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Een geïntegreerde aanpak voor de Durme

Sub report 6 – Scenarios intertidal areas

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Meire, D.; Nguyen, D.; Stark, J.; Vanlede, J.

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Abstract

Within the framework of the Sigma plan, several areas will be attached to the Durme river in the near future. In this report, the influence of these additional intertidal areas, both in the form of depoldered areas (Klein Broek, Groot Broek) as well as a flood control area with controlled reduced tide FCA-CRT (De Bunt) on the tidal characteristics and velocity patterns along the Durme is examined.

All Sigma areas lead to an increase in the tidal prism in the Durme. Among the three areas, the polder Groot Broek has the largest influence on the hydrodynamics of the Durme river and De Bunt shows the least effect. The implementation of Groot Broek alone or together with the other two Sigma areas results in lower high waters in the Durme river. The largest reduction was calculated for the middle river section where the water levels are highest along the Durme river. A strong effect of the three Sigma areas on the current velocity was calculated downstream of the areas with higher peak velocities.

The peak velocity asymmetry is flood dominated in most of the river section. Activating the polder Klein Broek and/or Groot Broek weakens the flood dominant tidal asymmetry. The polder Groot Broek shows stronger effect and even alters the velocity asymmetry to ebb dominance at the river section near the mouth. In terms of sediment transport, the polder Klein Broek and Groot Broek could slow down the sedimentation process in the downstream part of the Durme river.

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1 Introduction

In the Durme valley, different management measures have been planned. One of the measures is linking the Sigma areas Klein Broek, Groot Broek and De Bunt to the Durme river (see Figure 1 for the location). The implementation of new intertidal areas should contribute to a more sustainable river profile that can safely convey peaks in discharge, and that is more sustainable with regards to dredging cost.

In Nguyen et al., (2024), the hydrodynamic model for the Durme was setup and calibrated using the Telemac modelling system. The model has demonstrated to capture the hydrodynamics of the area. The calibrated model is applied to conduct the scenario runs presented in this report. The effect of the inclusion of the Sigma areas (Klein Broek, Groot Broek, and De Bunt) on the hydrodynamics in the Durme is studied in detail in this report.

The influences of these measures on the hydrodynamics and sediment dynamics are of interest. Relevant parameters such as tidal volume (tidal prism), maximum flood and ebb currents and tidal asymmetry are calculated. The sediment transport is not yet modeled but is discussed based on the hydrodynamic results.

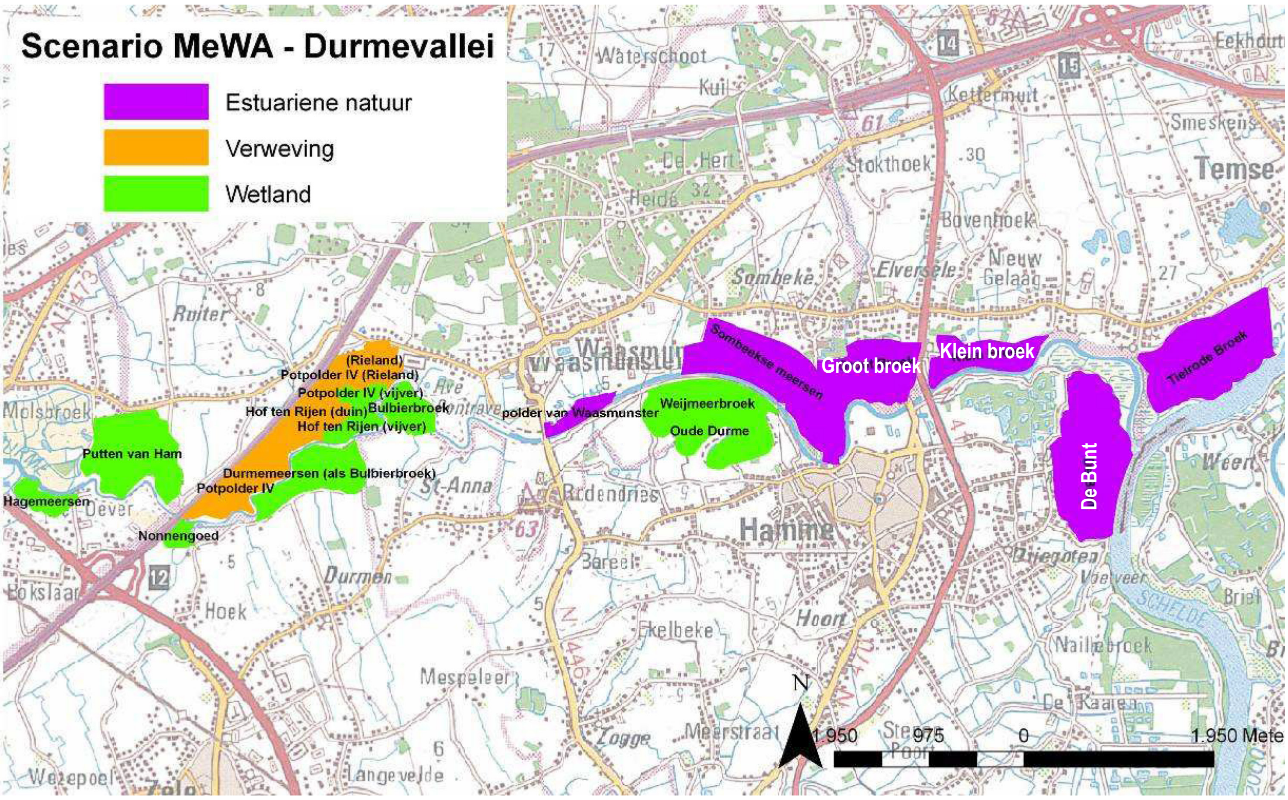


Figure 1 – The Durme valley (after Van Ryckegem, 2006)

2 Description of scenarios

2.1 The Durme model

All scenario runs in this report are conducted with the hydrodynamic model described in Nguyen et al. (2024). The model was set up particularly for the Durme region in a depth-averaged mode (i.e. 2Dh) within the Telemac software. The following presents briefly the Durme model, more details can be found in Nguyen et al. (2024).

The Durme model covers part of the Upper Sea Scheldt, between Temse and Sint-Amands, and the whole Durme valley, from the mouth of the Durme until the dam at Lokeren as the most upstream location (Figure 2). The model grid includes also several areas which are not yet connected to the Durme river but are foreseen within the MWeA (Meest Wenselijk Alternatief) of the Sigma plan. The grid resolution in the Durme river varies from 1.5 m at the upstream end to about 11 m near its mouth. In the Upper Sea Scheldt, the resolution ranges between 10 to 15 m. At the Sigma areas and the floodplain along the Scheldt river, the resolution is up to 20 m.

The Durme model has three open boundaries (Figure 2). The water levels are imposed at the two boundaries in the Uppers Sea Scheldt (at Temse and Sint-Amands) and discharge at the upstream end of the Durme river (i.e. at the dam in Lokeren).

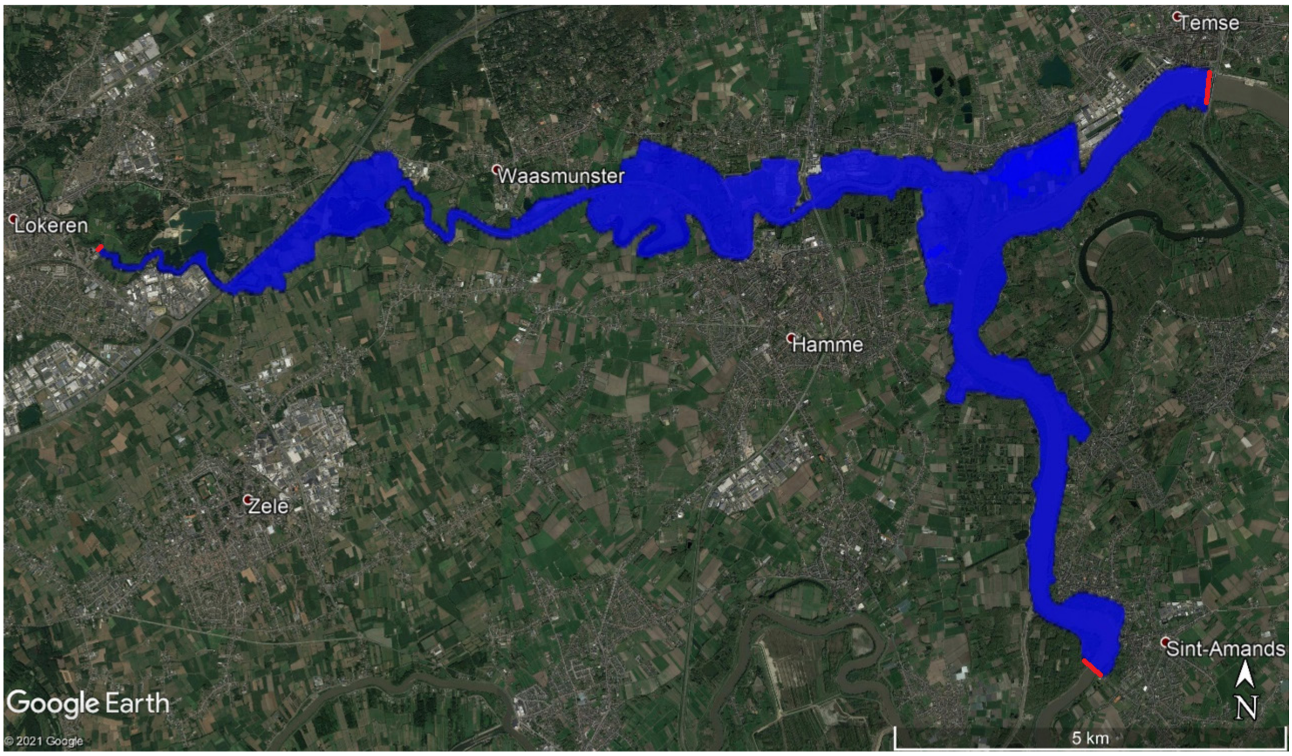


Figure 2 – The Durme model (blue) with three model boundaries (red) (Nguyen et al, 2024)

The model was calibrated for a spring - neap cycle and for a bathymetric situation in 2019 (after dredging) and 2010 (before dredging). The modeled water levels agree well with the measurements with quite a small error. The RMSE of HW is smaller than 8 cm for all locations, except the value of 12 cm for the most upstream location Zele, which might be explained by unknown upstream discharge and the increased uncertainty in the model bathymetry in the upstream part. Considering the whole timeseries at Driegoten, Tielrode, the total RMSE is smaller than 5 cm.

The model fairly reproduces the current velocities at Waasmunster-Brug cross-section located in the middle of the Durme river with the calculated RMSE and RMAE of 0.17 m/s and 0.64. The velocity magnitudes and directions along Weert/Driegoten transect, located in the Scheldt river, about 500 m south of the Durme river mouth are well represented by the model. The RMSE and RMAE are 0.18 m/s – 0.2 m/s and 0.21 – 0.25, respectively.

2.2 Model period

The model period chosen for the scenario runs (see §2.5) is the same as the calibration period selected in Nguyen et al., (2024). It covers one spring-neap cycle from 09/09/2019 to 23/09/2019 (see Figure 3) and two days of model initialization.

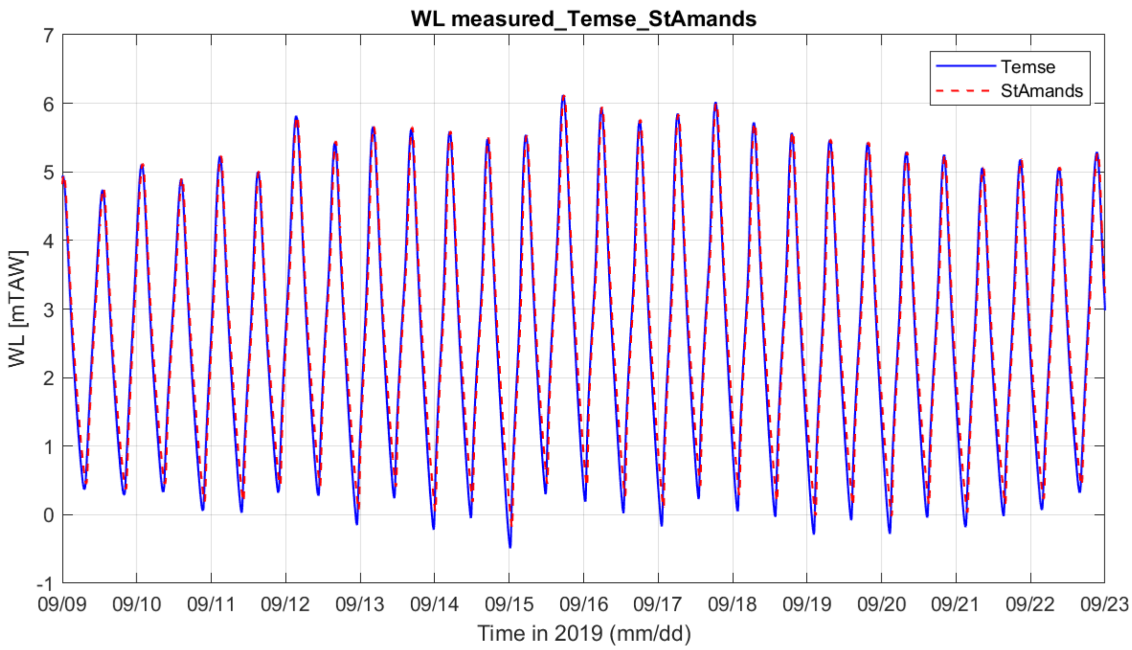


Figure 3 – Simulation period of the scenario runs (09/09/2019 – 23/09/2019)

2.3 Boundary conditions

As presented in §2.1, the Durme model has three open boundaries, where boundary conditions should be applied. At the two boundaries in the Scheldt (downstream at Temse and upstream at Sint-Amands), water levels are implemented. At the upstream side of the Durme river a discharge boundary condition is applied.

2.3.1 Water levels imposed at boundaries in the Scheldt

From the results of the Mike1D model (Coen et al., 2021), the inclusion of the Sigma areas De Bunt, Klein Broek and Groot Broek shows an effect on the water levels at the two stations Temse and Sint-Amands, which are the locations of the two water level boundaries of the Durme model.

In Figure 4 and Figure 5, the influence is presented for high water levels and tidal ranges for different tides of the considered spring-neap cycle 09/09/2019-23/09/2019. The three Sigma areas result in a reduction of high water levels and tidal ranges at the two boundaries of the Durme model. The effect increases with higher water levels and tidal ranges. The impact of the Sigma areas on HW and tidal range is limited for neap tides but the reduction of HW, tidal range during spring tides reaches a value of 9 to 10 cm if all three Sigma areas De Bunt, Klein Broek, and Groot Broek are considered. Groot Broek has the largest impact, De Bunt the smallest. Compared to the northern boundary at Temse, the southern boundary at Sint-Amands is subjected to higher influence, by about a factor of two.

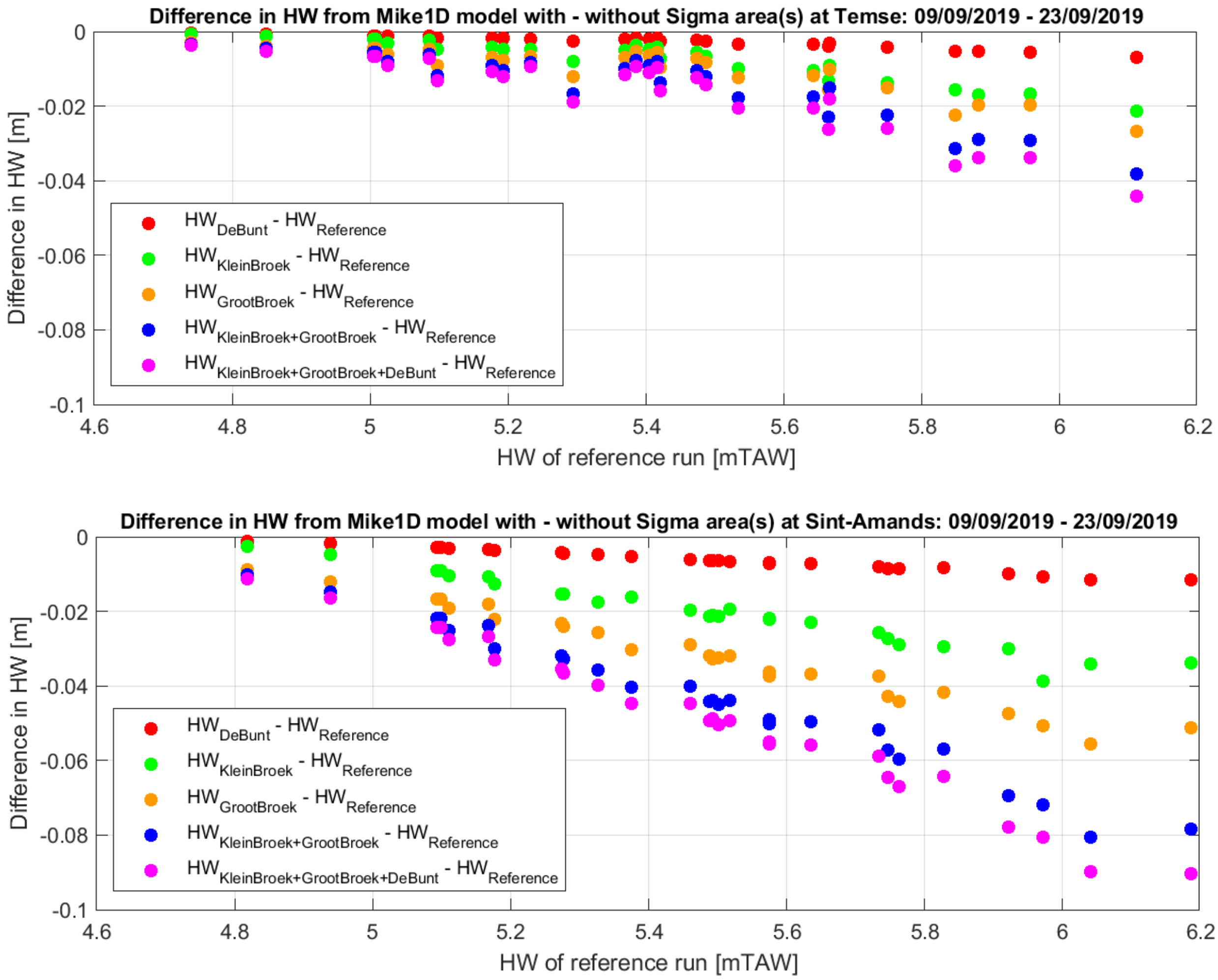
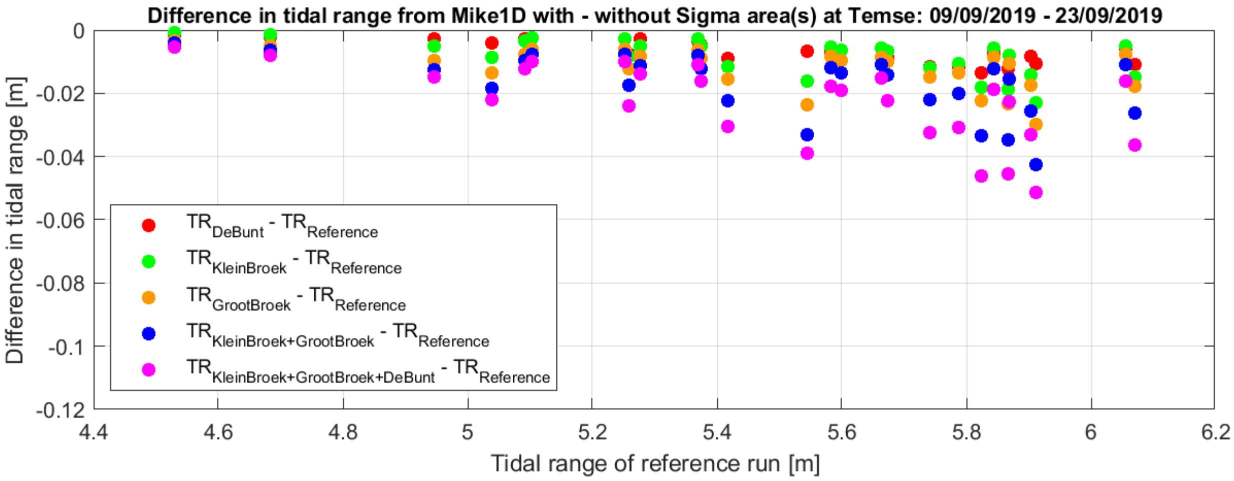


Figure 4 – Difference in high waters between (Mike1D model) runs with and without Sigma area(s) at Temse (upper) and Sint-Amands (lower)



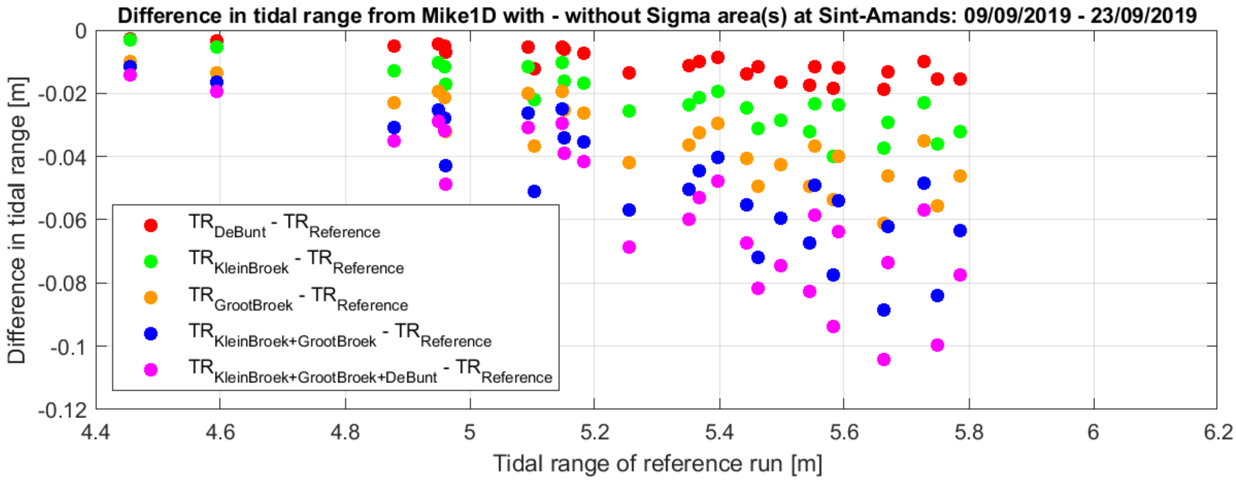


Figure 5 – Difference in tidal ranges between (Mike1D model) runs with and without Sigma area(s) at Temse (upper) and Sint-Amands (lower)

The effect of Sigma areas on the water levels at these two boundaries, Temse and Sint-Amands, needs to be taken into account. This can be done by adding the difference in water levels between the case with and without Sigma area(s) (REF) computed from Mike1D to the measured water levels:

$$WL1_{SigmaArea(s)} = WL1_{measured} + (WL1\_1D_{SigmaArea(s)} - WL1\_1D_{Reference})$$

$$WL2_{SigmaArea(s)} = WL1_{measured} + (WL2\_1D_{SigmaArea(s)} - WL2\_1D_{Reference})$$

in which:

$WL1_{SigmaArea(s)}$: water levels imposed at Durme model boundary at Temse for runs with Sigma area(s) active

$WL2_{SigmaArea(s)}$: water levels imposed at Durme mode boundary at Sint-Amands for runs with Sigma area(s) active

$WL1\_1D_{SigmaArea(s)}$: water levels computed with Mike1D at Temse for cases Sigma area(s) active

$WL2\_1D_{SigmaArea(s)}$: water levels computed with Mike1D at Sint-Amands for cases Sigma area(s) active

$WL1\_1D_{Reference}$: water levels computed with Mike1D at Temse for case Sigma areas not active

$WL2\_1D_{Reference}$: water levels computed with Mike1D at Sint-Amands for case Sigma areas not active

It is noted here that although the 1D model produces some errors in the computed water levels (see Appendix 1), the error introduced to the water levels at the boundaries with the above method is thought to be small as they are cancelled out through subtraction.

It should be mentioned here that at the reporting phase of the modelling work, a correction in the water level measurements at several stations in the Scheldt was foreseen (see also in Vereecken et al., 2023). Within the Durme model domain, the correction of -4 cm is applied to the water levels at Temse and -5 cm at Driegoten during the period 2011-2021. The effect of this correction is studied in Nguyen et al., (2022). The authors reported that high water along the Durme river is reduced by about 3 cm with the correction (reduction of 4 cm) of water levels at Temse.

The relative effect of the Sigma area(s) on the modelled hydrodynamics when applying the water level correction should not change much as the measured water levels are used both in the run with and without Sigma area(s).

2.3.2 Discharge imposed at Durme upstream boundary

As presented in Nguyen et al. (2022), there are different sources of discharge entering the Durme. However, the exact effective values are not available as no measurements take place, except for the daily discharge data of the wastewater treatment plant (RWZI) at Lokeren.

