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Sub report 7 – The effect of upstream discharge and flushing

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Een geïntegreerde aanpak voor de Durme

Sub report 7 – The effect of upstream discharge and flushing

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

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Abstract

In the Durme valley, various management measures are foreseen, such as implementation of new intertidal areas, changes in the upstream flushing regime and deepening of the river. In this report, the effects of the changes in upstream discharge and upstream deepening on the hydrodynamics of the Durme river are evaluated using a hydrodynamic Telemac model of the Durme river.

A series of model runs was carried out in which the upstream discharge was varied and the upstream bathymetry was altered. The results show variable responses of the water level, current velocity and tidal asymmetry. As the changes occur at the river upstream, the effects on river hydrodynamics are stronger in the upstream river section.

Upstream deepening causes higher velocity asymmetry within the deepened section, which enhances flood dominance (for case with small upstream discharge) or weakens ebb dominance (higher upstream discharge scenarios). Further downstream, the effect reverses and velocity asymmetry weakens. Higher river flow naturally results in a decrease of flood velocity and an increase of ebb flow. The flood dominant tidal asymmetry is therefore weaker for higher upstream discharge. An increase in the river discharge could even result in a transition from flood dominance to ebb dominance in some river sections. In terms of sediment transport, this could imply that accumulated sediment can be redistributed within the Durme river.

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1 Introduction

In the Durme valley (Figure 1), different management measures have been planned, among which are the implementation of new intertidal areas, changes in the upstream flushing regime and deepening of the river.

In this report, the effects of changes in upstream discharges and upstream deepening on the hydrodynamics of the Durme river are evaluated by means of numerical modelling. In Nguyen et al., (2024), a model for the Durme was setup using Telemac (EDF-R&D, 2014) and has been calibrated against the measurements of water levels and ADCP current velocities. The model has demonstrated to capture the tidal hydrodynamics along the river. The hydrodynamic model is used to conduct model scenarios with varying upstream discharge and an altered bathymetry of the upstream part of the Durme river. Next to the total water discharge, flushing events are also examined. Both flushing during flood and ebb phase are simulated, with the idea to reduce the upstream (sediment) transport (during flood) or to increase the downstream transport (during ebb). The resulted hydrodynamic parameters, such as water levels, current velocities and tidal asymmetry are analyzed. The sediment transport is not (yet) modeled but is discussed based on the hydrodynamic results.

