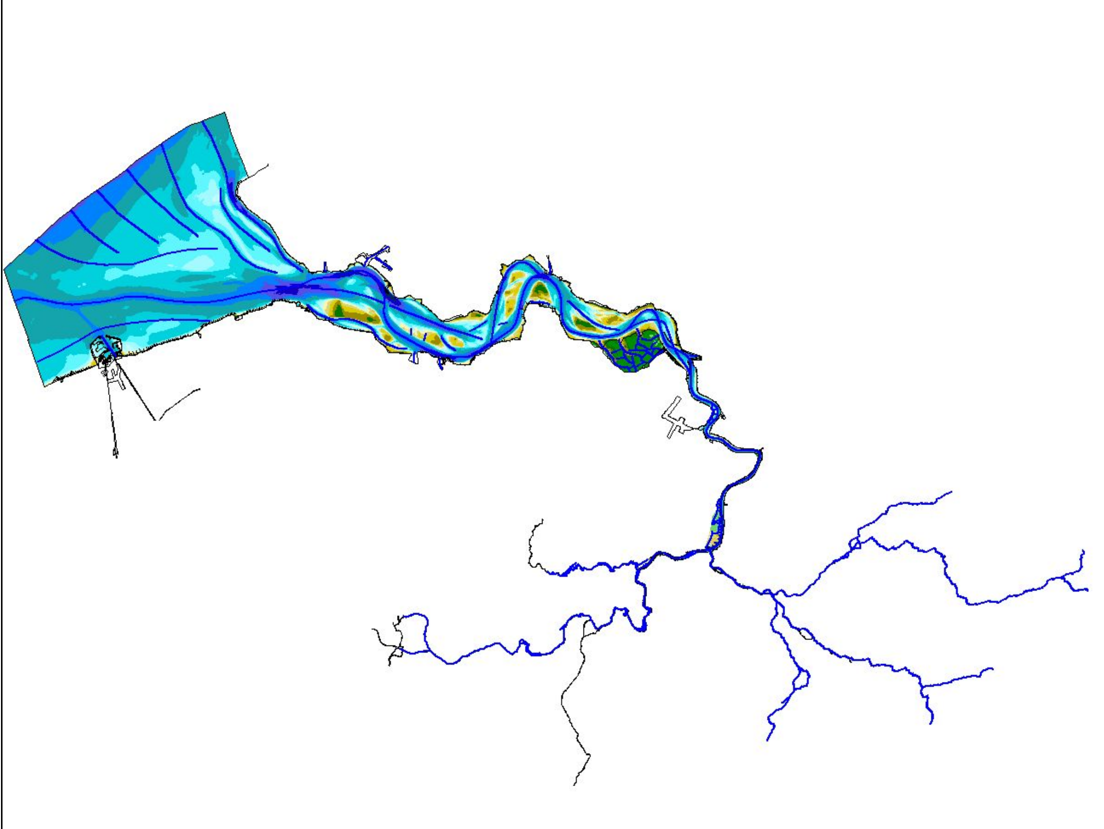

Figure 19: General schematization of the Extended-SIGMA-HD model.

Table 4: Summary of the Extended-SIGMA-HD model.

Extended-SIGMA-HD model	
Branches	438
Culverts	87
Weirs	13
Pumps	0
Dam break units	0
Run-off	0
H points	1969
Q points	1531
Computational points	3500

3.5. Wind

Wind friction on the water surface can be accounted for in MIKE 11 by inclusion of the wind shear stress in the momentum equation. If wind shear is to be included and a wind field has been specified as a boundary condition in the Boundary Editor then the switch in the Hydrodynamic Editor under the Wind tab has to be set.

The wind shear stress is expressed as:

$$\tau_w = t_{fac} C_w \rho_q V_{10}^2$$

Where

C_w = Wind friction coefficient (3,24 x10^{-6}).

t_{fac} = Factor depending on the surrounding topography.

V_{10} = Velocity 10 m above the water surface

ρ_a = Density of air

The wind force projection in the length direction of the channel is included in the local momentum equation in each *Q*-point. The wind direction and velocity specified as a time series is implemented in the boundary editor. The branch orientations are calculated from the network grid, which is always oriented north/south. The topographical factor (t_{fac}) can be defined globally or locally for each location (in the Hydrodynamic Editor under the Wind tab). The surface area to which the wind stress applies excludes any additional flooded areas and is equal to the width multiplied by the distance between *h*-points either side of the *Q*-point.

For the current simulations wind measurements at Vlissingen were available from 1959 to 2001. This information was obtained from the KNMI website (http://www.knmi.nl/). The topographical factor was already calibrated during the “actualization of the SIGMA Plan”.

4. CALIBRATION

The Existing-SIGMA-HD model was built to assess flood risk and therefore special attention was given to simulate storm conditions. This model was calibrated against measured water levels for the period from 10 to14 of June 2000 and the wind factor was calibrated by means of the simulation of different storm events.

A general check-up of ebb and flood volumes for the measuring station at Antwerp was performed, however no analysis of the residual volumes and discharges along the Western Scheldt was carried out at the time.

The recalibration in the current study was focused rather on the flow discharges than on the water levels. For this purpose the available measured flow discharges for different periods between 2001 and 2002 were used. Furthermore, the simulated water levels were compared to the measured ones for the same period of June 2000. It is important to note that the Modified-SIGMA-HD model has been used during this recalibration, because a historical time series of water levels and wind was available in Vlissingen.

A general verification of the residual discharges has been performed for the year (2000). The simulated residual discharges at the different channels have been compared to the residual discharges for the same channels, that can be estimated based on the average ebb and flood volumes since 1968 provided by RIKZ. Finally, the tidal range has also been verified.

The re-calibration was performed by means of changing the manning coefficient. A new feature has been introduced in MIKE 11 source code in order to reproduce properly the residual circulations along the different branches in the Western Scheldt. With this application a flow-direction-dependent bed friction term can be introduced for different branches, allowing the user to decrease the manning number at a given branch and for a defined reach.

In the following paragraphs the final results of the re-calibration, in regard of water levels, discharges, and residual circulation are discussed. A more detailed description of the calibration parameters, as well as some intermediate results, are given in Annex 4.

4.1. Water levels

The water levels at different stations along the Scheldt estuary are represented in Figure 20. Detailed figures per station are given in annex 2. As mentioned before, the current model is based on the Existing-SIGMA-HD model and therefore for each station the simulated water levels of the morphological model are not only compared to the measured water levels but also to the water levels simulated with the Existing-SIGMA-HD model.

The Modified-SIGMA-HD model, with a slightly different schematization of the Western Scheldt and considerable reduction of computational points in the upper reaches, appears to properly reproduce the water levels along the system. No significant differences are observed for the simulated water levels compared to the Existing-SIGMA-HD model. Hence it can be concluded that the Modified-SIGMA-HD model can properly reproduce the measured water levels.

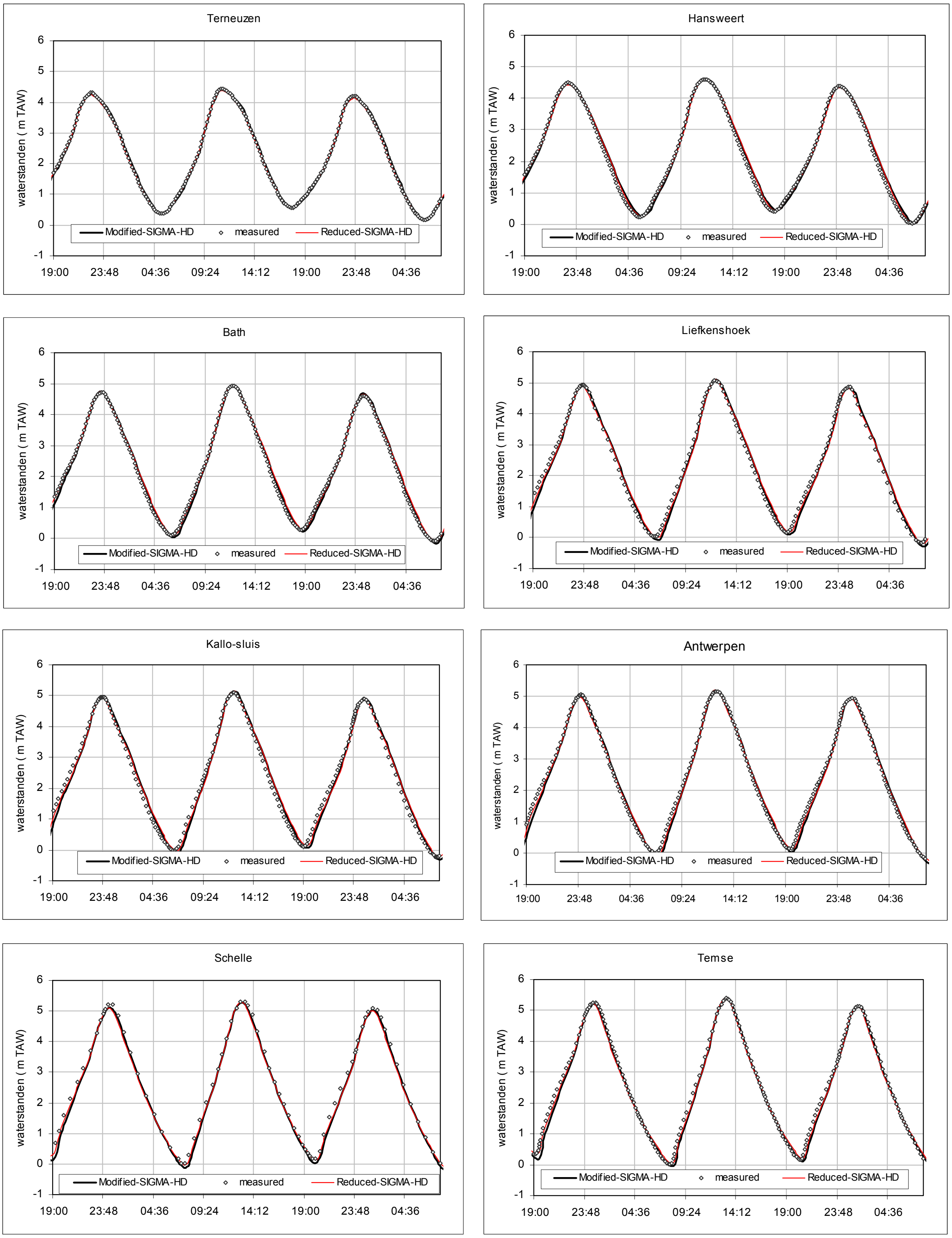

Figure 20: Simulated water levels at different stations in the Scheldt estuary, year 2000.

4.2. Tidal range

The tidal range or amplitude is an important factor that strongly influences the behavior of an estuary like the Scheldt. As it can be observed in Figure 21, the simulated tidal range at the estuary was correctly reproduced with the Reduced-SIGMA-HD model.

In the same figure the simulated tidal range with the Modified-SIGMA-HD model is also represented. From this figure it can be concluded that both models reproduce properly the observed tidal range along the Western Scheldt and the Sea Scheldt. Except for the station of Dendermonde where the simulated tidal range overestimates the observed one.

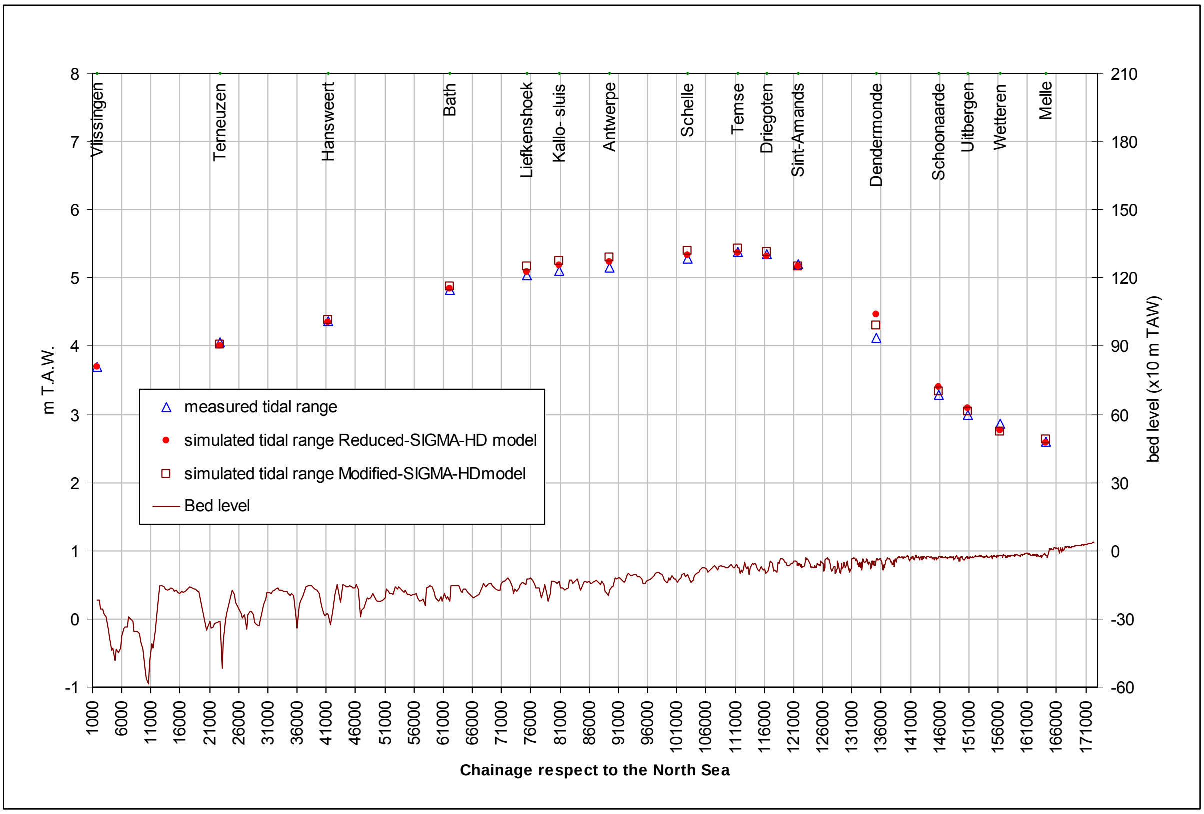

Figure 21: Longitudinal profile of the Western Scheldt and the Sea Scheldt with the tidal range at different stations

4.3. Discharges

The sediment transport is determined by the behavior of the flow discharges and respectively flow velocities at the different branches of the system. Therefore it is important to build a HD model able to reproduce not only the water levels, but also the flow discharges in the system and its distribution.

The current calibration process has focused on reproducing as good as possible the behavior of the discharges in the different branches in the Western Scheldt. To do so the simulated flow discharges were compared to available flow discharges. However, it is important to note that a certain degree of uncertainty must be accounted for discharge measurements, especially in a multiple flood and ebb channel network like the Western Scheldt.

A general overview of the measured discharges at different measurement tracks for the ebb and flood channel is given in Figure 24 and Figure 25. More detailed figures for each station are given in Annex 3. These figures demonstrate that, generally, the simulated discharges reproduce properly the measured discharges. However differences are observed in some locations.

At measurement track Nr.9 (Honte-Schaar v. Spijkerplaat) it is difficult to define clearly the limits between the ebb and flood channel. The measured discharges were provided by the WLH and RIKZ but no reference about the exact location of the limit between both channels was provided.(see Figure 22).

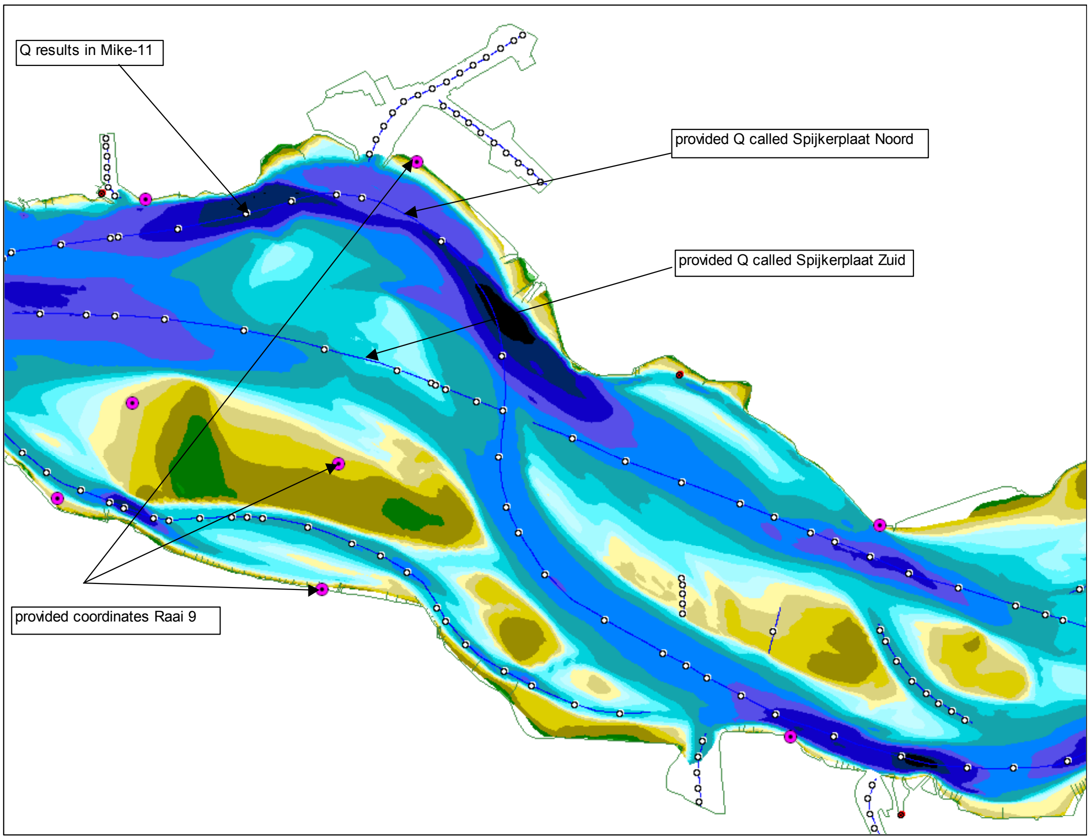

Figure 22: Network schematization at measurement track 9 (Raai 9)

The simulated flow discharges during flood in the flood channel of measurement track Nr. 6 (Gat van Ossenisse) overestimates the observed ones.

Measurement track Nr. 3 (Overloop v Valkenisse) is another location where the simulated discharges cannot be directly compared to the measured ones. In the new schematization (see Figure 23) the Zimmerman Geul is no longer modelled as an independent branch, but as part of the “SCHAAR-WAARDE” branch. Therefore the measured discharges at track Nr 3 “Overloop van Valkenisse” can be only compared to the sum of the flow discharges of two branches (SCHAAR-WAARDE_86500 and WESTERSCHELDE_56100).

Because of these differences, between the location of the measurements and the schematization, one would expect greater simulated volumes and discharges than the measured ones. This occurs because the discharges that in reality flows through Zimmermangeul, is simulated in the new schematization as to be part of the one through the Schaar van Waarde.

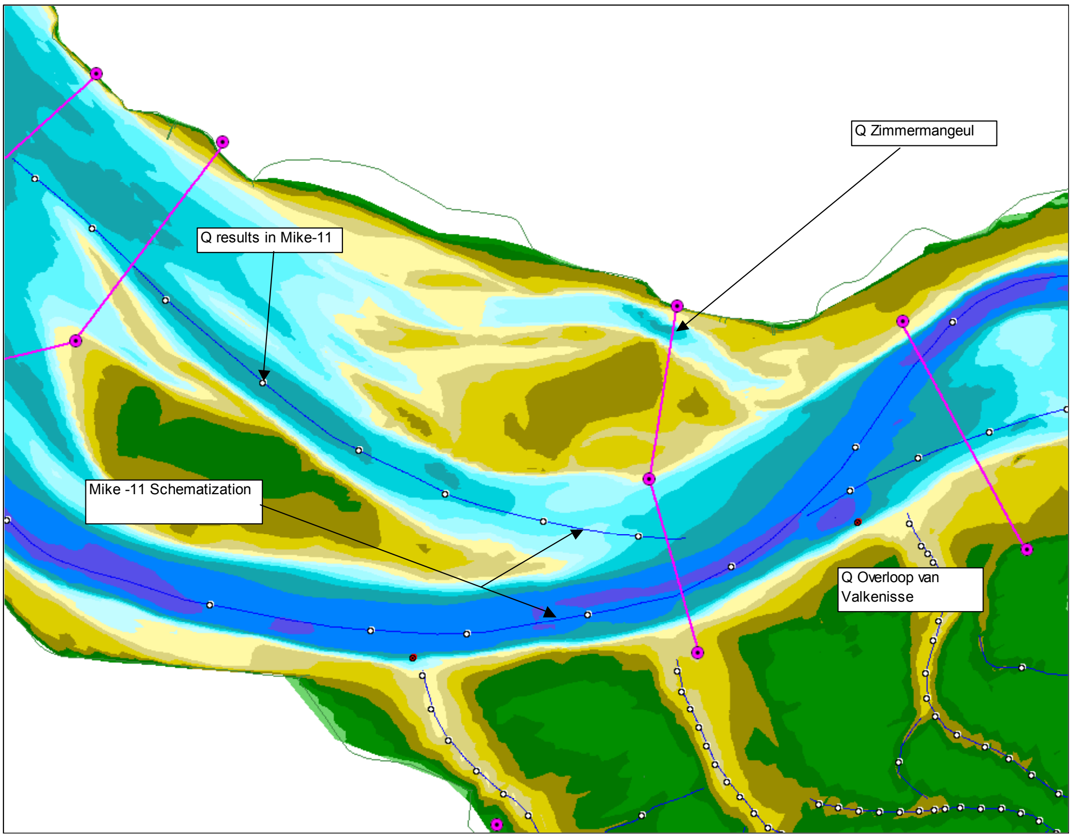

Figure 23: Network schematization at measurement track 3 (Raai 3)

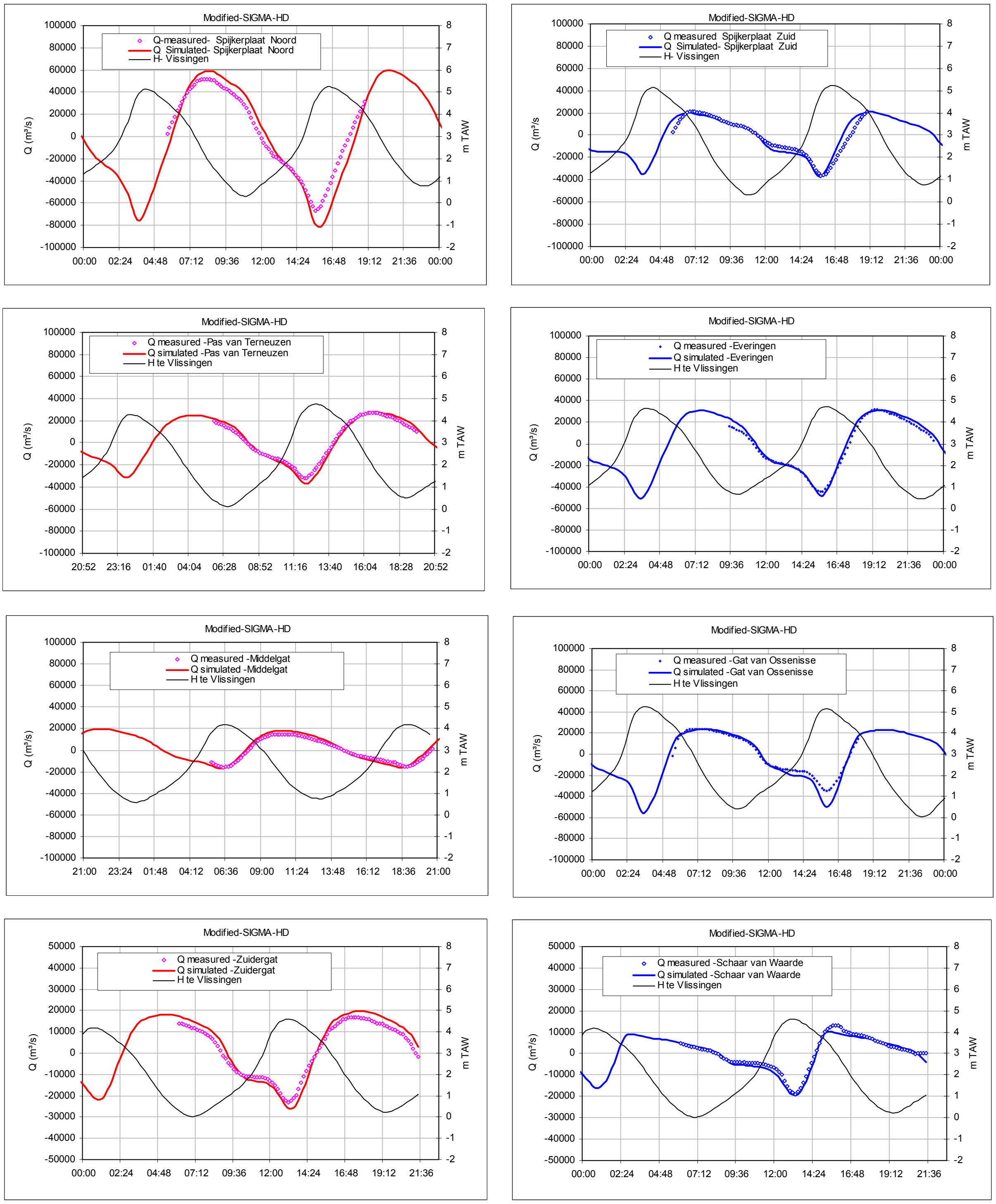

Figure 24: Simulated flow discharges at different measurement tracks at the Western Scheldt between Vlissingen and the Schaar van Waarde.