In all scenario runs, the mean discharge at the RWZI during year 2019 of 0.168 m^3/s was imposed at the Durme upstream boundary. Other discharge sources are not implemented in the model.

2.4 Bathymetry and Sigma areas

Within the framework of the Sigma plan, a number of areas along the Durme and Durme estuary have been planned to become flood control areas or being depolderd by De Vlaamse Waterweg. The Klein Broek and Groot Broek areas have been designed for managed realignment and De Bunt has been designed as a flood control area with controlled reduced tide (FCA-CRT). IMDC and SBE are responsible for the technical design of these areas (IMDC, 2019). The areas around Klein Broek, Groot Broek and De Bunt are measured as $395*10^3$, $564*10^3$ and $692*10^3$ m^2, respectively.

The topography/bathymetry of the areas is based on the DTM Flanders II with some modifications, among which adjustments are made on the canals, creeks based on survey data (De Bunt) and based on a developed width-depth relation or equilibrium dimensions of creeks in intertidal areas (Klein Broek and Groot Broek) (IMDC, 2019, 2020). Details on the design of the FCA-CRT De Bunt, polders Klein Broek and Groot Broek can be found in (IMDC, 2019, 2020). The most updated design of the three areas is used in the current study.

As presented in Nguyen et al. (2022), all planned Sigma areas are included in the Durme model grid. For the FCA-CRT De Bunt and the polders Klein Broek and Groot Broek, the grid was constructed following the design of IMDC. The canals, creeks within the areas were implemented with Channel Mesher or hard lines with high resolution to represent the designed bathymetry.

The scenario runs in this study (see §2.5) use the bathymetry situation after dredging (see the construction of the model bathymetry for the runs 2019 in Nguyen et al., 2024). It was constructed using different data sets in the years 2018, 2019, 2020 and planned bathymetries for De Bunt, Klein Broek and Groot Broek. In the scenario runs, if a Sigma area is not active, the bottom within the area is set to about the highest dike level of +8 mTAW.

2.4.1 Polder Klein Broek

The designed bathymetry, provided by IMDC, was interpolated to the Durme grid to construct the bathymetry of the polder (shown in Figure 6). The mean bottom level of Klein Broek is +4.9 mTAW. Klein Broek area has been designed with two openings to connect the area with the Durme river. The grid resolution at the openings is in the range of 3 m-4.5 m. The west and east openings respectively have a length of about 50 m and 60 m, in which the deepest part, at the level of +1 mTAW, is about 15 m long (Figure 6). The dike section between the two openings has been planned to be lowered to the level of +6.5 mTAW (Figure 6). The connection part of the openings to the Durme river was implemented following the design presented in IMDC (2020). The final bathymetry shows a smooth transition between the Durme river and the polder (Figure 6).

In Figure 7, the hypsometric curve of the polder Klein Broek calculated based on the model bathymetry is illustrated. More than 90% of the area has the bottom level in the range of 4 mTAW - 6.5 mTAW. Small proportion of the area shows the bed level down to +1 mTAW (at the connection to the Durme river) and some high elevated location up to about +8 mTAW.

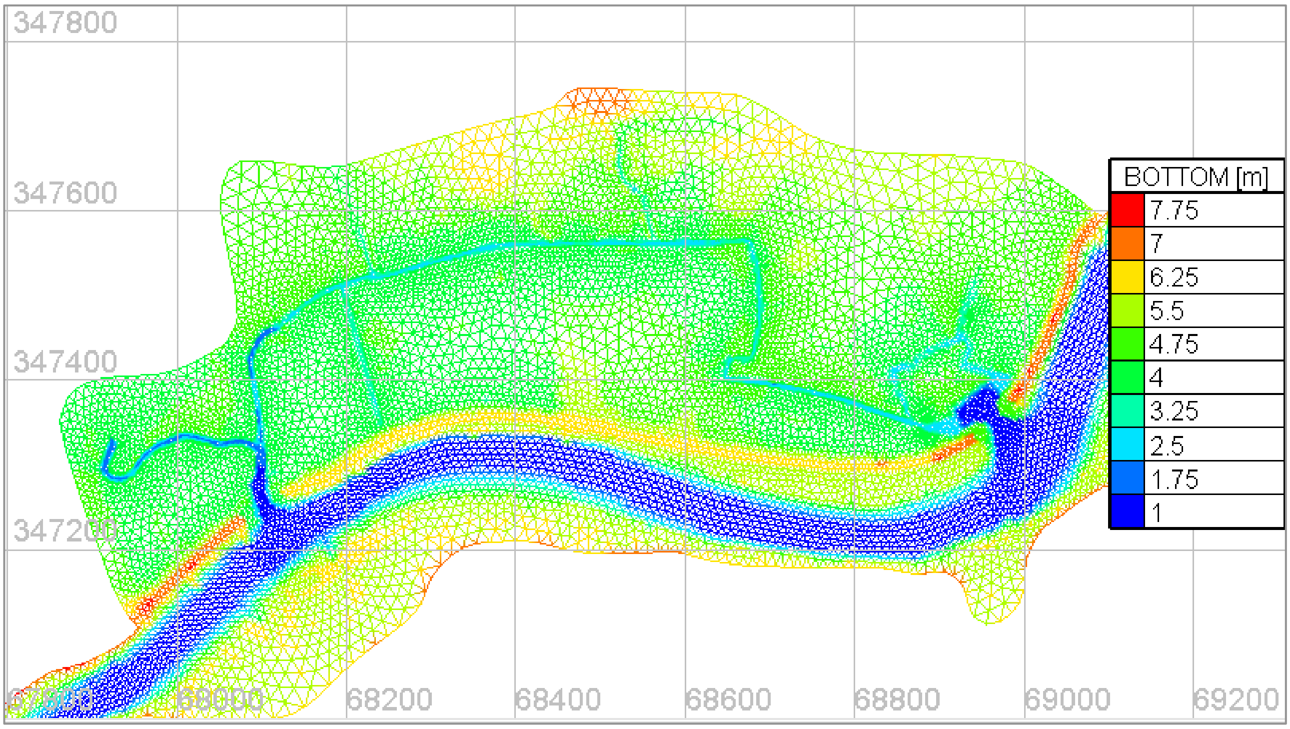


Figure 6 – Bathymetry of the polder Klein Broek

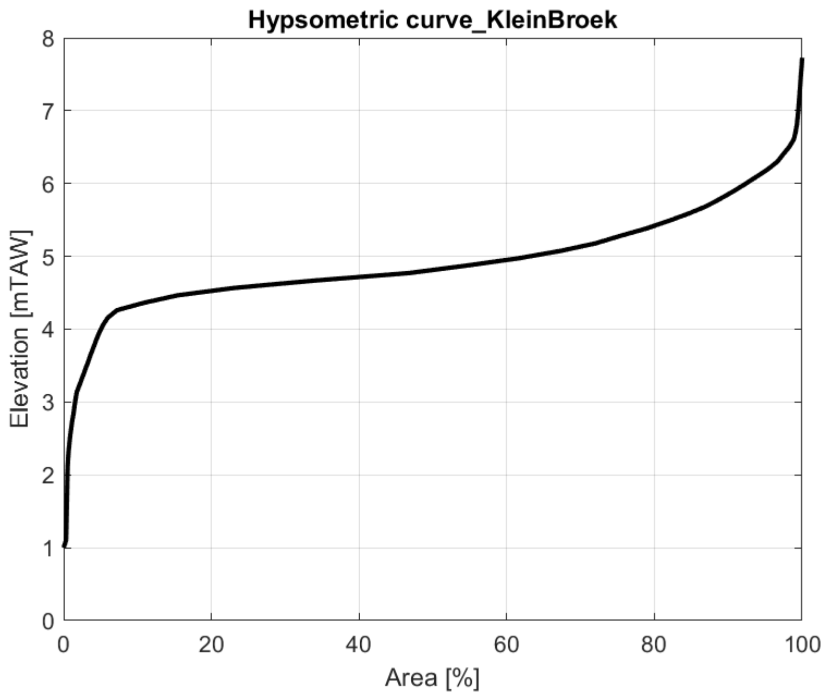


Figure 7 – Hypsometric curve of the polder Klein Broek

2.4.2 Polder Groot Broek

Figure 8 shows the bathymetry for the Groot Broek area, which was constructed using designed bathymetry provided by IMDC. Similar to Klein Broek, two openings have been designed to connect Groot Broek polder with the Durme river. The dike breaching length is about 110 m for the north opening and 30 m for the south one in which the sections of 25 m (north opening) and 15 m (south opening) are at the deepest level of +1 mTAW. The grid resolution at the openings is in the range of 5 m - 6 m. The dike between the two openings and the dike section west of the south opening has been designed to be lowered to the level +6.5 mTAW.

The hypsometric curve of the polder Groot Broek in Figure 9 shows that about 80% of the area with the bottom level at 4 mTAW - 5 mTAW. The mean bottom level of Groot Broek is +4.6 mTAW, which is slightly lower compared to Klein Broek (see §2.4.1). A small percentage of the high elevated area includes also the dike that splits Groot Broek into two parts.

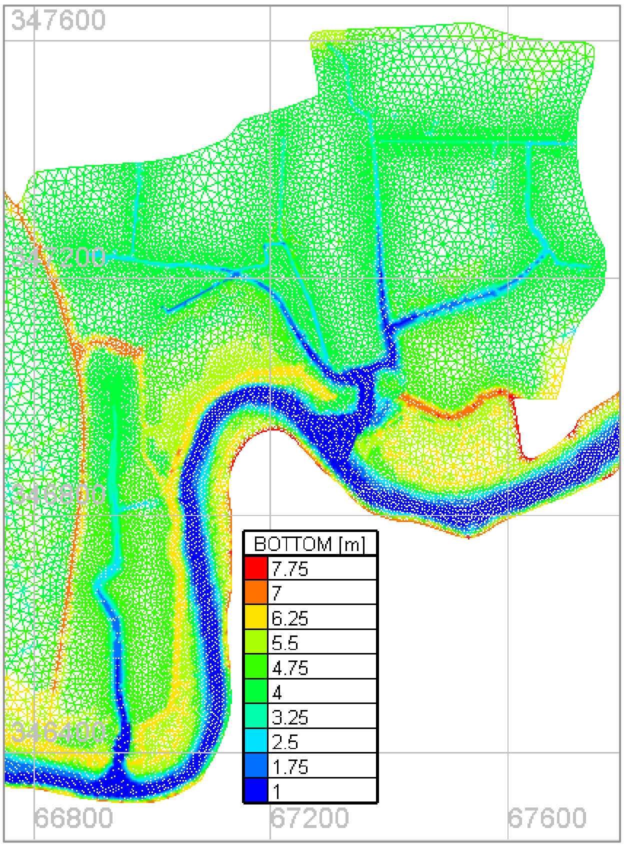


Figure 8 – Bathymetry of the polder Groot Broek

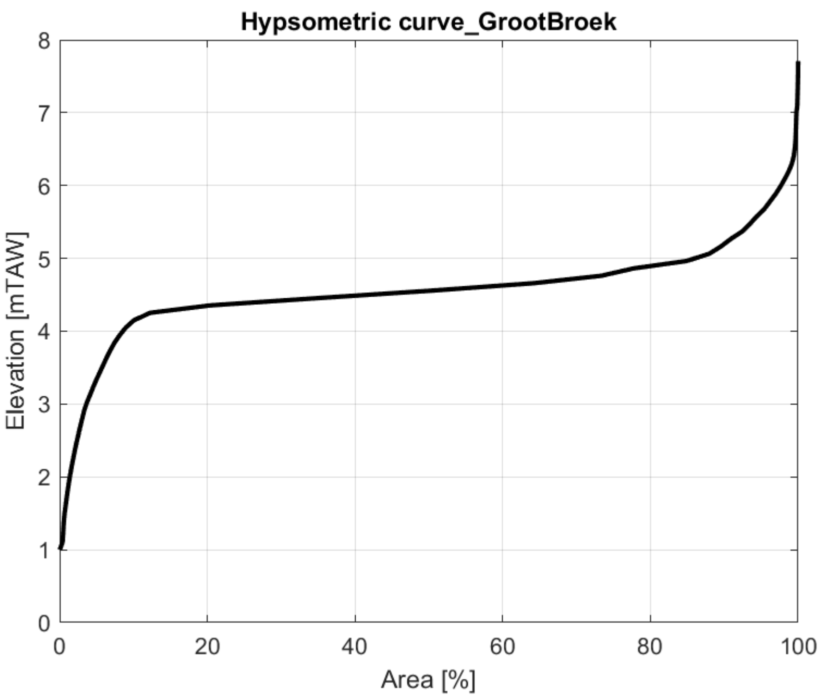


Figure 9 – Hypsometric curve of the polder Groot Broek

2.4.3 FCA-CRT De Bunt

De Bunt is designed to become a flood control area with reduced tides (FCA-CRT) with an area of about 84.5 ha. In IMDC (2019), a detailed flow model was constructed explicitly for the area of De Bunt. Different model scenarios were carried out with the adjustment of the sand area, ditches, sluices, culvert configuration to optimise the functionality of the area (see IMDC, 2019). The final version of the De Bunt bathymetry, sluice position and configuration were applied in this current model.

2.4.3.1 De Bunt bathymetry

The planned bathymetry for the FCA-CRT De Bunt provided by IMDC was interpolated to the Durme model grid for the scenario simulations that the De Bunt is active (Figure 10). Four sections of the dike with the total length of about 1 km are lowered to a level of about +6.8 mTAW (Figure 10).

The hypsometric curve of the FCA-CRT De Bunt is presented in Figure 11. About 80% of the area has the bottom level within the range 2 mTAW - 4 mTAW. The mean bottom level of De Bunt is +2.8 mTAW.

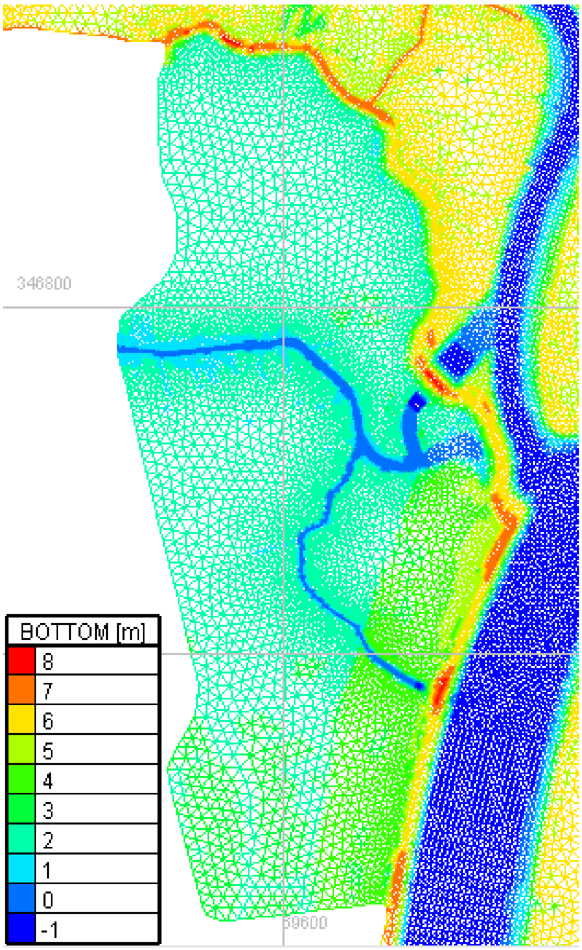


Figure 10 – Bathymetry of the FCA-CRT De Bunt

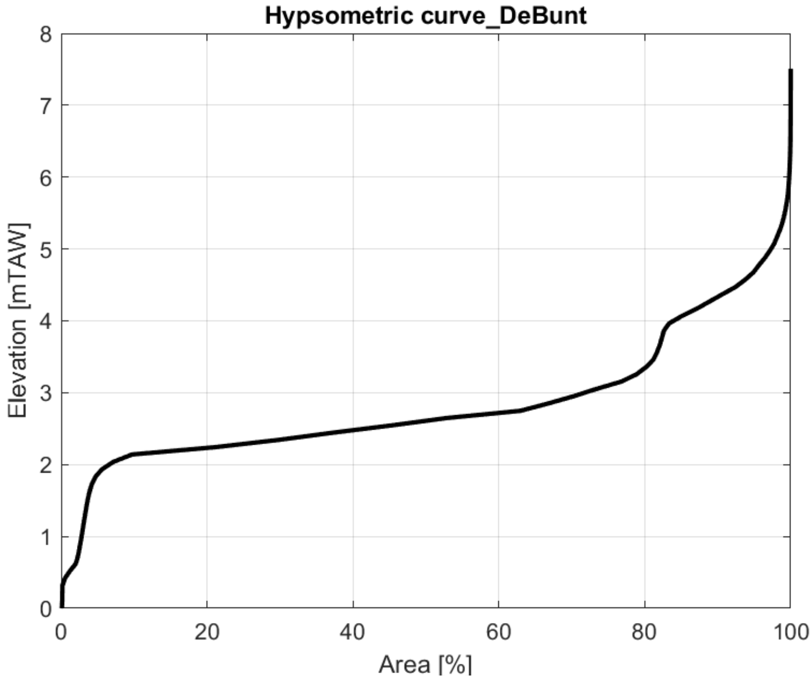


Figure 11 – Hypsometric curve of the FCA-CRT De Bunt

2.4.3.2 Culverts

Two sluices have been proposed: the combined inlet-outlet sluice connecting De Bunt to the Durme river (the northern sluice) and the southern outlet sluice to the Scheldt (Figure 12). On the polder side, the ditches are located at the toe of the dike (Figure 10 and Figure 12). The structural design of the two sluices was provided by De Vlaamse Waterweg and is shown in Figure 13, Figure 14 and Appendix 2. In total, there are 28 culverts: 24 northern culverts (12 inlet, 12 outlet) and 4 southern outlet culverts. The main dimensions of the culverts are presented in Table 1.

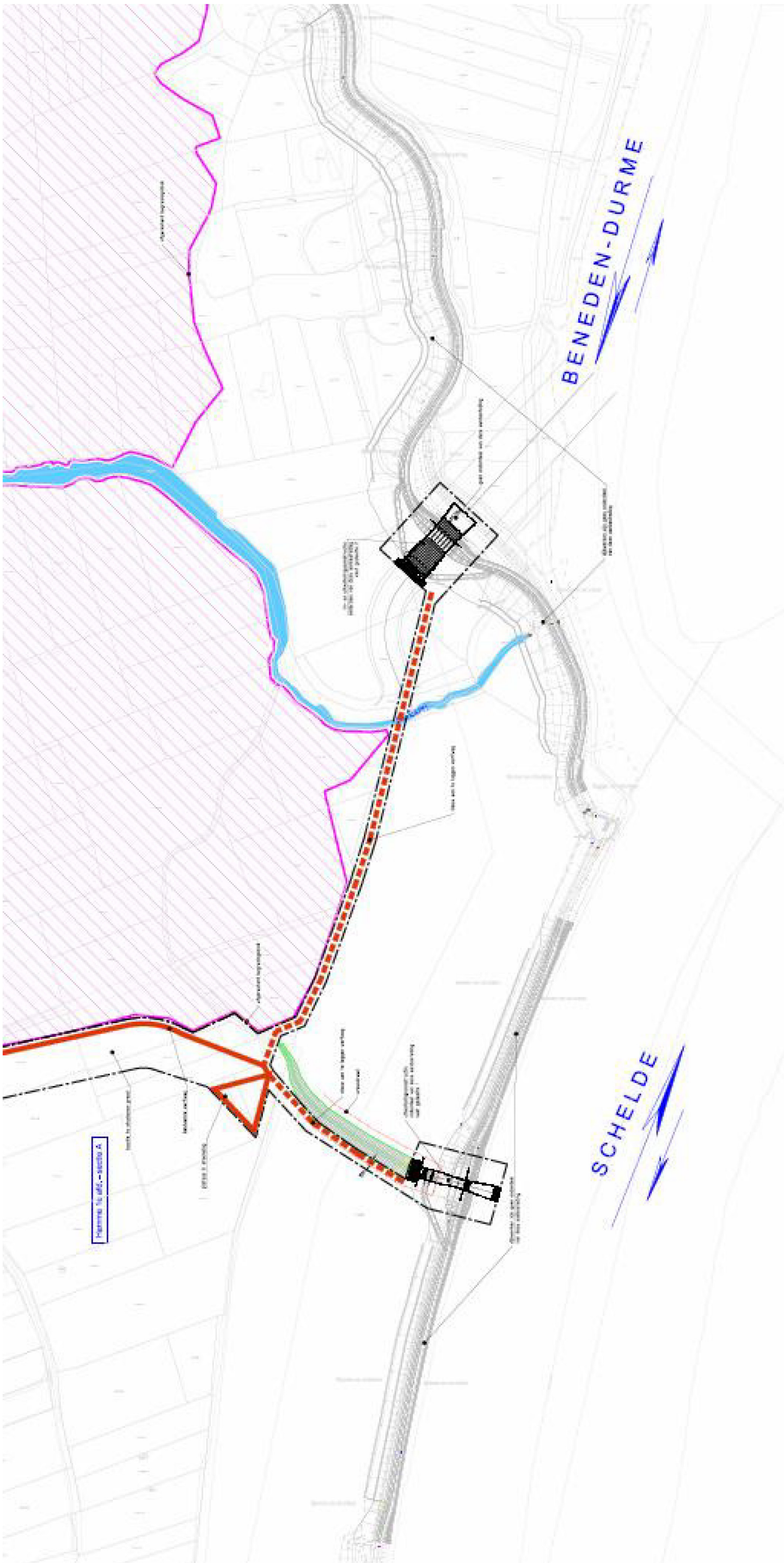


Figure 12 - Position of the northern inlet and outlet sluice and southern outlet sluice (IMDC, 2019)

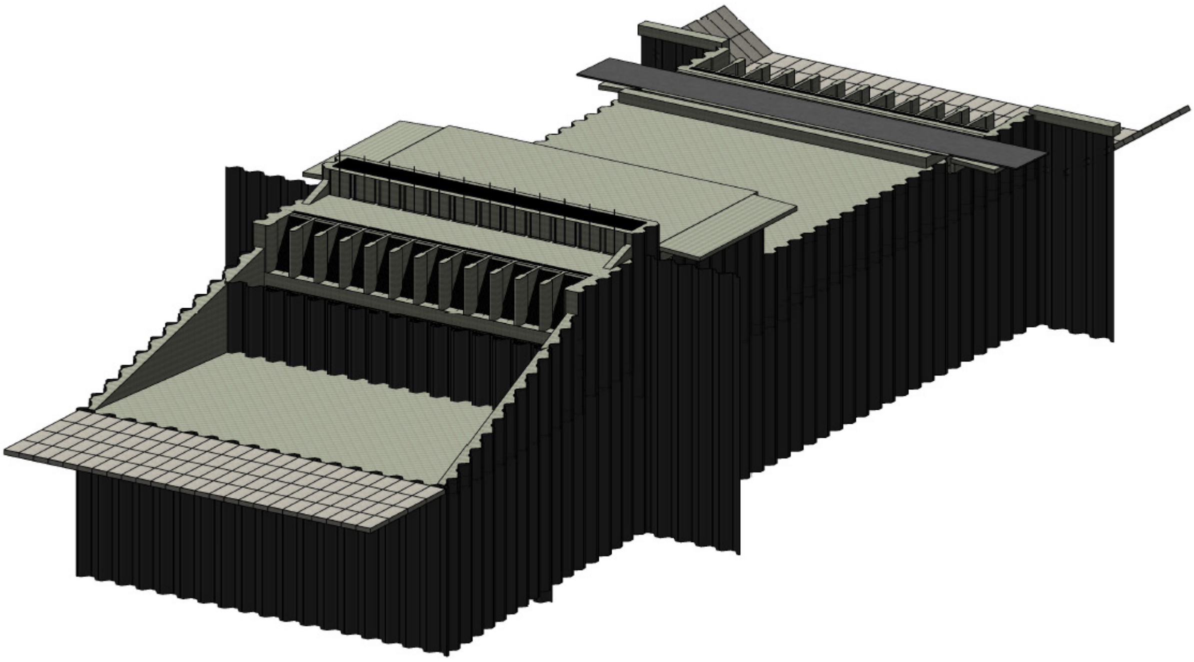


Figure 13 – 3D view of the northern inlet-outlet sluice (SBE, 2019c)

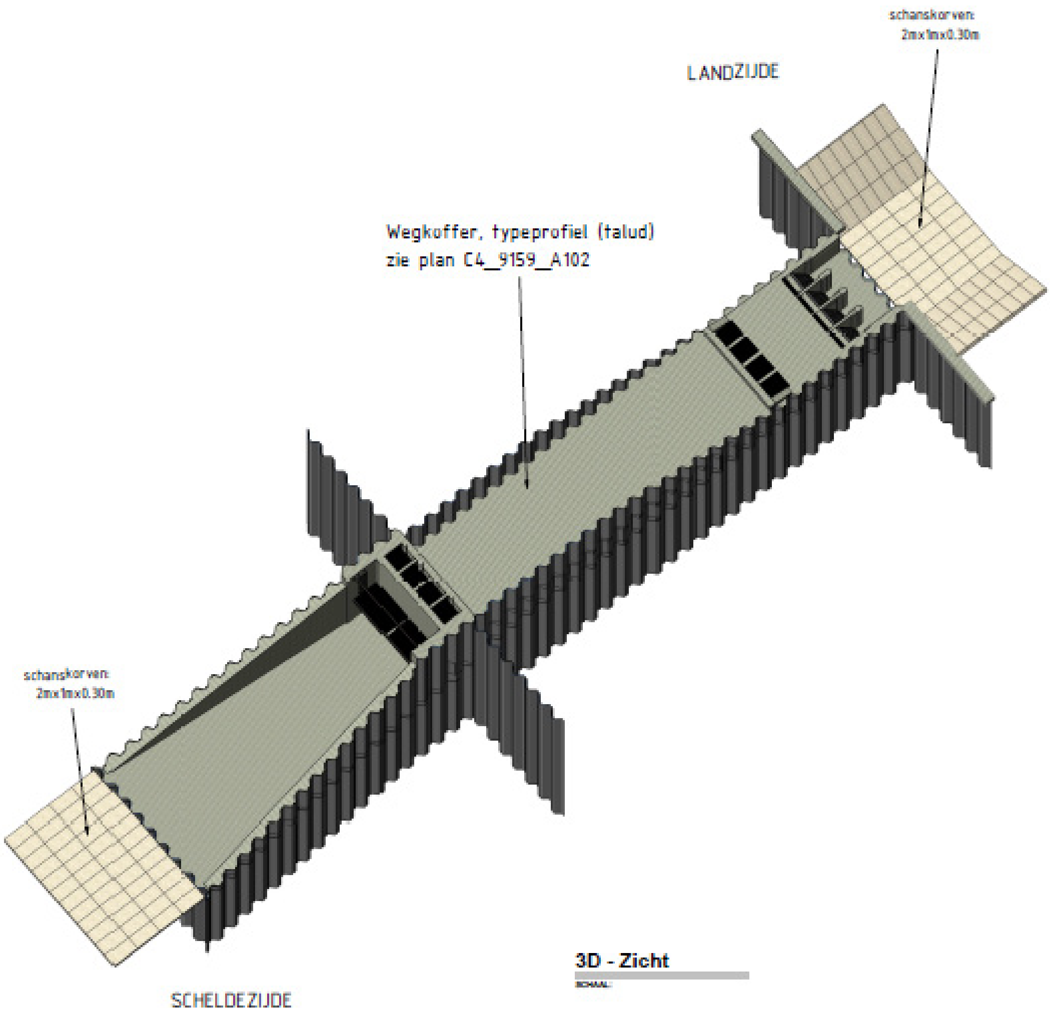


Figure 14 – 3D view of the southern outlet sluice (SBE, 2019a)

Table 1 – Characteristics of sluices of the FCA-CRT De Bunt

Sluice	Culvert type	Number of culverts	Culvert width x height		Culvert bottom level	Culvert length	Trash screen
			River side	De Bunt side			
Northern sluice	Inlet culverts	12	1.3 x 2.3 m	1.3 x 2.7 m	+4.0 mTAW	43 m	yes
	Outlet culverts	12	1.3 x 1.75 m	1.3 x 2.7 m	+0.8 mTAW	45 m	yes
Southern sluice	Outlet culverts	4	1.3 x 1.75 m	1.3 x 2.2 m	+0.8 mTAW	36 m	yes

In Telemac, culverts are described as couples of points between which flow may occur, as a function of the respective water level at these points (EDF-R&D, 2014). Figure 15 shows the nodes where the culverts are modelled. Each culvert is represented by two nodes (one at the polder side, one at the seaside). The culvert characteristics are provided into the model in the Culvert data file. The parameters for modelling culverts of FCT-CRT De Bunt are presented in Appendix 3.