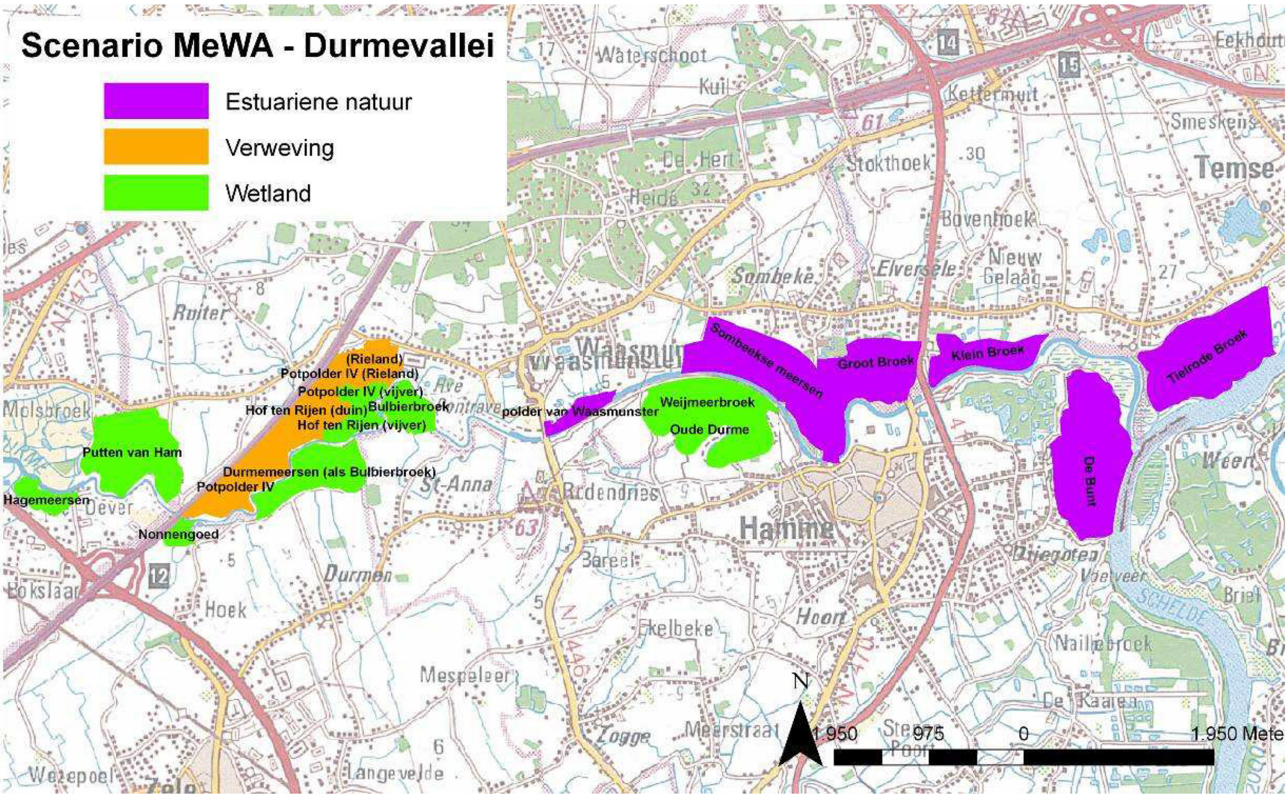


Figure 1 – The Durme valley (Van Ryckegem, 2006)

2 Units and reference plane

The horizontal coordinate reference used in the model is RD Parijs (EPGS code 28992). The vertical coordinate system (e.g. depths, heights and water levels) is expressed in m TAW ("Tweede Algemene Waterpassing"). The time zone used in the numerical model is MET or winter time (UTC + 1).

3 Methodology

3.1 Model description

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 Sigmaplan. 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 goes up to 20 m.

The Durme model has three open boundaries (Figure 2). Water levels are imposed at the two boundaries within the Upper Sea Scheldt, more precisely at Temse and Sint-Amands. A discharge boundary condition is set at the upstream end of the Durme river (i.e. the dam at Lokeren).

The model was calibrated for a spring - neap cycle and for a bathymetric situation in 2019 and 2010. Between 2010 and 2019 capital dredging works were performed in the downstream part of the Durme (between Tielrode and Waasmunster Brug), and in the upstream part some maintenance dredging works were performed as well in 2011. The modeled water levels agree well with the measurements with quite a small error. The RMSE for 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 – 0.2 m/s and 0.21 – 0.25, respectively.