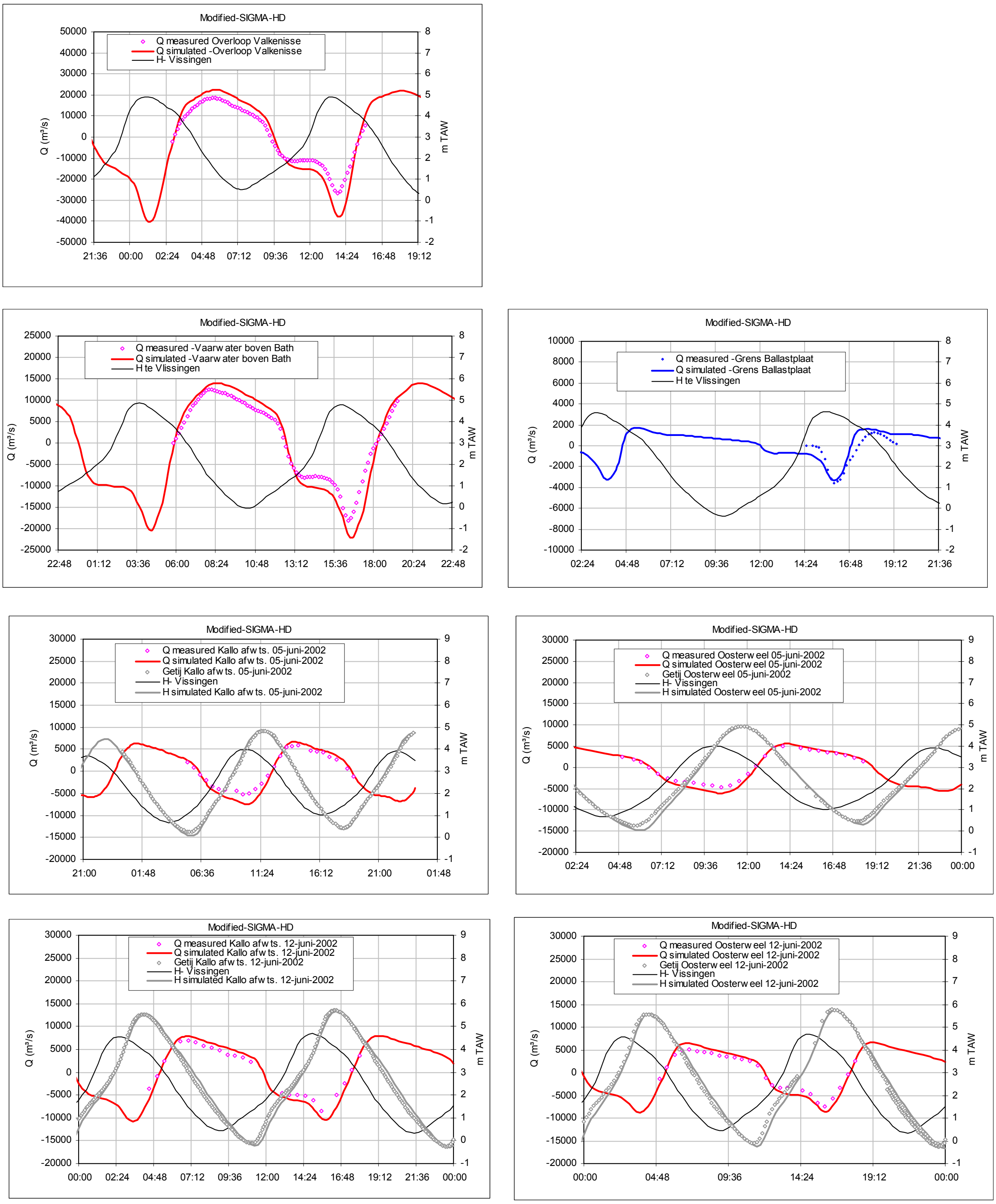

Figure 25: simulated discharge at different measurement tracks at the Western Scheldt and Sea Scheldt upstream the Overloop van Valkenisse.

4.4. Maximum discharges and volumes

For calibrating the flow discharge, a set of measured discharges along the Western Scheldt and the Sea Scheldt was available. Table 5 gives an overview of the available measurements. This table also shows the corresponding date and tidal coefficient. The tidal coefficient is calculated as follows:

$$Tid.Coef_{Ebb} = \frac{HW_{i-1} - LW_i}{Avg\Delta H}$$

$$Tid.Coef_{Flood} = \frac{HW_{i+1} - LW_i}{Avg\Delta H}$$

Where

- LW_i = low water level during the measurement campaign
- HW_{i-1} = previous high water level
- HW_{i+1} = next high water level
- Avg Δh = average tidal range

Table 5: Available flow discharge measurements and tide coefficients for different measurement tracks along the Western Scheldt.

Nr.	channel	date	Tidal coef Ebb	Tidal coef flood
Raai 9	Honte	13-mar-2001	1.26	1.29
	Spijkerplaat	13-mar-2001	1.26	1.29
Raai 7	Pas v Terneuzen	25-apr-2002	1.10	1.21
	Everingen	25-sep-2002	1.13	1.08
Raai 6	Gat van Ossenisse	20-sep-2001	0.89	0.91
	Middelgat	24-sep-2001	1.01	1.24
Raai 5A	Zuidergat	27-mar-2002	1.13	1.19
	Schaar van Waarde	27-mar-2002	1.13	1.19
Raai-3	Overloop Valkenisse	16-oct-2001	1.16	1.14
	Zimmermangeul	16-oct-2001	1.16	1.14
Raai-1A	Vaarwater boven Bath	22-feb-2000	1.26	1.25
	Grens Ballastplaat	21-feb-2000	1.26	1.25
	Deurgankdock	12-jun-2002		
	Kallo	12-jun-2002		
	Oosterweel	12-jun-2002		
	Kallo	05-jun-2002		
	Oosterweel	05-jun-2002		

Table 6 gives a summary of the measured and simulated maximum flow discharges at each measurement tracks and for each channel. These values are normalized to an average tide in Vlissingen. This table demonstrates that the model overestimates the maximum flow discharges during flood (negative sign). This overestimation can be observed in all branches (ebb or flood channels). For ebb the maximum flow discharge is underestimated in some measurement tracks (e.g. the Schaar van Waarde).

Table 6: Normalized maximum flow discharges for different channels at measurement tracks along the Western Scheldt.

Location	Maximum flow discharges Ebb (m³/s)			Maximum flow discharges Flood (m³/s)		
	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat Noord	41173	46727	13%	51593	63024	22%
Raai 9 Honte / Schaar v Spijkerplaat Zuid	16898	15866	-6%	28037	28654	2%
Raai7: Pas van Terneuzen	24759	25122	1%	26492	30301	14%
Raai 7:Everingen	28322	27523	-3%	41151	44580	8%
Raai 6 Middelgat	16541	20006	21%	16570	17453	5%
Raai 6-Gat van Ossenisse	23750	23255	-2%	27823	40242	45%
Raai 5A- Zuidergat	14812	17457	18%	19210	21894	14%
Raai 5A- Schaar van Waarde	11550	8993	-22%	15854	16358	3%
Raai 3 Overloop van Valkenisse	15977	19345	21%	23237	32759	41%
Raai 1A:Vaarwater boven Bath	9806	11072	13%	14575	17619	21%

Although, there is still an overestimation of the peak flow discharges, the total maximum flow discharge at each measurement track can be considered acceptable. The only exception is measurement track 3. As mentioned in §3.2.2 the measured discharges at this location cannot be directly compared to the simulated due to the difference in schematization of the model.

Table 7: Normalized maximum flow discharges for different measurement tracks along the Western Scheldt.

Location	Maximum flow discharges Ebb (m³/s)			Maximum flow discharges Flood (m³/s)		
	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat	58071	62593	8%	79630	91679	15%
Raai 7:Pas van Terneuzen-Everingen	53081	52645	-1%	67644	74881	11%
Raai 6 Middelgat-Gat van Ossenisse	40291	43261	7%	44392	57695	30%
Raai 5A- Zuidergat- Schaar van Waarde	26362	26450	0.3%	35064	38252	9%
Raai 3 Overloop van Valkenisse	15977	19345	21%	23237	32759	41%
Raai 1A:Vaarwater boven Bath	9806	11072	13%	14575	17619	21%

The flow volumes of each channel (Table 8) show same tendency for an overestimation of flow volumes during both ebb and flood. However, the difference between simulated and measured is smaller, if we consider flow volumes through the full measurement track (Table 9.

Overall the differences can be considered acceptable, except for measurement track 3 and 1A. However in measurement track 3 the model schematization (without Zimmermangeul as an individual branch) does not allow the direct comparison between simulated and measured volumes. In measurement track 1A the measured discharges do not cover the complete tidal cycle, and moreover the presence of guiding walls complicates the correct simulation of discharges across Appelzak.

Table 8: Normalized flow volumes for different channels at measurement tracks along the Western Scheldt.

	Ebb volumes (M m³)			Flood volumes (M m³)		
Location	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat Noord	620	726	17%	540	677	25%
Raai 9 Honte / Schaar v Spijkerplaat Zuid	217	219	1%	287	296	3%
Raai7: Pas van Terneuzen	376	388	3%	285	333	17%
Raai 7:Everingen	389	437	12%	500	496	-1%
Raai 6 Middelgat	257	327	27%	197	214	8%
Raai 6-Gat van Ossenisse	367	385	5%	317	408	29%
Raai 5A- Zuidergat	236	300	27%	217	248	14%
Raai 5A- Schaar van Waarde	131	115	-12%	133	160	20%
Raai 3 Overloop van Valkenisse	250	334	33%	242	327	35%
Raai 1A:Vaarwater boven Bath	161	199	23%	141	190	35%

Table 9: Normalized flow volumes for different measurement tracks along the Western Scheldt.

	Ebb volumes (M m³)			Flood volumes (M m³)		
Location	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat	837	945	13%	827	973	18%
Raai 7:Pas van Terneuzen-Everingen	765	825	8%	786	829	6%
Raai 6 Middelgat-Gat van Ossenisse	624	712	14%	514	622	21%
Raai 5A- Zuidergat- Schaar van Waarde	367	415	13%	351	409	17%

Similar tables with the measured flow discharges and volumes without the correction of the tidal coefficient are presented in Annex 5. In these tables the residual discharges for the measured tidal cycles are also given.

4.5. Residual discharges

The residual discharges are very important for correctly modelling the sediment transport. To compare the general behavior of the model a complete year has been simulated (2001) with the morphological model and the reduced SIGMA model.

The simulated residual discharges have been compared to the residual discharges estimated from the ebb and flood volumes provided by RIKZ. Figure 26 to Figure 28 show the residual discharges. These figures demonstrate that the Existing-Sigma-HD model is not able to reproduce properly the flow discharge distribution in the Western Scheldt. In particular at measurement track 9 where the ebb channel behaves like a flood channel and vice versa. Further upstream the order of magnitude of the residual discharges is not correctly estimated.

After the different changes introduced in the modified-SIGMA-HD model, the general behavior of the residual discharges is satisfactorily reproduced, for all branches at the Western Scheldt, and in general at the Sea Scheldt. Only the areas with guiding walls give less accurate results.

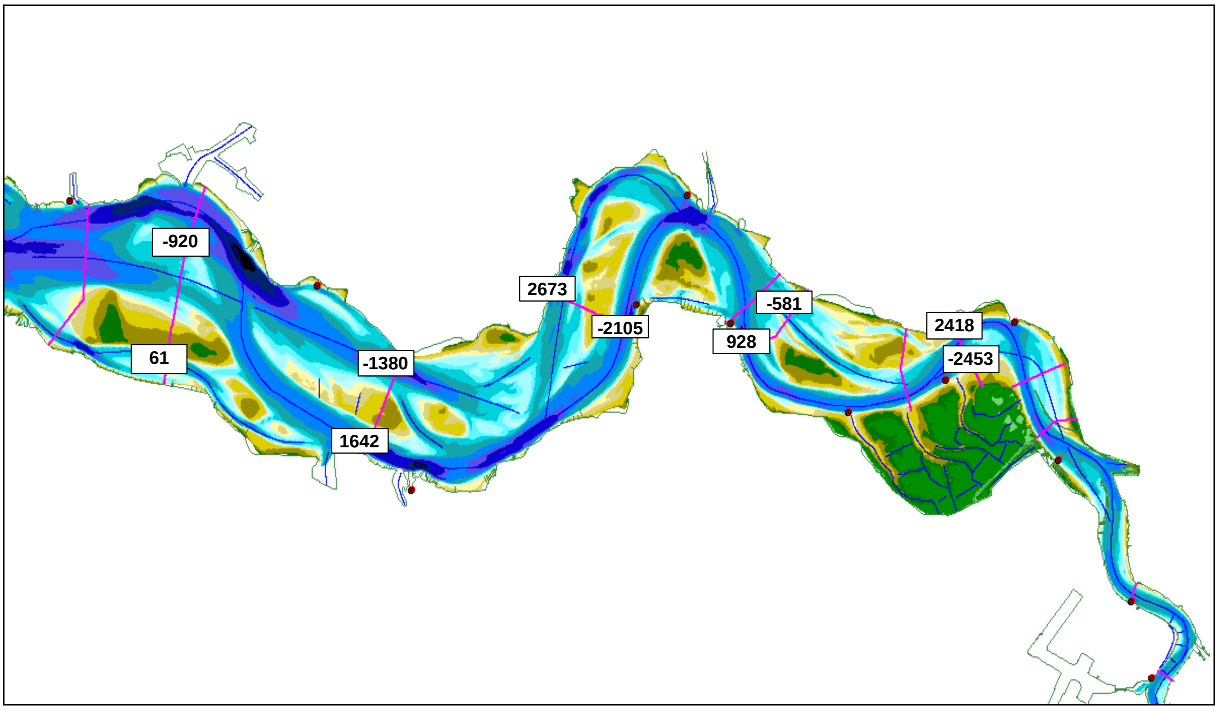

Figure 26: Residual discharges derived from the measured ebb and flood volumes. (Negative= inland direction).

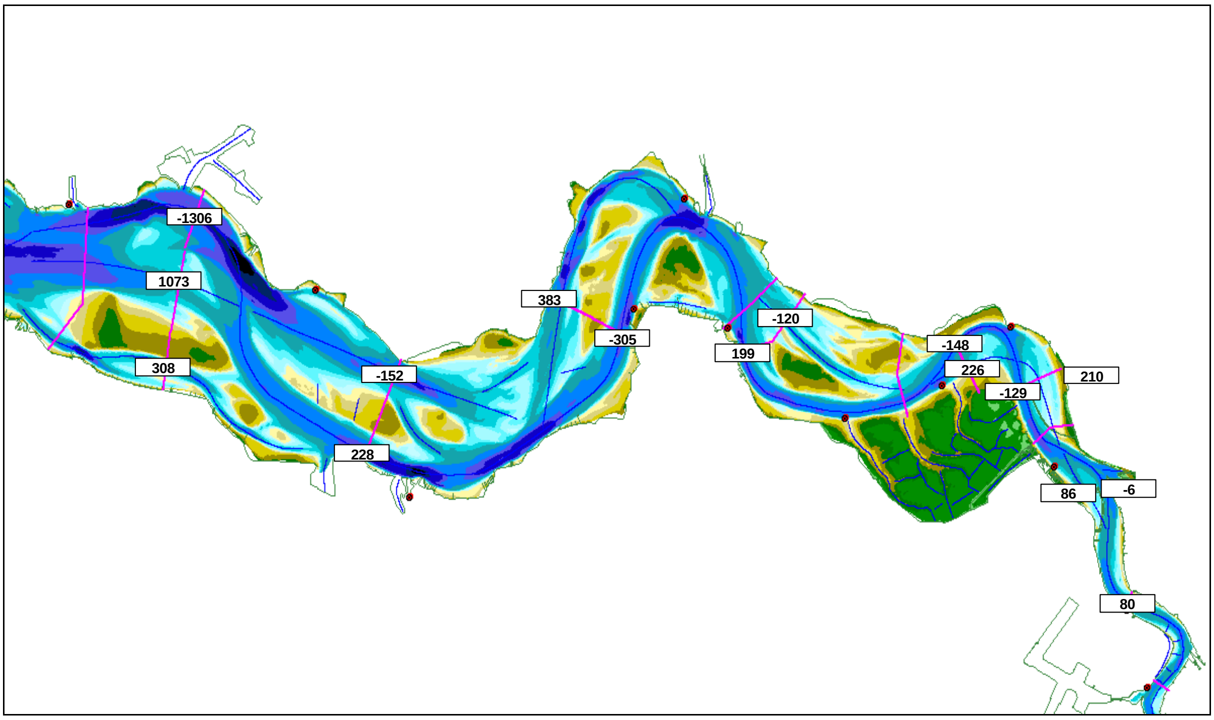

Figure 27: Residual discharges simulated with the Existing-SIGMA-HD model, year 2001. (Negative= inland direction).

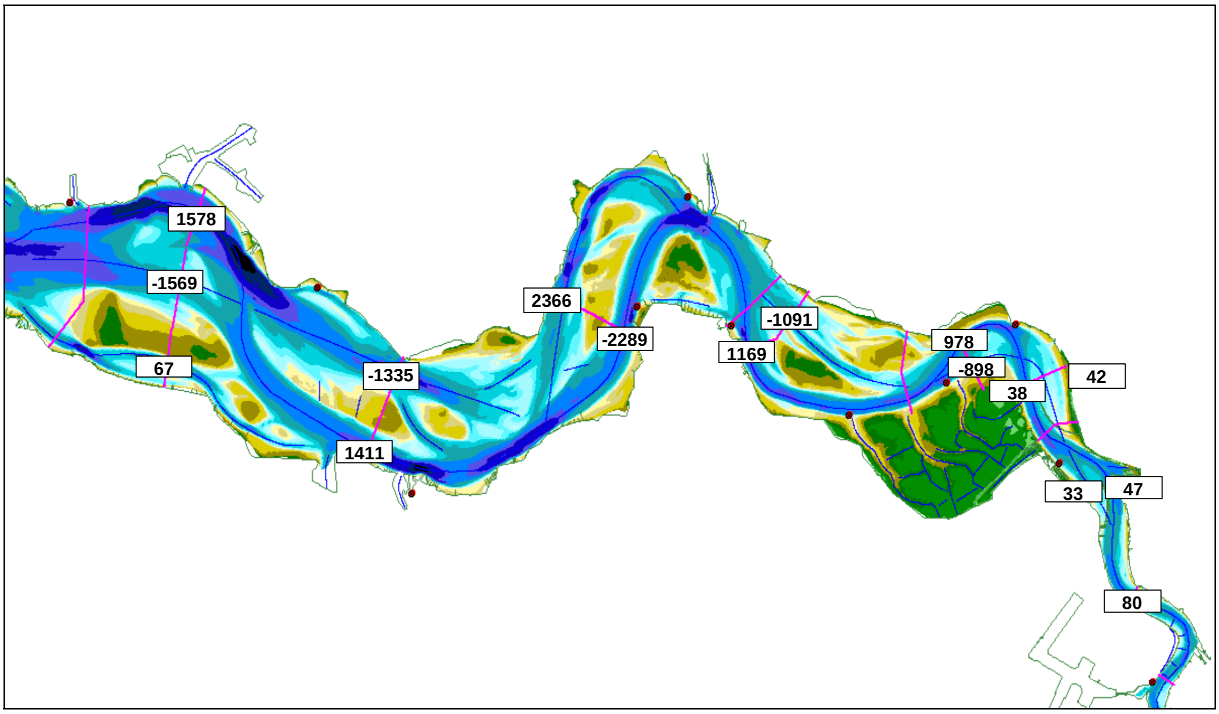

Figure 28: Residual discharges simulated with the Modified-SIGMA-HD model, year 2001. (Negative= inland direction).

5. VERIFICATION AND VALIDATION

5.1. Evaluation of the extension into the North Sea

In order to compare the MIKE 11 model with the SOBEK model it was necessary to extend the MIKE 11 model into the North Sea. This extension gives additional uncertainties to the model. In order to be consistent in the comparison of the models it was necessary to use the same boundary conditions as the SOBEK model. Therefore boundary conditions had to be introduced at 8 points in the North Sea (see Figure 18).

The 8 time series with water levels for the period September 2002, and generated by DELFT 3-D have been provided by WL\Delft Hydraulics. Furthermore, to validate the results, measured water levels at different station for the same period have been also provided.

The calibration of the extension in the North Sea occurred by means of changing the manning coefficients at the new branches, starting with the same manning numbers as in the Western Scheldt close to Vlissingen. The final set of manning numbers is given in Table 12.

Figure 29 gives an overview of the results for different stations. In general the Extended-SIGMA-HD model gives good results. The simulated water levels in Vlissingen correspond to the observed ones, although a small phase shift is observed during the rising phase of some tides below 0 m T.A.W. The tidal range, on the other hand remains in the same order of magnitude.

The extension of the model into of the North Sea does not lead to significant differences further upstream, with respect to the model calibrated with measured water levels at Vlissingen.