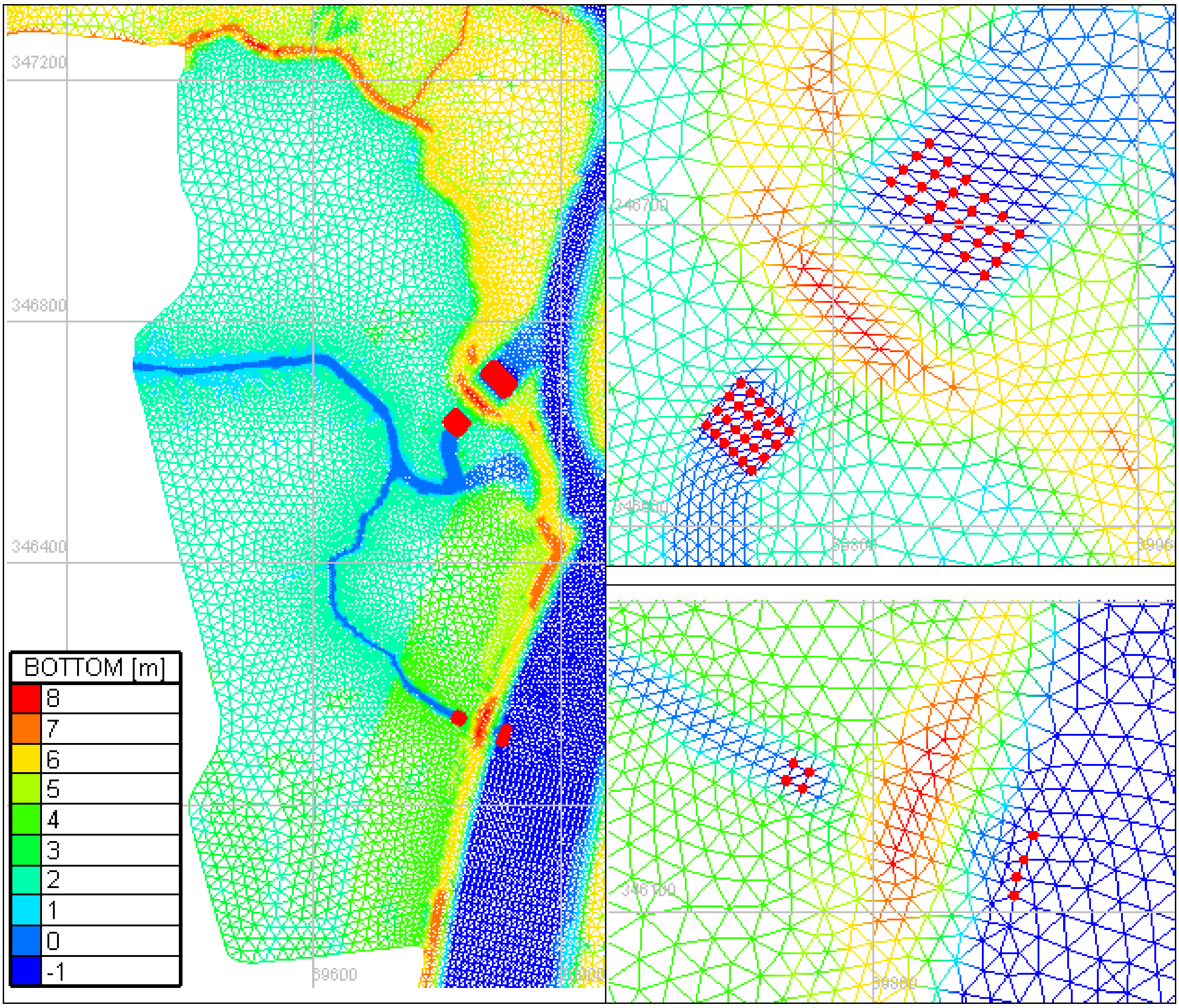


Figure 15 – Implementation of the inlet and oulet sluices of FCA-CRT De Bunt

2.5 Scenario runs

Table 2 presents an overview of the model scenario runs with different combination of the Sigma areas De Bunt (DB), Klein Broek (KB), and Groot Broek (GB) assessed within this report. The first run (Run58) is the reference run with no active Sigma areas. In the following three runs, only one of the Sigma areas is activated: Run81 (De Bunt), Run82 (Klein Broek), and Run83 (Groot Broek). Run84 is a scenario with Klein Broek and Groot Broek active, both designed as depoldered areas. In Run85 all three Sigma areas are connected to the river.

Table 2 – Model scenario runs

Scenario	**RunID**	**Active Sigma area**		
		De Bunt (BD)	**Klein Broek (KB)**	**Groot Broek (GB)**
1: Reference (Ref.)	Run58	no	no	no
2	Run81	**yes**	no	no
3	Run82	no	**yes**	no
4	Run83	no	no	**yes**
5	Run84	no	**yes**	**yes**
6	Run85	**yes**	**yes**	**yes**

3 Scenario results and discussion

In this chapter, the results of different model scenarios regarding the Sigma areas De Bunt, Klein Broek and Groot Broek (see §2.5) are discussed. The analysis is performed for the spring-neap cycle 09/09/2019-23/09/2019, with a detailed discussion for a selected spring tide (16/09/2019 13:00 - 17/09/2019 01:20) and neap tide (22/09/2019 03:50 - 22/09/2019 16:00) (see Figure 16 and Table 3). The following results are considered:

- Water volume exchange between the Durme tributary and the Upper Sea-Scheldt, Sigma areas De Bunt, Klein Broek and Groot Broek.
- Water levels computed during the spring-neap tidal cycle at six tidal stations: Driegoten, Tielrode, Hamme, Waasmunster-Brug, Waasmunster-Manta, and Zele (see Figure 17).
- Cross-sectional averaged velocities along the Durme.
- Longitudinal variation of HW, peak flood, ebb current velocity
- Tidal asymmetry along the Durme: two types of the tidal asymmetry are investigated:
  - *Asymmetry in tidal duration:* represented by the ratio of tidal duration during flood and ebb. The ratio is larger than 1 indicates flood dominance and the ratio smaller than 1 means ebb dominance.
  - *Asymmetry in peak current velocity:* represented by the ratio of peak flood velocity and peak ebb velocity. If the ratio is larger than 1, flood dominance occurs (i.e. flood velocity is larger than the ebb velocity) and vice versa, the ratio smaller than 1 indicates ebb dominance. The asymmetry in current velocities can be used as a proxy for sediment transport as sediment transport formulas are mostly dependent on velocity magnitude.

Along the Durme river, 91 cross-sections were defined with approximately 200 m interval, as shown in Figure 17. On these transects the model results are extracted and analyzed. The water volumes, water levels and current velocities, tidal asymmetry are discussed for the selected spring tide and neap tide. Except for the water volumes, the longitudinal results of water levels, current velocities and tidal asymmetry are smoothed with three-point moving averages.

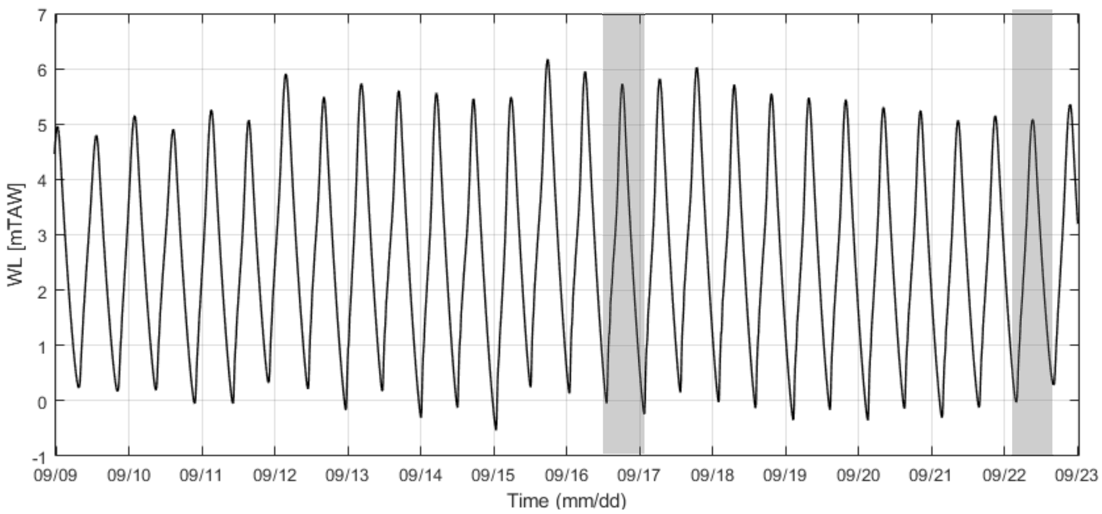


Figure 16 – Selected spring tide and neap tide for the scenarios analysis

Table 3 – Characteristics of the tides (at Tielrode) selected for the result analysis. Values in bracket show the average five-year data 2011-2015 (Hertoghs et. al., 2018)

Tide	LW	HW	TR
Spring tide: 16/09/2019 13:00 - 17/09/2019 01:20 *(Average spring tides 2011-2015)*	-0.2 *(-0.08)*	5.7 *(5.98)*	5.9 *(6.06)*
Neap tide: 22/09/2019 03:50 - 22/09/2019 16:00 *(Average neap tides 2011-2015)*	0 *(0.35)*	5.1 *(5.08)*	5.1 *(4.74)*

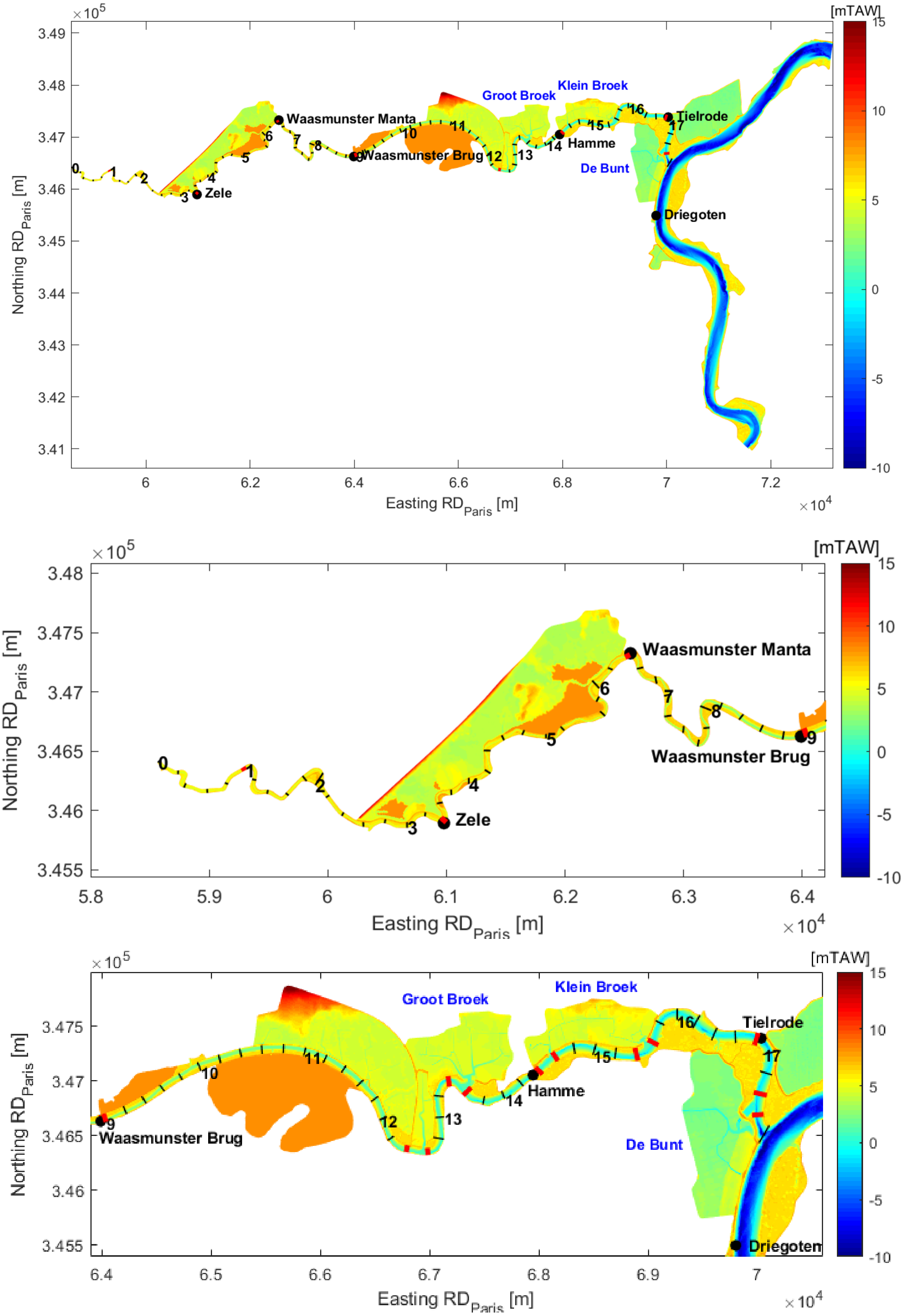


Figure 17 – Observation stations and cross-sections used in the scenarios analysis: the whole model area (top) and zoom to half of the Durme river in the section upstream (middle) and downstream (bottom). The numbers show the distance in km from river upstream end at Lokeren. Transects used for detailed analysis are in red

3.1 Effect on water volumes

3.1.1 Water volume at Durme mouth and in the Scheldt

Figure 18 shows the water volume during the flood at the Durme river mouth and in the Scheldt at location right downstream of Durme mouth for different Sigma area scenarios during the spring tide and neap tide. The ratio between the volume entering the Durme mouth and in the Scheldt is shown in Figure 19.

As expected, the spring tide shows higher volume than the neap tide. Activating a Sigma area causes higher volume in the Scheldt and at the mouth of the Durme river (Figure 18). The inclusion of the Sigma areas also result in a higher proportion of water entering the Durme river (Figure 19). The water amount flowing into the Durme river accounts for 8% - 12% of the volume in the Scheldt.

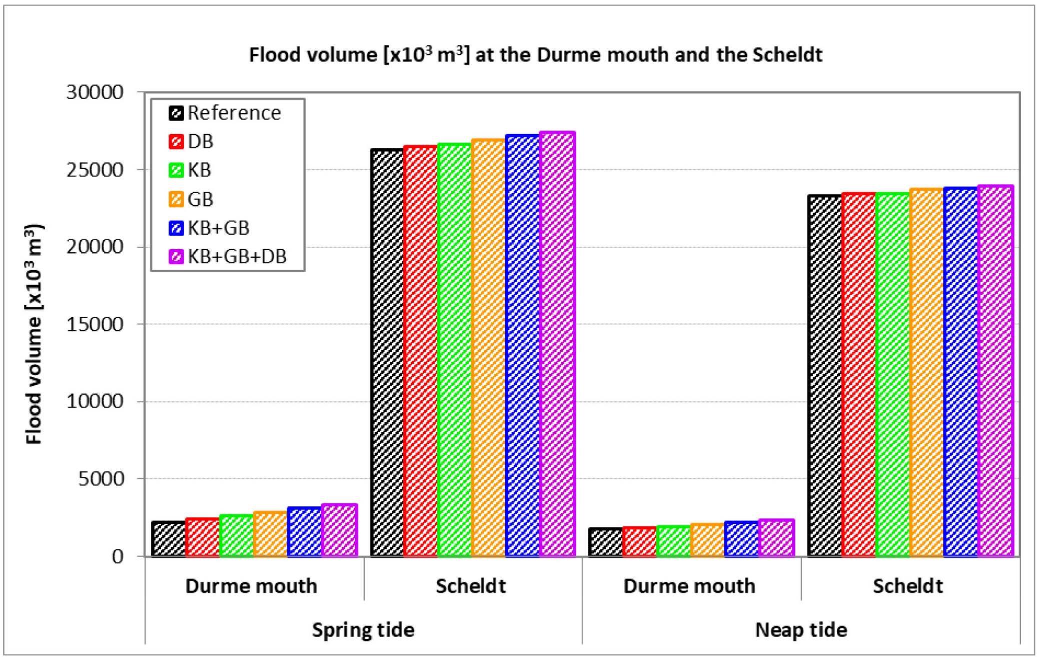


Figure 18 – Flood volumes enter Durme mouth and in the Scheldt (at location right downstream of Durme mouth) during spring tide and neap tide

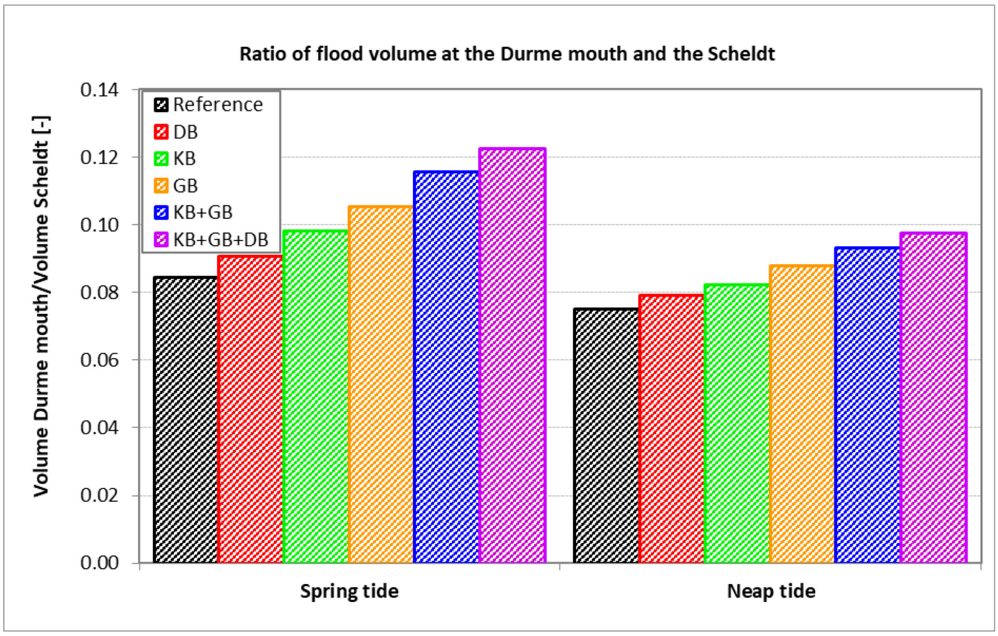


Figure 19 – Ratio between water volume enter Durme mouth and in the Scheldt (at location right downstream of Durme mouth) for spring tide and neap tide

The water exchange at the Durme mouth is analysed in more details in Table 4. Among the three Sigma areas, De Bunt shows the smallest effect on the tidal volume, while Groot Broek gives the largest effect. Compared to the reference run, the runs with De Bunt, Klein Broek, Groot Broek, Klein Broek + Groot Broek and Klein Broek + Groot Broek + De Bunt result in an increase of the flood volume at the mouth by 8%, 18%, 28%, 42% and 51% respectively during the spring tide. For the neap tide the effect is slightly smaller, with the respective increases of 6%, 10%, 19%, 27% and 33%.

Table 4 – Flood volume (x10^3 m^3) at the Durme mouth for different Sigma area scenarios. Numbers in brackets indicate the increase of volume (in x10^3 m^3 and %) compared to the reference run

Active Sigma area	Spring tide	Neap tide
Reference (Sigma areas not active)	2216 *(+0; +0%)*	1752 *(+0; +0%)*
De Bunt	2402 *(+185; +8%)*	1855 *(+103; +6%)*
Klein Broek	2617 *(+401; +18%)*	1929 *(+178; +10%)*
Groot Broek	2834 *(+618; +28%)*	2084 *(-332; +19%)*
Klein Broek + Groot Broek	3144 *(+928; +42%)*	2221 *(+469; +27%)*
Klein Broek + Groot Broek + De Bunt	3351 *(+1134; +51%)*	2330 *(+579; +33%)*

3.1.2 Exchange volume to the Sigma areas

Figure 20 and Figure 21 show the exchange of water volumes to the Sigma areas De Bunt, Klein Broek and Groot Broek during flood and ebb periods for different scenarios during the spring tide and the neap tide, respectively. Additionaly, the ebb and flood water volumes at the Durme river mouth, in the middle of the river (at km 9, coinciding with the location of Waasmunster Brug, see Figure 17) and at the upstream end are also presented. The volumes in the figures are indicated in ($x10^3$ m^3). Positive values represent flood volumes, negative values indicate ebb volumes.

Due to the imposed discharge of 0.168 m^3/s at the upstream boundary (see §2.3), about 7.5x10^3 m^3 and 7.4x10^3 m^3 of water flushes into the river through the upstream boundary (km 0) during the spring tide and neap tide, respectively (Figure 20, Figure 21). The slightly higher volume enters at the upstream in the spring tide is due to its slightly longer duration (12 hrs 20 mins vs. 12 hrs 10 mins).