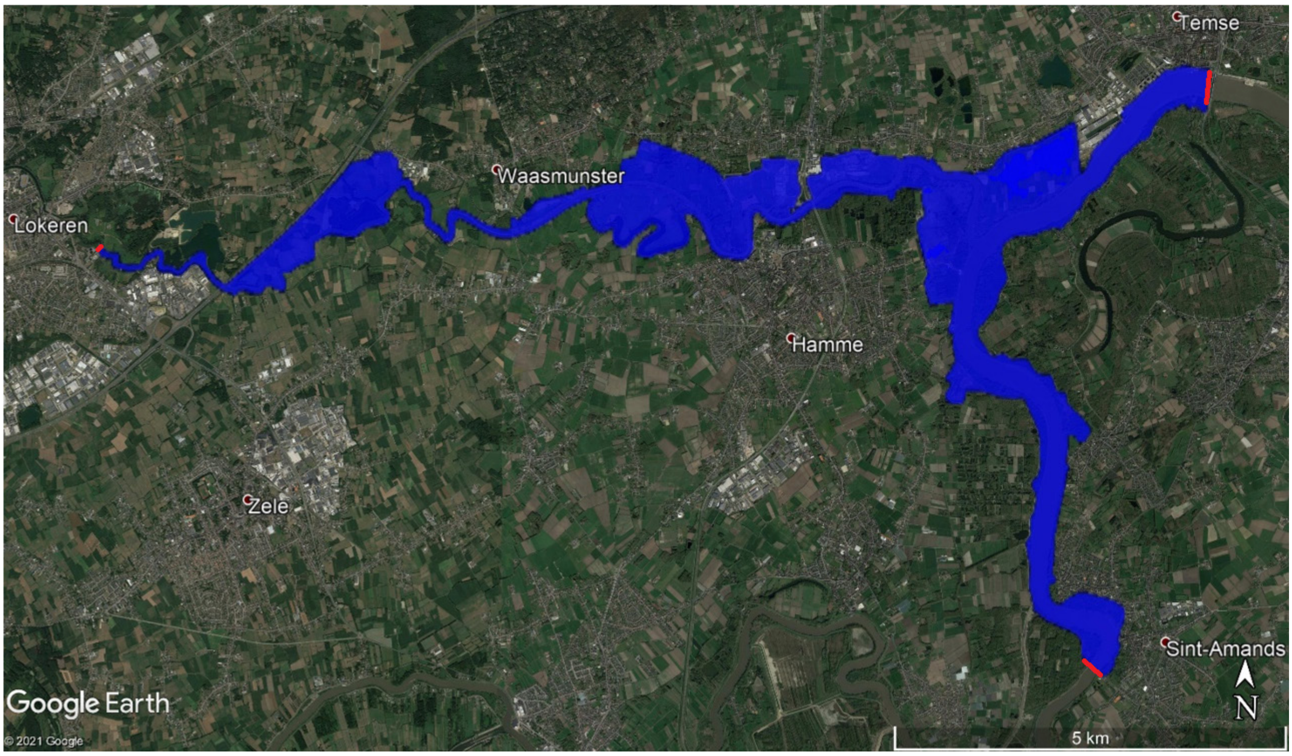


Figure 2 – The Durme model (blue) with three model boundaries (red) (Nguyen et al, 2024)

3.1.1 Model period

The model period chosen for the scenario runs 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.

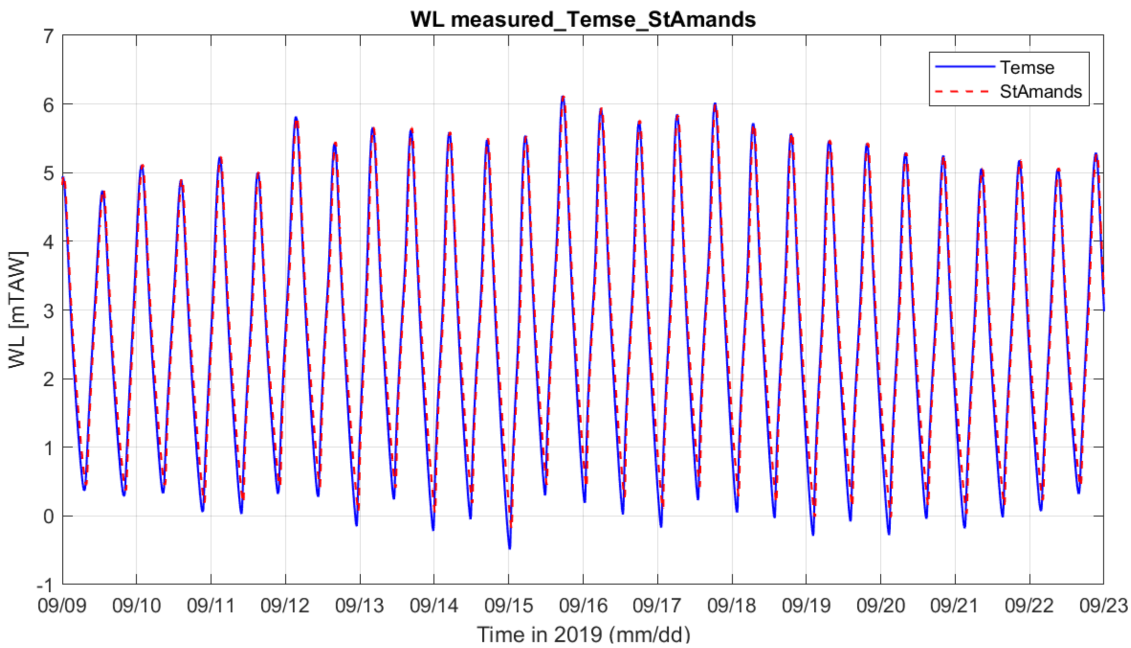


Figure 3 – Water levels at the two boundaries (Temse and St. Amands) at the Scheldt river during the model scenario runs

3.1.2 Discharge

As presented in Nguyen et al. (2024), there are different sources of discharge entering the tidal Durme (Figure 4), especially in the upstream zone. However, the exact values are not available as no measurements are performed, except for the daily discharge data of the wastewater treatment plant (RWZI) at Lokeren. Only the theoretical pumping capacity is available for other point sources. The theoretical maximal discharge in the Durme, upstream Waasmunster Brug, is 20.3 m³/s. In the next section, the effect of the discharge imposed at the upstream on the river hydrodynamics is investigated.