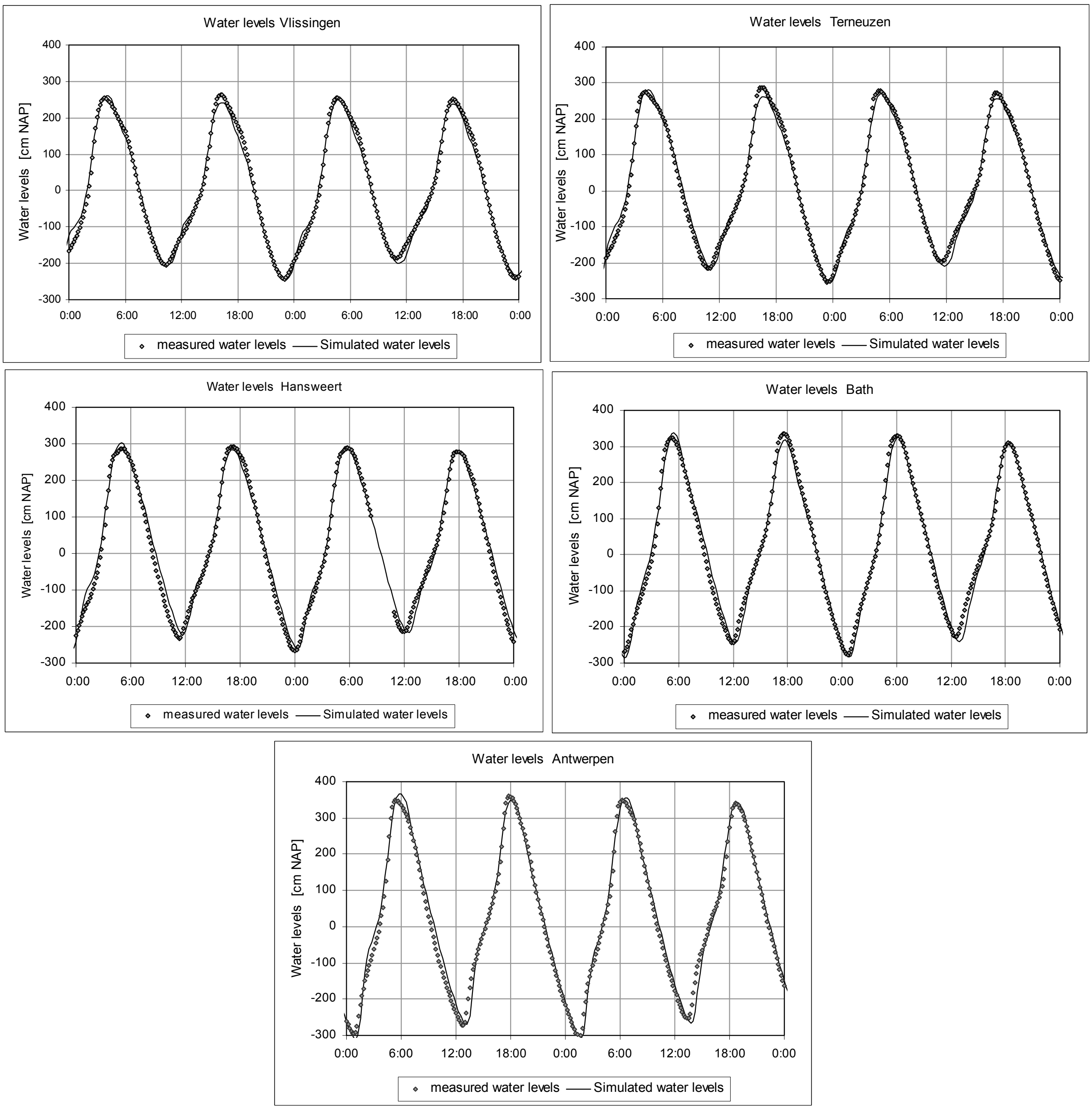

Figure 29: Simulated water levels at the Scheldt estuary with the Extended-SIGMA-HD model. Period September 2002.

5.2. Comparison with the SIGMA model for a storm event

As discussed in chapter 3, during the process of adapting the existing MIKE 11 model to the needs of the sediment transport model, different verifications have been carried out in order to generate similar and consistent results with the SIGMA model.

As can be observed in figures 19 to 23, the Modified-SIGMA-HD model gives better results for the discharges without significant differences in water levels compared to the Sigma model. In order to evaluate the difference between the two models (and as it has been requested by the WLH, in the meeting of 31st January 2006) a simulation with the Modified-SIGMA-HD model has been performed for a storm condition.

The event of October 1992, which is one of the events used in the calibration of the SIGMA model, has been used for this purpose. Figure 30 gives a longitudinal profile where the simulated high waters for the two models are compared to the measured values and where is possible to see that the Modified-SIGMA-HD model gives similar results than the SIGMA model.

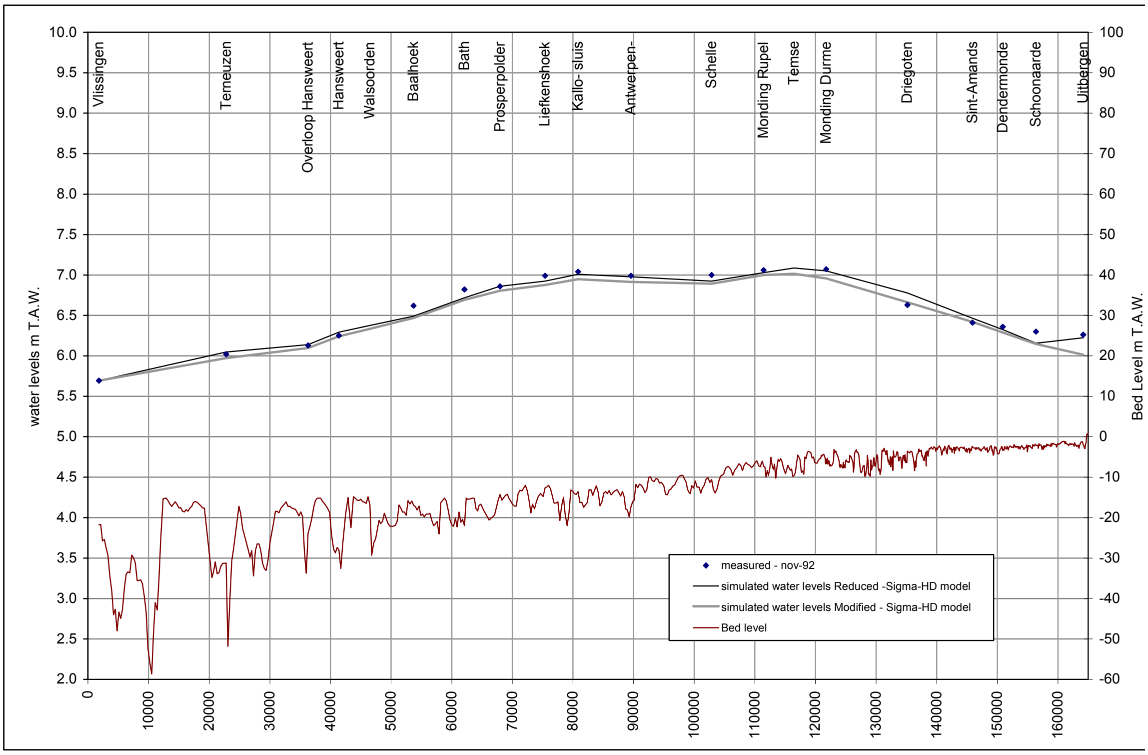

Figure 30: Longitudinal profile of the maximum water levels along the Western Scheldt- Sea Scheldt simulated with the Reduced-SIGMA-HD model and the Modified-SIGMA-HD model, storm event October 1992

6. CONCLUSIONS

Based on the results of the calibration and verification process the following conclusions can be formulated:

- The water levels are properly simulated with the Modified-SIGMA-HD model for the different stations along the system. No significant differences can be observed with respect to the water levels simulated with the SIGMA model.
- The simulated tidal range satisfactorily matches the measured tidal range.
- The flow discharge distribution in the ebb and flood channels is correctly simulated, for most of the reaches in the Western Scheldt and Sea Scheldt.
- The general residual discharges are correctly reproduced, however the simulated ebb and flood volumes are slightly overestimated.
- The Modified-SIGMA-HD model lead, for storm events, to similar results as the Reduced-SIGMA-HD model.
- The extension into the North Sea (Extended-SIGMA-HD) does not lead to significant differences in water levels compared to the Modified-SIGMA-HD model

Finally we can conclude that the Extended-SIGMA-HD model based on the SIGMA model is able to reproduce properly and with adequate accuracy the hydrodynamics of the system. The model properly accounts for the distribution of the tidal flow over the ebb and flood channels, which makes it suitable for applications in sediment transport computations and advection dispersion computations.

The Modified-SIGMA-HD model properly reproduces the water levels along the Western Scheldt and the Sea Scheldt. However, the model does not include the flooding areas of the Sea Scheldt and its tributaries, therefore, is recommended to use the Existing-Sigma-HD model in case flood risk analysis should be performed.

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ANNEX 1: EBB AND FLOOD VOLUMES OF THE SCHELDT ESTUARY

Table 10:Tide characteristics of the ebb and flood channels at different measurement tracks (RIKZ 2005)

nr.	year	ebb-volume (M m³)		Flood volume (M m³)		Q max ebb (10³ m³/s)		Q max flood (10³ m³/s)		Area. Profile (m² below NAP)	
		NvB	SvdN	NvB	SvdN	NvB	SvdN	NvB	SvdN	NvB	SvdN
2	1972	126.5	84.6	67.2	140.9	7.5	5.9	6.6	13.5	9110	7785
2	1982	146.5	60.1	93.7	117.4	9.4	4.5	7.7	10.3	10150	8500
2	1989	139.4	51.8	92.1	106.3	10.5	5.1	7.3	10.5	7973	9515
2	1994	159.8	68.8	106.1	117.8	10.3	5.5	8.4	11.3	10535	8335
2	1998	154.1	73.2	106.1	121.0	10.0	4.9	9.6	12.6	10305	8060
		OvV	Zim	OvV	Zim	OvV	Zim	OvV	Zim	OvV	Zim
3	1933	202.5	56.5	187.5	61.5	12.2	3.9	15.2	5.9	11788	4875
3	1963	186.2	58.8	175.2	64.1	11.2	4.5	17.6	7.6	11570	3020
3	1980	214.0	59.8	194.3	62.0	13.5	3.6	20.2	7.6	13200	4550
3	1988*	224.5	34.3	228.6	28.8	14.1	3.4	21.5	4.0	14503	3382
3	1990	220.6	24.5	230.5	27.4	14.2	2.1	18.9	2.8	15260	3218
3	1995	229.0	27.8	214.7	21.5	14.0	4.0	23.1	3.8	15640	2400
3	1996	238.6	23.1	236.3	19.8	14.7	2.2	22.8	3.2	16060	2490
3	2001	254.1	17.9	247.7	13.0	16.3	1.8	23.9	2.5	17575	2355
		Zgat	SvW	Zgat	SvW	Zgat	SvW	Zgat	SvW	Zgat	SvW
5	1937	176.6	213.4	134.7	233.8	10.6	14.4	12.6	20.6	13313	19625
5	1957	182.4	198.0	113.2	259.1	9.8	12.3	12.5	26.9	10934	18867
5	1964	188.4	170.6	126.6	225.5	10.3	11.8	14.4	22.5	12585	16025
5	1970	190.4	157.0	158.8	224.4	10.7	11.8	17.0	23.3	14190	16375
5	1975	219.3	146.5	172.3	201.1	13.4	10.9	17.0	20.7	14900	15075
5	1981	245.1	155.5	169.2	206.2	14.9	12.0	19.3	24.4	16950	17000
5	1988	197.2	155.2	165.7	204.3	12.9	12.8	16.3	20.6	16566	16736
5A	1990	239.2	114.6	203.9	124.6	14.9	9.0	15.7	11.8	18321	11155
5A	1995	228.8	126.3	205.2	147.5	13.6	10.7	18.7	17.5	18120	12760
5A	1996	235.6	144.2	211.6	159.4	13.9	11.5	19.9	17.4	18013	12870
5A	1997	223.0	125.8	214.4	148.9	13.2	10.0	19.8	18.3	18155	13105
5A	1998	234.6	132.1	220.1	139.6	15.0	11.2	19.7	16.2	18500	13300
5A	1999	228.6	140.9	220.8	149.7	14.6	11.2	21.1	18.4	18895	13460
5A	2000	236.5	124.2	219.0	141.7	14.1	10.0	20.4	16.9	18630	13495
5A	2001	246.9	128.7	214.4	135.3	14.3	10.6	20.8	17.4	17930	12995
5A	2002	238.0	134.7	221.3	137.7	14.9	11.7	19.6	16.1	19115	13440
		Mgat	GvO	Mgat	GvO	Mgat	GvO	Mgat	GvO	Mgat	GvO
6	1932	388.0	157.0	298.0	246.0	23.8	10.0	24.0	17.5	24030	19400
6	1957	326.2	165.2	257.0	232.3	18.1	10.7	24.9	20.0	23529	16600
6	1968	340.5	201.5	249.2	273.3	20.4	13.9	24.4	23.9	22250	18800
6	1972	279.6	226.3	230.8	273.0	17.6	15.6	21.4	23.9	22100	18950
6	1978	294.3	245.9	234.4	306.1	17.6	17.2	25.9	31.5	20200	19000
6	1983	292.3	244.4	215.1	298.3	18.4	16.3	22.6	30.1	20050	19570
6	1988	252.6	245.6	211.1	293.3	16.2	15.8	23.5	26.2	18110	17670
6	1989	260.7	270.5	206.4	303.5	16.0	17.0	21.2	28.3	18790	18183
6	1994	254.8	259.1	221.4	283.2	16.0	16.9	21.9	26.6	17950	19700
6	2001	253.9	307.3	198.4	333.7	16.4	20.0	16.4	29.4	16920	20830

		PvT	Ever	PvT	Ever	PvT	Ever	PvT	Ever	PvT	Ever
7	1961	379	310	301	373	24	22	28	32	22700	23850
7	1974	325	359	292	430	22	26	27	40	21590	26350
7	1982	371	353	284	399	24	28	28	35	22130	27400
7	1989	363	326	287	384	25	26	31	37	21830	24458
7	1996	344	375	278	433	22	26	28	39	22575	27950
7	1997	312	340	285	442	24	24	28	37	24445	28250
7	1998	360	373	293	421	24	25	28	35	22797	23875
7	1999	365	371	286	435	23	27	29	37	22945	25065
7	2000	374	359	292	426	24	24	29	36	22670	25140
7	2001	356	364	275	417	23	26	28	36	22640	26650
7	2002	380	395	289	426	25	29	27	37	22850	27350
7	2003	360	380	275	435	23	27	28	39	22105	27685
		VlH	H+SSp	VlH	H+SSp	VlH	H+SSp	VlH	H+SSp	VlH	H+SSp
9	1960	118.2	77.2	118.2	772.6	7.9	56.7	12.3	71.5	10000	65300
9	1979	122.4	832.0	111.4	831.7	9.2	59.9	11.9	79.2	9680	66350
9	1986**	101.5	655.0	97.3	760.7	8.0	59.1	10.5	78.8	10600	67900
9	1991	94.6	744.1	101.3	733.1	7.3	53.6	12.3	75.7	8883	69075
9	1996	93.8	840.7	96.5	852.8	7.5	59.4	11.1	78.5	8345	66685
9	2001	89.5	843.4	88.7	836.3	7.1	58.5	10.2	80.8	8110	63700
		VlH	H	VlH	H	VlH	H	VlH	H	VlH	H
10	1958	151.6	834.0	140.2	847.7	11.1	57.0	12.5	75.1	10700	66875
10	1971	128.6	862.6	119.4	847.7	9.8	60.7	12.6	83.8	9500	68275
10	1982	127.8	852.9	108.5	868.9	6.7	61.8	11.3	84.9	9025	68850
10	1989	117.6	818.6	102.6	825.3	8.8	59.2	11.1	80.2	9790	67785
10	1997	118.5	887.8	129.2	881.7	8.9	65.2	13.4	82.8	10630	67715
10	2002	112.1	923.4	106.6	925.3	8.1	67.0	10.8	82.1	10150	68080
		Wiel	Sard	Wiel	Sard	Wiel	Sard	Wiel	Sard	Wiel	Sard
11	1932	988.0	107.0	950.0	126.0	69.0	7.6	85.7	8.8	77000	9250
11	1966	991.0	91.5	1012.1	106.8	70.7	6.8	93.4	8.0	73250	8750
11	1985	938.7	92.8	813.5	112.8	64.3	7.3	74.6	8.9	71125	9125
11	1995	1035.4	93.3	987.4	113.8	74.9	7.4	93.8	9.1	70300	9810
11	1997	1058.2	114.7	1027.5	137.0	71.9	8.0	95.7	11.5	71970	9950
11	2000	1060.7	119.5	989.0	123.6	75.0	8.9	97.0	10.6	71570	9635

Where:

Raai 2:	NvB =	Nauw van Bath	SvdN =	Schaar van de Noord
Raai 3:	OvV =	Overloop van Valkenisse	Zim =	Zimmermangeul
Raai 5:	Zgat =	Zuidergat	SvW =	Schaar van Waarde
Raai 6:	Mgat =	Middelgat	GvO =	Gat van Ossenisse
Raai 7:	PvT =	Pas van Terneuzen	Ever =	Everingen
Raai 9:	VlH =	Vaarwater langs Hoofdplaat	H+SSp=	Honte + Schaar v.d. Spijkerplaat
Raai 10:	VlH =	Vaarwater langs Hoofdplaat	H =	Honte
Raai 11:	Wiel =	Wielingen	Sard =	Sardijngeul

ANNEX 2: SIMULATED WATER LEVELS

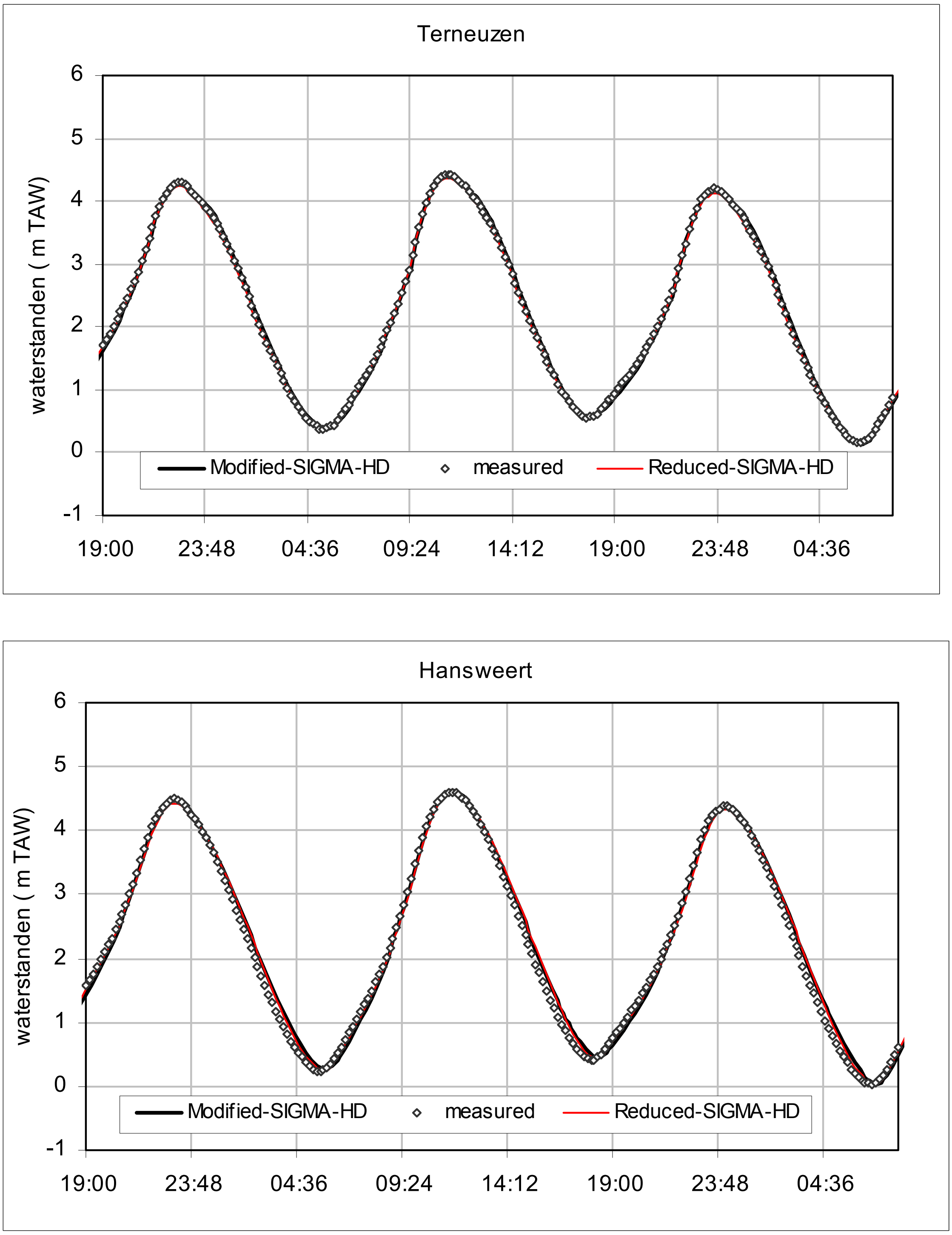


Figure 31: Simulated water levels at Terneuzen and Hansweert. 10 to 14 June 2000.

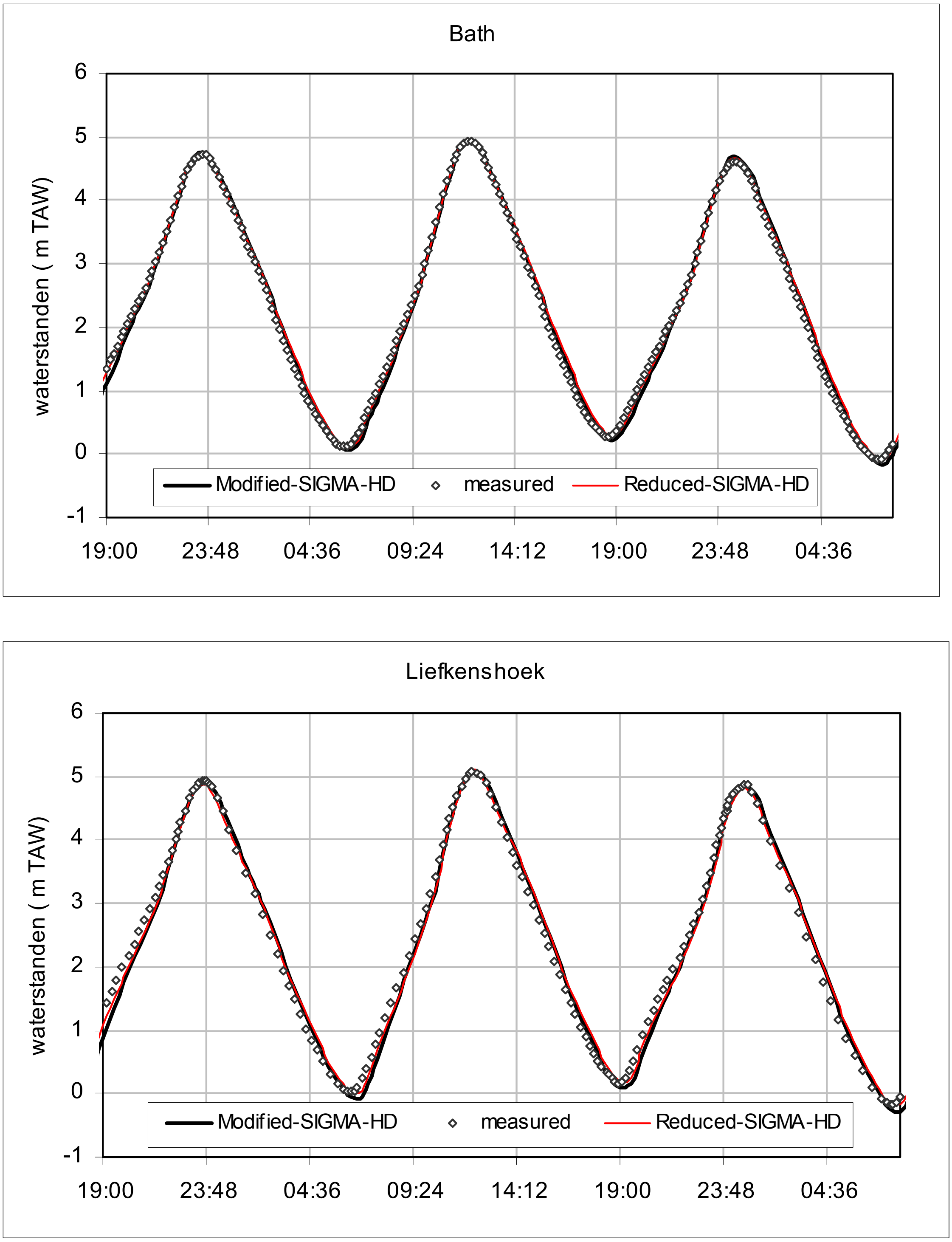
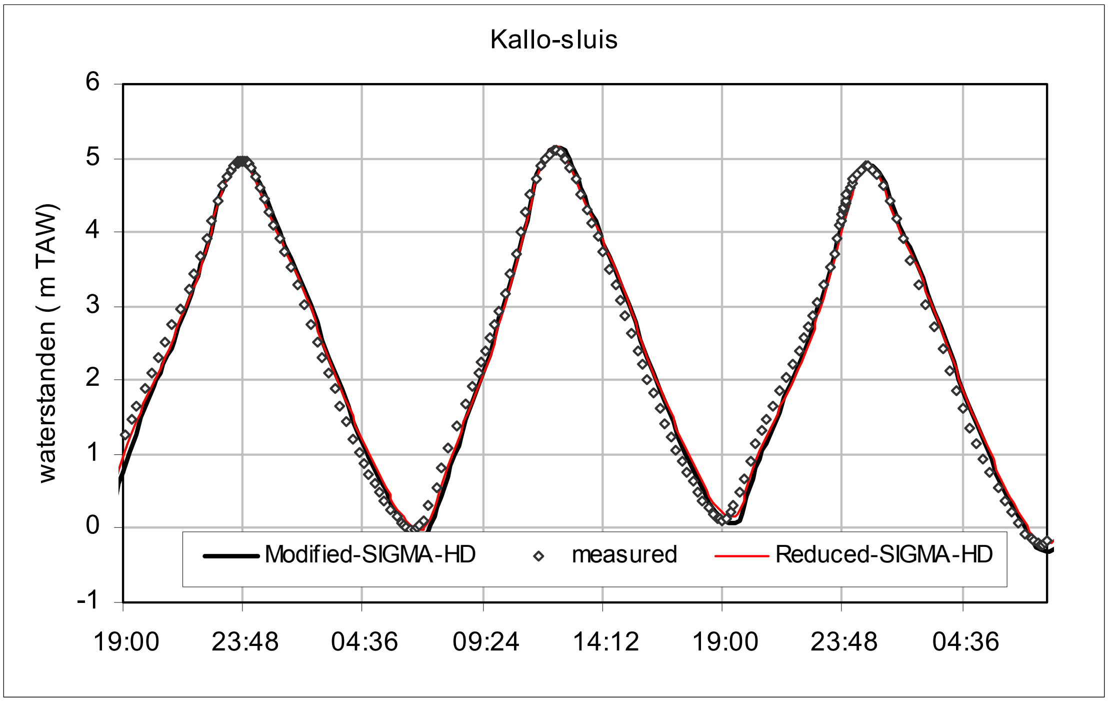


Figure 32: Simulated water levels at Bath and Liefkenshoek. 10 to 14 June 2000.