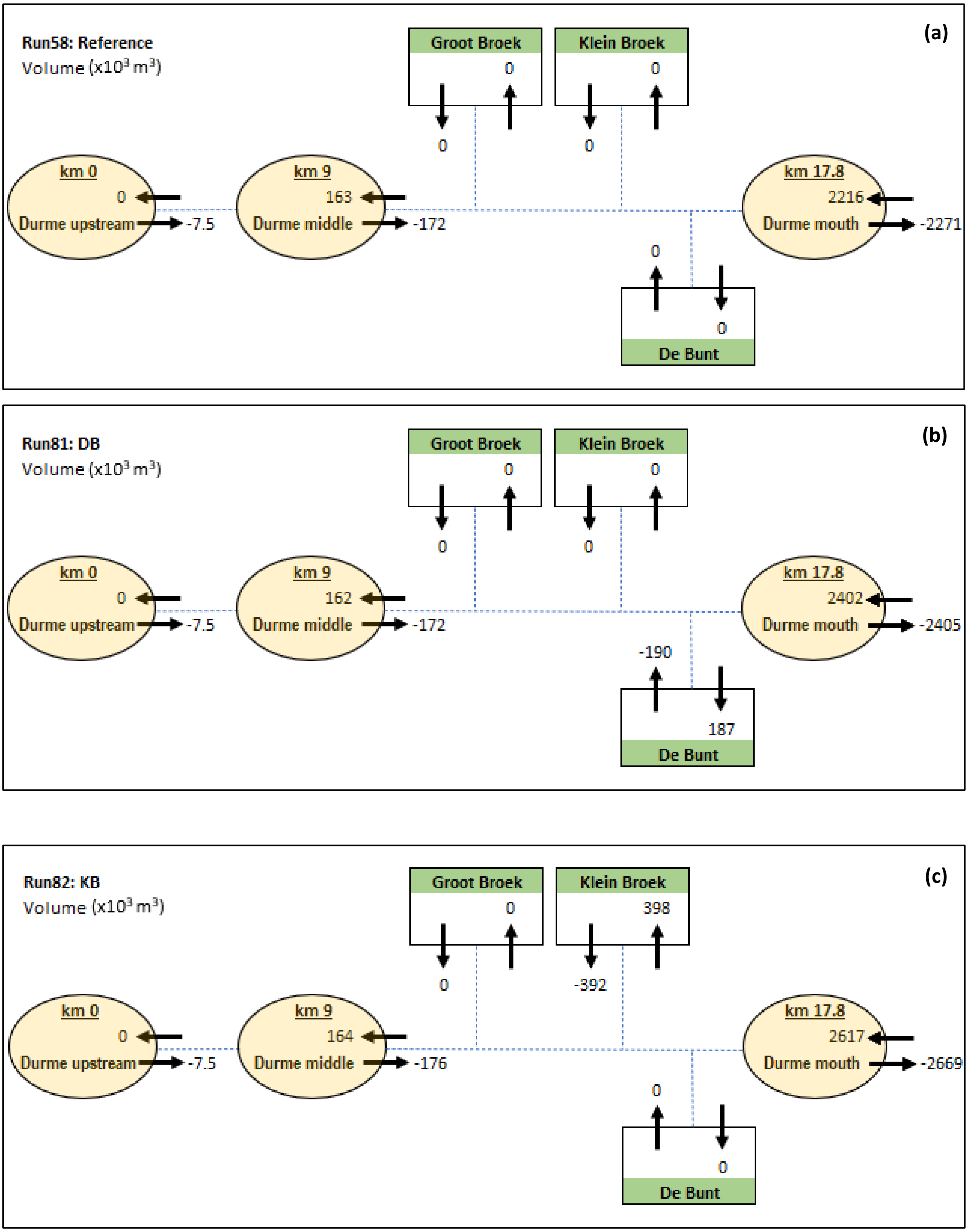
In all scenarios, the same order of magnitude of water volume enters and leaves the river (through the Durme river mouth), and more or less the same amount of water enters and leaves the Sigma areas, as expected.

Once being activated, the water exchange through De Bunt is smallest and Groot Broek the largest. For the cases of single area activated (Run81, Run82, Run83), around 187x10^3 m^3 of water enters De Bunt during the spring tide while the polders Klein Broek and Groot Broek get 398x10^3 m^3 and 697x10^3 m^3, respectively (Figure 20 and Table 5). These account for 8%, 22% and 46% of the volume entering the river through transect right downstream of the areas, respectively. The neap tide shows lower volume and percentage which are 102x10^3 m^3 (6%) for De Bunt, 162x10^3 m^3 (13%) for Klein Broek, and 361x10^3 m^3 (37%) for Groot Broek.

Table 5 – Volume entering the Sigma areas during flood for cases with single area activated. Numbers in blanket indicate the percentage of volume entering the Sigma areas compared to volume through transect right downstream of the areas

	Volume ($x10^3$ m^3)		
	De Bunt	**Klein Broek**	**Groot Broek**
Spring tide	187 *(8%)*	398 *(22%)*	697 *(46%)*
Neap tide	102 *(6%)*	162 *(13%)*	361 *(37%)*

The water volume dramatically decreases (during flood) and increases (during ebb) in the Durme river section from the mouth to the middle of the river with the difference of about 95% (Figure 20, Figure 21, see also §3.1.3). The water exchange at the middle segment is not influenced much by the Sigma areas, being in the range of 152x10^3 - 164x10^3 m^3 for the spring tide and aroud 100x10^3 m^3 for the neap tide. This is due to the fact that the Sigma areas De Bunt, Klein Broek and Groot Broek are located further downstream, close to the mouth (see Figure 17).


(a)
Run58: Reference
Volume (x10³ m³)
Groot Broek
0
0
Klein Broek
0
0
km 0
0
Durme upstream
-7.5
km 9
163
Durme middle
-172
km 17.8
2216
Durme mouth
-2271
0
0
De Bunt
(b)
Run81: DB
Volume (x10³ m³)
Groot Broek
0
0
Klein Broek
0
0
km 0
0
Durme upstream
-7.5
km 9
162
Durme middle
-172
km 17.8
2402
Durme mouth
-2405
-190
187
De Bunt
(c)
Run82: KB
Volume (x10³ m³)
Groot Broek
0
0
Klein Broek
398
-392
km 0
0
Durme upstream
-7.5
km 9
164
Durme middle
-176
km 17.8
2617
Durme mouth
-2669
0
0
De Bunt

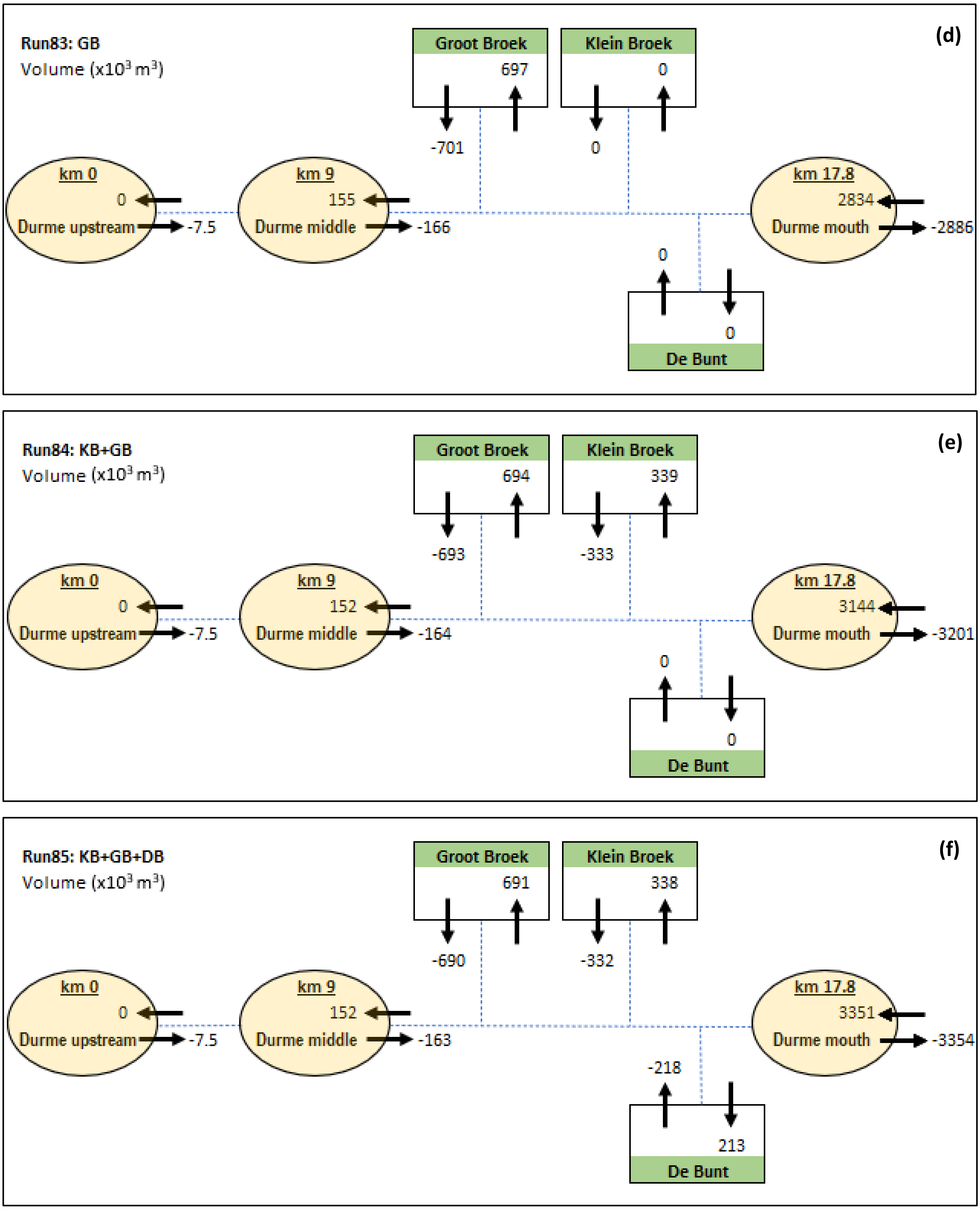
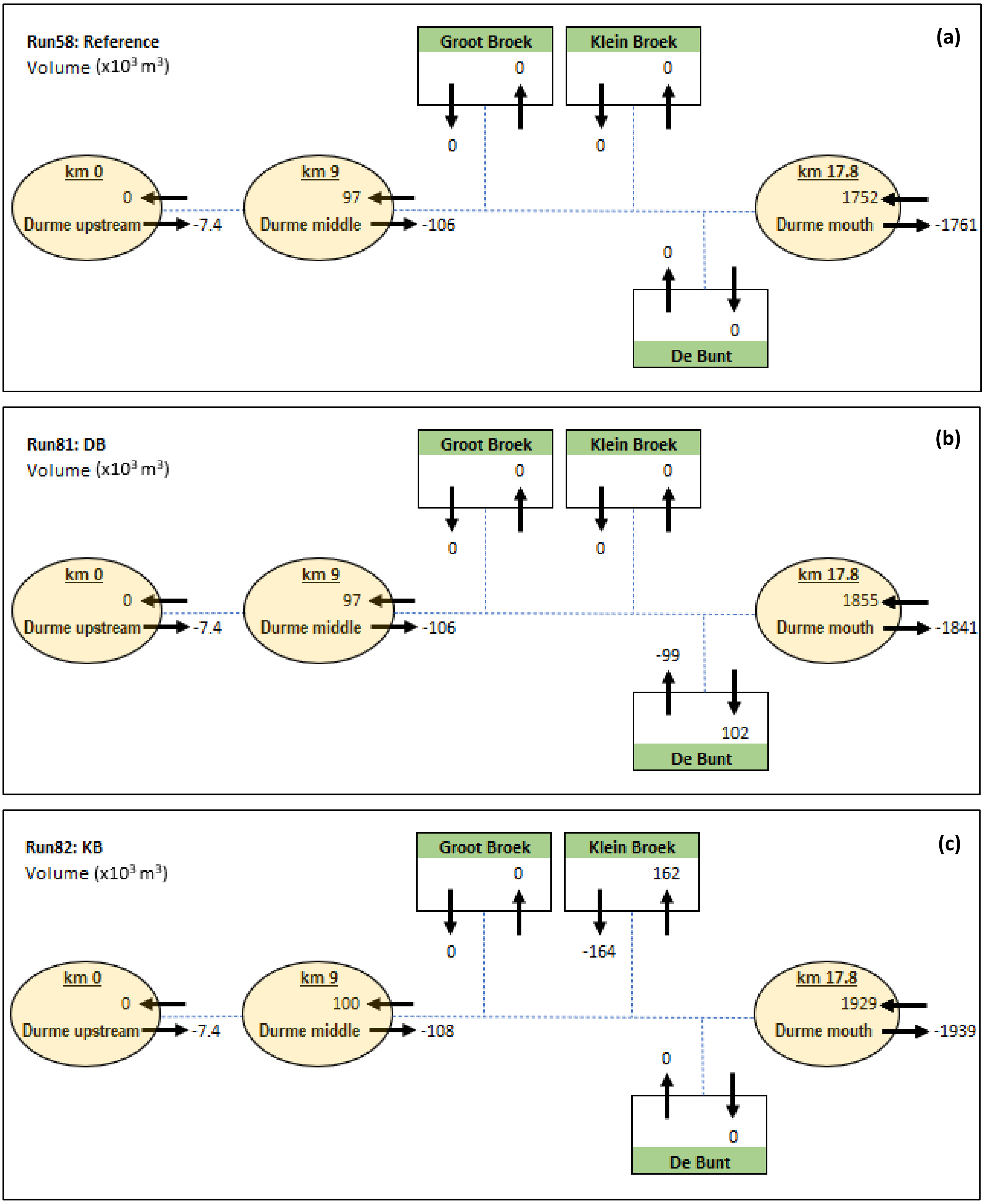


Figure 20 – Flood (+) and ebb (-) volumes (x10^3 m^3) enter and leave the Sigma areas and Durme river during spring tide


Run58: Reference
Volume (x10³ m³)
(a)
Groot Broek
0
0
Klein Broek
0
0
km 0
0
Durme upstream
-7.4
km 9
97
Durme middle
-106
km 17.8
1752
Durme mouth
-1761
0
0
De Bunt
Run81: DB
Volume (x10³ m³)
(b)
Groot Broek
0
0
Klein Broek
0
0
km 0
0
Durme upstream
-7.4
km 9
97
Durme middle
-106
km 17.8
1855
Durme mouth
-1841
-99
102
De Bunt
Run82: KB
Volume (x10³ m³)
(c)
Groot Broek
0
0
Klein Broek
162
-164
km 0
0
Durme upstream
-7.4
km 9
100
Durme middle
-108
km 17.8
1929
Durme mouth
-1939
0
0
De Bunt

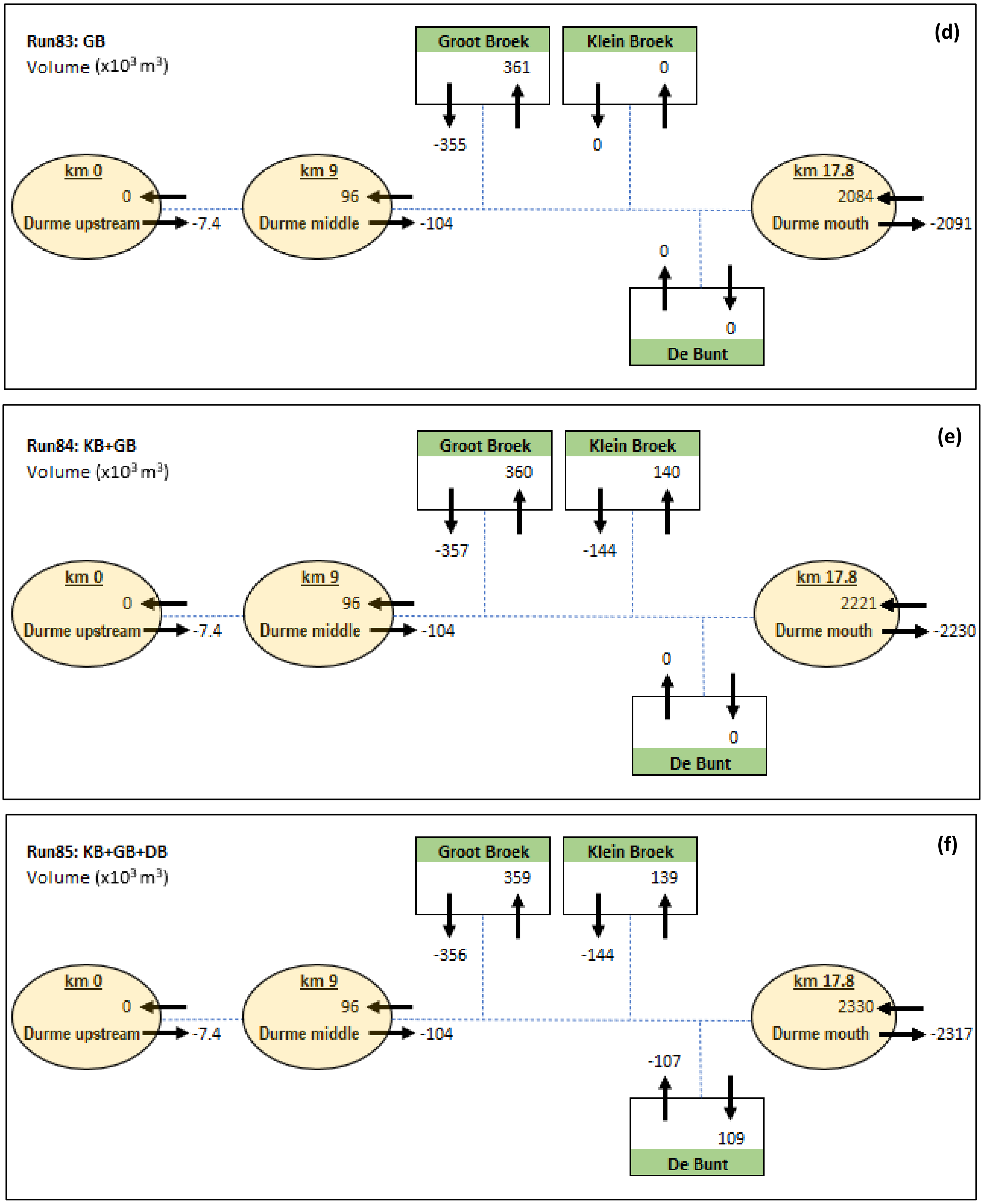


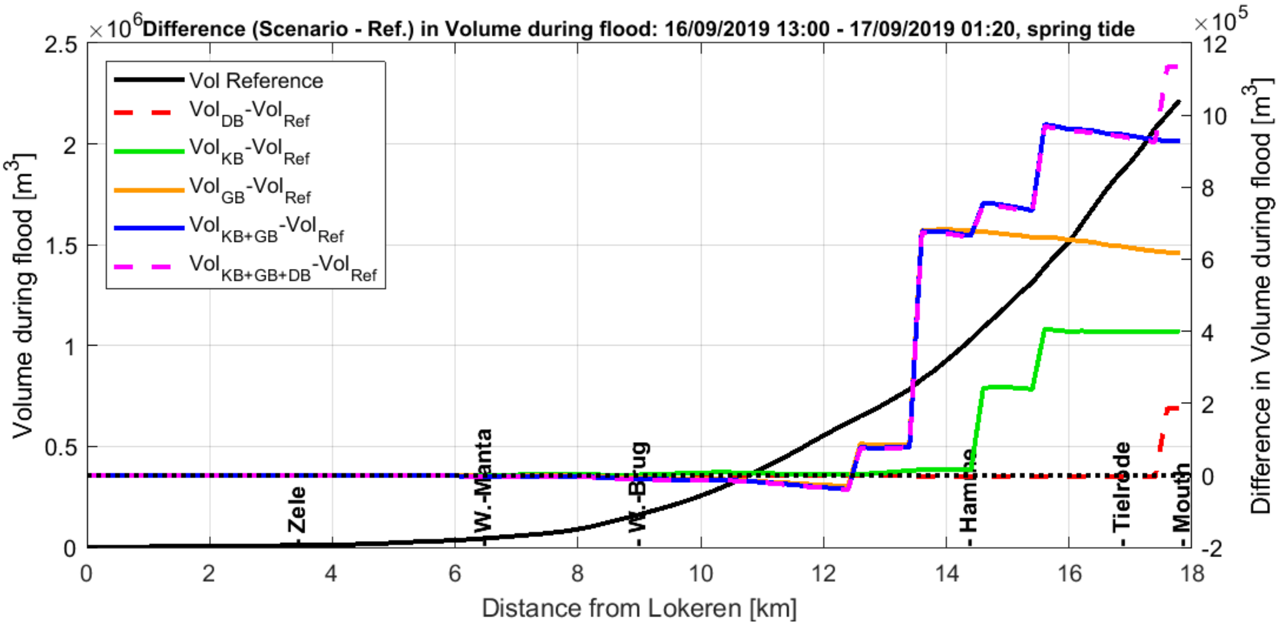
Figure 21 – Flood (+) and ebb (-) volumes (x10^3 m^3) enter and leave the Sigma areas and Durme river during neap tide

3.1.3 Water volume along the Durme river

Figure 22 and Figure 23 shows the effect of the Sigma area(s) on flood and ebb water volumes in the Durme for the selected spring tide and neap tide. The computed flood and ebb volumes along the river for the reference run is also added in the plots. The flood volumes are presented as positive values and ebb as negative.

As dicussed in §3.1.2, the model calculates a significant change in the water volume in the Durme river section from the mouth to the middle of the river (see Figure 22 and Figure 23 for the water volumes of the reference run). The Sigma areas have almost no influence on the water exchange from the middle of the river (km 10) to the upstream (km 0).

Abrupt changes in the water volume are observed in the Durme river between km 17.4 - km 17.6 (De Bunt scenario), km 15.4 - km 15.6 and km 15.4 - km 15.6 (Klein Broek) and km 13.4 - km 13.6 km and km 12.4 - km 12.6 (Groot Broek) (Figure 22, Figure 23). These are due to the fact that the northern inlet-outlet sluice of De Bunt and the two openings of the polders Klein Broek and Groot Broek are located within these sections (see Figure 17). Therefore, the flood volumes in the Durme decrease upstream of the Sigma areas. In parallel, the ebb volumes in the Durme increase downstream of the areas.