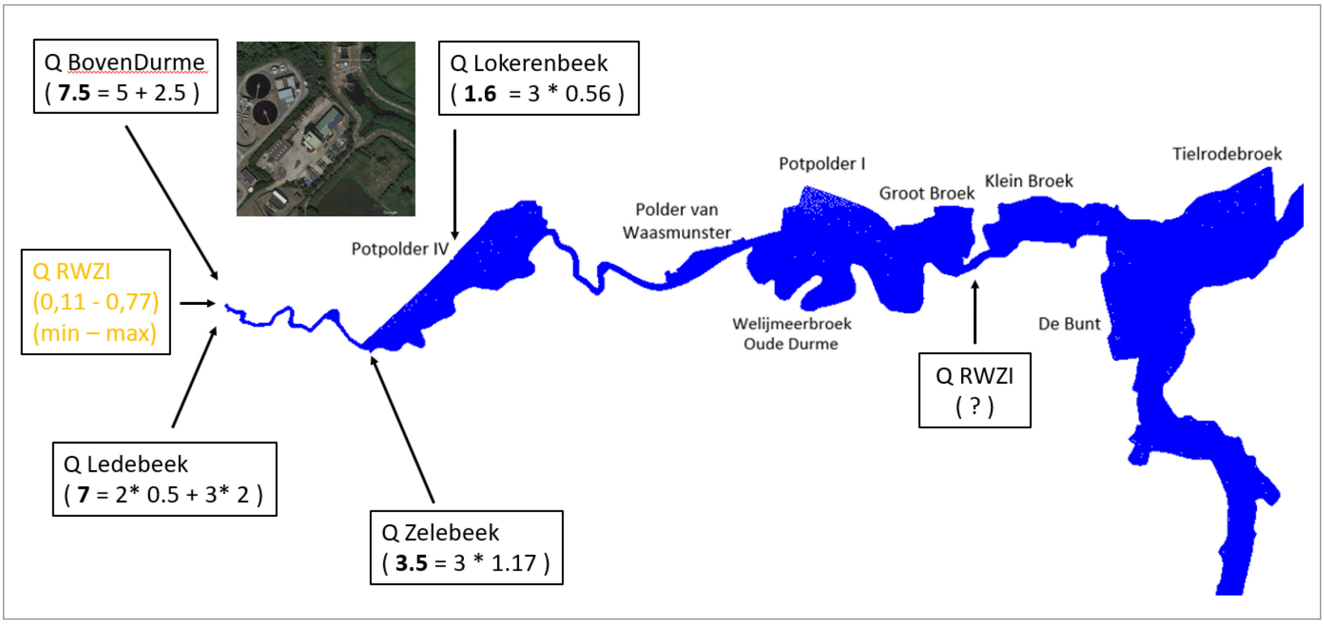


Figure 4 – Overview of the discharge sources, with their theoretical pump capacities in m³/s (Nguyen et al., 2024)

3.1.3 Bathymetry

Two model bathymetries are examined in the scenario analysis: the current bathymetry (CB) and the planned bathymetry (PB) (Figure 5):

- The current bathymetry is the bathymetry for the 2019 runs in Nguyen et al. (2024). It was constructed using different data sets in the years 2018, 2019, 2020. As in the scenario runs in the current report, the Sigma areas De Bunt, Klein Broek and Groot Broek are not active, the bottom within the areas was set to about the highest dike level of +8 mTAW.
- In the planned bathymetry, about 8 km upstream part of the Durme river is deepened to +2 mTAW (Figure 5, Figure 6) with a dredging volume of about 300.000 m³. The designed bottom data within the upstream part has been provided by De Vlaamse Waterweg.

The comparison of the two bathymetries is shown in Figure 5, Figure 6 and Figure 7. A significant deepening at the upstream, from km 0 to km 8 is observed in the planned bathymetry. Within this river section, the thalweg of the PB is fairly constant in height (at around +2 mTAW) while the CB shows higher elevation towards upstream (from 2 – 4.5 mTAW). In the 6 km most upstream, the thalweg of the planned bathymetry is 2 to 2.5 m lower compared to that of the current bathymetry. The shape of the river cross-sections is also altered, which can be seen in Figure 7, where some cross sections are shown.