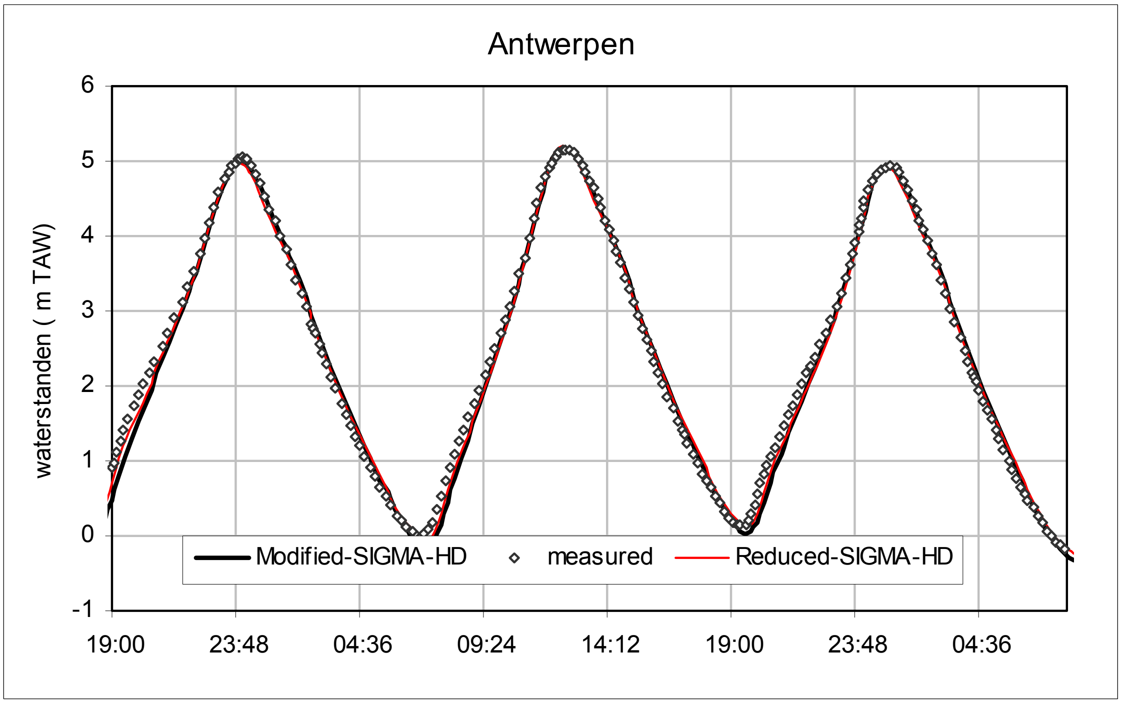
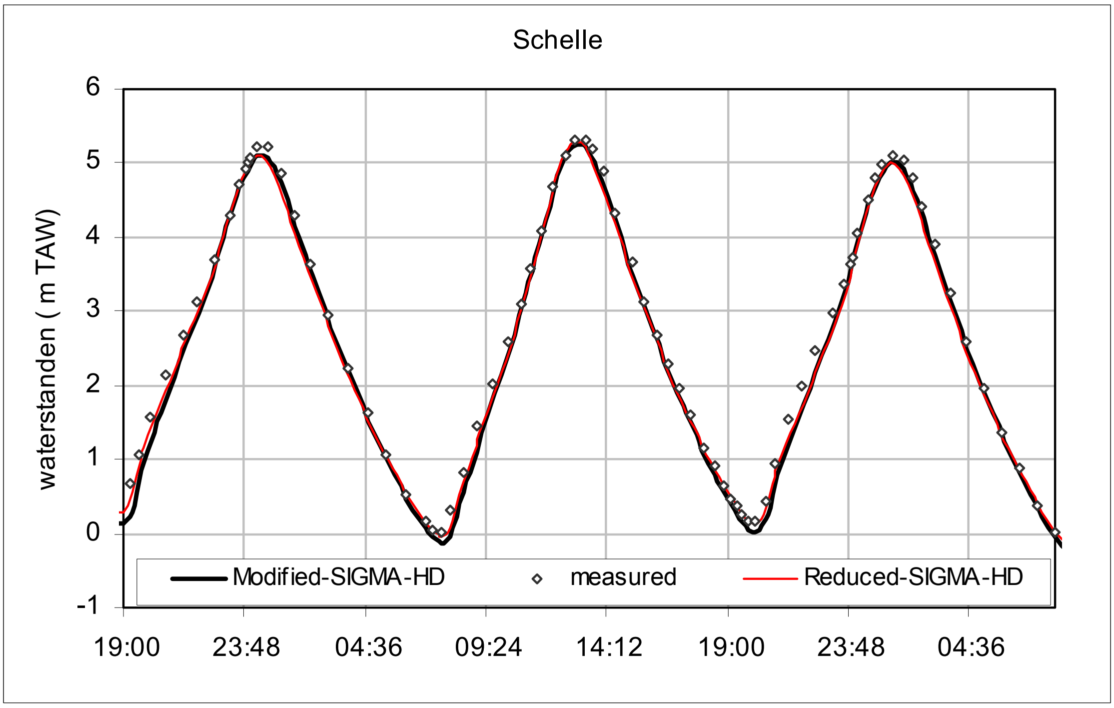


Figure 33: Simulated water levels at Kallo and Antwerp. 10 to 14 June 2000.



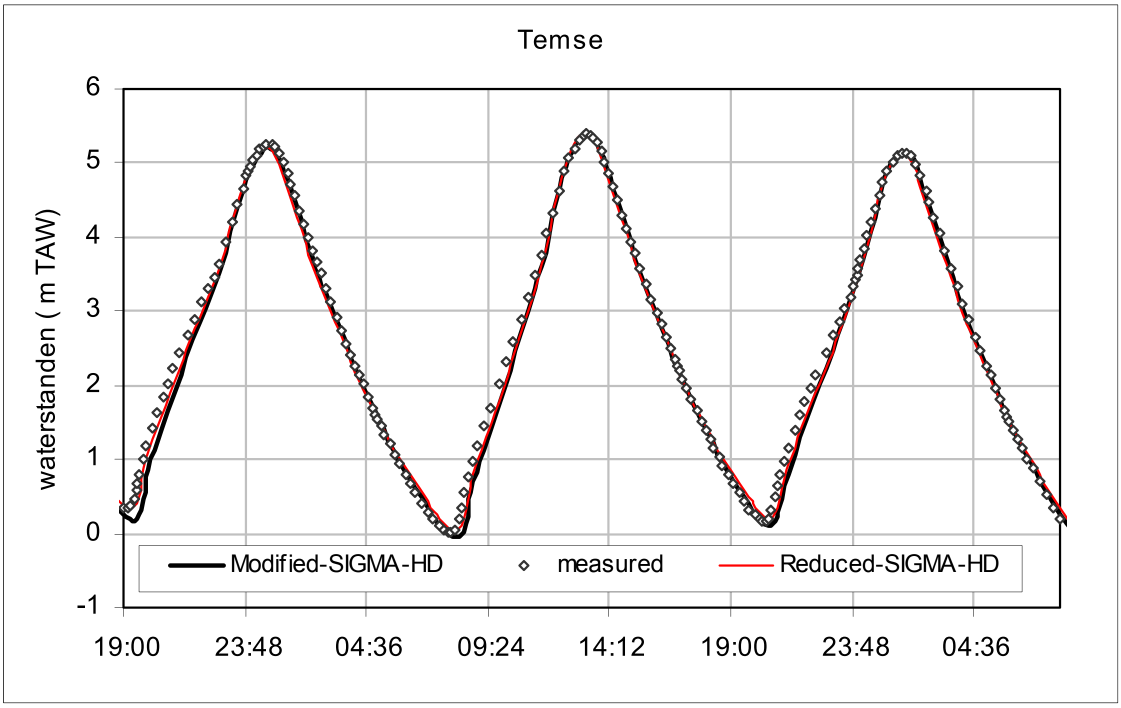
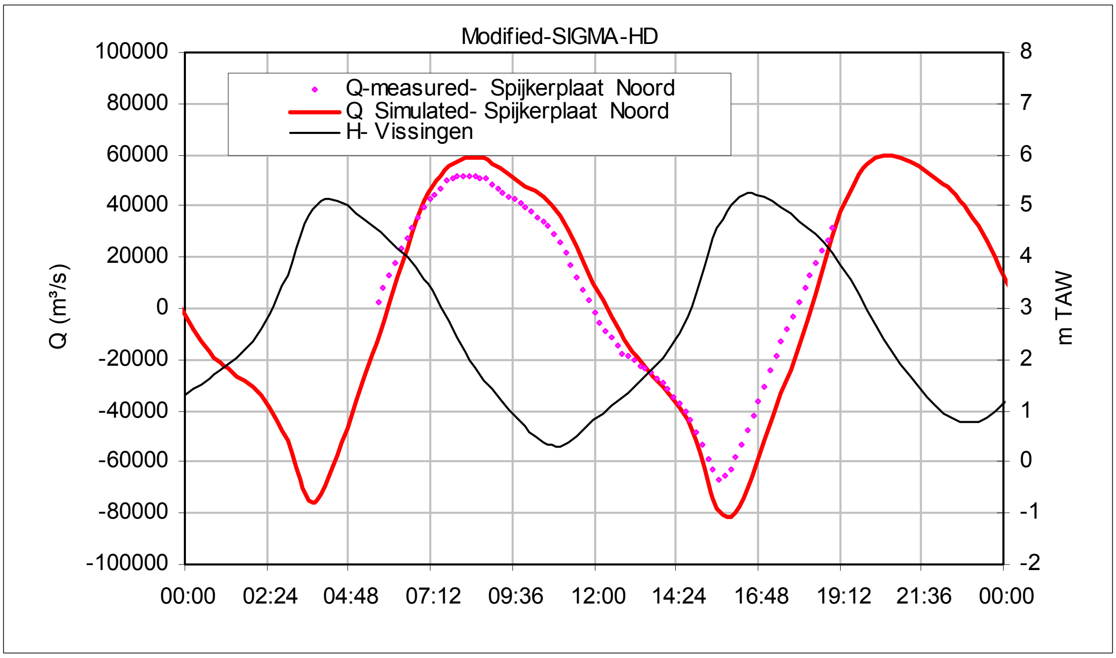


Figure 34: Simulated water levels at Schelle and Temse. 10 to 14 June 2000.

ANNEX 3: SIMULATED DISCHARGES



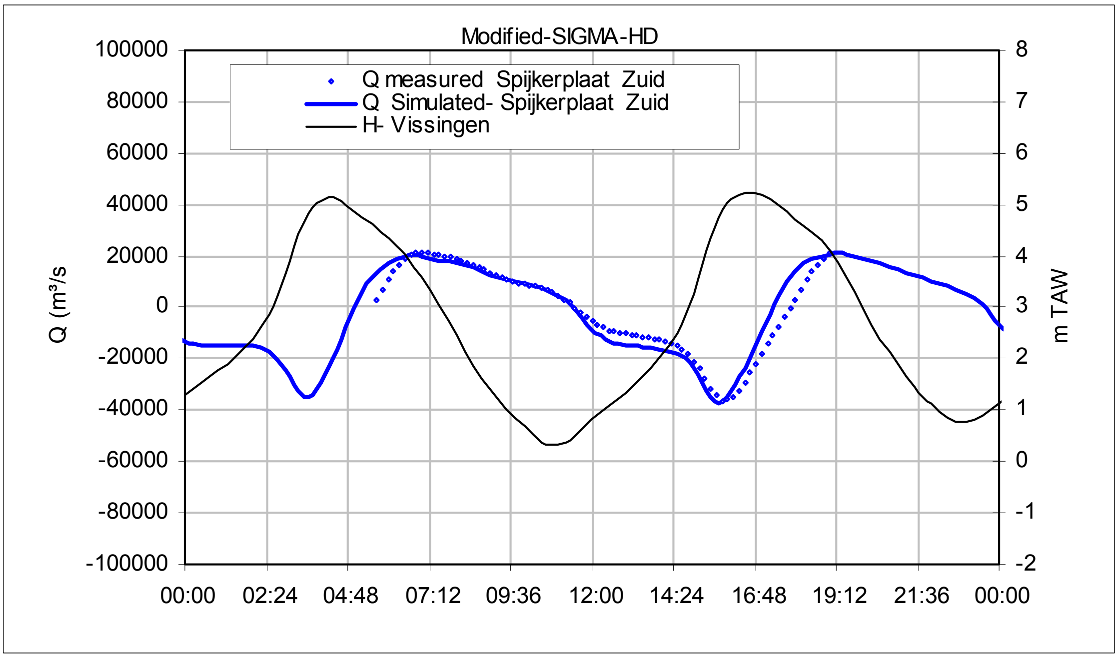
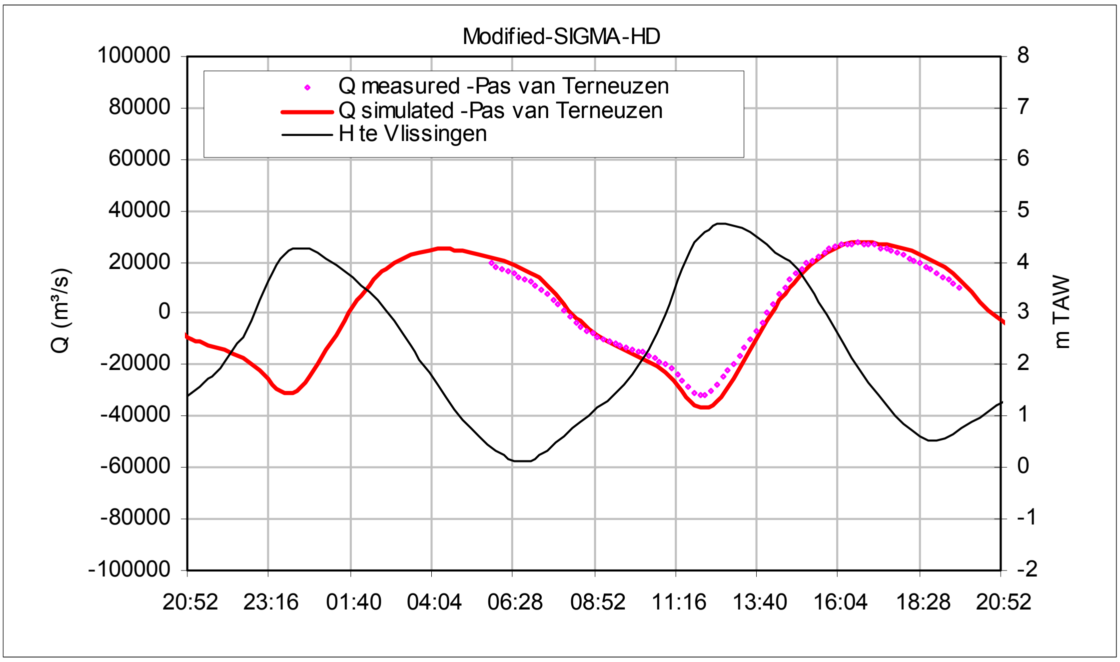


Figure 35:Simulated discharges at Measurement track (Raai) 9.



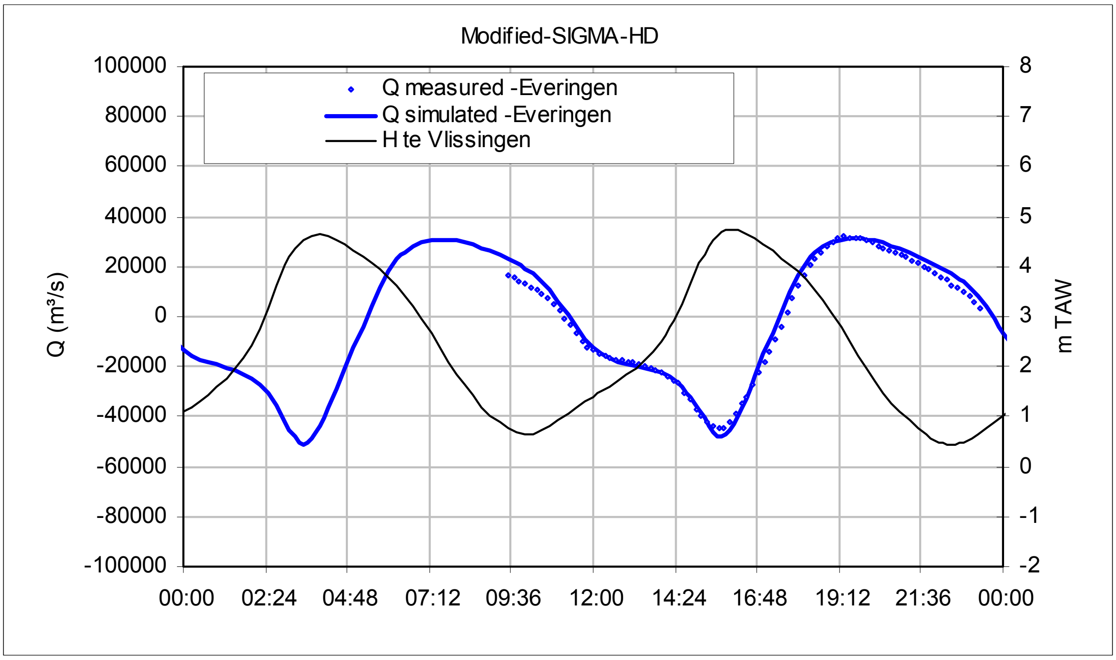
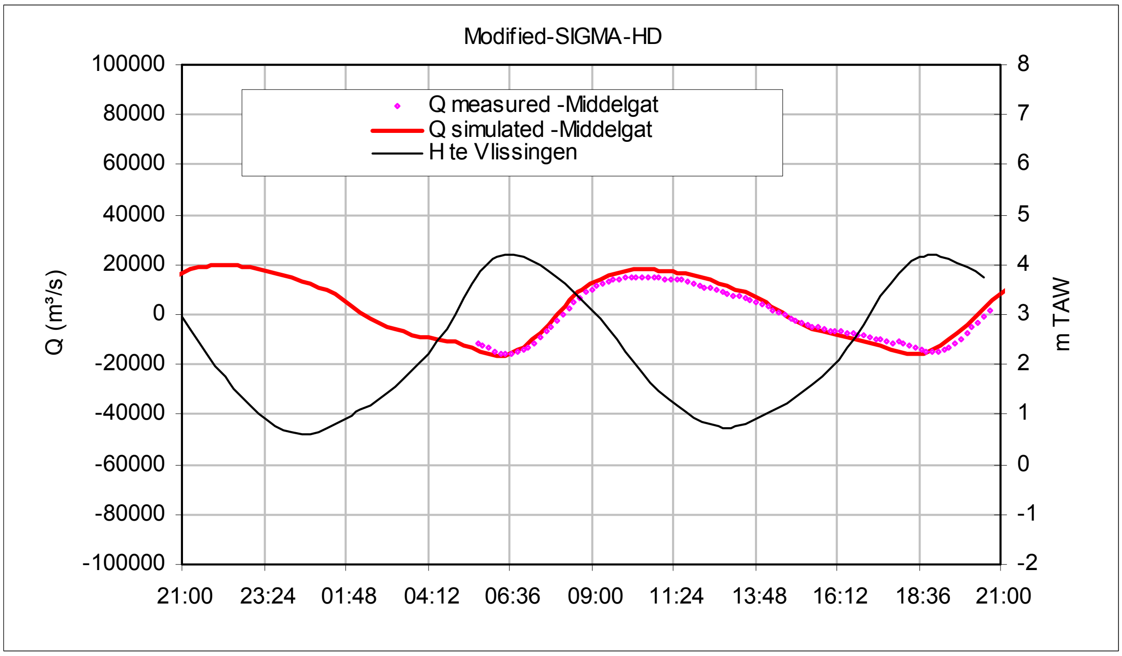


Figure 36: Simulated discharges at Measurement track (Raai) 7.