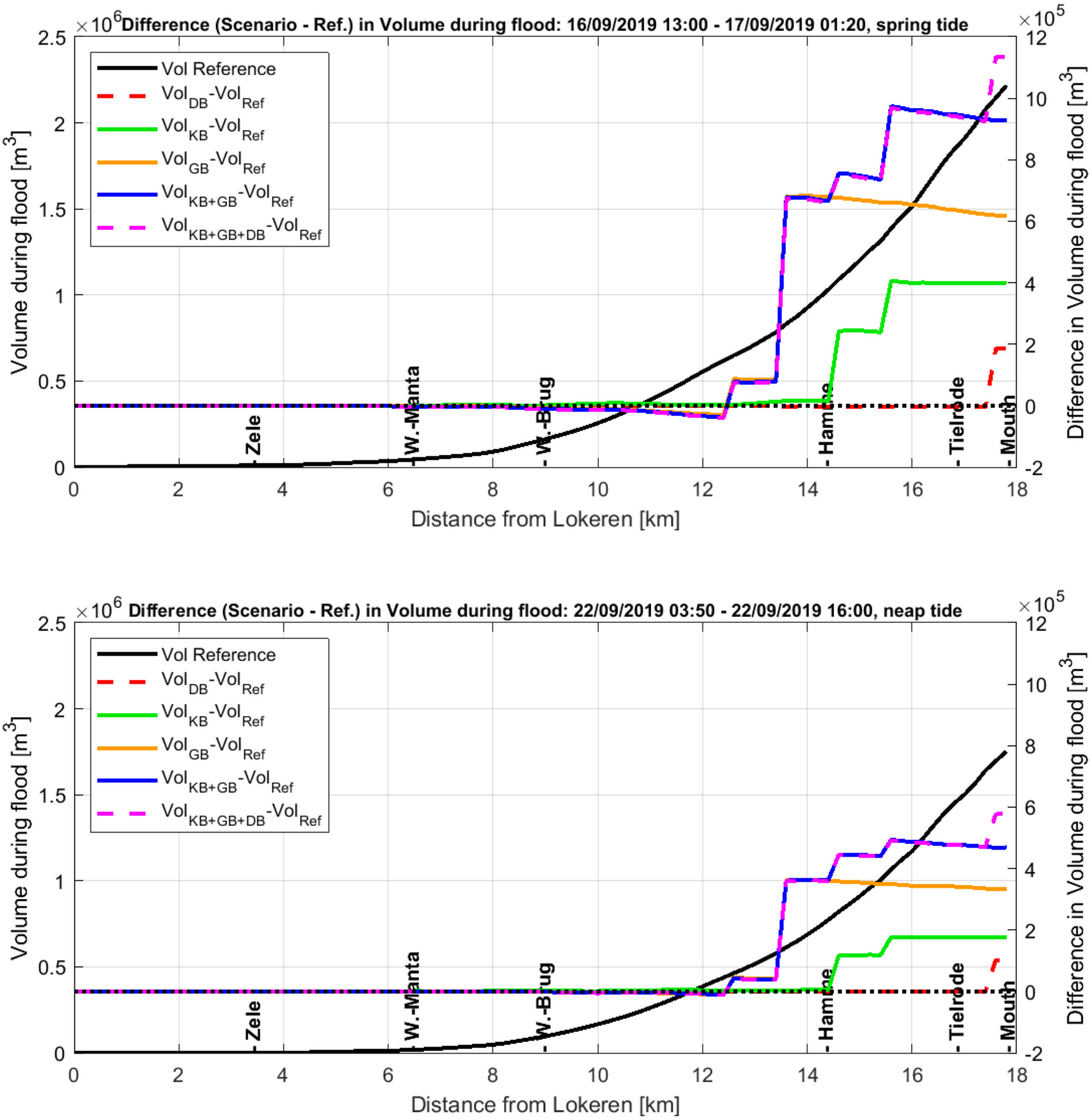
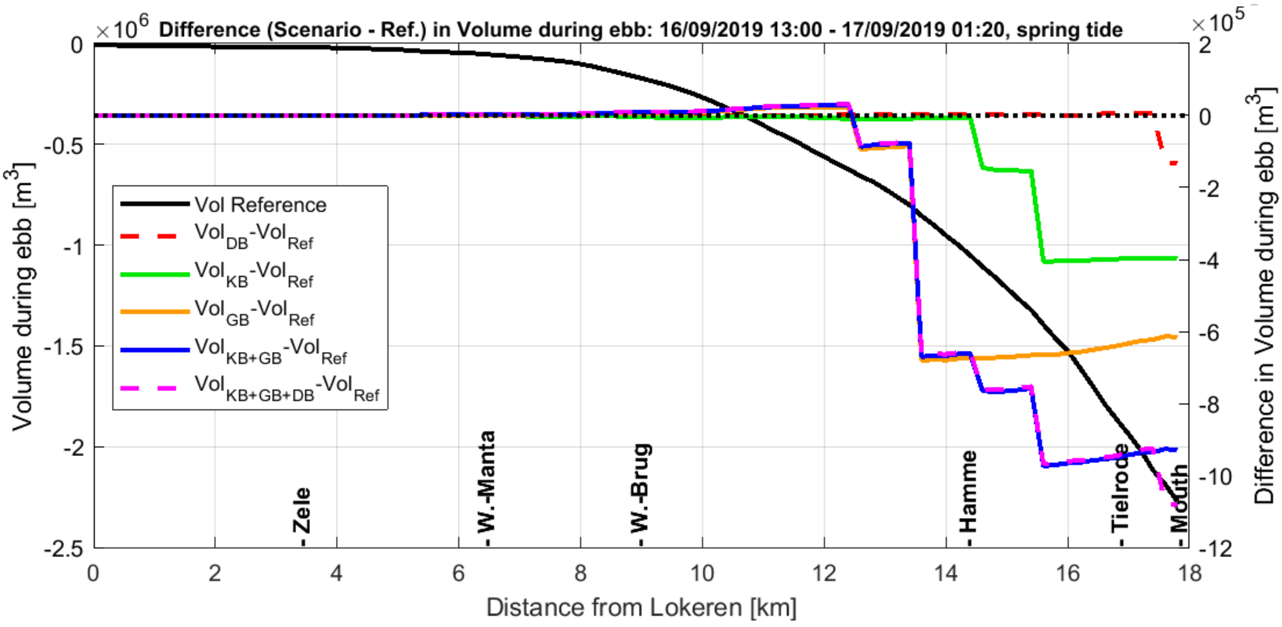


Figure 22 – Difference in flood volumes along the Durme river between runs with activated Sigma area(s) and reference run. Upper: spring tide, lower: neap tide



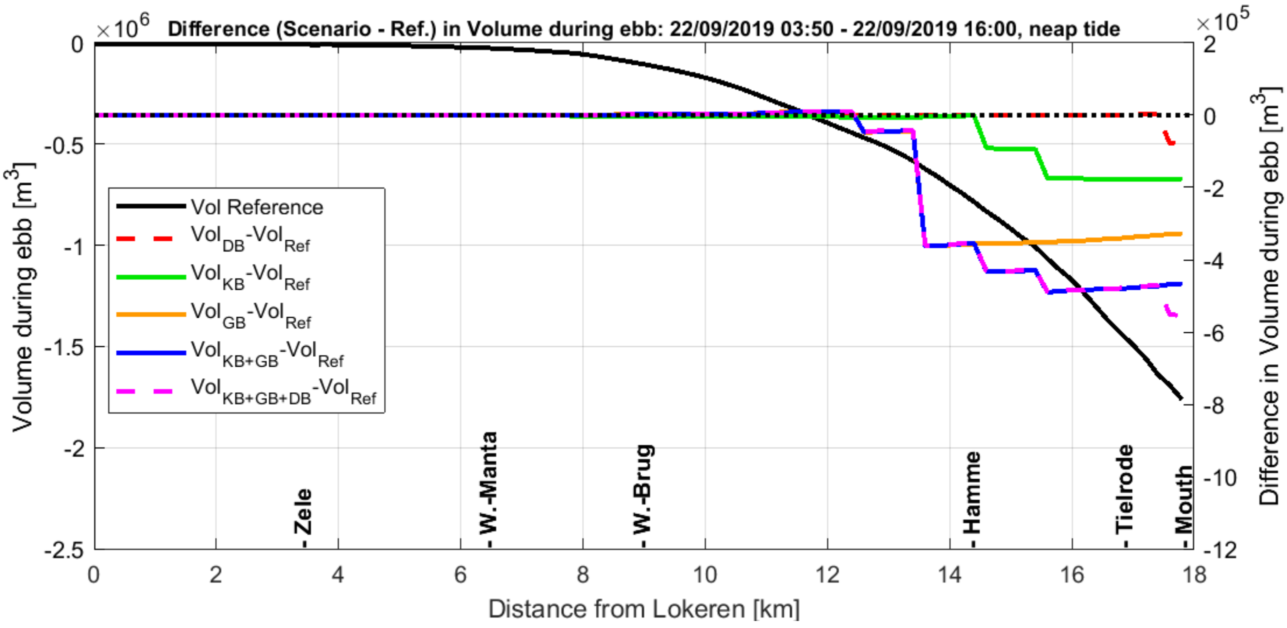


Figure 23 – Difference in ebb volumes along the Durme river between runs with activated Sigma area(s) and reference run. Upper: spring tide, lower: neap tide

3.2 Effect on water levels

Along the Durme river, eight representative cross-sections were selected for the analysis of the scenario results of the water level and velocity (in §3.3): from the river mouth to the upstream end: km 17.6, km 16.8, km 14.4, km 12.4, km 9, km 6.4, km 3.4 and km 1 (see Figure 17). They were chosen in such a way that their locations are just upstream, downstream of the Sigma areas or/and close to tidal stations within the Durme river (Table 6). The water levels are presented for the deepest point along a cross-section.

Table 6 – Selected cross-sections to present the scenario results

Cross-sections	Location
km 17.6	just downstream of the northern sluice of De Bunt
km 16.8	close to Tielrode
km 14.4	close to Hamme and just upstream Klein Broek
km 12.4	just upstream Groot Broek
km 9	close to Waasmunster-Brug
km 6.4	close to Waasmunster-Manta
km 3.4	close to Zele
km 1	river upstream

In Figure 24 and Figure 25, the water levels computed from the six scenarios at eight selected cross-sections are compared for the spring tide and neap tide, respectively. Figure 26 and Figure 27 zoom in the effect of the Sigma areas on the high waters in the Durme.

The expansion of the storage area due to the implementation of the Sigma area(s) results in the distortion of the tidal curves (Figure 24 - Figure 27). Among the three areas, the polder Groot Broek shows the largest effect and De Bunt the least (in fact the inclusion of De Bunt has almost no influence on the water levels in the Durme river). This is related to their storage volume. For the selected tides, the volume stored in Groot Broek is about as twice as large the volume in Klein Broek (697x10^3 m^3 vs. 398x10^3 m^3 for the spring tide and 361x10^3 m^3 vs. 162x10^3 m^3 for the neap tide, see Table 5). Compared to the volumes entering De Bunt of 187x10^3 m^3 and 102x10^3 m^3 for the spring tide and neap tide (Table 5), the volumes in Groot Broek are a factor 3.5 higher. Moreover De Bunt is located almost at the mouth of the Durme.

The water level signals of the simulations with Groot Broek (Run83, Run84, Run85) start deviating from those of the reference run as soon as the water levels reach the level of about 4.5 mTAW - 5 mTAW during flood phase (Figure 24 - Figure 27). From this moment, the water levels continue increasing to HW levels but with more gentle slope compared to the reference run. It is noted that most of the area (90%) within the polder Groot Broek is at the level of 4 mTAW - 5 mTAW (see Figure 9), with a dike breach elevation of +1 mTAW. Therefore, a large amount of water in the river is distributed to the polder once the water levels reach this range. The resulted HW is lower and about 0.5 hour lag behind that of the reference case. This phase lag of HW results in a longer flood and shorter ebb duration (see also discussion in §3.4.1).

The phase shift is also observed for the case of Klein Broek, but much less pronounced.

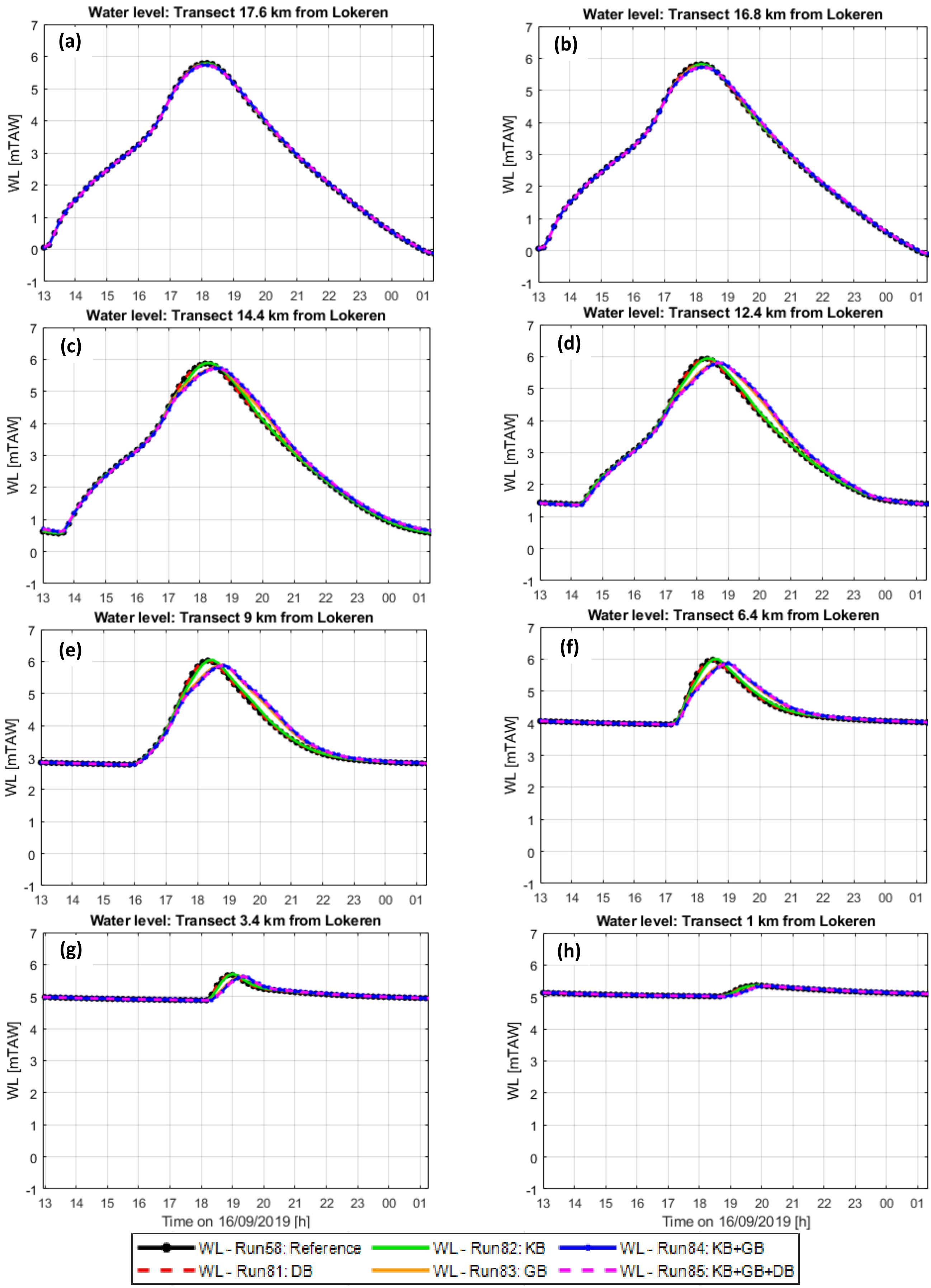


Figure 24 – Water level for different scenarios of activating Sigma areas during spring tide

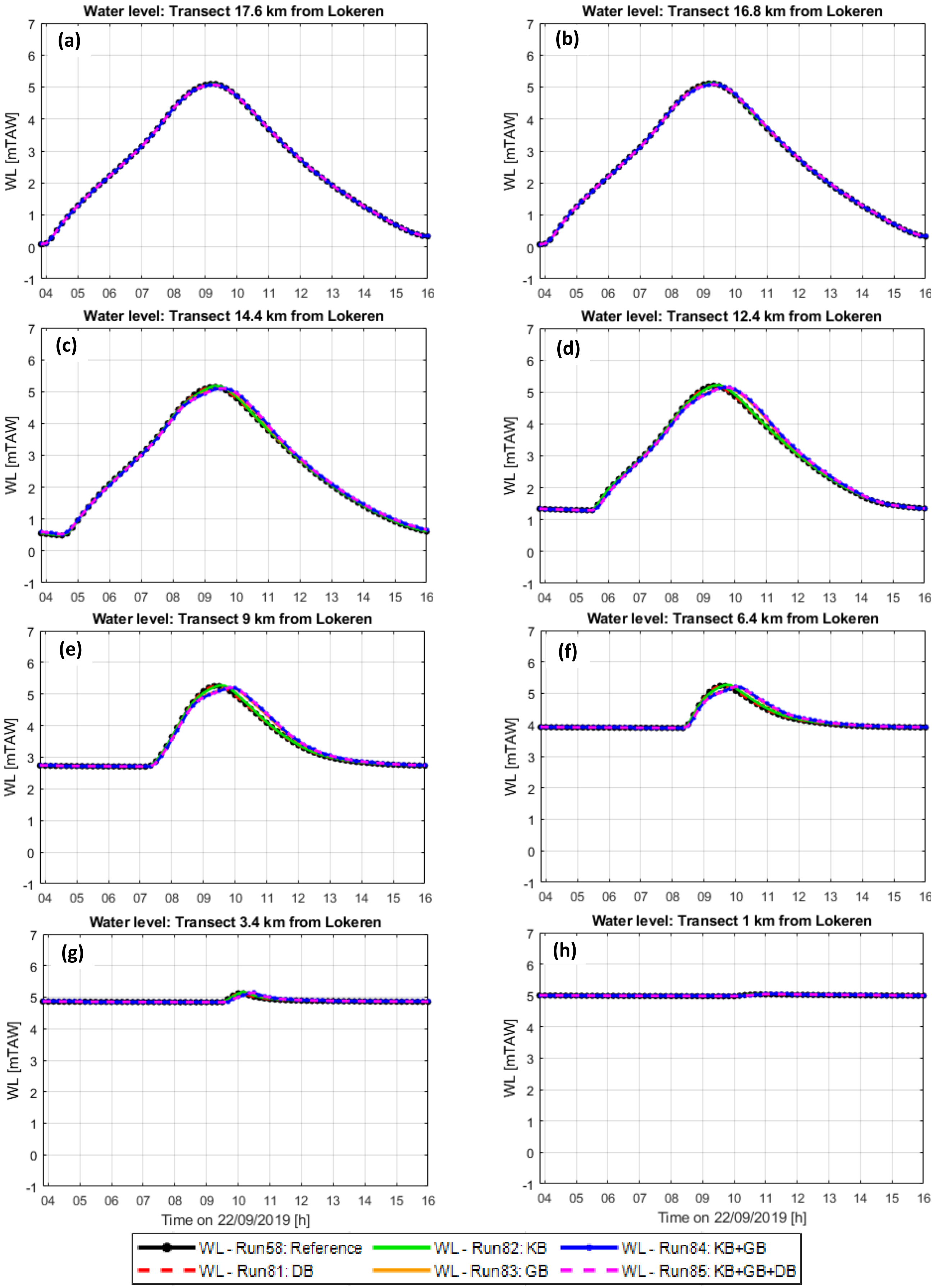


Figure 25 – Water level for different scenarios of activating Sigma areas during neap tide

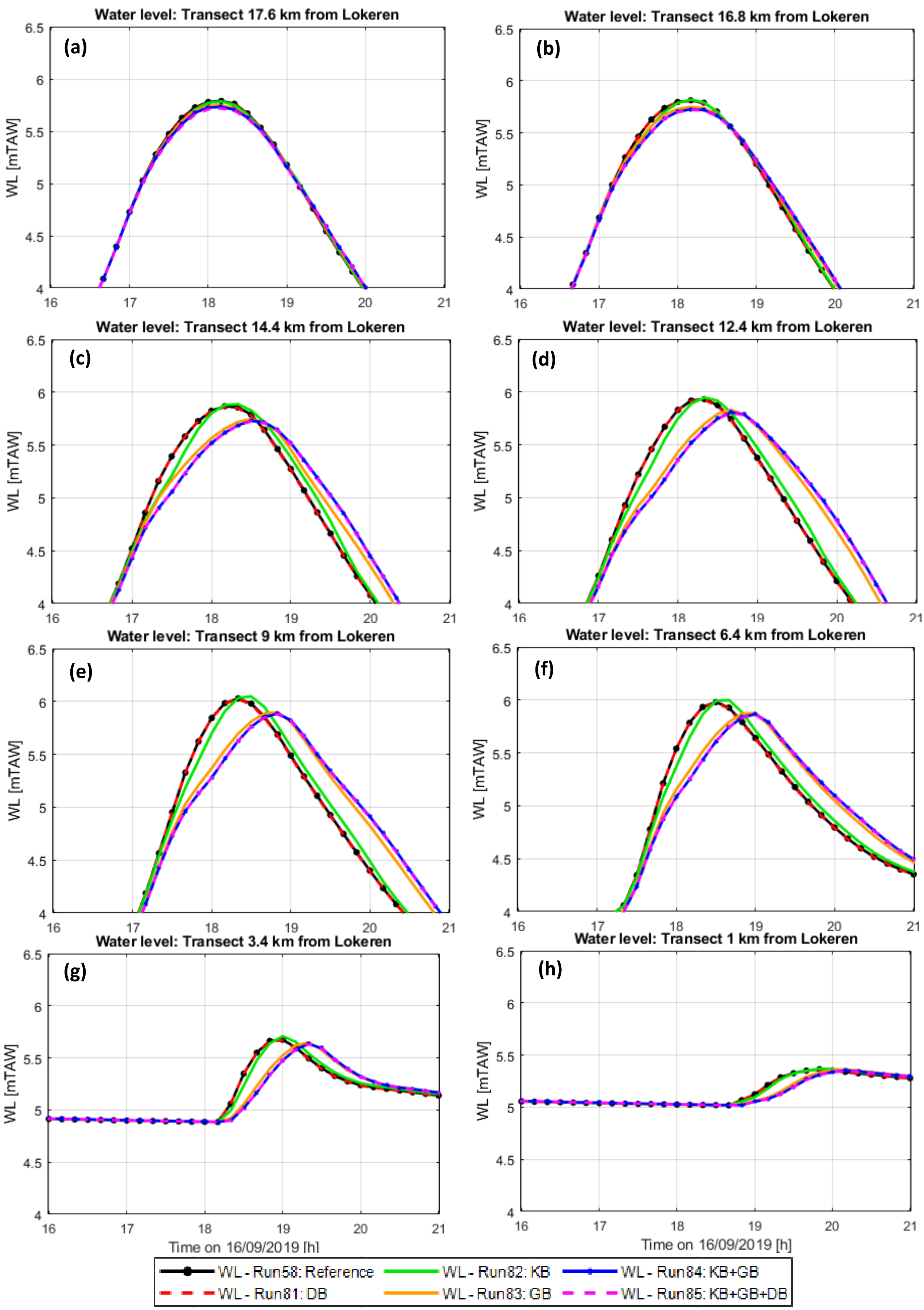


Figure 26 – Water level for different scenarios of activating Sigma areas during spring tide, zoom to HW

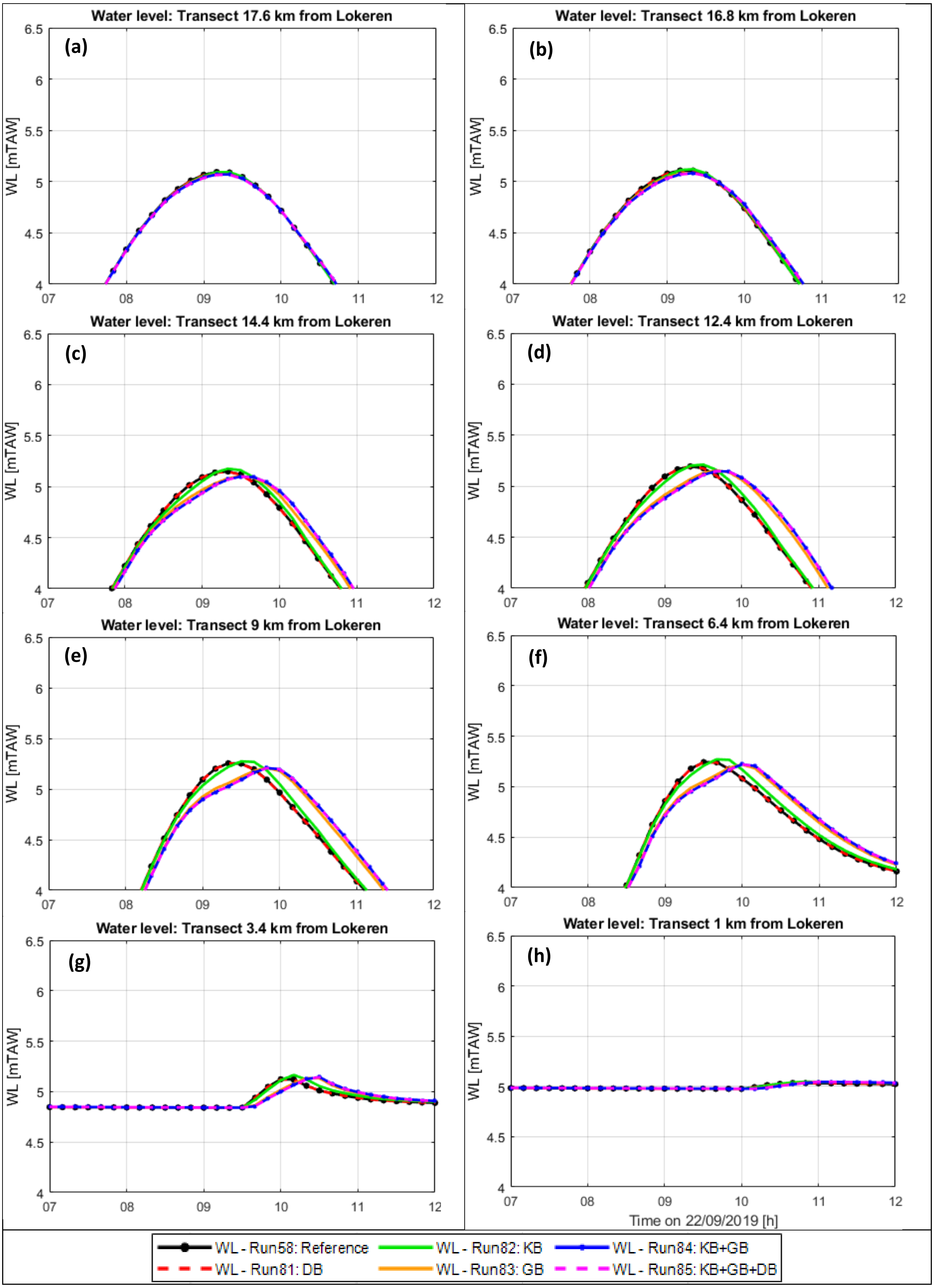
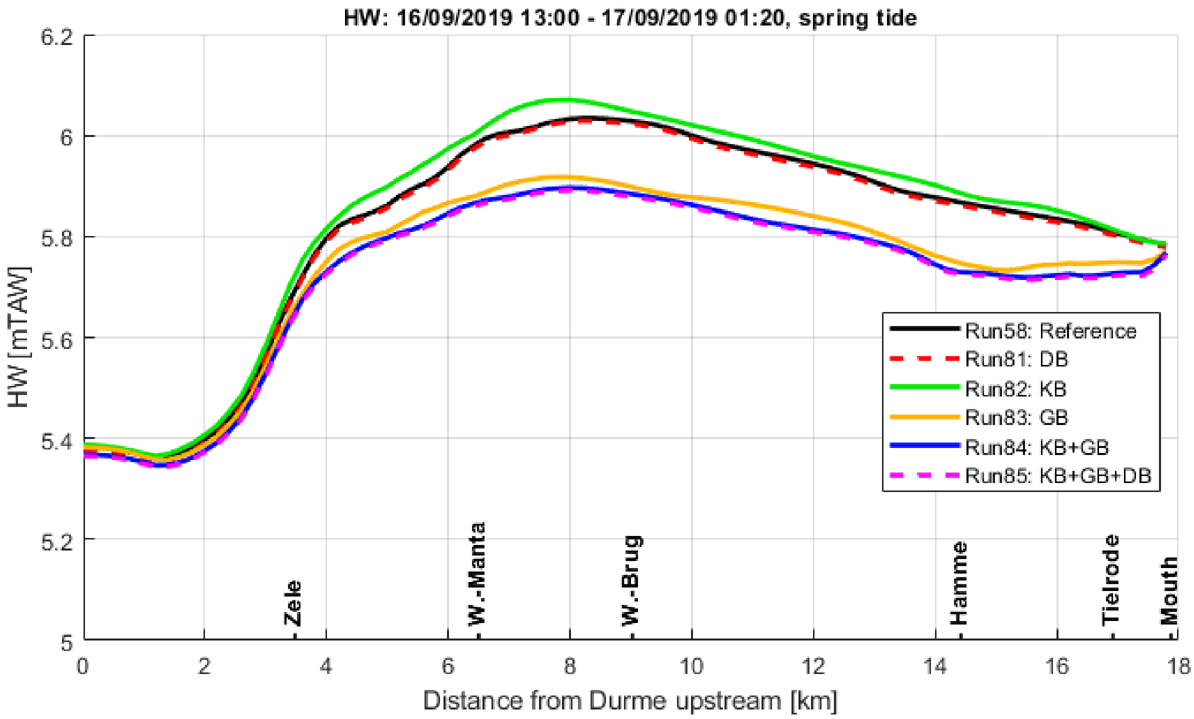


Figure 27 – Water level for different scenarios of activating Sigma areas during neap tide, zoom to HW

Figure 28 and Figure 29 present the effect of the Sigma areas (De Bunt, Klein Broek and Groot Broek) on high waters along the Durme river for the spring tide and neap tide, respectively. The high water levels resulted from the reference run and the runs with activated Sigma area(s) are shown in Figure 28. The difference in HW between the scenario runs and reference run is illustrated in Figure 29. Positive value indicates that Sigma area(s) causes higher HW and vice versa. The HW computed from the reference run is also added in the figures.

In the current situation (reference run), the water levels reach a maximum of about +6 mTAW and +5.3 mTAW for the selected spring tide at around km 8 (Figure 28 and Figure 29). The effect on HW from the FCT-CRT De Bunt is negligible as already discussed above. The polder Groot Broek has the largest influence. It lowers HW along the Durme, except for the most upstream part of about 2-5 km with almost no effect (Figure 29). It is noted here that the polder Groot Broek also causes changes in longitudinal HW variation. The largest reduction in HW of about 10 cm - 13 cm for the spring tide and 5 cm - 6 cm for the neap tide was calculated at the river section from km 7 to km 10. This is the river part with the highest water level along the Durme river (Figure 28 and Figure 29).

The water levels are slightly higher when the polder Klein Broek is active (Figure 28, Figure 29). However, when activating both polders Groot Broek and Klein Broek, the HW along the entire river during the spring tide is further reduced compared to the case of Groot Broek only, leading to a reduction in HW up to 15 cm (around Waasmunster-Brug). These can be explained by examining the water volumes at the river mouth in Table 4. For the spring tide, activating Klein Broek results in about $401x10^3$ m^3 more water entering the Durme tributary (through the river mouth) while the polder itself receives smaller amount ($398x10^3$ m^3) (Figure 20c). The excess volume of $3x10^3$ m^3 is distributed in the river, leading to a raise in the water levels compared to the reference case. This issue does not appear in the case of the Groot Broek polder as it has much larger storage capacity. Activating Groot Broek alone, the volume entering the mouth is $618x10^3$ m^3 higher than that in the reference run but the polder Groot Broek takes higher amount ($697x10^3$ m^3) (Figure 20d). Therefore, the water levels in the river are reduced due to the presence of Groot Broek. Once Klein Broek is also activated (Run84), Groot Broek receives more or less the same amount of water as for Run83 (only Groot Broek active) and Klein Broek receives $339x10^3$ m^3 (Figure 20e). The amount entering Klein Broek is higher than the excess water of $310x10^3$ m^3 flowing to the Durme tributary due to the addition of Klein Broek to Groot Broek (Figure 20d vs. Figure 20e). Thus less water flows in the river compared to the case of Groot Broek alone.



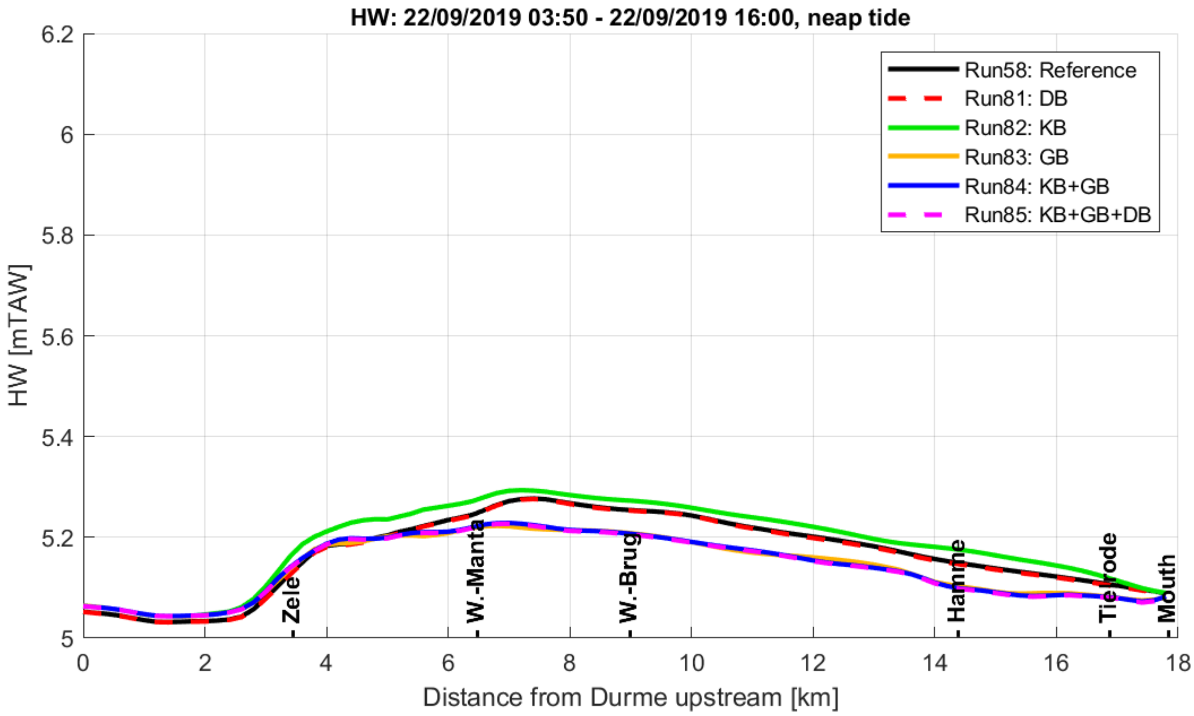


Figure 28 – High water along the Durme river from Sigma area scenario runs. Upper: spring tide, lower: neap tide

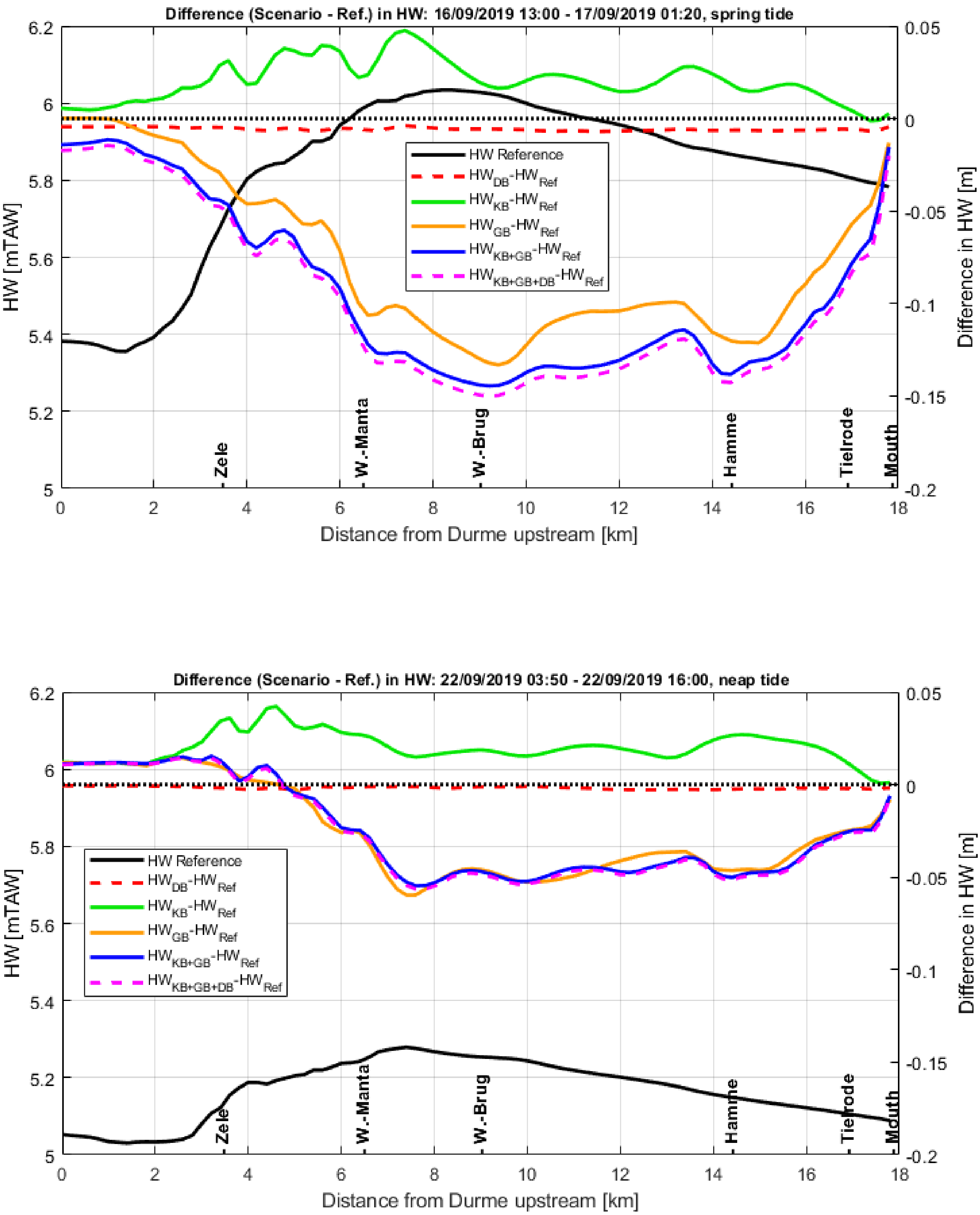
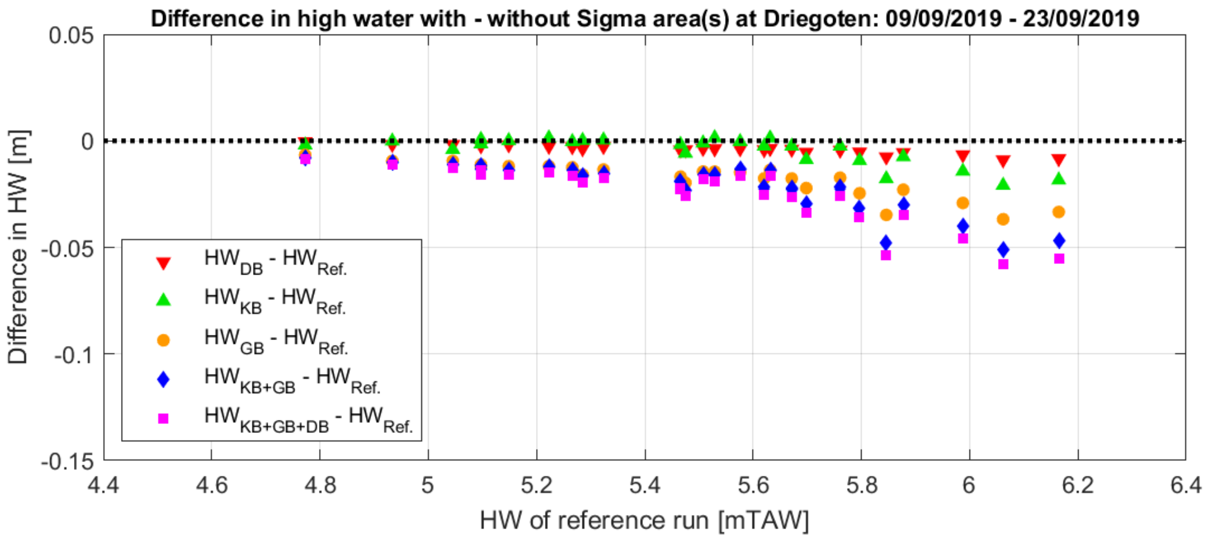


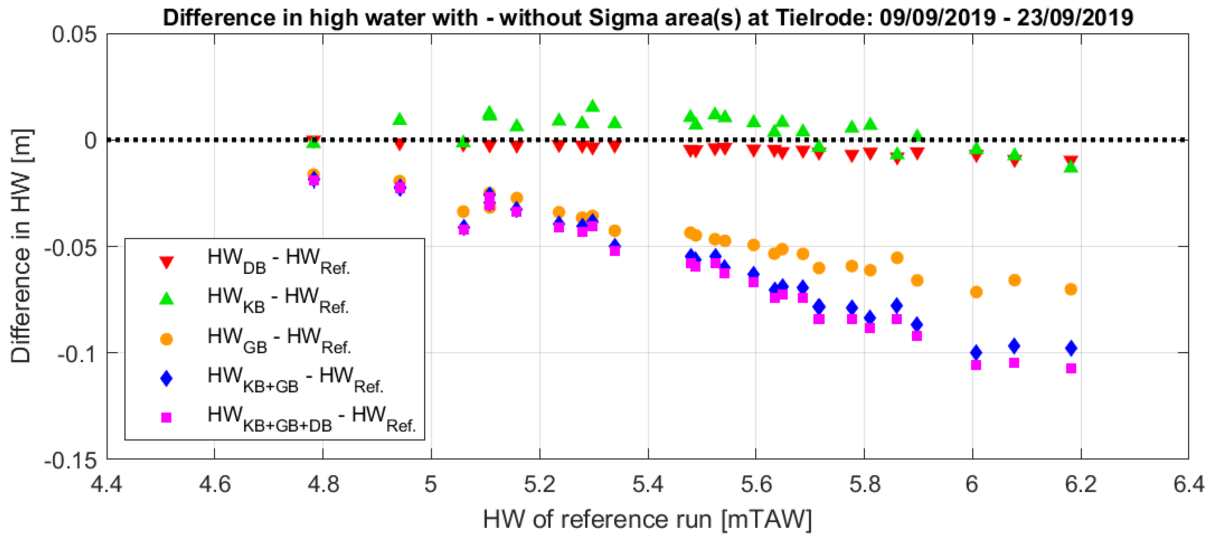
Figure 29 – Effect of Sigma areas on high water. Upper: spring tide, lower: neap tide

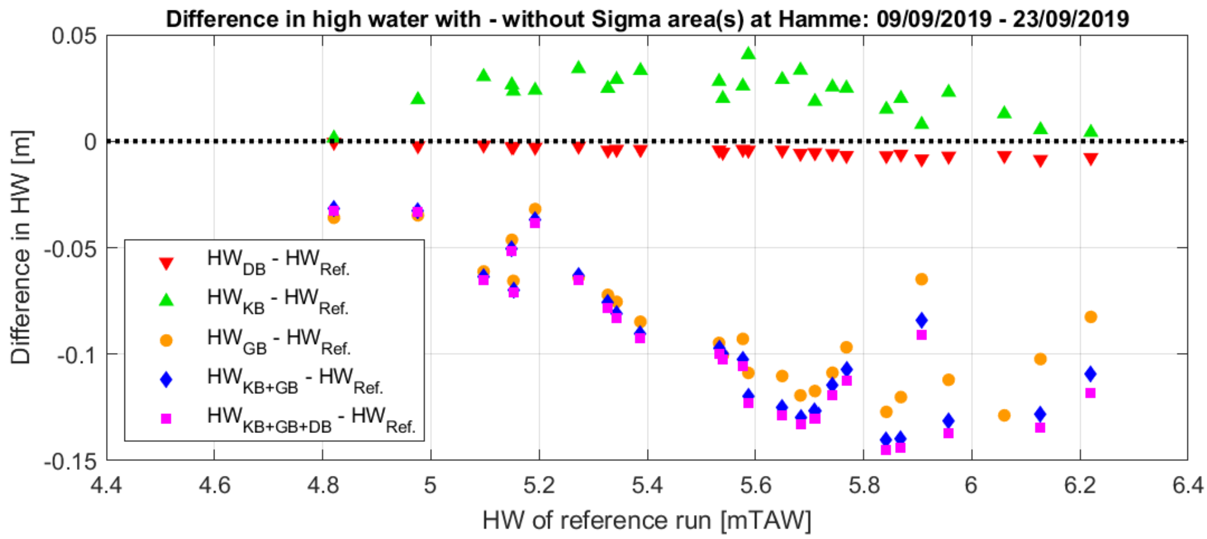
Figure 30 presents the differences in HW between scenario runs with activated Sigma area(s) and the reference run (without Sigma areas) for six tidal stations Driegoten, Tielrode, Hamme, Waasmunster-Brug, Waasmunster-Manta, and Zele (see Figure 17 for the location). The comparisons are made for the two-week period 09/09/2019 -23/09/2019.

As discussed above, the effect of the Sigma area De Bunt on the water level is also very small at all six stations (Figure 30). Only little reduction in HW (in order of several millimeters) are found for the average and spring tides (Figure 30). The implementation of the polder Klein Broek leads to a slight increase in the water level in the Durme river with rather limited influence for low and high range of HW (Figure 30).

The polder Groot Broek influences strongly the high water levels in the river. The reduction of the HW reaches 14 cm at Waasmunster-Brug (Figure 30). The effect of Groot Broek is more or less linearly dependent on the HW levels for the locations at the Upper Sea Scheldt (Driegoten) and near the Durme mouth (Tielrode). This is not observed for other locations further inside the river. The difference in HW of the run with Groot Broek and the reference run shows large scatter, especially for the high range of HW.


Difference in high water with - without Sigma area(s) at Driegoten: 09/09/2019 - 23/09/2019
Difference in HW [m]
HW of reference run [mTAW]
HWDB - HWRef.
HWKB - HWRef.
HWGB - HWRef.
HWKB+GB - HWRef.
HWKB+GB+DB - HWRef.
0.05
0
-0.05
-0.1
-0.15
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4


Difference in high water with - without Sigma area(s) at Tielrode: 09/09/2019 - 23/09/2019
Difference in HW [m]
HW of reference run [mTAW]
HWDB - HWRef.
HWKB - HWRef.
HWGB - HWRef.
HWKB+GB - HWRef.
HWKB+GB+DB - HWRef.
0.05
0
-0.05
-0.1
-0.15
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4


Difference in high water with - without Sigma area(s) at Hamme: 09/09/2019 - 23/09/2019
Difference in HW [m]
HW of reference run [mTAW]
HWDB - HWRef.
HWKB - HWRef.
HWGB - HWRef.
HWKB+GB - HWRef.
HWKB+GB+DB - HWRef.
0.05
0
-0.05
-0.1
-0.15
4.4
4.6
4.8
5
5.2
5.4
5.6
5.8
6
6.2
6.4

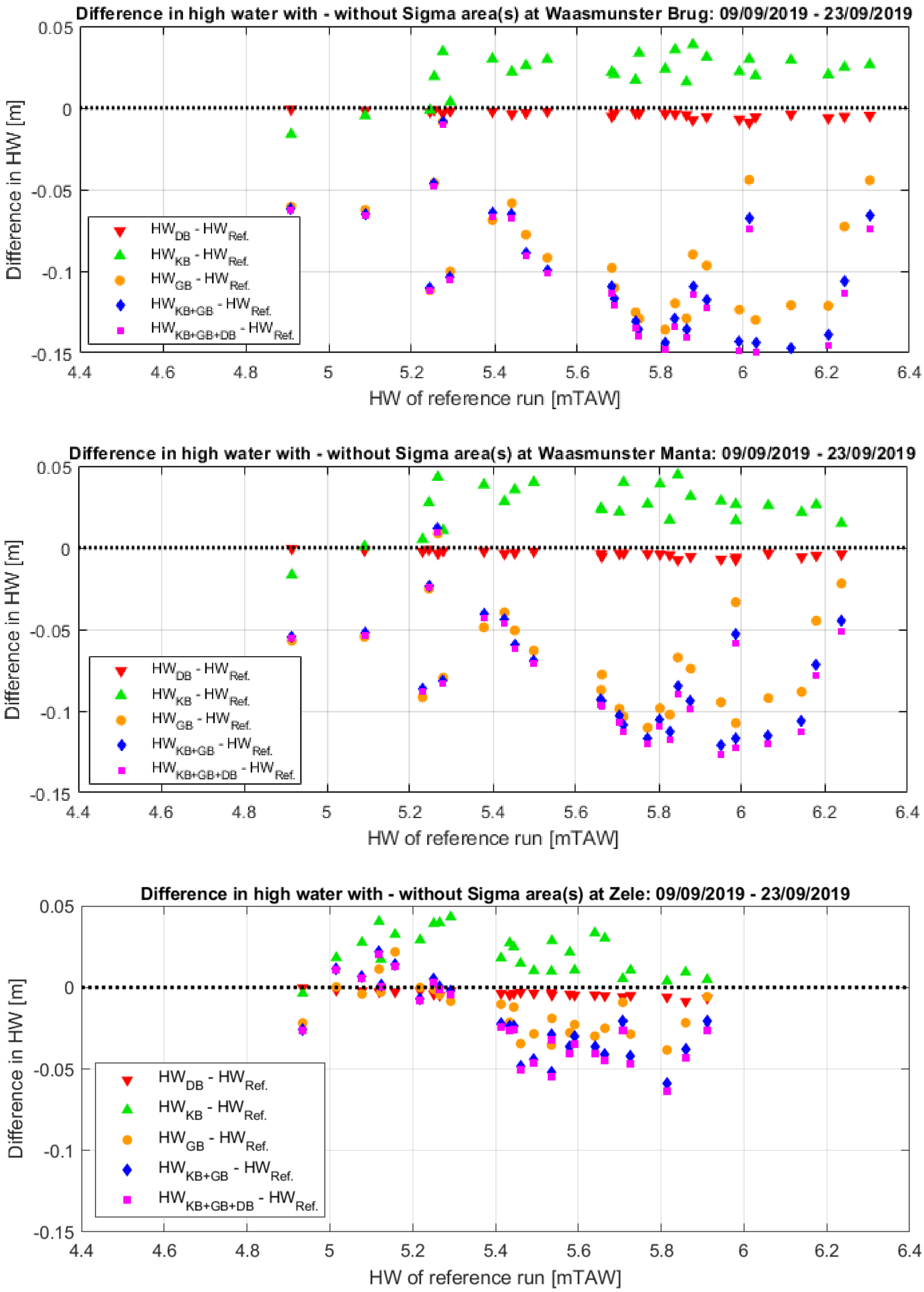


Figure 30 – Difference in HW between runs with and without Sigma area(s) at Driegoten, Tielrode, Hamme, Waasmunster-Brug, Waasmunster-Manta, and Zele. Positive values indicate an increase in HW

3.3 Effect on current velocities

The cross-sectional average velocities at the eight cross-sections along the Durme river (Table 6) computed from six scenarios are compared in Figure 31 for the spring tide and Figure 32 for the neap tide. The variation of the peak current velocities along ~18 km Durme river during flood and ebb for the six model runs are presented in Figure 33 and Figure 34. Positive values indicate flood current velocity and negative values represent ebb flow.

A strong effect of the three Sigma areas on the current velocity was calculated downstream of the areas. For the FCT-CRT De Bunt (Run81 and Run85), its influence is only obvious at the transect near the mouth at km 17.6, right downstream of the inlet-outlet sluice. The ebb current velocities increase suddenly once the water levels decrease to around +2 mTAW (Figure 31a and Figure 32a). This increase is contributed by the ebb flow from De Bunt through the culverts (note that the outlet sluice is at the level of +0.8 mTAW). For the polders Klein Broek and Groot Broek, the river sections near the mouth, downstream of the polders (km 17.6, km 16.8 for case of activating Klein Broek; km 17.6, km 16.8 and km 14.4 for Groot Broek) show higher peaks, both in the flood and ebb phase. The peaks are also shifted, falling later in the ebb pahse, compared to those from the reference case. The effect is stronger for Groot Broek than Klein Broek. Upstream the polder, the inclusion of Groot Broek modifies the shape of the velocity signal with lower flood peak, longer flood duration and shorter ebb. These modifications are also found for Klein Broek but less pronounced.

The peak velocities in the Durme river are hardly affected by FCT-CRT De Bunt (Figure 33 and Figure 34). The polder Klein Broek has a limited impact on the peak velocities during the neap tide (Figure 33 and Figure 34, lower panel) but a clear effect during the spring tide (Figure 33 and Figure 34, upper panel). A strong increase of flood and ebb peaks was simulated for the river section near the mouth, up to around km 14.4 (Figure 33 and Figure 34, upper panel). This is the upstream section of the western opening of the polder Klein Broek (see Figure 17 for the location). The model with Klein Broek calculated a slight decrease of flood peak while slight or no increase of ebb peak for about 10 km, from km 14.4 till km 4 from upstream.