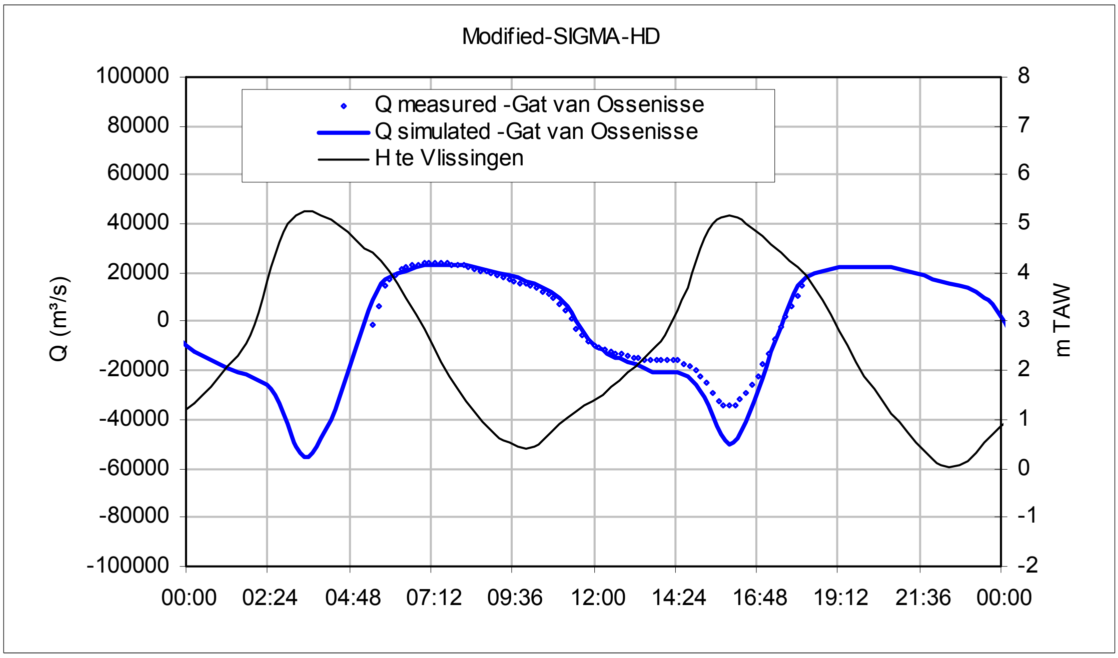
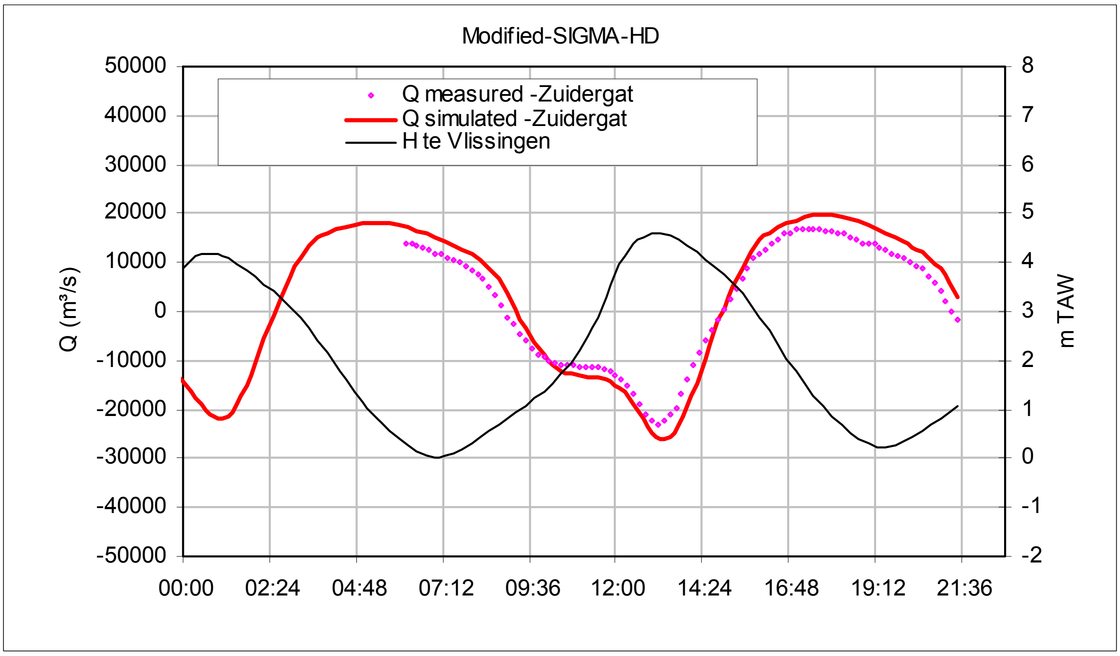


Figure 37: Simulated discharges at Measurement track (Raai) 6.



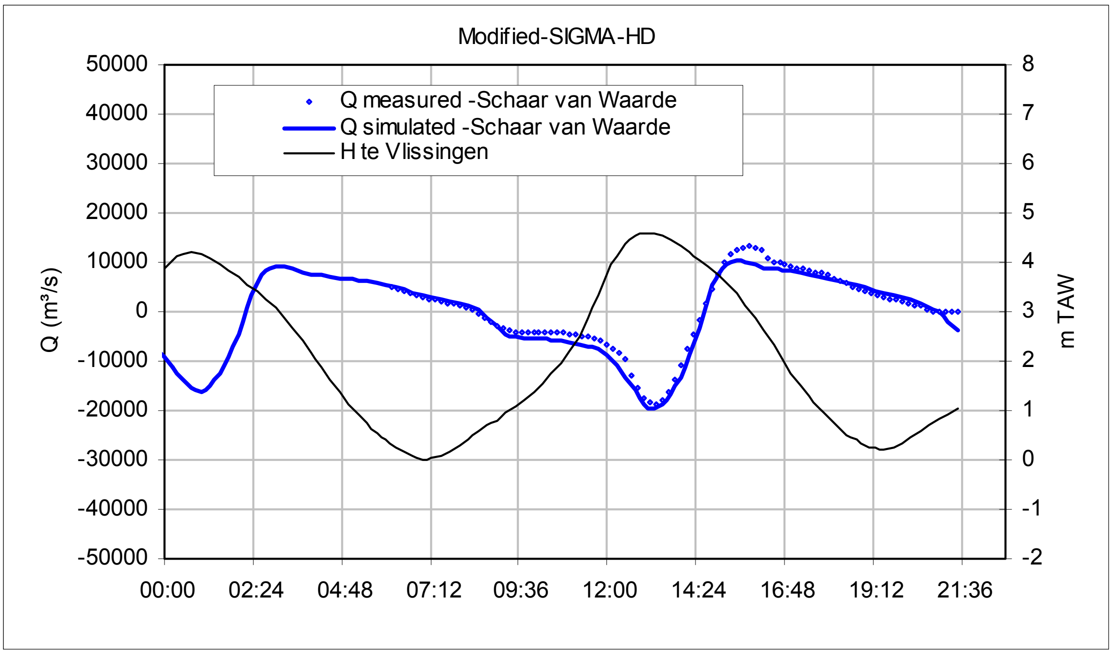


Figure 38: Simulated discharges at Measurement track (Raai) 5A.

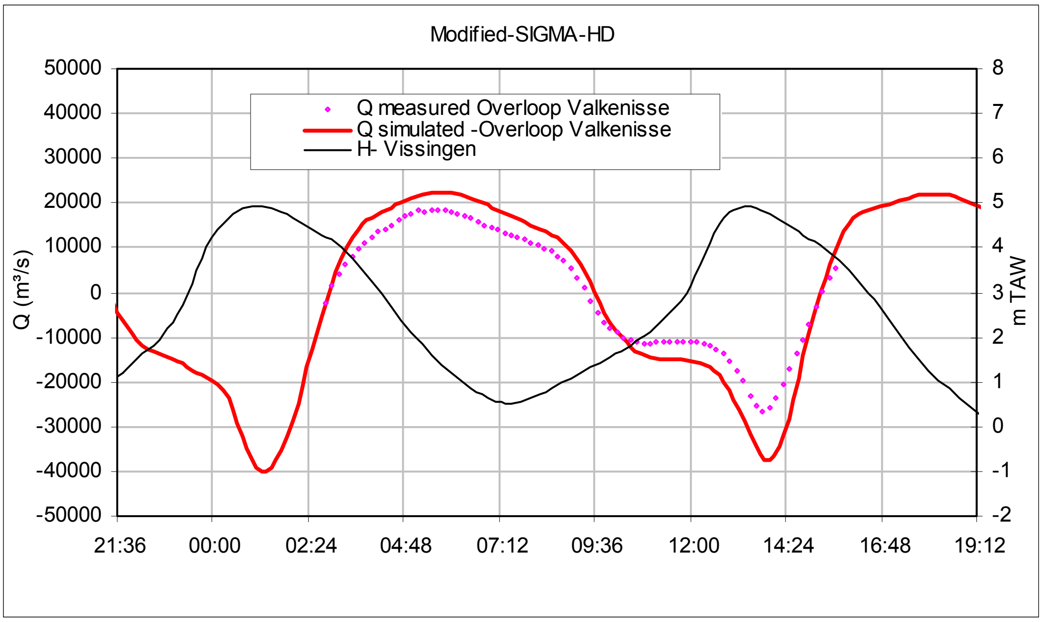
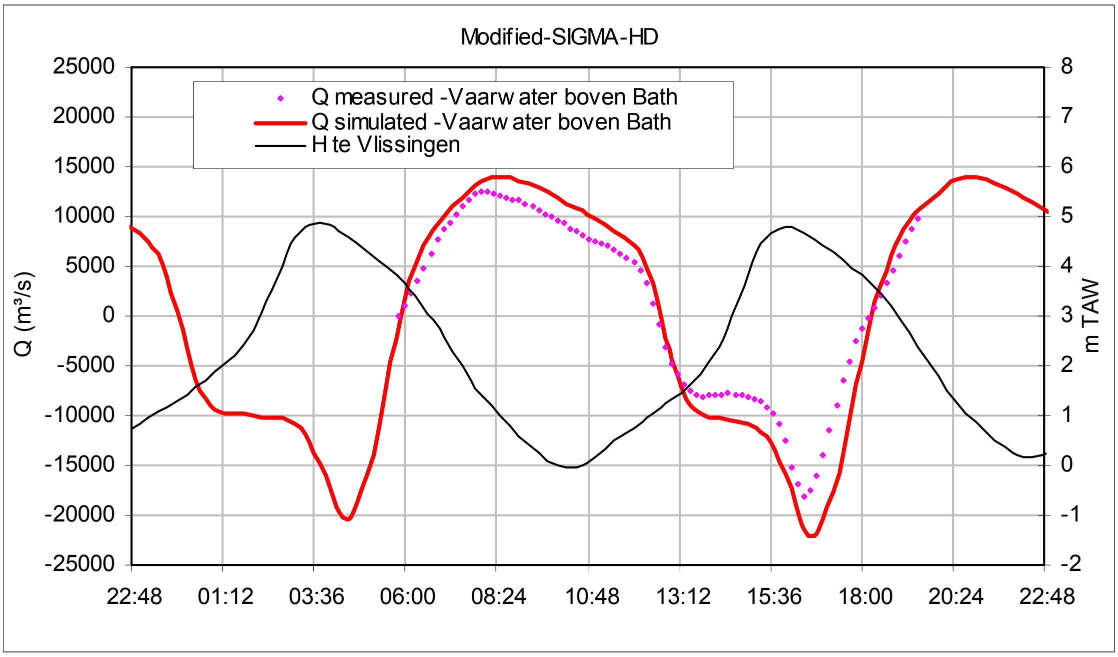


Figure 39: Simulated discharges at Measurement track (Raai) 3.



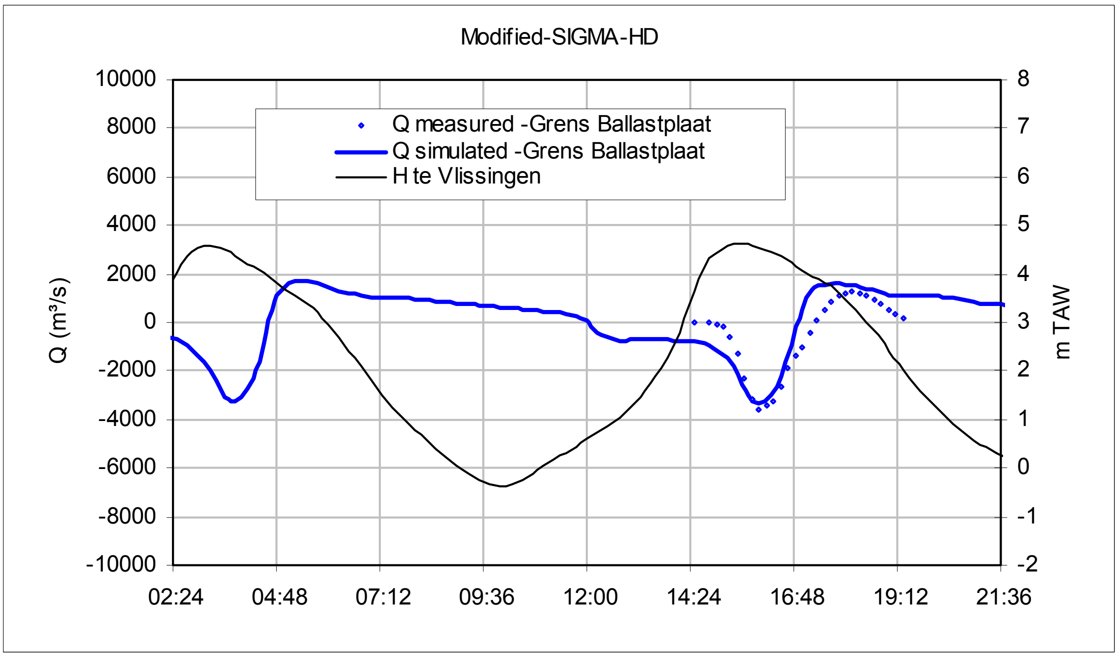
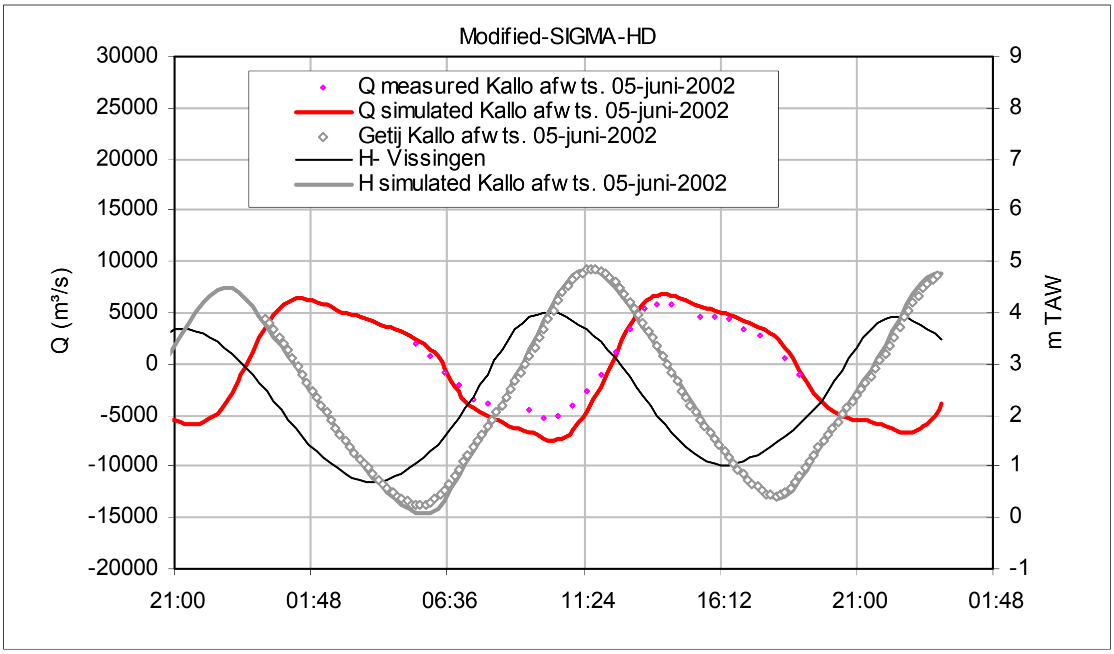


Figure 40: Simulated discharges at Measurement track (Raai) 1A.



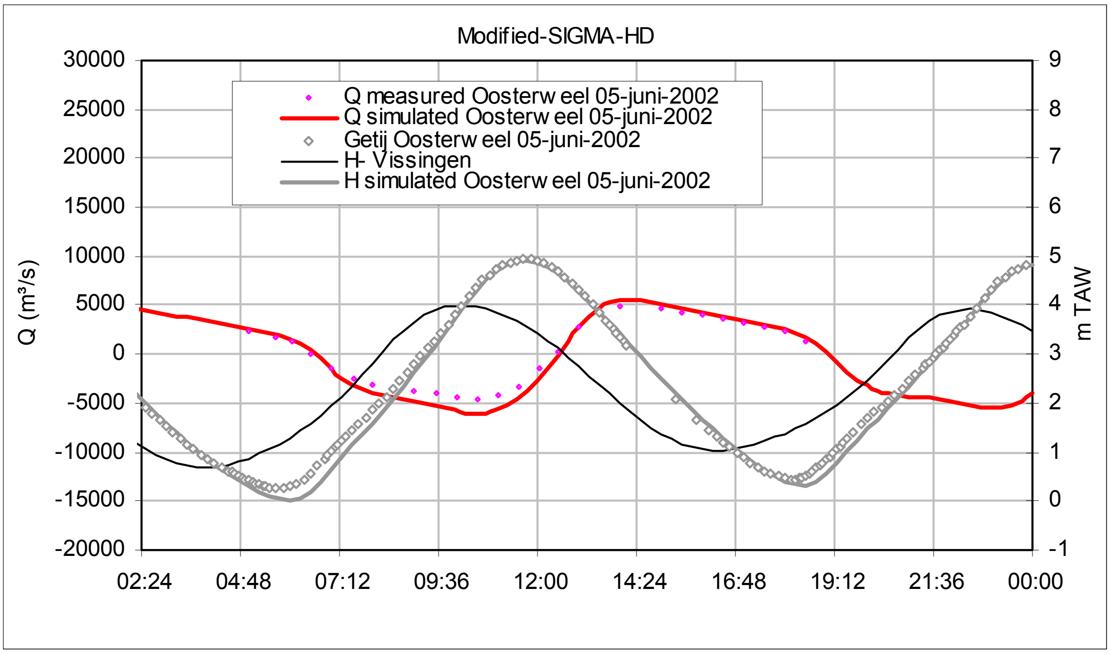
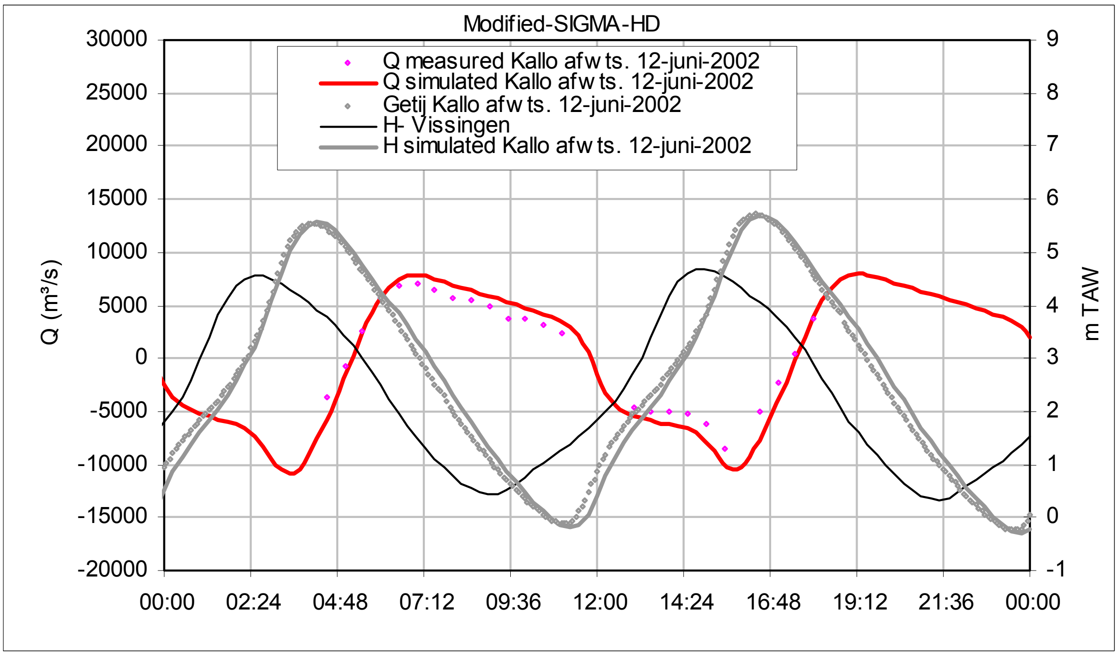


Figure 41: Simulated discharges at Kallo and Osterweel. 5 juni 2002.



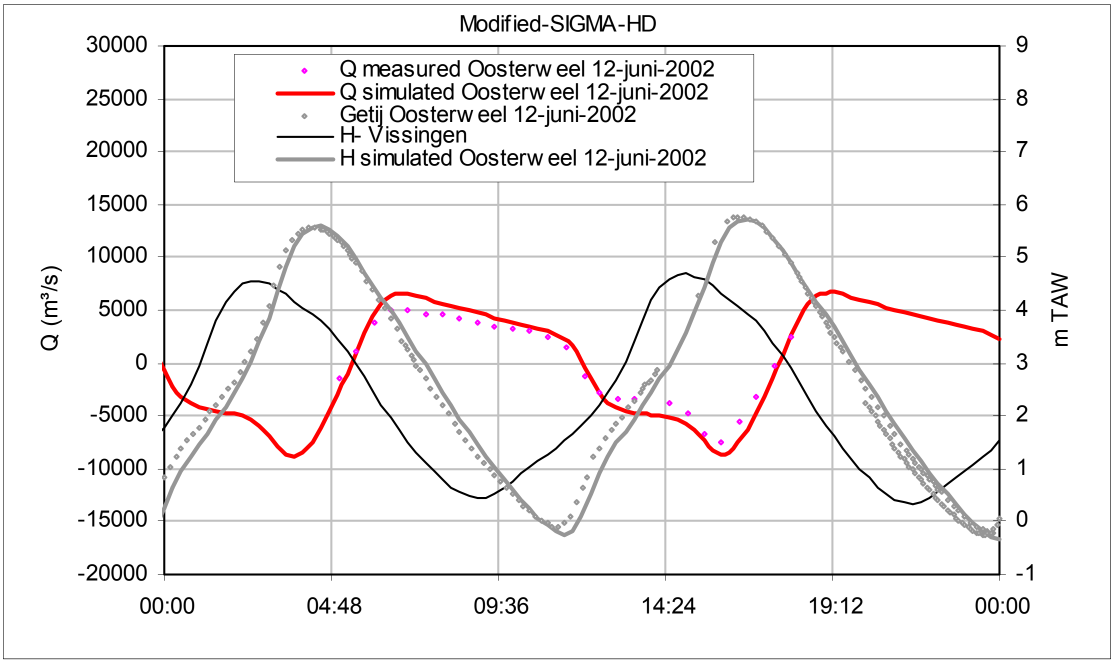


Figure 42: Simulated discharges at Kallo and Osterweel. 12 juni 2002.

ANNEX 4: CALIBRATION PARAMETERS

The calibration process comprises a sequence of trial simulations, in which the manning number in the different branches is changed. The starting set of parameters corresponds to the calibrated set of the SIGMA model. This set of parameters gave good results for water levels, but the flow discharge distribution in the different channels at the Western Scheldt was not correctly reproduced.

Once the schematization of the network was changed, different simulations were tried in order to evaluate the effect of a local change of the manning coefficient, channel by channel. Table 11 gives an overview of the different manning numbers at the main branches of the system, and in Table 12 the final set of manning numbers is given for all the branches.

Increasing significantly the manning number “n” at the area close to the mouth in the North Sea, was the only way to achieve a better distribution in the discharges. However this set of parameters lead to less accurate results for the water levels.

Later, a new feature was introduced in MIKE 11 source code in order to reproduce properly the residual circulations along the different branches in the Western Scheldt. With this application a flow-direction-dependent bed friction term can be introduced for different branches, allowing the user to decrease the manning number at a given branch and for a defined reach, with a given percentage. In Table 13 the final set of flow-dependant coefficients is presented.

Different figures and tables with results are shown for the SIGMA model, as well as for an intermediate simulation (i.e. simulation “T”). Finally the results for the last version, without the flow-dependant manning, are presented. The final results were already presented in section 4.