Similar effects on the peak velocities are also observed for the polder Groot Broek (Run83, Run84 and Run85) but much stronger and both for the spring tide and neap tide. The significant increase of flood and ebb peaks was computed at the downstream section of the eastern Groot Broek's opening, from the Durme river mouth up to km 13.2 (see Figure 17 for the location). The highest peak is about 1.3 m/s for the spring tide for the case of activating only Groot Broek. Adding Klein Broek results in a higher peak near the mouth, up to km 14.4 but has little effect on the rest of the river.

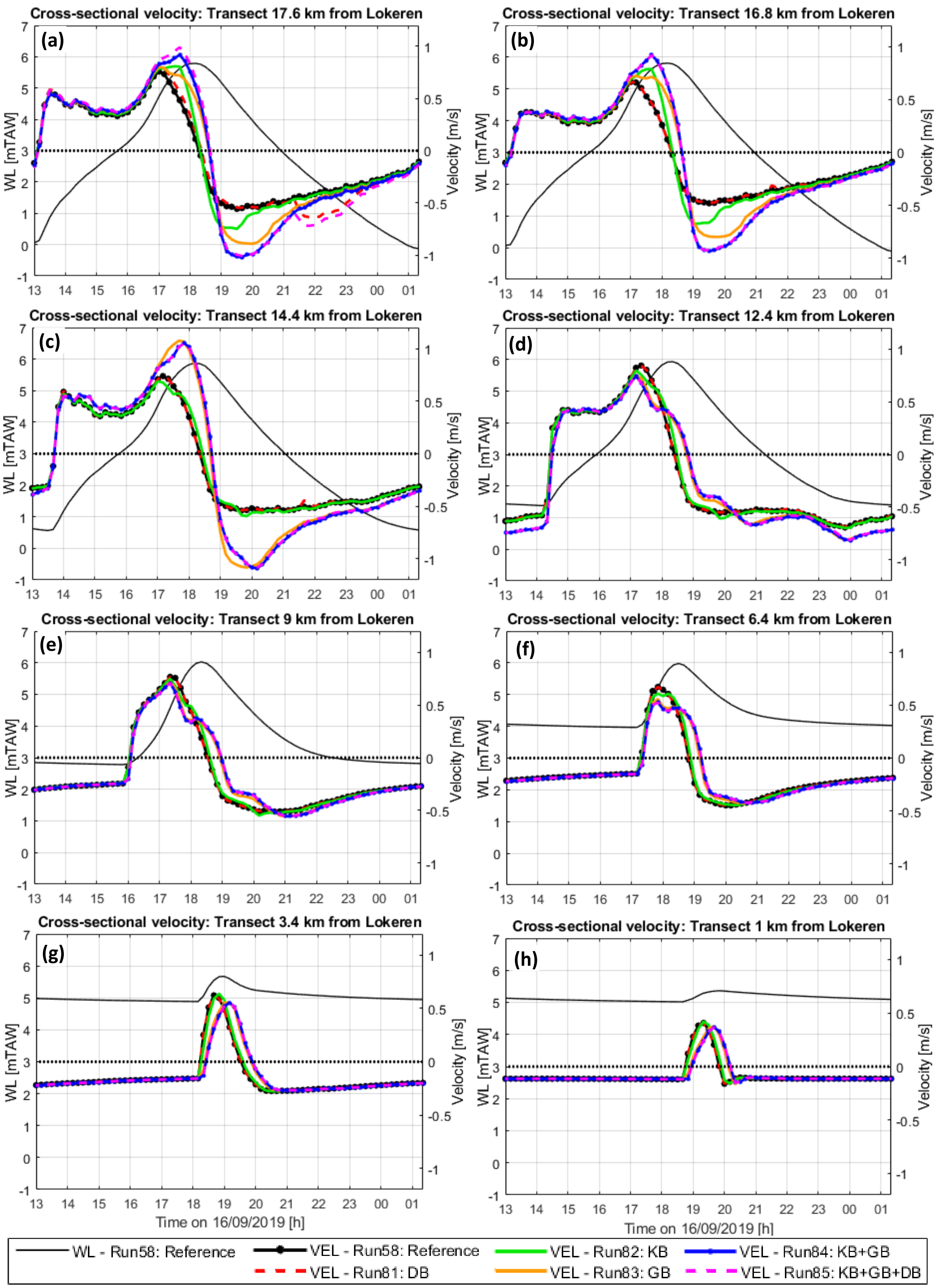


Figure 31 – Cross-sectional current velocity for different scenarios of activating Sigma areas during spring tide. Positive is flood

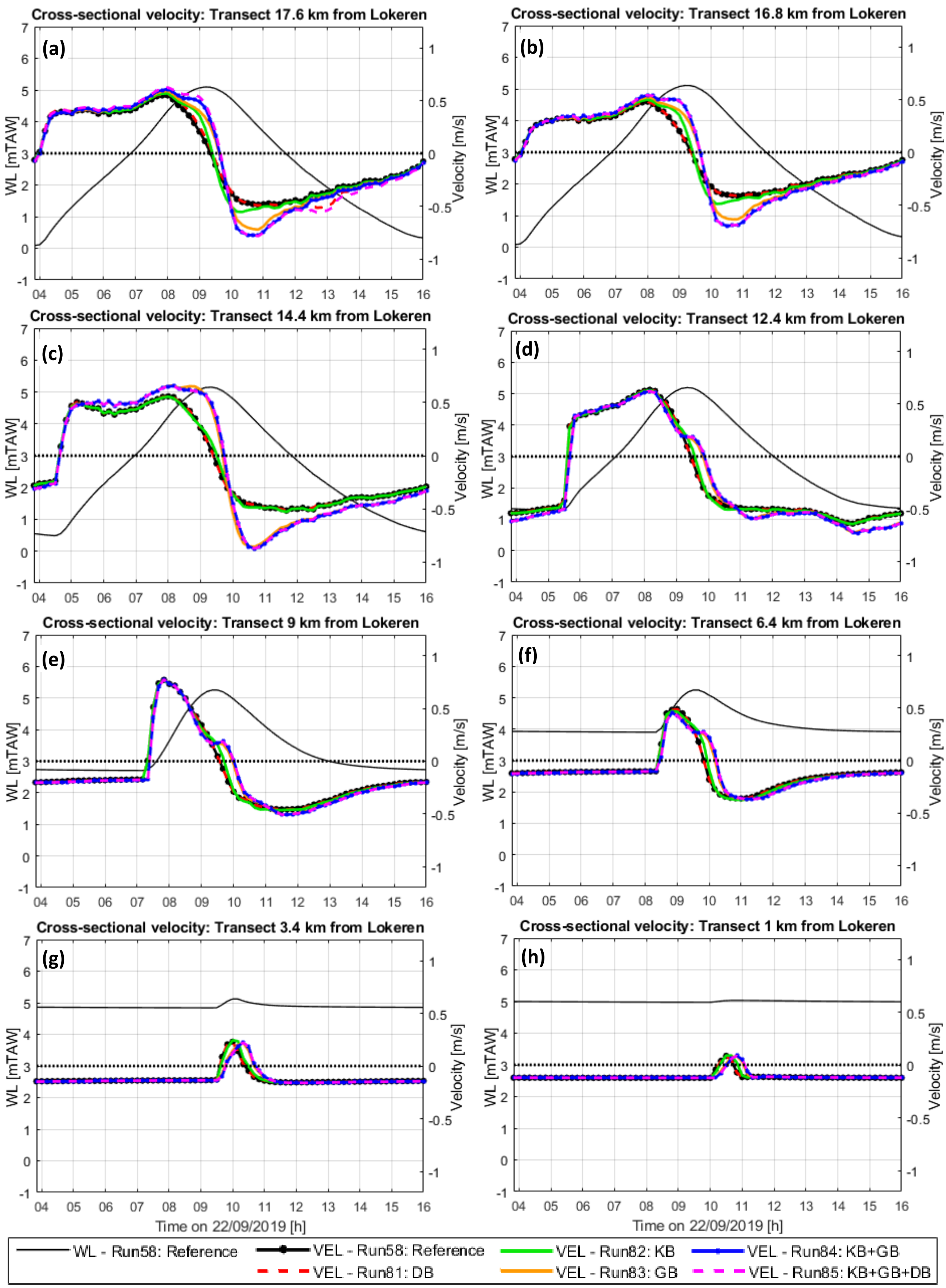


Figure 32 – Cross-sectional current velocity for different scenarios of activating sigma areas during neap tide. Positive is flood

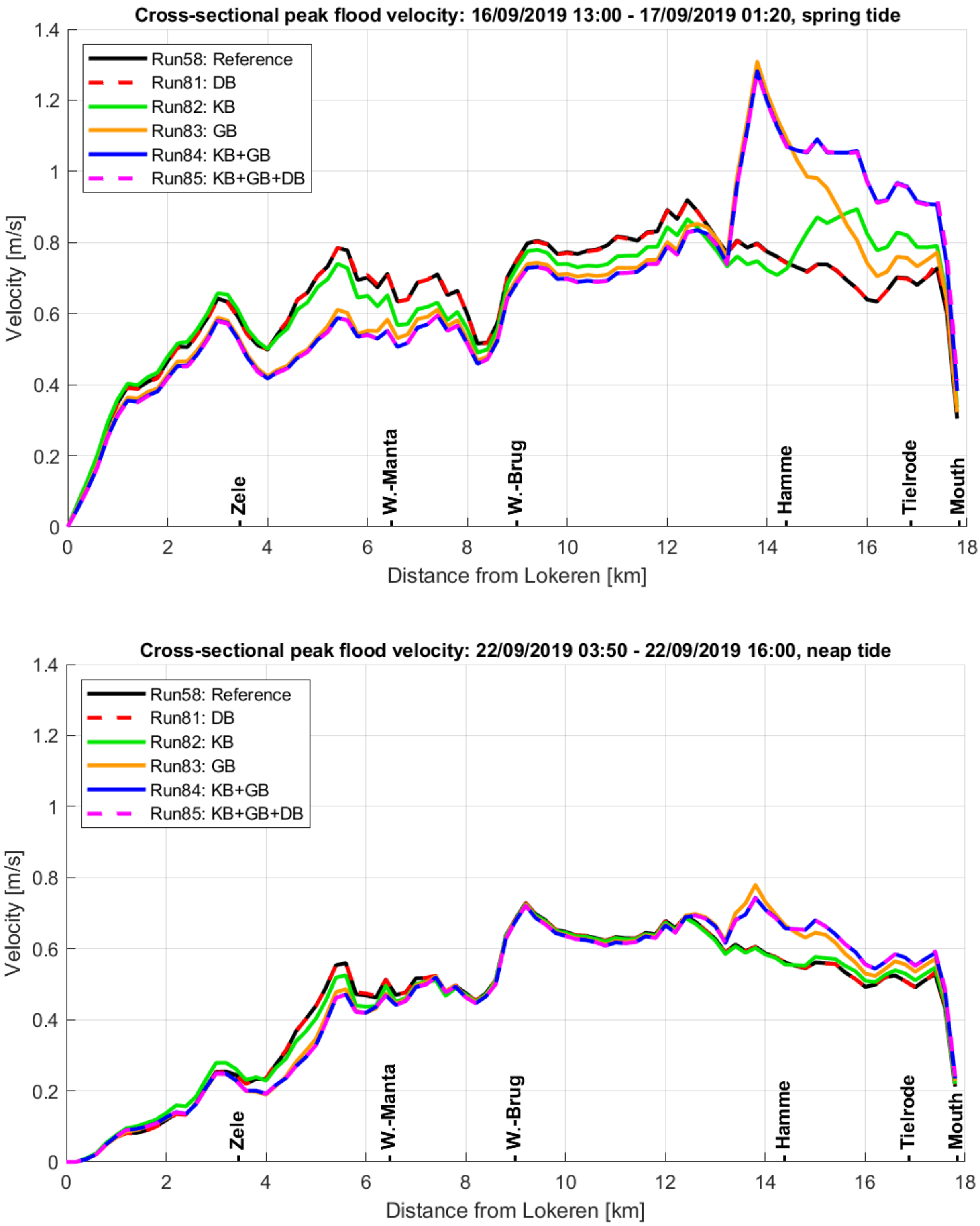
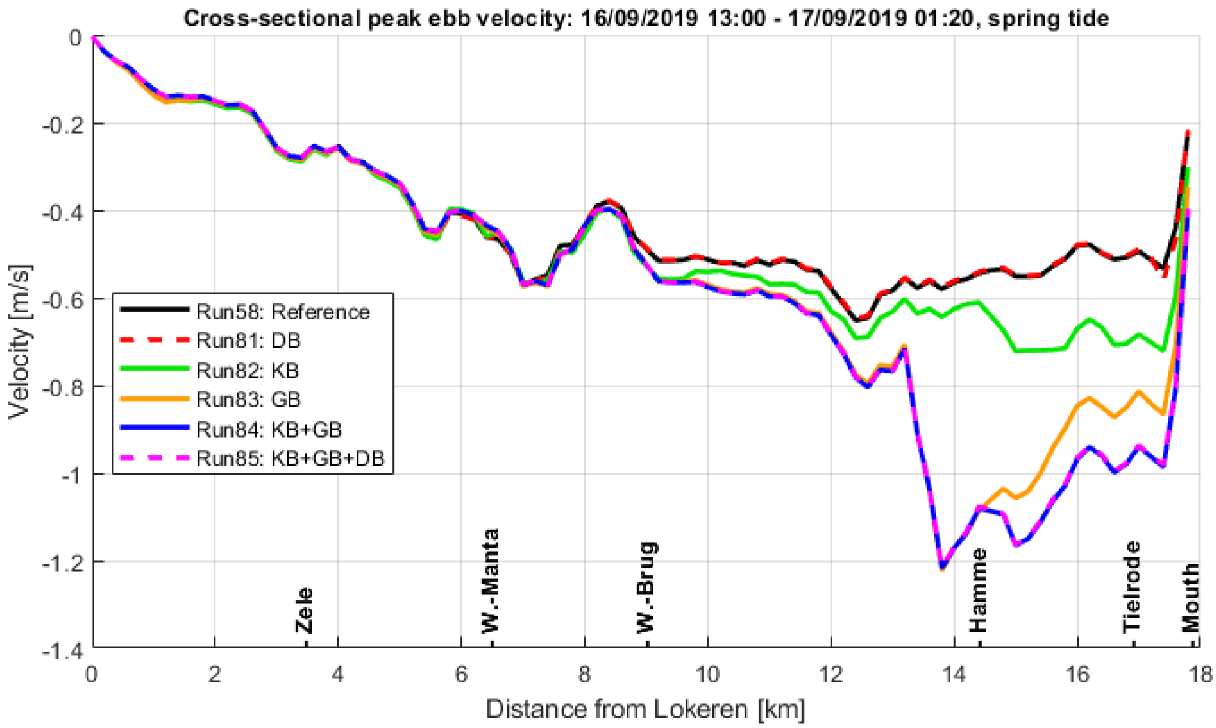


Figure 33 – Cross-sectional peak flood velocity along the Durme river. Upper: spring tide, lower: neap tide



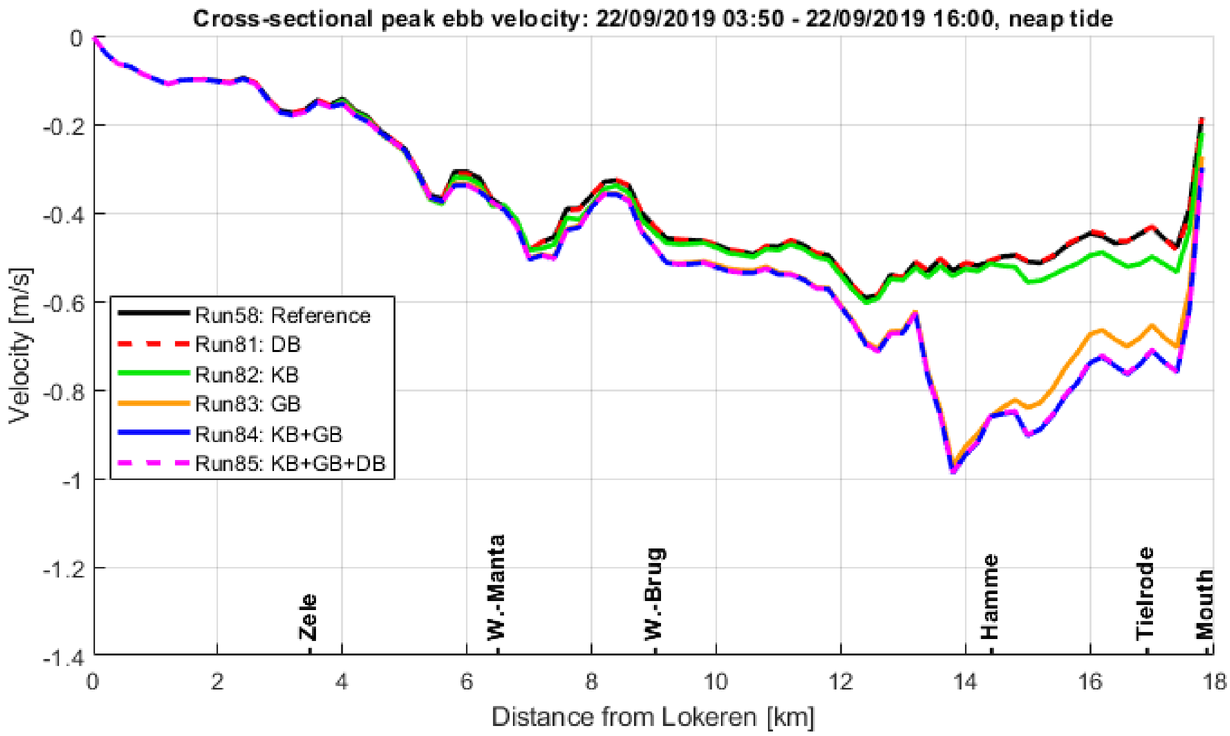
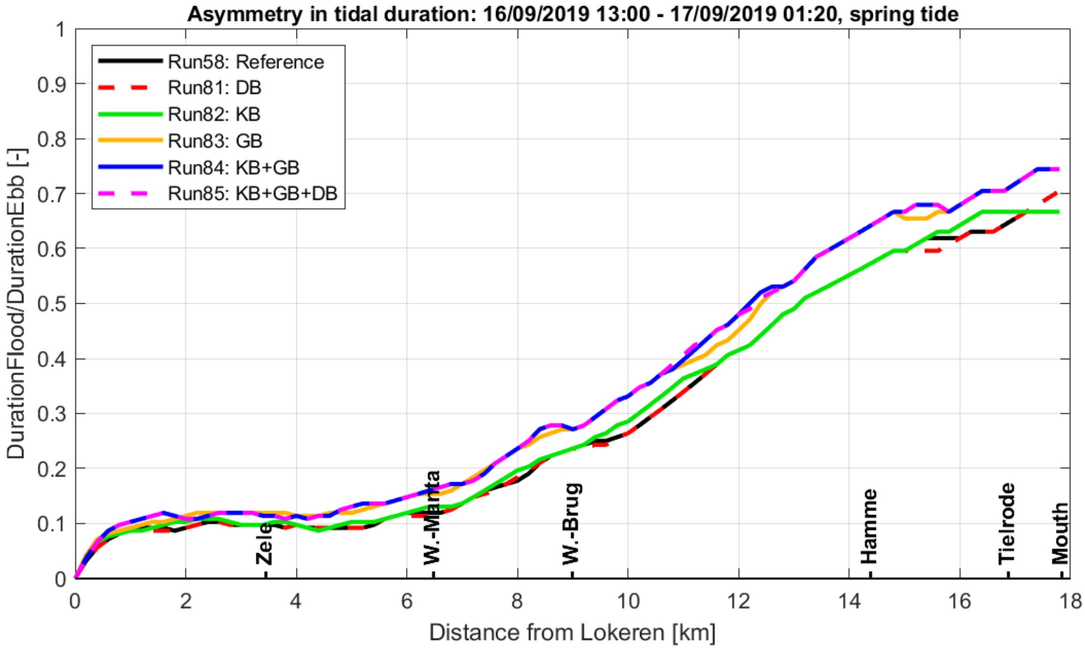


Figure 34 – Cross-sectional peak ebb velocity along the Durme river. Upper: spring tide, lower: neap tide

3.4 Effect on tidal asymmetry

3.4.1 Asymmetry in flood, ebb duration

Figure 35 shows the longitudinal variation of the tidal duration asymmetry computed from the six Sigma area scenarios for the spring tide and the neap tide. A clear ebb dominance of the tidal duration asymmetry is observed, with the ratio of flood duration and ebb duration smaller 0.8. The ebb dominance increases towards upstream for all cases. Run81 with De Bunt activated does not have the impact on the duration asymmetry while the Groot Broek (Run83) show a clear effect with higher ratio of flood and ebb duration. The influence of Klein Broek is also observed at some river section but not significant.



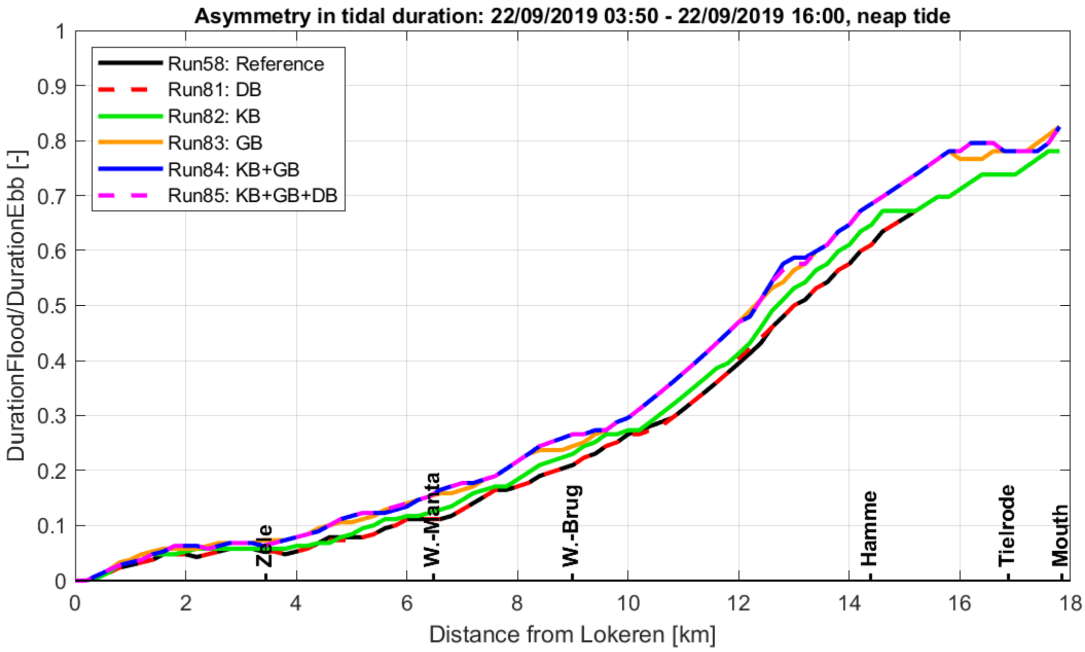


Figure 35 – Asymmetry in flood ebb durations along the Durme river for Sigma area scenarios. Upper: spring tide, lower: neap tide

3.4.2 Asymmetry in peak current velocity

Figure 36 presents the variation of the velocity asymmetry along the river for the spring tide and neap tide. As opposed to the duration asymmetry in §3.4.1, the velocity asymmetry is flood dominated in most of the river section (Figure 36). The ebb dominance occurs only at the most upstream section for all runs and near the mouth for runs with Groot Broek active (Run83, Run84, and Run85). This ebb dominance is stronger for the neap tide than spring tide.

As for the duration asymmetry (discussed in §3.4.1), the inclusion of De Bunt has almost no influence on the velocity asymmetry. Adding Klein Broek leads to a weaker flood dominance in the middle and downstream sections of the river. The effect of Groot Broek is stronger and extends more upstream. Furthermore, the polder Groot Broek alters the peak velocity asymmetry to ebb dominance at the river section near the mouth.

In terms of sediment transport, the implementation of the polders Klein Broek and Groot Broek could slow down the sedimentation process in the downstream part of the Durme river. A shift towards an ebb-dominant velocity asymmetry in the river section near the mouth due to Groot Broek suggests this reduced intention of sedimentation.

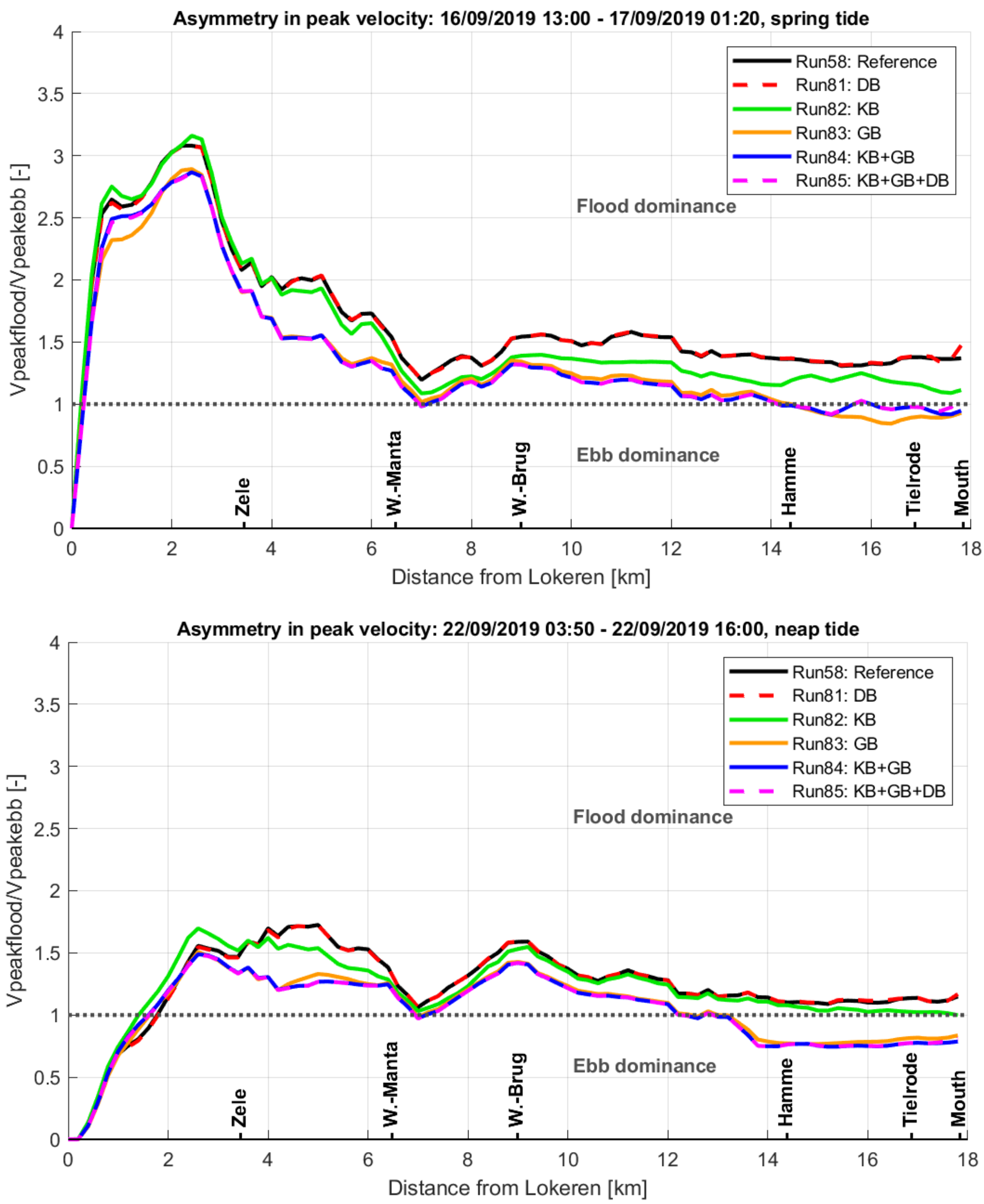


Figure 36 – Asymmetry in peak velocity along the Durme for Sigma area scenarios. Upper: spring tide, lower: neap tide

4 Conclusions and recommendation

In this report, the effects of the Sigma areas FCT-CRT De Bunt and the depoldering of Klein Broek and Groot Broek on the hydrodynamics in the Durme tributary have been studied by means of numerical modelling. The Durme hydrodynamic model constructed and calibrated within Telemac (Nguyen et al., 2024) has been used. Six model scenarios with the three Sigma areas inactive, activated separately or together were conducted. To take into account the effect of Sigma areas on the water levels at the two boundaries of the Durme model, at Temse and Sint-Amands, the difference in water levels between the case with and without Sigma area(s) computed from Mike1D are added to the measured water levels to construct boundary condition for each scenario. The model runs were carried out for one spring-neap tidal cycle. The analysis was done for this period, with a detailed discussion for a selected spring tide and neap tide.

A larger tidal prism in the Durme was calculated when one or more Sigma areas are activated. Among the three areas, the water exchange through De Bunt is smallest and through Groot Broek the largest. Activating all three Sigma areas leads to an increase in the flood volume at the mouth by 51% and 33% for the selected spring tide and neap tide, respectively. The model calculated sudden changes in the water volume in the Durme river at the inlet-outlet sluice of FCA De Bunt and at the openings of the polders Klein Broek and Groot Broek.

The implementation of the Sigma area(s) result(s) in the distortion of the tidal wave in the Durme river, with the largest effect due to the polder Groot Broek. The HW levels computed from runs with Groot Broek are lower and lag about 0.5 hour behind those of the reference case. This phase lag leads to a longer flood and shorter ebb duration. The phase shift is also observed for the case of Klein Broek, but much less pronounced. The polder Groot Broek results in lower HW in the river with the largest reduction in HW of 10 - 15 cm for the selected spring tide at the river section from km 7 to km 10. This is the river part with the highest water level along the Durme river. Activating Klein Broek together with Groot Broek could lead to further reduction of HW along the entire river compared to the case of Groot Broek alone. A drop in HW reaches 15 cm at Waasmunster-Brug for the selected spring tide when all three Sigma areas are active.

A strong effect of the three Sigma areas on the current velocity was calculated downstream of the areas with higher velocity peaks.

The velocity asymmetry, based on peak velocities, is flood dominated in most of the river section. Activating Klein Broek and/or Groot Broek leads to a weaker flood dominance in the middle and downstream sections of the river. The effect of Groot Broek is stronger and extends more upstream. The polder Groot Broek even alters the velocity asymmetry to ebb dominance at the river section near the mouth. In terms of sediment transport, the polder Klein Broek and Groot Broek could slow down the sedimentation process in the downstream part of the Durme river.

No morphological evolution is taken into account, implying that the described effects are probably an overestimation of the actual effects which could be observed on the longer term. As sedimentation can be expected in the flood control areas, the exchange volumes will probably reduce again over time. Moreover, the findings are made for a normal spring-neap cycle and shouldn't be extrapolated for higher (storm) tides. A further study would be recommended to evaluate the effects of the Sigma areas for storm conditions.

Information of water level corrections (in the measurements) was provided at the reporting phase of the modelling work. All model runs had been carried out applying recorded water levels at Temse (the northern model boundary) that are 4 cm higher compared to the, nowadays, corrected values., As the correction in boundary condition would be present in both reference run and scenario runs, the results of this report still hold. Future works should take this correction into account.

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Appendix 1 Evaluation of Mike1D model

In this study, the water levels computed from Mike1D model are used in the calculation of the water levels imposed at the boundaries of the Durme model for the case of Sigma area(s) activated (in §2.3.1). In this Appendix, the performance of the Mike1D model is evaluated by comparing the water levels from Mike1D model for the case without activating Sigma areas and measurements.

Figure 37 compares the time series of water levels from measurement and Mike1D model at Temse and Sint-Amands during the two weeks from 09/09/2019 – 23/09/2019. Both measurement and model water levels are at 10-minute intervals. The results of the statistical analysis for the whole time series, at high waters and low waters are presented in Table 7.

The model underestimates low waters at the two locations with BIAS and RMSE of 14 cm at Temse and 5 cm - 6 cm at Sint-Amands (Figure 37, Table 7). Better model performance is shown for HW levels with RMSE equal to 7 cm and 5 cm for Temse and Sint-Amands, respectively. The HW levels are underestimated by the model at Temse but overestimated at Sint-Amands. Considering the whole time series, the model underestimates the water levels with BIAS of 8 cm and 3 cm for Temse and Sint-Amands (Table 7). The corresponding RMSE is 12 cm and 16 cm. Regarding the phase, the model performs well at Temse but shows a delay in HW and LW of 9 minutes at Sint-Amands (Table 7).

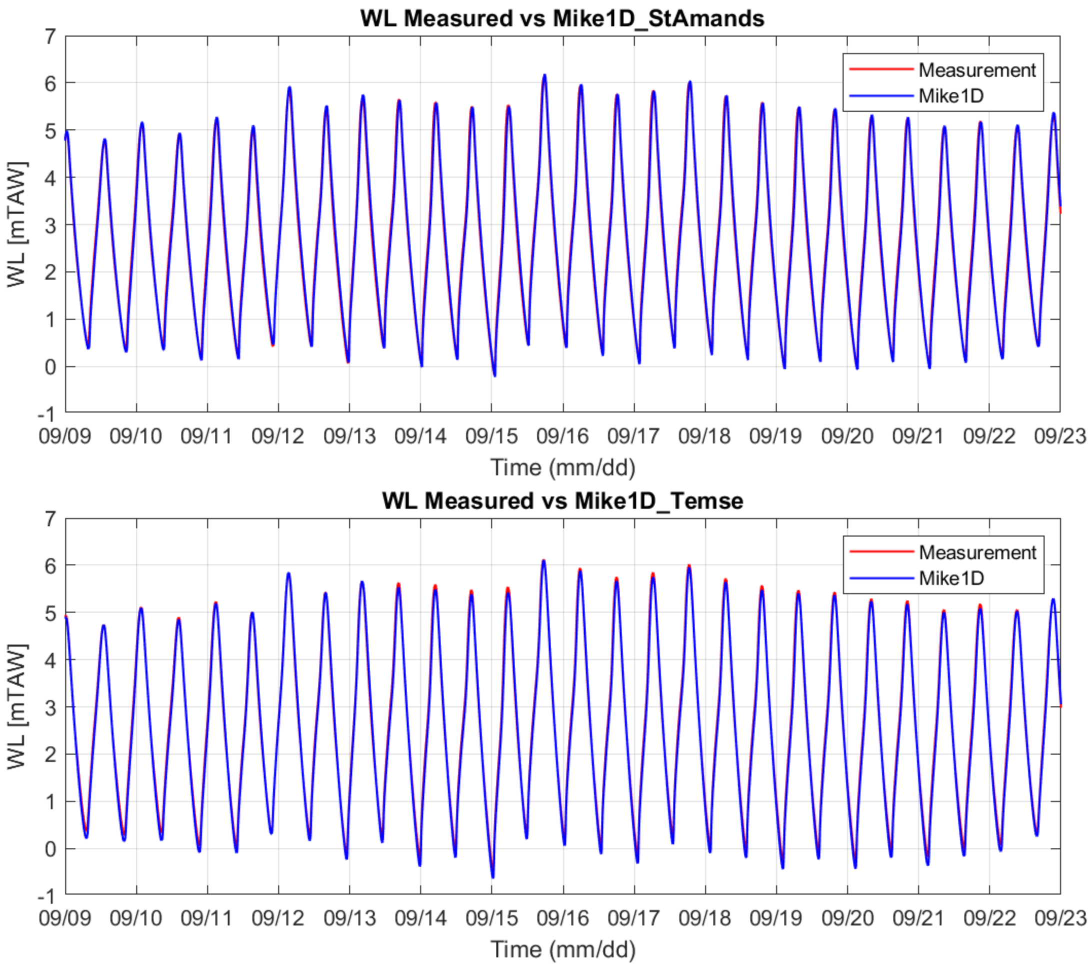

Figure 37 – Measured and Mike1D modeled water levels at Sint-Amands and Temse during the spring-neap cycle

Table 7 – *RMSE and BIAS of Mike1D modeled* water levels

Station	**BIAS [m]**			**RMSE [m]**			**BIAS [min]**		**RMSE [min]**	
	Time series	**HW**	**LW**	**Time series**	**HW**	**LW**	**HW**	**LW**	**HW**	**LW**
Temse	-0.08	-0.05	-0.14	0.12	0.07	0.14	0.37	0	3.33	1.92
Sint-Amands	-0.03	0.03	-0.05	0.16	0.05	0.06	9.07	8.52	9.86	9.43

Appendix 2 Dimensions of sluices of De Bunt

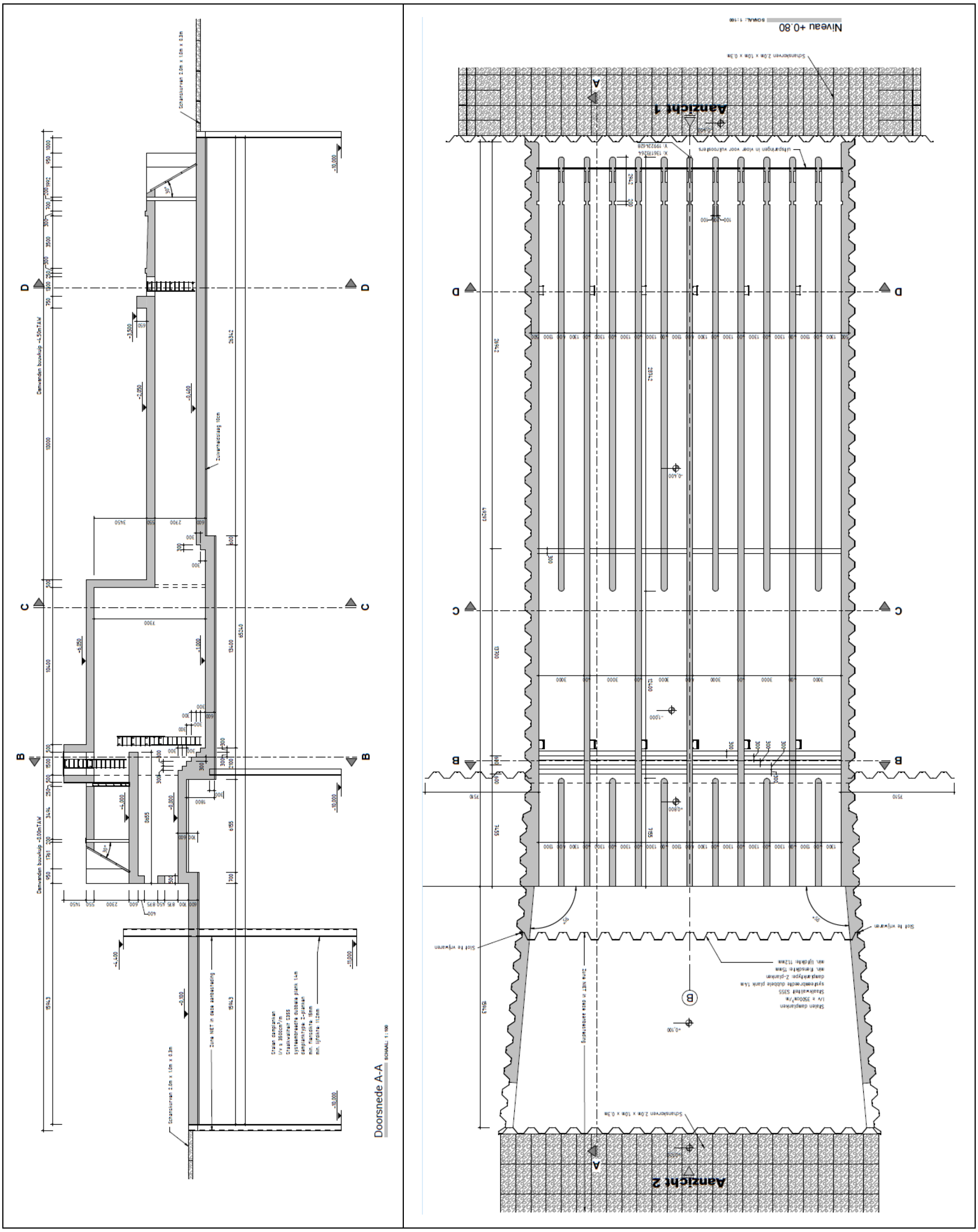

Figure 38 – Cross section (left) and plan view (right) of the northern inlet-outlet sluice of FCA-CRT De Bunt (SBE, 2019c,d)

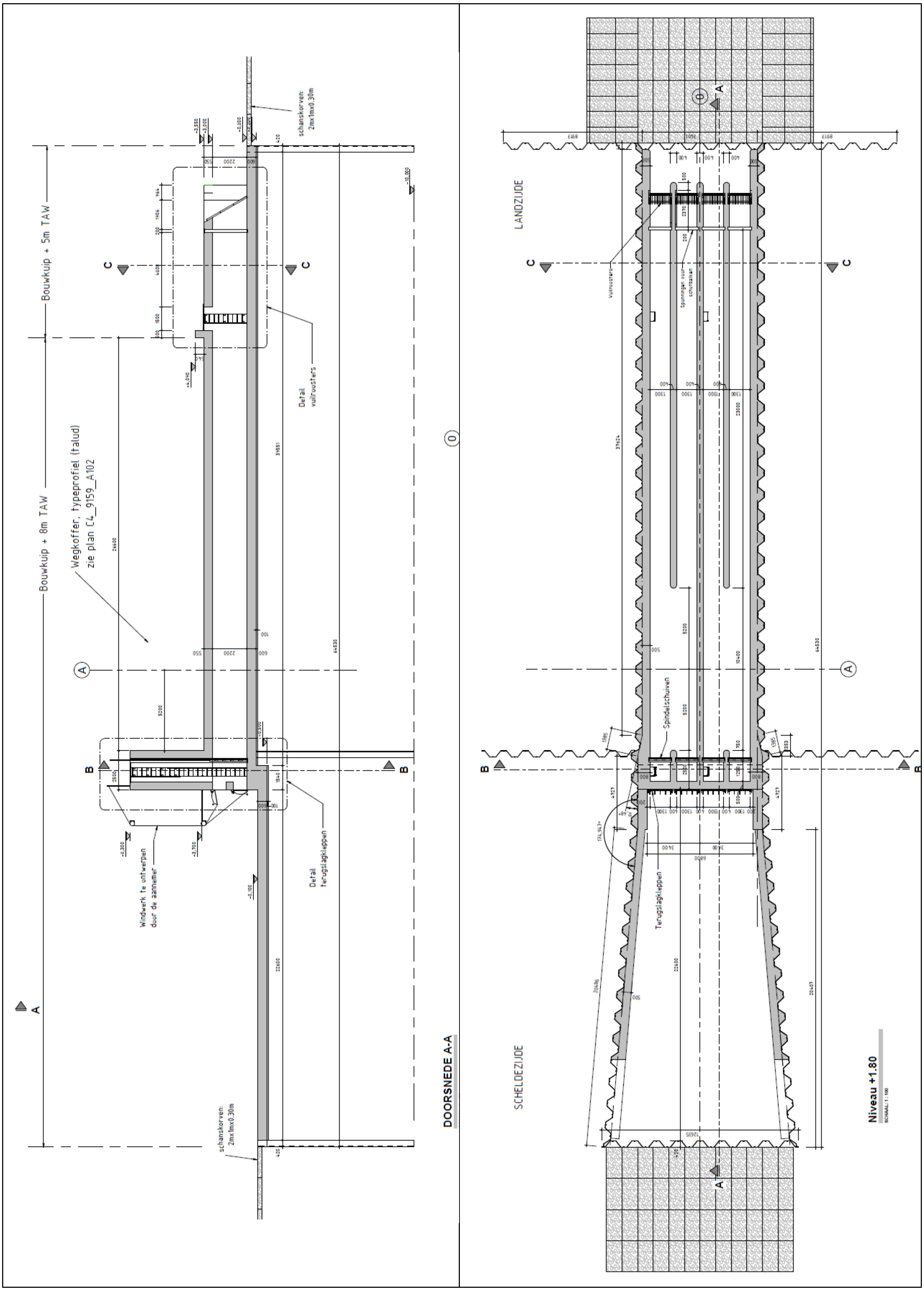

Figure 39 – Cross section (left) and plan view (lower) of the southern outlet sluice of FCA-CRT De Bunt (SBE, 2019a,b)

Appendix 3 Parameter settings for modelling culverts of FCT-CRT De Bunt

Table 8 – Parameter settings for modelling culverts of FCT-CRT De Bunt

Relaxation Number of culverts																				
0.8 28																				
I1	I2	CE1	CE2	CS1	CS2	LRGbus	Haut1	CLP	LBUS	z1	z2	CV	C56	CV5	C5	Ctrash	Haut2	Fric	length	circ
112419	112436	0.5	0.5	1	1	1.3	2.3	0	0.2	4	4	1	10	0	6	0.5	2.7	0.015	43	0
112565	112582	0.5	0.5	1	1	1.3	2.3	0	0.2	4	4	1	10	0	6	0.5	2.7	0.015	43	0
112712	112729	0.5	0.5	1	1	1.3	2.3	0	0.2	4	4	1	10	0	6	0.5	2.7	0.015	43	0
112860	112877	0.5	0.5	1	1	1.3	2.3	0	0.2	4	4	1	10	0	6	0.5	2.7	0.015	43	0
113009	113026	0.5	0.5	1	1	1.3	2.3	0	0.2	4	4	1	10	0	6	0.5	2.7	0.015	43	0
113159	113176	0.5	0.5	1	1	1.3	2.3	0	0.2	4	4	1	10	0	6	0.5	2.7	0.015	43	0
112420	112437	0.5	0.5	1	1	1.3	2.3	0	0.2	4	4	1	10	0	6	0.5	2.7	0.015	43	0
112566	112583	0.5	0.5	1	1	1.3	2.3	0	0.2	4	4	1	10	0	6	0.5	2.7	0.015	43	0
112713	112730	0.5	0.5	1	1	1.3	2.3	0	0.2	4	4	1	10	0	6	0.5	2.7	0.015	43	0
112861	112878	0.5	0.5	1	1	1.3	2.3	0	0.2	4	4	1	10	0	6	0.5	2.7	0.015	43	0
113010	113027	0.5	0.5	1	1	1.3	2.3	0	0.2	4	4	1	10	0	6	0.5	2.7	0.015	43	0
113160	113177	0.5	0.5	1	1	1.3	2.3	0	0.2	4	4	1	10	0	6	0.5	2.7	0.015	43	0
112421	112438	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.7	0.015	45	0
112567	112584	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.7	0.015	45	0
112714	112731	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.7	0.015	45	0
112862	112879	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.7	0.015	45	0
113011	113028	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.7	0.015	45	0
113161	113178	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.7	0.015	45	0
112422	112439	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.7	0.015	45	0
112568	112585	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.7	0.015	45	0
112715	112732	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.7	0.015	45	0
112863	112880	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.7	0.015	45	0
113012	113029	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.7	0.015	45	0
113162	113179	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.7	0.015	45	0
92086	113389	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.2	0.015	36	0
92010	113488	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.2	0.015	36	0
92043	113390	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.2	0.015	36	0
92030	113489	0.5	0.5	1	1	1.3	1.75	2	0.2	0.8	0.8	1	10	1.5	6	0.5	2.2	0.015	36	0

Relaxation — Relaxation between results computed at current and previous time step [0-1]. In this study, the value of 0.8 is chosen.

I1 — Node number of culvert at the riverside

I2 — Node number of culvert at the floodplain side

CE1 — Head loss coefficient for the entrance of the culvert at the river side. (Smolders et al., 2016: CE1 is taken as 0.5 but CE1 = 0.9 with the presence of pillars). This study uses CE1 = 0.5.

CE2 — Head loss coefficient for the entrance of the culvert at the floodplain side (Smolders et al., 2016: CE1 is taken as 0.5 but CE1 = 0.9 with the presence of pillars). The value of 0.5 is employed.

CS1 — Head loss coefficient for the exit of the culvert at the river side. (Smolders et al., 2016: CS1 = 1). CS1 = 1 is used.

CS2	Head loss coefficient for the exit of the culvert at the floodplain side (Smolders et al., 2016: CS2 = 1). CS2 = 1 is used.
LRGbus	Width of the culvert.
HAUT1	Height of the culvert at the river side.
CLP	This value represents the direction of the flow: = 0: flow in both ways = 1: flow only from the river to the floodplain = 2: flow only from the floodplain to the river
LBUS	Linear head loss coefficient: - If OPTION FOR CULVERTS = 1, LBUS is used - If OPTION FOR CULVERTS = 2, LBUS is calculated. In this Durme model, OPTION FOR CULVERTS = 2 => LBUS is calculated.
Z1	Culvert bottom elevation at river side.
Z2	Culvert bottom elevation at floodplain side.
CV	Head loss coefficient due to the presence of a valve. CV = 1 is used. (Smolders et al., 2016: valve wide open: CV = 0.2; ¾ open: CV=1; ½ open: CV = 5.6; ¼ open: CV = 17).
C56	Constant used to differentiate between flow types 5 and 6. (Smolders et al., 2016: C56 = 10).
CV5	Correction coefficient for the C1 (present in CE1 and CE2) and to CV coefficients due to the occurrence of the type 5 flow. (Smolders et al., 2016: CV5 = 0 for inlet culverts; = 1.5 for outlet culverts).
CTRASH	Head loss coefficient due to the presence of trash screens. (Smolders et al., 2016: CTRASH is in the range of 0 (no trash screen) to 1.4 (the net flow area is negligibly small compared to the gross rack area). In this study, CTRASH is chosen as 0.5.
HAUT2	Height of culvert at floodplain side
FRIC	Manning friction coefficient for culvert wall friction
LENGTH	Length of the culvert
CIRC	This value represents the shape of the culverts: 1 for circular culverts and 0 for rectangular. The designed culverts are rectangular ones => CIRC = 1

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