River Name	Chainage	Location	SIGMA	HD-8B	HD-8C	HD-8D	HD-8E	HD-8F	HD-8G	HD-8H	C	I	J	K-1	L	M	N	O	Q	R	S	T	U	V	W	X-1	x-2	Final niet reverse	Final-reverse-report
VAARWATER-HOOFDPLAAT	0		0.0250	0.0320	0.0250	0.0300	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0340	0.0300	0.0300	0.0200
VAARWATER-HOOFDPLAAT	14520		0.0250	0.0320	0.0250	0.0300	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0340	0.0300	0.0300	0.0200
SCHAAR-SPIJKERPLAAT	0		0.0250	0.0320	0.0250	0.0300	0.0300	0.0300	0.0300	0.0320	0.0250	0.0300	0.0250	0.0250	0.0300	0.0280	0.0260	0.0250	0.0260	0.0260	0.0270	0.0280	0.0270	0.0280	0.0320	0.0340	0.0320	0.0300	0.0200
SCHAAR-SPIJKERPLAAT	9700		0.0250	0.0320	0.0250	0.0300	0.0300	0.0300	0.0300	0.0320	0.0250	0.0300	0.0250	0.0250	0.0300	0.0280	0.0260	0.0250	0.0260	0.0260	0.0270	0.0280	0.0270	0.0280	0.0320	0.0340	0.0320	0.0300	0.0200
WESTERSCHELDE	0	monding noordzee	0.0250	0.0320	0.0350	0.0300	0.0350	0.0320	0.0350	0.0350	0.0350	0.0320	0.0250	0.0250	0.0300	0.0300	0.0270	0.0270	0.0260	0.0260	0.0260	0.0260	0.0260	0.0260	0.0340	0.0340	0.0300	0.0300	0.0220
WESTERSCHELDE	10100	end-raai-9	0.0250	0.0320	0.0350	0.0300	0.0350	0.0320	0.0350	0.0350	0.0350	0.0320	0.0250	0.0250	0.0300	0.0300	0.0270	0.0270	0.0260	0.0260	0.0260	0.0260	0.0260	0.0260	0.0340	0.0340	0.0300	0.0300	0.0220
WESTERSCHELDE	13900	Begin-raai--7	0.0252	0.0320	0.0300	0.0300	0.0300	0.0300	0.0300	0.0350	0.0300	0.0300	0.0252	0.0252	0.0300	0.0300	0.0270	0.0270	0.0270	0.0270	0.0220	0.0250	0.0250	0.0250	0.0250	0.0240	0.0300	0.0250	0.0250
WESTERSCHELDE	29100	End-raai-7	0.0262	0.0270	0.0262	0.0300	0.0262	0.0300	0.0262	0.0350	0.0262	0.0250	0.0262	0.0350	0.0300	0.0300	0.0270	0.0270	0.0270	0.0270	0.0220	0.0250	0.0250	0.0250	0.0250	0.2000	0.0300	0.0240	0.0250
WESTERSCHELDE	31000	Begin-Raai-6	0.0263	0.0270	0.0263	0.0300	0.0263	0.0280	0.0263	0.0350	0.0263	0.0250	0.0263	0.0350	0.0300	0.0300	0.0270	0.0270	0.0270	0.0270	0.0220	0.0250	0.0260	0.0250	0.0250	0.1800	0.0250	0.0230	0.0220
WESTERSCHELDE	39600	End-Raai-6	0.0269	0.0270	0.0269	0.0300	0.0269	0.0280	0.0269	0.0300	0.0269	0.0250	0.0269	0.0350	0.0300	0.0300	0.0270	0.0270	0.0250	0.0250	0.0220	0.0220	0.0200	0.0220	0.0220	0.1800	0.0200	0.0220	0.0220
WESTERSCHELDE	41700	+o- Hasweert	0.0270	0.0270	0.0270	0.0300	0.0270	0.0270	0.0270	0.0300	0.0270	0.0270	0.0270	0.0350	0.0300	0.0300	0.0270	0.0240	0.0250	0.0250	0.0220	0.0220	0.0200	0.0220	0.0220	0.1800	0.0200	0.0220	0.0200
WESTERSCHELDE	54600		0.0270	0.0240	0.0270	0.0300	0.0270	0.0270	0.0270	0.0300	0.0270	0.0270	0.0270	0.0270	0.0270	0.0350	0.0270	0.0240	0.0250	0.0250	0.0220	0.0220	0.0200	0.0220	0.0220	0.1800	0.0200	0.0220	0.0200
WESTERSCHELDE	59508		0.0270	0.0240	0.0270	0.0300	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0350	0.0270	0.0240	0.0250	0.0250	0.0220	0.0220	0.0200	0.0220	0.0220	0.1800	0.0200	0.0220	0.0200
WESTERSCHELDE	62100	Bath	0.0270	0.0240	0.0270	0.0300	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0350	0.0270	0.0240	0.0250	0.0250	0.0220	0.0220	0.0200	0.0220	0.0220	0.1800	0.0200	0.0220	0.0200
WESTERSCHELDE	65000		0.0270	0.0240	0.0270	0.0300	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0350	0.0350	0.0240	0.0250	0.0250	0.0220	0.0220	0.0200	0.0220	0.0220	0.1800	0.0200	0.0220	0.0220
ZEESCHELDE2	100		0.0290	0.0240	0.0290	0.0300	0.0290	0.0290	0.0290	0.0290	0.0290	0.0290	0.0290	0.0290	0.0290	0.0350	0.0350	0.0240	0.0250	0.0250	0.0220	0.0220	0.0200	0.0200	0.0200	0.1800	0.0200	0.0200	0.0220
ZEESCHELDE2	6600		0.0290	0.0240	0.0290	0.0300	0.0290	0.0290	0.0290	0.0290	0.0290	0.0290	0.0290	0.0290	0.0290	0.0350	0.0350	0.0240	0.0250	0.0250	0.0220	0.0240	0.0200	0.0200	0.0200	0.1800	0.0200	0.0200	0.0240
ZEESCHELDE2	10129		0.0290	0.0240	0.0290	0.0300	0.0290	0.0290	0.0290	0.0290	0.0290	0.0290	0.0290	0.0290	0.0290	0.0350	0.0350	0.0240	0.0250	0.0250	0.0220	0.0240	0.0200	0.0200	0.0200	0.1800	0.0200	0.0200	0.0240
ZEESCHELDE	10129		0.0240	0.0240	0.0240	0.0300	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0350	0.0350	0.0240	0.0250	0.0250	0.0220	0.0240	0.0250	0.0200	0.0200	0.1800	0.0200	0.0200	0.0240
ZEESCHELDE	15678	kallosluis	0.0240	0.0240	0.0240	0.0300	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0350	0.0350	0.0240	0.0250	0.0250	0.0220	0.0240	0.0250	0.0200	0.0200	0.1800	0.0220	0.0200	0.0240
ZEESCHELDE	23005	oosterweel	0.0240	0.0240	0.0240	0.0300	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0350	0.0350	0.0350	0.0250	0.0250	0.0220	0.0240	0.0250	0.0200	0.0200	0.1800	0.0230	0.0200	0.0240
ZEESCHELDE	24708	antwerpen	0.0240	0.0240	0.0240	0.0200	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0350	0.0350	0.0350	0.0250	0.0250	0.0220	0.0240	0.0250	0.0200	0.0200	0.1800	0.0240	0.0200	0.0240
ZEESCHELDE	37998	schelle	0.0240	0.0240	0.0240	0.0200	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0350	0.0350	0.0350	0.0250	0.0250	0.0220	0.0240	0.0250	0.0200	0.0200	0.0200	0.0240	0.0200	0.0240
ZEESCHELDE	46787	temse	0.0240	0.0240	0.0240	0.0200	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0350	0.0350	0.0350	0.0250	0.0250	0.0220	0.0240	0.0250	0.0200	0.0200	0.0200	0.0240	0.0200	0.0240
ZEESCHELDE	50195	monding durme	0.0240	0.0240	0.0240	0.0200	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0240	0.0350	0.0350	0.0350	0.0250	0.0250	0.0220	0.0240	0.0250	0.0200	0.0200	0.0200	0.0240	0.0200	0.0250
ZEESCHELDE	51597	driegoten	0.0244	0.0243	0.0244	0.0200	0.0244	0.0244	0.0244	0.0244	0.0244	0.0244	0.0244	0.0244	0.0244	0.0350	0.0350	0.0350	0.0250	0.0250	0.0220	0.0240	0.0244	0.0200	0.0200	0.0200	0.0240	0.0200	0.0260
ZEESCHELDE	65507	sint Amands	0.0274	0.0272	0.0274	0.0200	0.0274	0.0274	0.0274	0.0274	0.0274	0.0274	0.0274	0.0274	0.0274	0.0350	0.0350	0.0350	0.0250	0.0250	0.0220	0.0240	0.0274	0.0200	0.0200	0.0200	0.0240	0.0200	0.0290
ZEESCHELDE	70100	Dendermonde	0.0285	0.0283	0.0285	0.0200	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0350	0.0350	0.0350	0.0250	0.0250	0.0220	0.0240	0.0285	0.0240	0.0240	0.0240	0.0240	0.0240	0.0290
ZEESCHELDE	81158	Schoonaarde	0.0308	0.0305	0.0308	0.0200	0.0308	0.0308	0.0308	0.0308	0.0308	0.0308	0.0308	0.0308	0.0308	0.0350	0.0350	0.0350	0.0250	0.0250	0.0220	0.0240	0.0308	0.0240	0.0240	0.0240	0.0240	0.0240	0.0290
ZEESCHELDE	99799		0.0350	0.0350	0.0350	0.0200	0.0350	0.0350	0.0350	0.0350	0.0350	0.0350	0.0350	0.0350	0.0350	0.0350	0.0350	0.0350	0.0250	0.0250	0.0220	0.0240	0.0350	0.0240	0.0240	0.0240	0.0240	0.0240	0.0350
RINGVAART	99799		0.0370	0.0370	0.0370	0.0200	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370
RINGVAART	103298	Gent	0.0370	0.0370	0.0370	0.0200	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370
EVERINGEN	0		0.0250	0.0350	0.0250	0.0300	0.0300	0.0300	0.0300	0.0320	0.0250	0.0300	0.0250	0.0250	0.0320	0.0320	0.0300	0.0290	0.0290	0.0290	0.0280	0.0280	0.0280	0.0280	0.0280	0.0280	0.0300	0.0280	0.0250
EVERINGEN	5900		0.0250				0.0300	0.0300	0.0300	0.0320		0.0300	0.0250	0.0250	0.0320	0.0320	0.0300	0.0290	0.0290	0.0290	0.0280	0.0280	0.0280	0.0280	0.0280	0.0280	0.0300	0.0280	0.0250
EVERINGEN	10100		0.0250				0.0320	0.0320	0.0320	0.0350		0.0320	0.0250	0.0250	0.0320	0.0320	0.0300	0.0290	0.0290	0.0290	0.0280	0.0280	0.0280	0.0280	0.0280	0.0280	0.0300	0.0280	0.0250
EVERINGEN	14400		0.0250	0.0350	0.0250	0.0300	0.0350	0.0350	0.0350	0.0320	0.0250	0.0350	0.0250	0.0250	0.0320	0.0320	0.0300	0.0290	0.0290	0.0290	0.0280	0.0280	0.0280	0.0280	0.0280	0.0280	0.0300	0.0280	0.0250
MIDDELGAT	0		0.0250	0.0400	0.0250	0.0300	0.0250	0.0250	0.0250	0.0350	0.0250	0.0250	0.0250	0.0350	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0290	0.0290	0.0290	0.0290	0.0290	0.0300	0.0300	0.0290	0.0290
MIDDELGAT	10525		0.0250	0.0400	0.0250	0.0300	0.0250	0.0250	0.0250	0.0350	0.0250	0.0250	0.0250	0.0350	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0290	0.0290	0.0290	0.0290	0.0290	0.0300	0.0300	0.0290	0.0290
SCHAAR-OSSENISSE	0		0.0250	0.0250	0.0250	0.0300	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0350	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220
SCHAAR-OSSENISSE	2650		0.0250	0.0250	0.0250	0.0300	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0350	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220
SCHAAR-WAARDE	0		0.0270	0.0270	0.0270	0.0300	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0250	0.0240	0.0240	0.0240	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0200
SCHAAR-WAARDE	9600		0.0270	0.0270	0.0270	0.0300	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0250	0.0240	0.0240	0.0240	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0200
SCHAAR-NOORD	0		0.0295	0.0295	0.0295	0.0300	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295
SCHAAR-NOORD	4000		0.0295	0.0295	0.0295	0.0300	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295	0.0295
APPELZAK	0		0.0270	0.0270	0.0270	0.0300	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270
APPELZAK	4100		0.0270	0.0270	0.0270	0.0300	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270
SCHAAR-OUDEN-DOEL	0		0.0270	0.0270	0.0270	0.0300	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270
SCHAAR-OUDEN-DOEL	3600		0.0270	0.0270	0.0270	0.0300	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270
RUPEL	294	upper tributaries	0.0270	0.0270	0.0270	0.0200	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270
RUPEL	11841	upper tributaries	0.0270	0.0270	0.0270	0.0200	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270	0.0270
durme	61	upper tributaries	0.0250	0.0250	0.0250	0.0200	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250
durme	17469	upper tributaries	0.0250	0.0250	0.0250	0.0200	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250

Table 11: Different Manning parameters during the simulation, along the Western Scheldt and Sea Scheldt.

River Name	Chainage	Location	n
VAARWATER-HOOFDPLAAT	0		0.0200
VAARWATER-HOOFDPLAAT	14520		0.0200
SCHAAR-SPIJKERPLAAT	0		0.0200
SCHAAR-SPIJKERPLAAT	9700		0.0200
WESTERSCHELDE	0	monding noordzee	0.0220
WESTERSCHELDE	10100	end-raai-9	0.0220
WESTERSCHELDE	13900	Begin-raai--7	0.0250
WESTERSCHELDE	29100	End-raai-7	0.0250
WESTERSCHELDE	31000	Begin-Raai-6	0.0220
WESTERSCHELDE	39600	End-Raai-6	0.0220
WESTERSCHELDE	41700	+o- Hasweert	0.0200
WESTERSCHELDE	54600		0.0200
WESTERSCHELDE	59508		0.0200
WESTERSCHELDE	62100	Bath	0.0200
WESTERSCHELDE	65000		0.0220
ZEESCHELDE2	100		0.0220
ZEESCHELDE2	6600		0.0240
ZEESCHELDE2	10129		0.0240
ZEESCHELDE	10129		0.0240
ZEESCHELDE	15678	kallosluis	0.0240
ZEESCHELDE	23005	oosterweel	0.0240
ZEESCHELDE	24708	antwerpen	0.0240
ZEESCHELDE	37998	schelle	0.0240
ZEESCHELDE	46787	temse	0.0240
ZEESCHELDE	50195	monding durme	0.0250
ZEESCHELDE	51597	driegoten	0.0260
ZEESCHELDE	65507	sint Amands	0.0290
ZEESCHELDE	70100	Dendermonde	0.0290
ZEESCHELDE	81158	Schoonaarde	0.0290
ZEESCHELDE	99799		0.0350
RINGVAART	99799		0.0370
RINGVAART	103298	Gent	0.0370
EVERINGEN	0		0.0250
EVERINGEN	5900		0.0250
EVERINGEN	10100		0.0250
EVERINGEN	14400		0.0250
MIDDELGAT	0		0.0290
MIDDELGAT	10525		0.0290
SCHAAR-OSSENISSE	0		0.0220
SCHAAR-OSSENISSE	2650		0.0220
SCHAAR-WAARDE	0		0.0200
SCHAAR-WAARDE	9600		0.0200
SCHAAR-NOORD	0		0.0295
SCHAAR-NOORD	4000		0.0295
APPELZAK	0		0.0270
APPELZAK	4100		0.0270
SCHAAR-OUDEN-DOEL	0		0.0270
SCHAAR-OUDEN-DOEL	3600		0.0270
RUPEL	294	upper tributaries	0.0270
RUPEL	11841	upper tributaries	0.0270
durme	61	upper tributaries	0.0250
durme	17469	upper tributaries	0.0250
VAARWATER-HOOFDPLAAT-M	0	extension North Sea	0.0250
VAARWATER-HOOFDPLAAT-M	1800	extension North Sea	0.0250
SCHAAR-SPIJKERPLAAT-M	0	extension North Sea	0.0260
SCHAAR-SPIJKERPLAAT-M	1800	extension North Sea	0.0260
WESTERSCHELDE-M	0	extension North Sea	0.0260
WESTERSCHELDE-M	1800	extension North Sea	0.0260
Oostgat	0	extension North Sea	0.0180
Oostgat	23810	extension North Sea	0.0180
WESTERSCHELDE-MONDING	0	extension North Sea	0.0180
WESTERSCHELDE-MONDING	38500	extension North Sea	0.0180
WANDELAAR	0	extension North Sea	0.0180
WANDELAAR	9470	extension North Sea	0.0180
WIELINGEN	0	extension North Sea	0.0180
WIELINGEN	13720	extension North Sea	0.0180
ZEEBRUGGE	0	extension North Sea	0.0180
ZEEBRUGGE	3100	extension North Sea	0.0180
MONDING-2	0	extension North Sea	0.0180
MONDING-2	12585	extension North Sea	0.0180
MONDING-1	0	extension North Sea	0.0180
MONDING-1	23295	extension North Sea	0.0180
VLAKTE-VD-RAAN	0	extension North Sea	0.0180
VLAKTE-VD-RAAN	24150	extension North Sea	0.0180
KBR1	0	wetlands-inundation areas	0.1000
KBR1	2359	wetlands-inundation areas	0.1000
KBR6	0	wetlands-inundation areas	0.1000
KBR6	860	wetlands-inundation areas	0.1000
KBR2	0	wetlands-inundation areas	0.1000
KBR2	1350	wetlands-inundation areas	0.1000
SCH-LO18	0	wetlands-inundation areas	0.1000
SCH-LO18	2029	wetlands-inundation areas	0.1000
GOG9	0	wetlands-inundation areas	0.1000
GOG9	930	wetlands-inundation areas	0.1000
GOG10	0	wetlands-inundation areas	0.1000
GOG10	767	wetlands-inundation areas	0.1000
GOG11	0	wetlands-inundation areas	0.1000
GOG11	823	wetlands-inundation areas	0.1000
GOG12	0	wetlands-inundation areas	0.1000
GOG12	990	wetlands-inundation areas	0.1000
KLEINENDIJK	0	wetlands-inundation areas	0.1000
KLEINENDIJK	5065	wetlands-inundation areas	0.1000
KLEINENDIJK-OOST	0	wetlands-inundation areas	0.1000
KLEINENDIJK-OOST	3315	wetlands-inundation areas	0.1000
KLEINENDIJK-WEST	0	wetlands-inundation areas	0.1000
KLEINENDIJK-WEST	1800	wetlands-inundation areas	0.1000
KLEINENDIJK-ZUID	0	wetlands-inundation areas	0.1000
KLEINENDIJK-ZUID	2018	wetlands-inundation areas	0.1000
SAFTINGER-EE	0	wetlands-inundation areas	0.1000
SAFTINGER-EE	5194	wetlands-inundation areas	0.1000
SCHAAPSKOOI	0	wetlands-inundation areas	0.1000
SCHAAPSKOOI	1300	wetlands-inundation areas	0.1000
SPEELMANSGAT	152	wetlands-inundation areas	0.1000
SPEELMANSGAT	6279	wetlands-inundation areas	0.1000
ZANDVLIETSLUIS	0	wetlands-inundation areas	0.0295
ZANDVLIETSLUIS	879	wetlands-inundation areas	0.0295
BRAAKMAN	0	wetlands-inundation areas	0.0295
BRAAKMAN	1400	wetlands-inundation areas	0.0295
TERNEUZEN	76	wetlands-inundation areas	0.0295
TERNEUZEN	1486	wetlands-inundation areas	0.0295
KLNDJKO_SFTGRE-1200	0	wetlands-inundation areas	0.0295
KLNDJKO_SFTGRE-1200	1000	wetlands-inundation areas	0.0295
SPLMSGT_KLNDJKW-3322	0	wetlands-inundation areas	0.0295
SPLMSGT_KLNDJKW-3322	1255	wetlands-inundation areas	0.0295
SPLMSGT_KLNDJK-2459	0	wetlands-inundation areas	0.0295
SPLMSGT_KLNDJK-2459	1335	wetlands-inundation areas	0.0295
SFTGRE_SCHPSK-1200	0	wetlands-inundation areas	0.0295
SFTGRE_SCHPSK-1200	1275	wetlands-inundation areas	0.0295
HAVENVLISSINGEN-OOST2	0	harbours	0.0295
HAVENVLISSINGEN-OOST2	2640	harbours	0.0295
HAVENVLISSINGEN-OOST	0	harbours	0.0295
HAVENVLISSINGEN-OOST	4000	harbours	0.0295
BUITENHAVEN-VLISSINGEN	0	harbours	0.0295
BUITENHAVEN-VLISSINGEN	1285	harbours	0.0295
ZUID-BEVELAND	0	harbours	0.0295
ZUID-BEVELAND	1700	harbours	0.0295
KLNDJK_KLNDJKO-4200	0	wetlands-inundation areas	0.0295
KLNDJK_KLNDJKO-4200	500	wetlands-inundation areas	0.0295
KLNDJKO_SFGRE-3000	0	wetlands-inundation areas	0.0295
KLNDJKO_SFGRE-3000	500	wetlands-inundation areas	0.0295
SPLMSGT_KLNDJKZ-5833	0	wetlands-inundation areas	0.0295
SPLMSGT_KLNDJKZ-5833	500	wetlands-inundation areas	0.0295
KLNDJKW_KLDJKZ-1800	0	wetlands-inundation areas	0.0295
KLNDJKW_KLDJKZ-1800	200	wetlands-inundation areas	0.0295
KLNDJKZ_KLNDJK-1500	0	wetlands-inundation areas	0.0295
KLNDJKZ_KLNDJK-1500	500	wetlands-inundation areas	0.0295
SAFTINGER-EE_ZSCH2-4000	0	wetlands-inundation areas	0.0295
SAFTINGER-EE_ZSCH2-4000	1000	wetlands-inundation areas	0.0295
BINNENNETE	0	upper tributaries	0.1000
BINNENNETE	1296	upper tributaries	0.1000
KLEINENETE	0	upper tributaries	0.0350
KLEINENETE	16972	upper tributaries	0.0300
BENEDENNETE	0	upper tributaries	0.0250
BENEDENNETE	10300	upper tributaries	0.0250
BENEDENNETE	15516	upper tributaries	0.0350
NETEAFLEIDING	0	upper tributaries	0.0300
NETEAFLEIDING	2127	upper tributaries	0.0300
GROTENETE	50	upper tributaries	0.0300

Table 12: Final set of Manning parameters for all the branches.

River Name	Upst.Ch	DownStr Ch.	Flow direction	Method	Δ Manning (%)
Westerschelde	1800	10100	Pos	Rel	0
Schaar-Spijkerplaat	1800	9700	Pos	Rel	-50
VAARWATER-HOOFDPLAAT	1800	14520	Pos	Rel	-35
Westerschelde	13900	29100	Pos	Rel	0
Everingen	500	13200	Pos	Rel	-25
Westerschelde	29700	39600	Pos	Rel	-50
MIDDELGAT	500	10525	Pos	Rel	0
Westerschelde	39600	52000	Pos	Rel	0
Schaar-Waarde	900	8700	Pos	Rel	-45
Westerschelde	54000	64000	Pos	Rel	0
Schaar-Noord	1500	4000	Pos	Rel	-80
APPELZAK	0	4100	Pos	Rel	-80
SCHAAR-OUDEN-DOEL	0	3600	Pos	Rel	-80
VAARWATER-HOOFDPLAAT-M	0	1800	Pos	Rel	-35
SCHAAR-SPIJKERPLAAT-M	0	1800	Pos	Rel	-50
WESTERSCHELDE-M	0	1800	Pos	Rel	0
Oostgat	0	23810	Pos	Rel	0
WESTERSCHELDE-MONDING	0	38500	Pos	Rel	0
WANDELAAR	0	9470	Pos	Rel	0
WIELINGEN	0	13720	Pos	Rel	0
ZEEBRUGGE	0	3100	Pos	Rel	0
MONDING-2	0	12585	Pos	Rel	0
MONDING-1	0	23295	Pos	Rel	0
VLAKTE-VD-RAAN	0	24150	Pos	Rel	0
MONDING-4	0	8250	Pos	Rel	0
MONDING-3	0	10370	Pos	Rel	0
DEURLOOP	0	10850	Pos	Rel	0

Table 13: Final set of flow-dependant coefficients.

In this table is possible to define for each branch (River name) and at different locations (upstream and downstream chainage) a reduction of the manning (Δ Manning (%) for a given direction of the flow (Pos= positive flow, in this case flow in the sea direction). Furthermore it is also possible to define instead of a relative reduction an absolute reduction in the manning number. In the current study only a relative reduction was adopted.

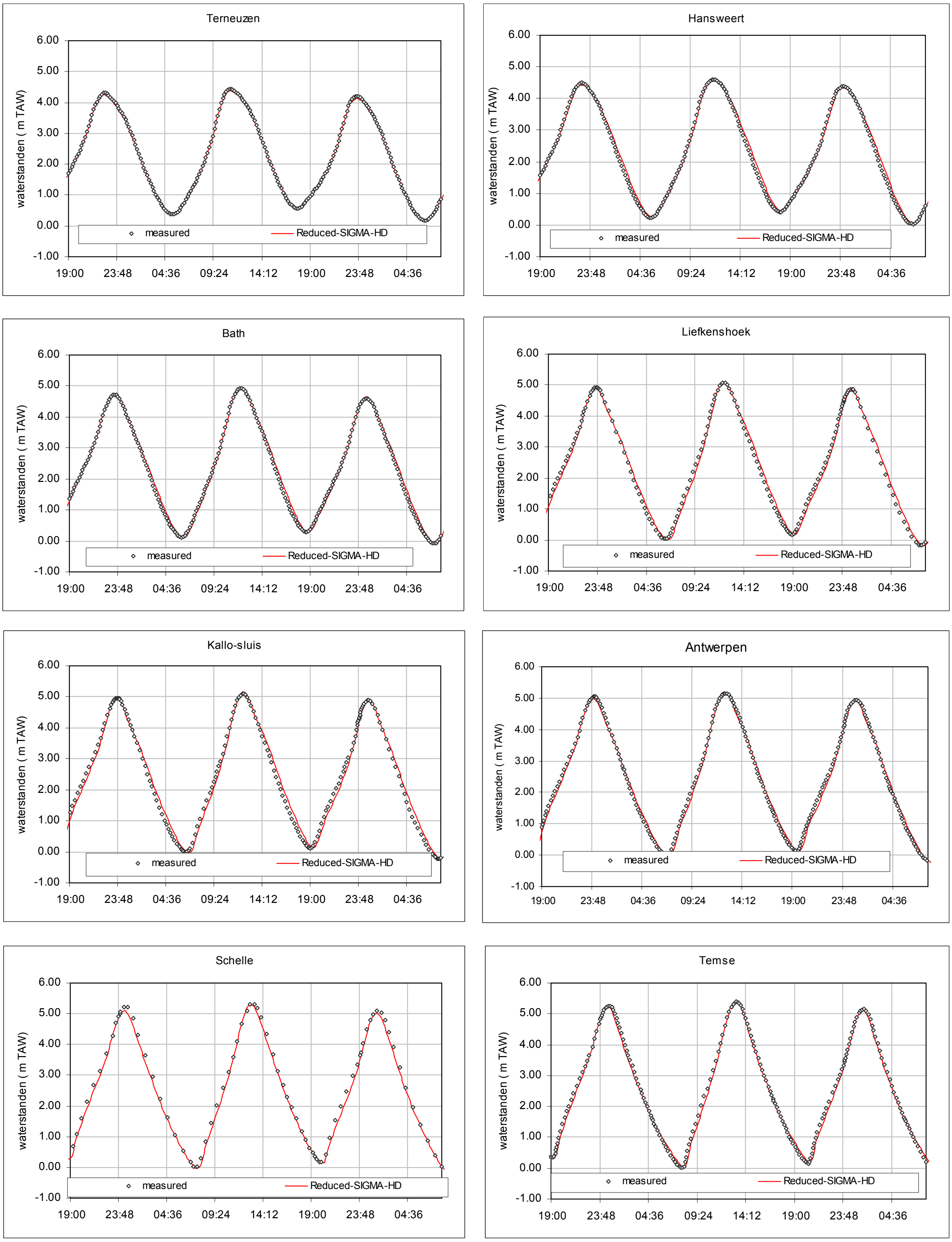


Figure 43: Simulated water levels at different stations in the Scheldt estuary, year 2000. Sigma model.

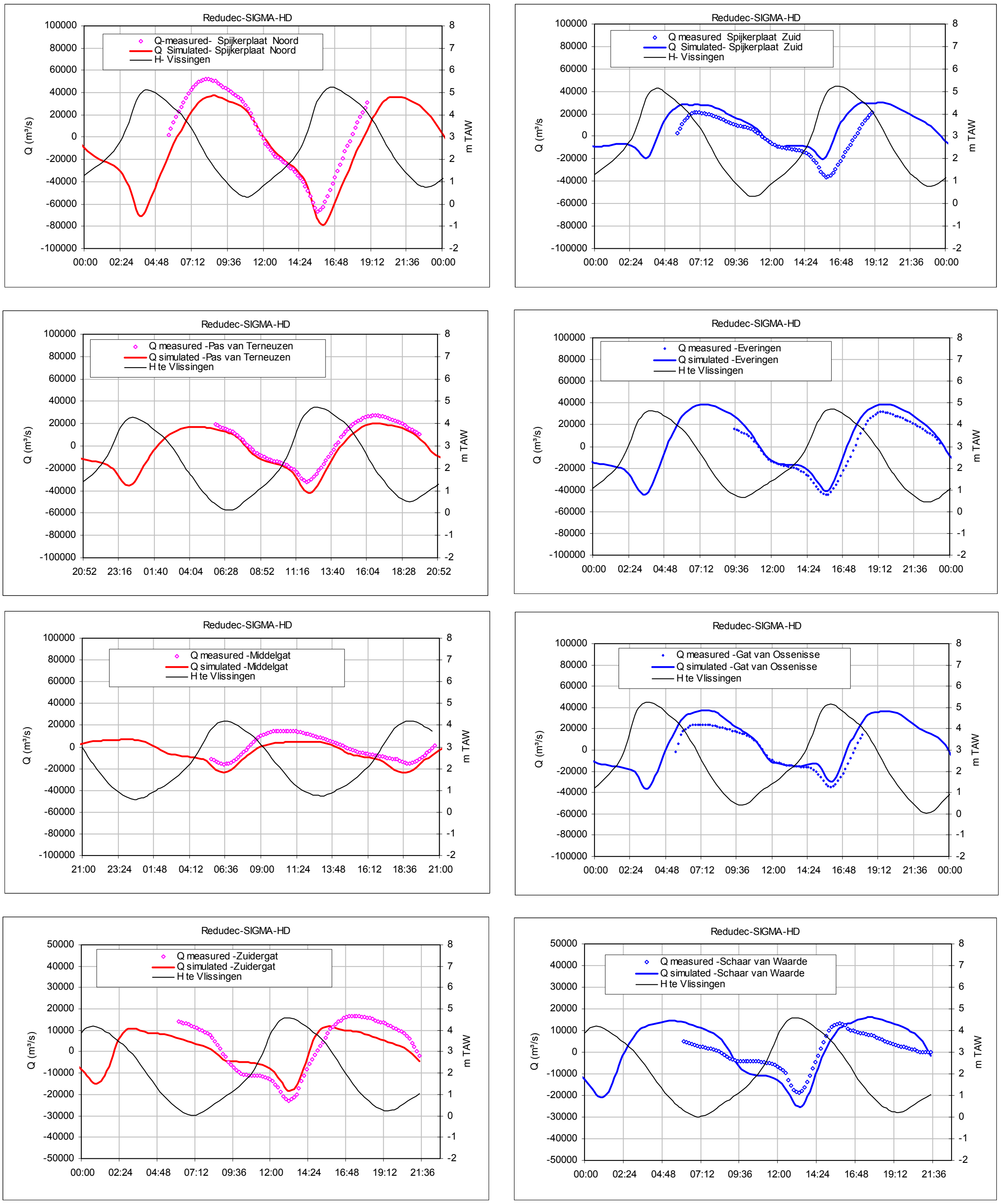


Figure 44: Simulated flow discharges at different measurement tracks at the Western Scheldt between Vlissingen and the Schaar van Waarde. Sigma model.

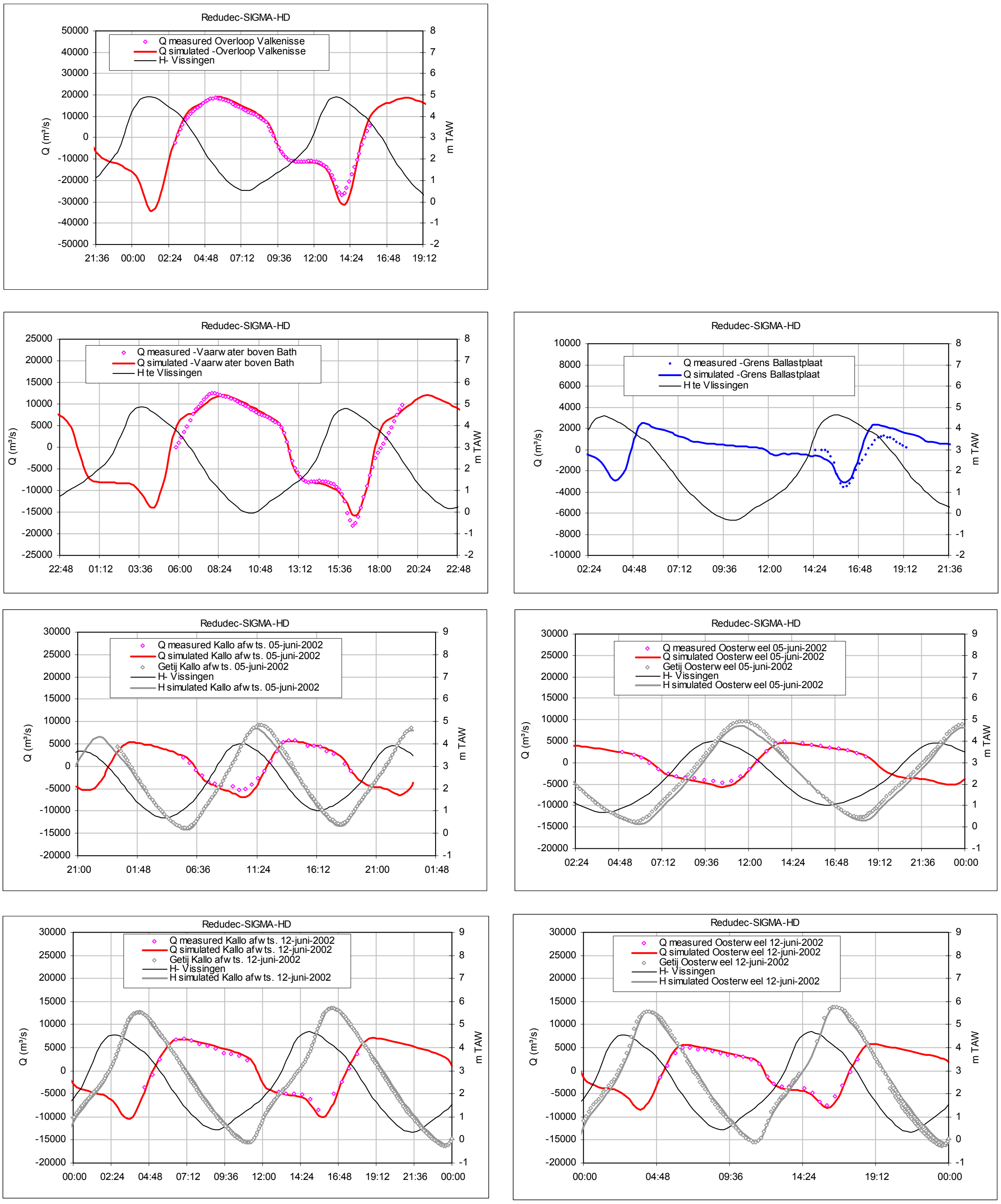


Figure 45: simulated discharge at different measurement tracks at the Western Scheldt and Sea Scheldt upstream the Overloop van Valkenisse. Sigma model.

Table 14: Normalized maximum flow discharges for different channels at measurement tracks along the Western Scheldt. Sigma model.

	Maximum flow discharges Ebb (m³/s)			Maximum flow discharges Flood (m³/s)		
Location	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat Noord	41173	29591	-28%	51593	61093	18%
Raai 9 Honte / Schaar v Spijkerplaat Zuid	16898	22689	34%	28037	15215	-46%
Raai7: Pas van Terneuzen	24759	18138	-27%	26492	34688	31%
Raai 7:Everingen	28322	34449	22%	41151	38371	-7%
Raai 6 Middelgat	16541	5253	-68%	16570	25738	55%
Raai 6-Gat van Ossenisse	23750	37010	56%	27823	24194	-13%
Raai 5A- Zuidergat	14812	10404	-30%	19210	15435	-20%
Raai 5A- Schaar van Waarde	11550	14107	22%	15854	21055	33%
Raai 3 Overloop van Valkenisse	15977	16409	3%	23237	27343	18%
Raai 1A:Vaarwater boven Bath	9806	9569	-2%	14575	12573	-14%

Table 15: Normalized maximum flow discharges for different measurement tracks along the Western Scheldt. Sigma model.

	Maximum flow discharges Ebb (m³/s)			Maximum flow discharges Flood (m³/s)		
Location	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat	58071	52280	-10%	79630	76309	-4%
Raai 7:Pas van Terneuzen-Everingen	53081	52587	-1%	67644	73059	8%
Raai 6 Middelgat-Gat van Ossenisse	40291	42263	5%	44392	49932	12%
Raai 5A- Zuidergat- Schaar van Waarde	26362	24510	-7.0%	35064	36490	4%
Raai 3 Overloop van Valkenisse	15977	16409	3%	23237	27343	18%
Raai 1A:Vaarwater boven Bath	9806	9569	-2%	14575	12573	-14%

Table 16: Normalized flow volumes for different channels at measurement tracks along the Western Scheldt. Sigma model.

Location	Ebb volumes (M m³)			Flood volumes (M m³)		
	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat Noord	620	412	-34%	540	672	24%
Raai 9 Honte / Schaar v Spijkerplaat Zuid	217	394	82%	287	136	-53%
Raai7: Pas van Terneuzen	376	259	-31%	285	387	36%
Raai 7:Everingen	389	537	38%	500	407	-19%
Raai 6 Middelgat	257	73	-71%	197	331	68%
Raai 6-Gat van Ossenisse	367	554	51%	317	253	-20%
Raai 5A- Zuidergat	236	137	-42%	217	140	-36%
Raai 5A- Schaar van Waarde	131	232	78%	133	229	72%
Raai 3 Overloop van Valkenisse	250	274	10%	242	271	12%
Raai 1A:Vaarwater boven Bath	161	177	10%	141	139	-1%

Table 17: Normalized flow volumes for different measurement tracks along the Western Scheldt. Sigma model.

Location	Ebb volumes (M m³)			Flood volumes (M m³)		
	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat	837	806	-4%	827	808	-2%
Raai 7:Pas van Terneuzen-Everingen	765	796	4%	786	794	1%
Raai 6 Middelgat-Gat van Ossenisse	624	627	0%	514	583	13%
Raai 5A- Zuidergat- Schaar van Waarde	367	369	1%	351	369	5%

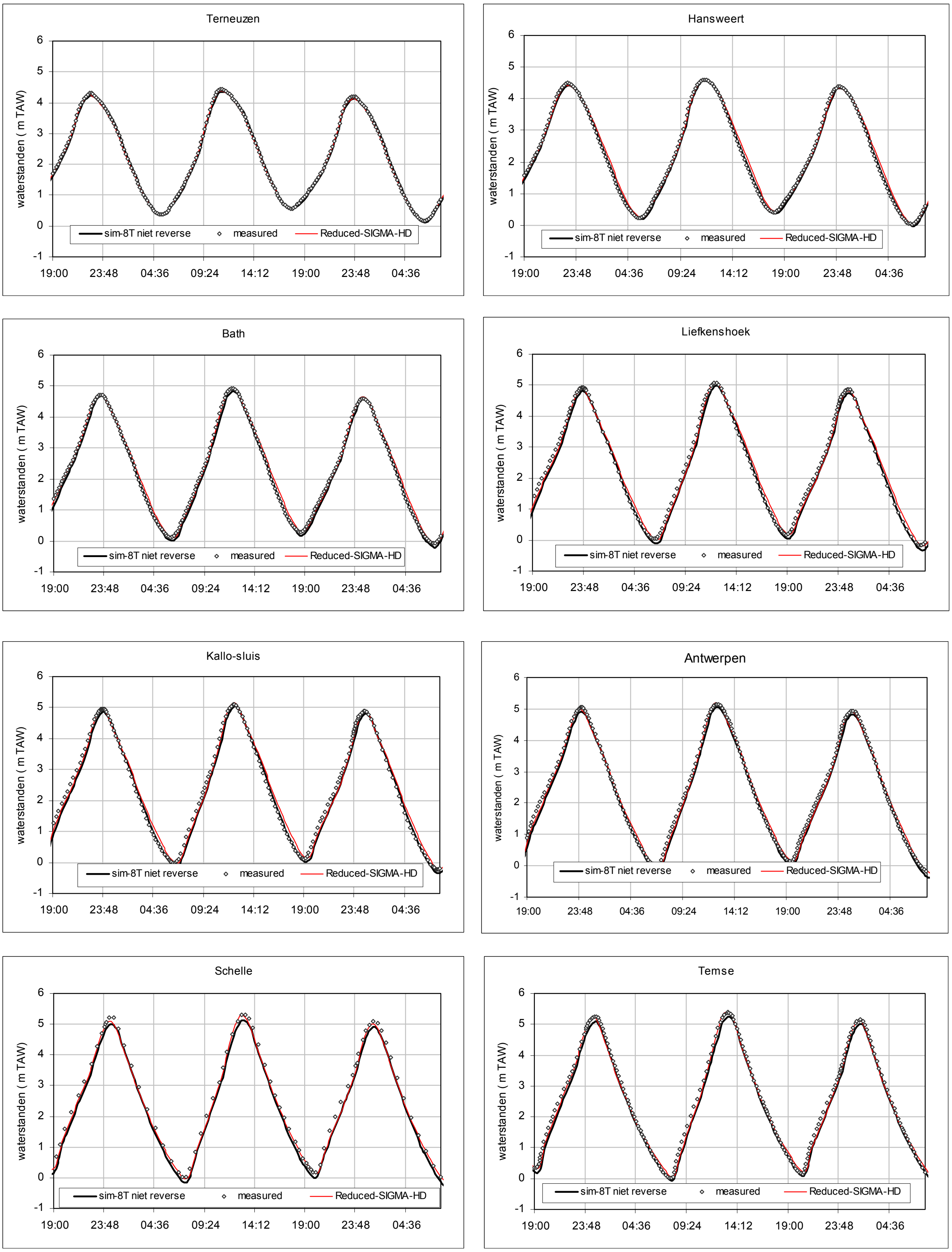


Figure 46: Simulated water levels at different stations in the Scheldt estuary, year 2000. Simulation “T”.

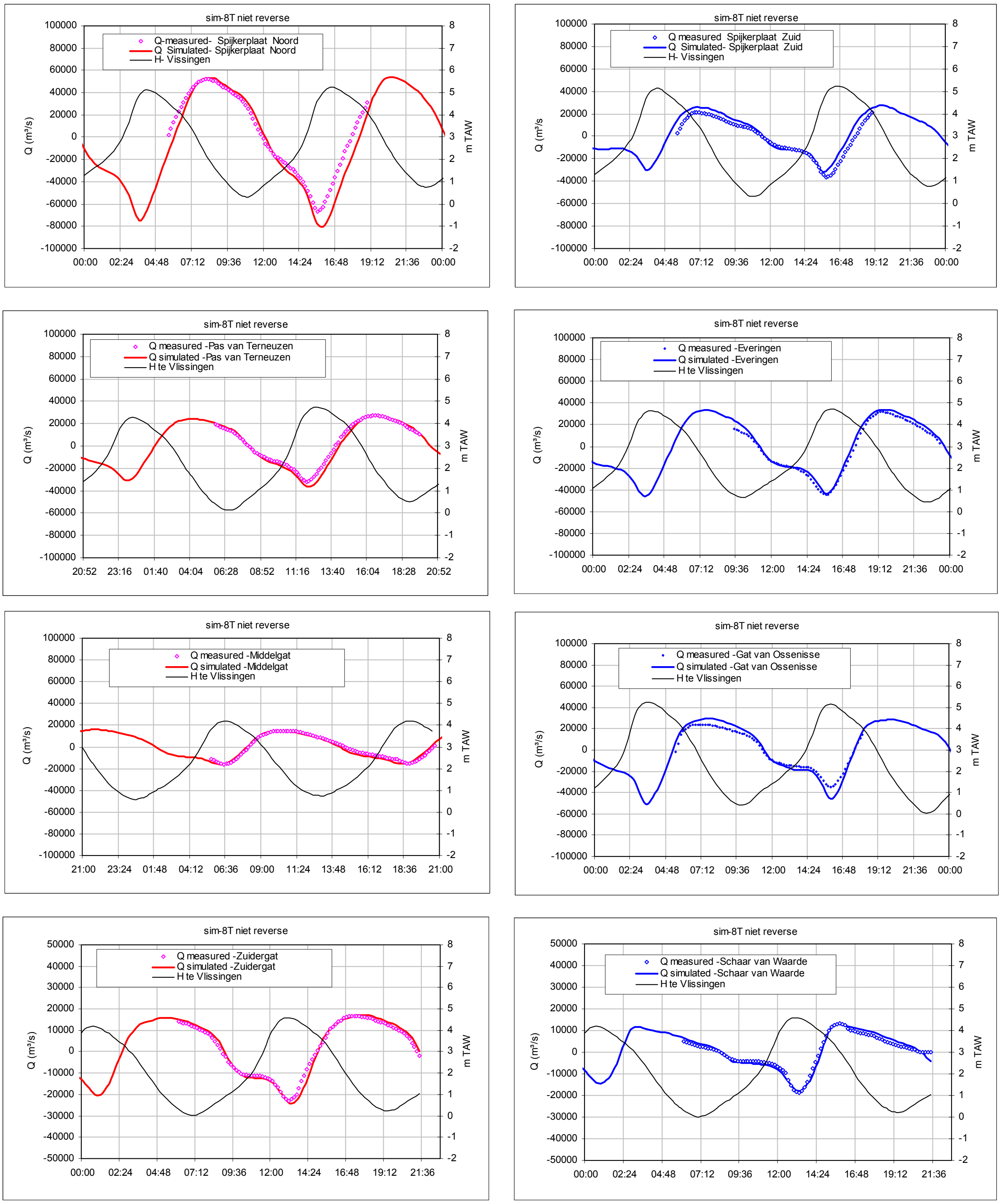


Figure 47: Simulated flow discharges at different measurement tracks at the Western Scheldt between Vlissingen and the Schaar van Waarde. Simulation "T".

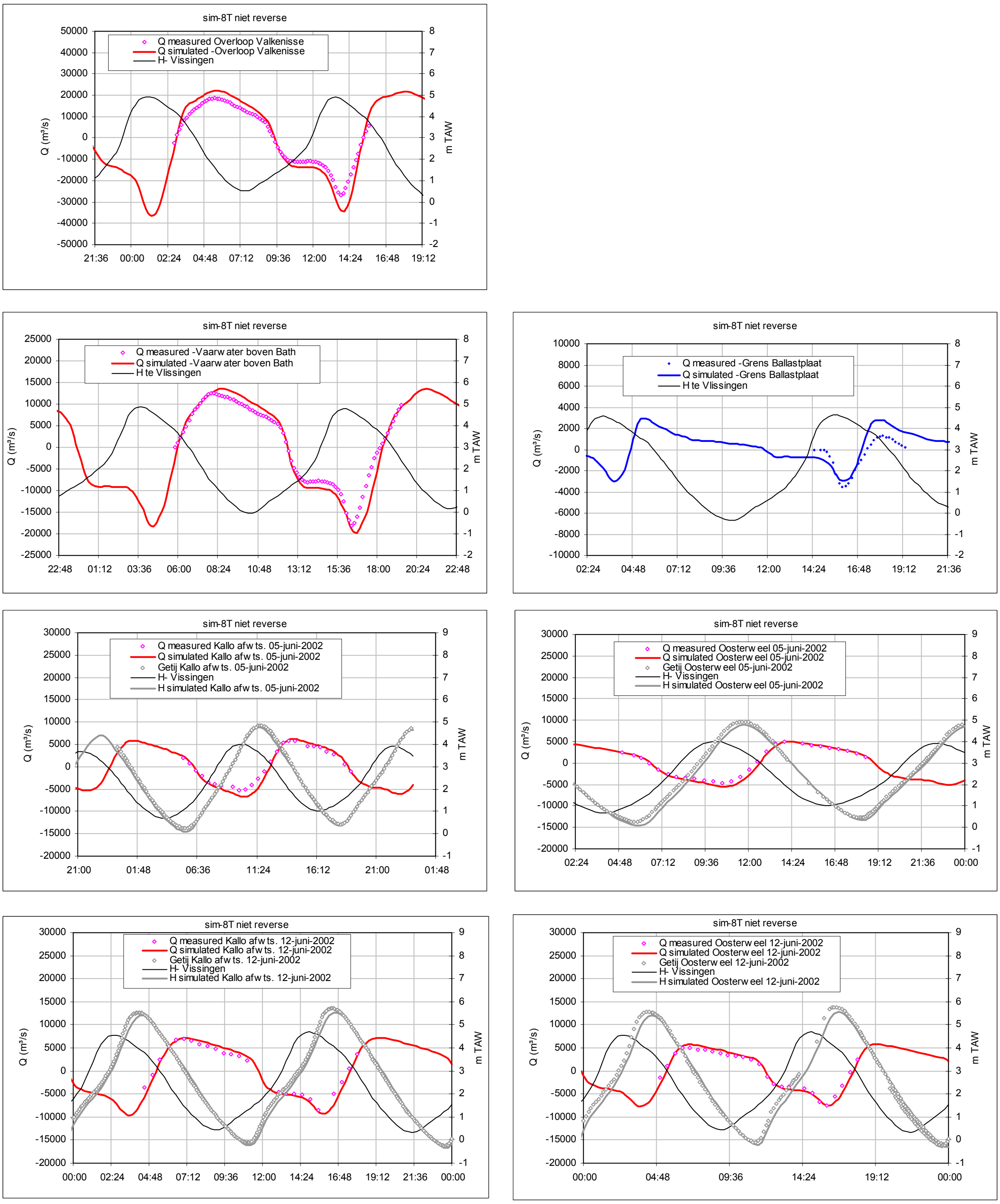


Figure 48: simulated discharge at different measurement tracks at the Western Scheldt and Sea Scheldt upstream the Overloop van Valkenisse. Simulation "T".

Table 18: Normalized maximum flow discharges for different channels at measurement tracks along the Western Scheldt. Simulation "T"..

Location	Maximum flow discharges Ebb (m³/s)			Maximum flow discharges Flood (m³/s)		
	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat Noord	41173	41967	2%	51593	62175	21%
Raai 9 Honte / Schaar v Spijkerplaat Zuid	16898	20388	21%	28037	24329	-13%
Raai7: Pas van Terneuzen	24759	24487	-1%	26492	30135	14%
Raai 7:Everingen	28322	29832	5%	41151	40317	-2%
Raai 6 Middelgat	16541	16094	-3%	16570	16901	2%
Raai 6-Gat van Ossenisse	23750	29193	23%	27823	36855	32%
Raai 5A- Zuidergat	14812	15165	2%	19210	20216	5%
Raai 5A- Schaar van Waarde	11550	11374	-2%	15854	14932	-6%
Raai 3 Overloop van Valkenisse	15977	19086	19%	23237	29963	29%
Raai 1A:Vaarwater boven Bath	9806	10676	9%	14575	15777	8%

Table 19: Normalized maximum flow discharges for different measurement tracks along the Western Scheldt. Simulation "T".

Location	Maximum flow discharges Ebb (m³/s)			Maximum flow discharges Flood (m³/s)		
	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat	58071	62355	7%	79630	86504	9%
Raai 7:Pas van Terneuzen-Everingen	53081	54319	2%	67644	70452	4%
Raai 6 Middelgat-Gat van Ossenisse	40291	45287	12%	44392	53756	21%
Raai 5A- Zuidergat- Schaar van Waarde	26362	26538	0.7%	35064	35148	0%
Raai 3 Overloop van Valkenisse	15977	19086	19%	23237	29963	29%
Raai 1A:Vaarwater boven Bath	9806	10676	9%	14575	15777	8%

Table 20: Normalized flow volumes for different channels at measurement tracks along the Western Scheldt. Simulation "T".

Location	Ebb volumes (M m³)			Flood volumes (M m³)		
	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat Noord	620	621	0%	540	713	32%
Raai 9 Honte / Schaar v Spijkerplaat Zuid	217	292	35%	287	247	-14%
Raai7: Pas van Terneuzen	376	363	-4%	285	354	24%
Raai 7:Everingen	389	453	17%	500	463	-7%
Raai 6 Middelgat	257	247	-4%	197	226	15%
Raai 6-Gat van Ossenisse	367	462	26%	317	384	21%
Raai 5A- Zuidergat	236	254	7%	217	242	11%
Raai 5A- Schaar van Waarde	131	148	13%	133	151	13%
Raai 3 Overloop van Valkenisse	250	320	28%	242	313	30%
Raai 1A:Vaarwater boven Bath	161	182	13%	141	181	29%

Table 21: Normalized flow volumes for different measurement tracks along the Western Scheldt. Simulation "T".

Location	Ebb volumes (M m³)			Flood volumes (M m³)		
	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat	837	913	9%	827	961	16%
Raai 7:Pas van Terneuzen-Everingen	765	816	7%	786	817	4%
Raai 6 Middelgat-Gat van Ossenisse	624	709	14%	514	610	19%
Raai 5A- Zuidergat- Schaar van Waarde	367	402	9%	351	392	12%

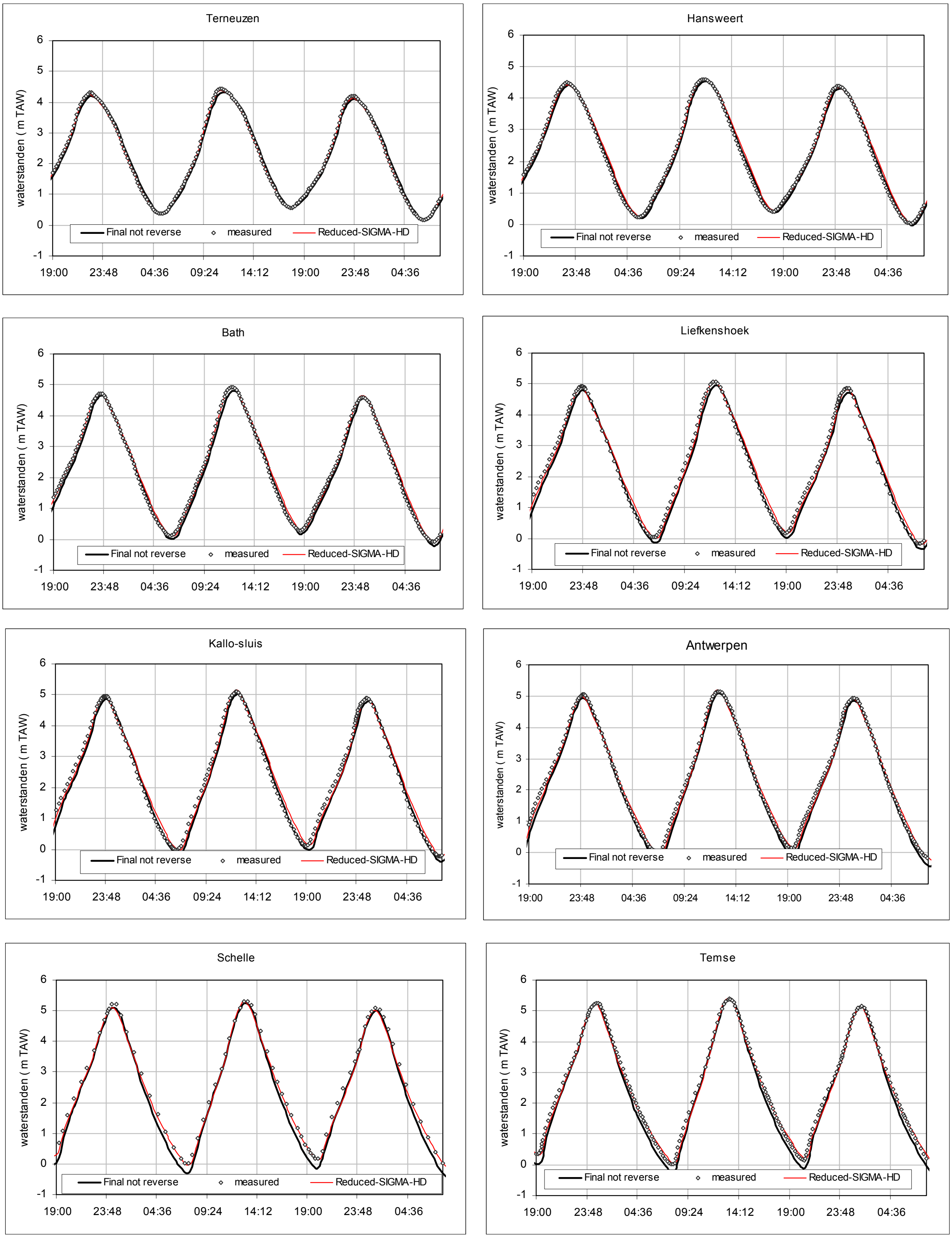


Figure 49: Simulated water levels at different stations in the Scheldt estuary, year 2000. Final, constant Manning.

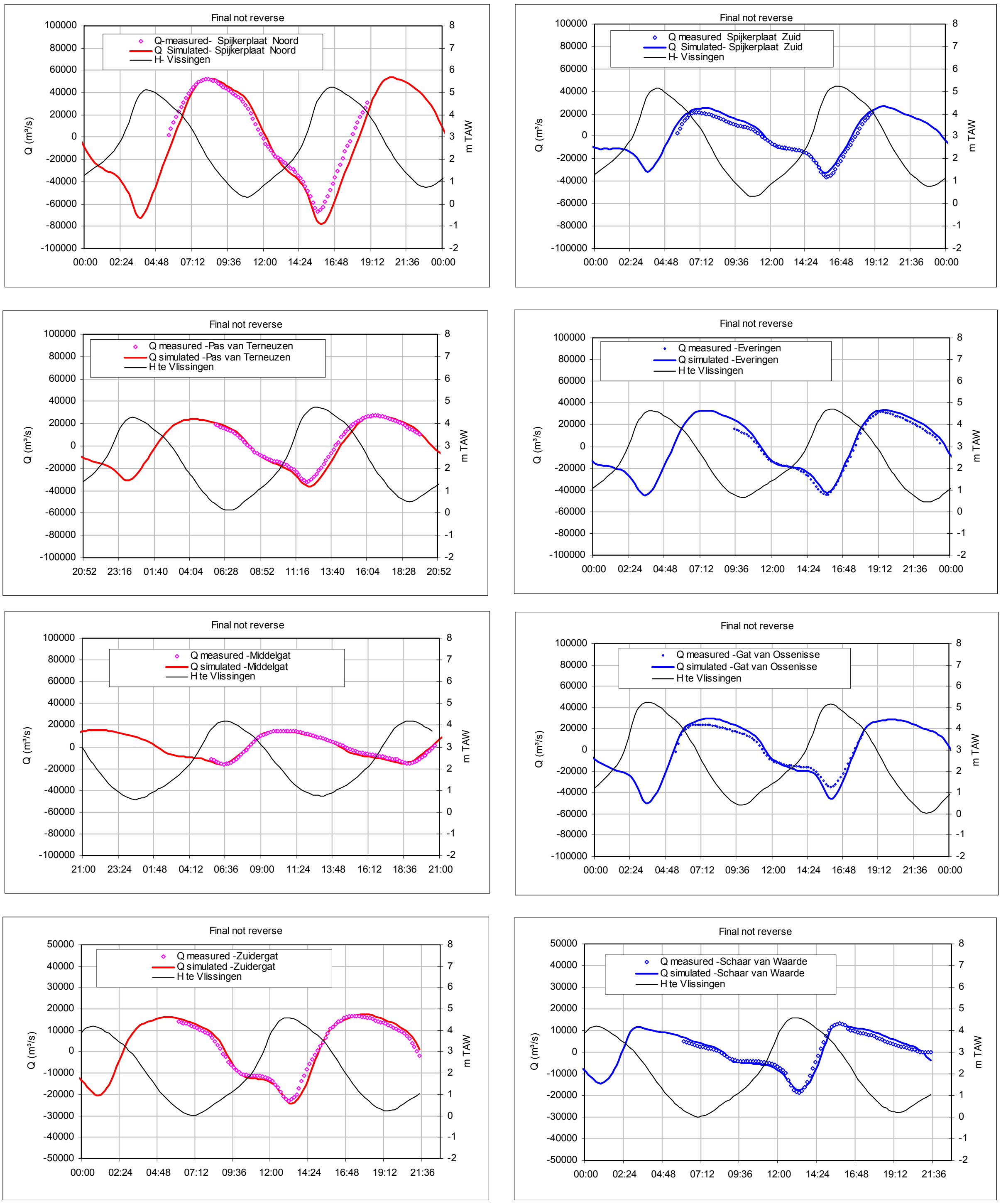


Figure 50: Simulated flow discharges at different measurement tracks at the Western Scheldt between Vlissingen and the Schaar van Waarde. Final, constant Manning.

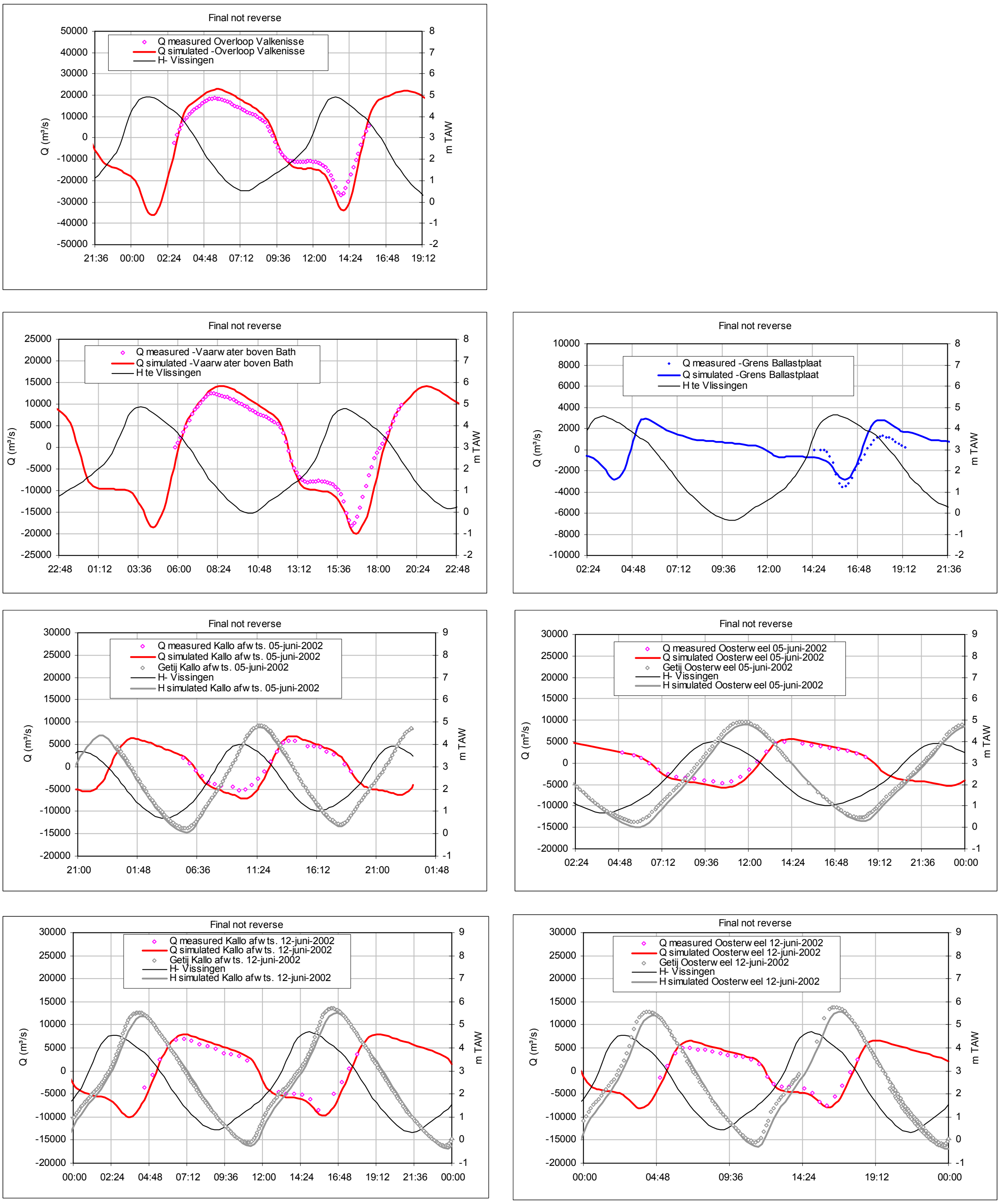


Figure 51: simulated discharge at different measurement tracks at the Western Scheldt and Sea Scheldt upstream the Overloop van Valkenisse. Final, constant Manning.

Table 22: Normalized maximum flow discharges for different channels at measurement tracks along the Western Scheldt. Best constant Manning.

	Maximum flow discharges Ebb (m³/s)			Maximum flow discharges Flood (m³/s)		
Location	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat Noord	41173	41729	1%	51593	59935	16%
Raai 9 Honte / Schaar v Spijkerplaat Zuid	16898	19833	17%	28037	25102	-10%
Raai7: Pas van Terneuzen	24759	24124	-3%	26492	29887	13%
Raai 7:Everingen	28322	29565	4%	41151	39854	-3%
Raai 6 Middelgat	16541	15871	-4%	16570	16680	1%
Raai 6-Gat van Ossenisse	23750	29292	23%	27823	36613	32%
Raai 5A- Zuidergat	14812	15429	4%	19210	20132	5%
Raai 5A- Schaar van Waarde	11550	11197	-3%	15854	14596	-8%
Raai 3 Overloop van Valkenisse	15977	19605	23%	23237	29701	28%
Raai 1A:Vaarwater boven Bath	9806	11151	14%	14575	15937	9%

Table 23: Normalized maximum flow discharges for different measurement tracks along the Western Scheldt. Best constant Manning..

	Maximum flow discharges Ebb (m³/s)			Maximum flow discharges Flood (m³/s)		
Location	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat	58071	61562	6%	79630	85037	7%
Raai 7:Pas van Terneuzen-Everingen	53081	53690	1%	67644	69740	3%
Raai 6 Middelgat-Gat van Ossenisse	40291	45162	12%	44392	53293	20%
Raai 5A- Zuidergat- Schaar van Waarde	26362	26626	1.0%	35064	34728	-1%
Raai 3 Overloop van Valkenisse	15977	19605	23%	23237	29701	28%
Raai 1A:Vaarwater boven Bath	9806	11151	14%	14575	15937	9%

Table 24: Normalized flow volumes for different channels at measurement tracks along the Western Scheldt. Best constant Manning..

Location	Ebb volumes (M m³)			Flood volumes (M m³)		
	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat Noord	620	627	1%	540	689	28%
Raai 9 Honte / Schaar v Spijkerplaat Zuid	217	286	32%	287	261	-9%
Raai7: Pas van Terneuzen	376	361	-4%	285	354	24%
Raai 7:Everingen	389	456	17%	500	462	-8%
Raai 6 Middelgat	257	246	-4%	197	225	14%
Raai 6-Gat van Ossenisse	367	467	27%	317	387	22%
Raai 5A- Zuidergat	236	258	9%	217	245	13%
Raai 5A- Schaar van Waarde	131	150	15%	133	152	14%
Raai 3 Overloop van Valkenisse	250	325	30%	242	318	32%
Raai 1A:Vaarwater boven Bath	161	187	16%	141	188	34%

Table 25: Normalized flow volumes for different measurement tracks along the Western Scheldt. Best constant Manning..

Location	Ebb volumes (M m³)			Flood volumes (M m³)		
	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat	837	914	9%	827	950	15%
Raai 7:Pas van Terneuzen-Everingen	765	818	7%	786	816	4%
Raai 6 Middelgat-Gat van Ossenisse	624	713	14%	514	611	19%
Raai 5A- Zuidergat- Schaar van Waarde	367	407	11%	351	397	13%

ANNEX 5: MAXIMUM FLOW DISCHARGES AND FLOW VOLUMES

Table 26: Not normalized maximum flow discharges for different channels at measurement tracks along the Western Scheldt.

	Maximum flow discharges Ebb (m³/s)			Maximum flow discharges Flood (m³/s)		
Location	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat Noord	51900	58900	13%	66800	81600	22%
Raai 9 Honte / Schaar v Spijkerplaat Zuid	21300	20000	-6%	36300	37100	2%
Raai7: Pas van Terneuzen	27300	27700	1%	32000	36600	14%
Raai 7:Everingen	31900	31000	-3%	44400	48100	8%
Raai 6 Middelgat	14800	17900	21%	15000	15800	5%
Raai 6-Gat van Ossenisse	24000	23500	-2%	34500	49900	45%
Raai 5A- Zuidergat	16800	19800	18%	22900	26100	14%
Raai 5A- Schaar van Waarde	13100	10200	-22%	18900	19500	3%
Raai 3 Overloop van Valkenisse	18500	22400	21%	26600	37500	41%
Raai 1A:Vaarwater boven Bath	12400	14000	13%	18200	22000	21%

Table 27: Not normalized maximum flow discharges for different measurement tracks along the Western Scheldt.

	Maximum flow discharges Ebb (m³/s)			Maximum flow discharges Flood (m³/s)		
Location	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat	73200	78900	8%	103100	118700	15%
Raai 7:Pas van Terneuzen-Everingen	59200	58700	-1%	76400	84700	11%
Raai 6 Middelgat-Gat van Ossenisse	38800	41400	7%	49500	65700	33%
Raai 5A- Zuidergat- Schaar van Waarde	29900	30000	0%	41800	45600	9%
Raai 3 Overloop van Valkenisse	18500	22400	21%	26600	37500	41%
Raai 1A:Vaarwater boven Bath	12400	14000	13%	18200	22000	21%

Table 28: Not normalized flow volumes for different channels at measurement tracks along the Western Scheldt.

Location	Ebb volumes (M m³)			Flood volumes (M m³)		
	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat Noord	782	915	17%	699	877	25%
Raai 9 Honte / Schaar v Spijkerplaat Zuid	274	277	1%	371	383	3%
Raai7: Pas van Terneuzen	415	427	3%	345	402	17%
Raai 7:Everingen	438	492	12%	540	535	-1%
Raai 6 Middelgat	230	293	27%	178	194	8%
Raai 6-Gat van Ossenisse	371	389	5%	393	507	29%
Raai 5A- Zuidergat	268	341	27%	259	296	14%
Raai 5A- Schaar van Waarde	148	130	-12%	159	191	20%
Raai 3 Overloop van Valkenisse	290	386	33%	277	374	35%
Raai 1A:Vaarwater boven Bath	204	252	23%	175	238	35%

Table 29: Not normalized flow volumes for different measurement tracks along the Western Scheldt.

Location	Ebb volumes (M m³)			Flood volumes (M m³)		
	measured	simulated	difference	measured	simulated	difference
Raai 9 Honte/Schaar v Spijkerplaat	1055	1191	13%	1070	1260	18%
Raai 7:Pas van Terneuzen-Everingen	853	920	8%	884	938	6%
Raai 6 Middelgat-Gat van Ossenisse	601	682	13%	572	700	22%
Raai 5A- Zuidergat- Schaar van Waarde	416	471	13%	418	487	17%