The impact of the river deepening on the hydrodynamics of the Durme river is investigated in the scenario runs.

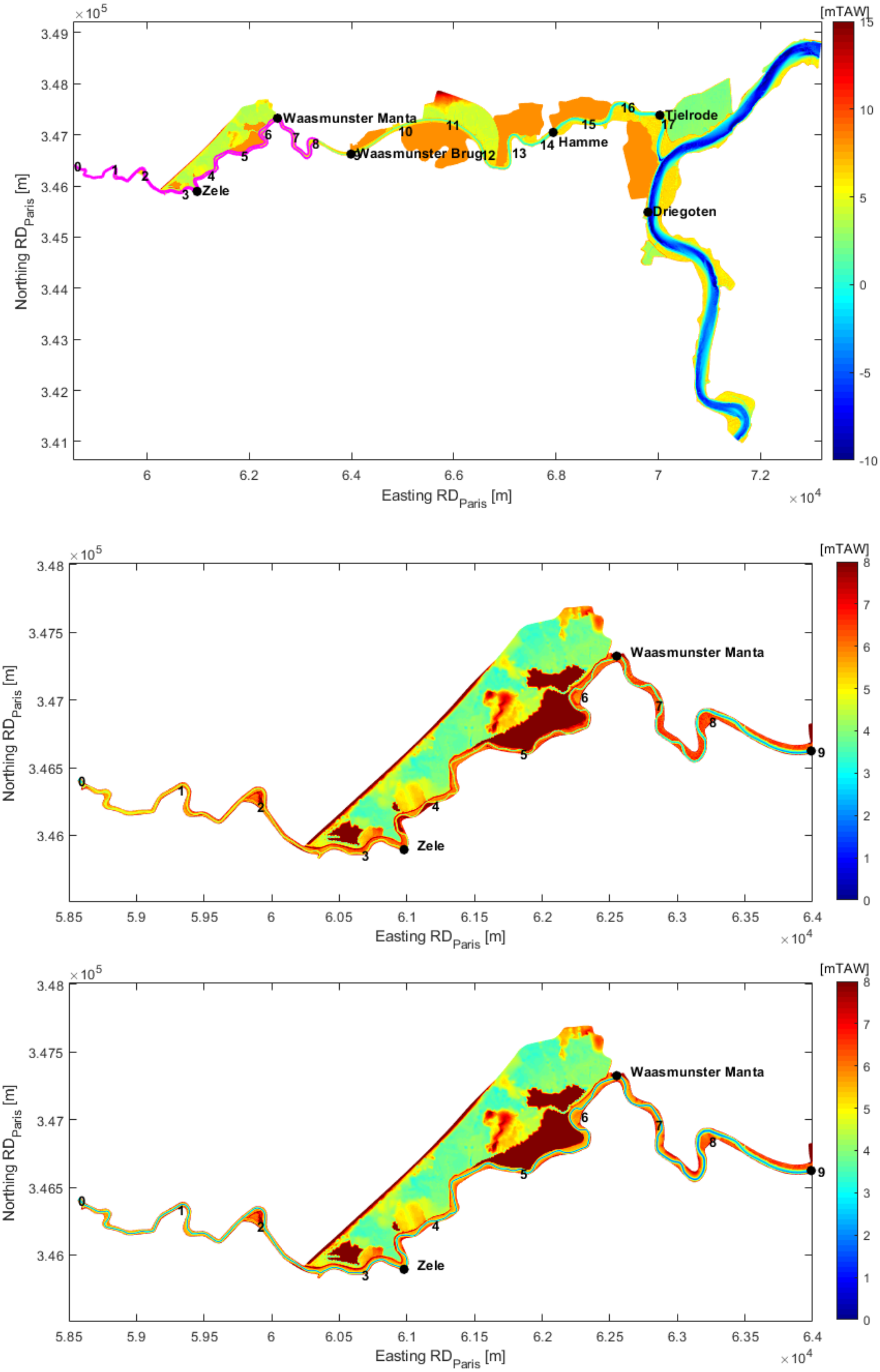


Figure 5 – Current and planned bathymetry: extent of planned dredging area at Durme upstream (within magenta polygon) (top); upstream part of current bathymetry (middle) and planned bathymetry (bottom). The numbers show the distance in km from upstream end of the Durme river

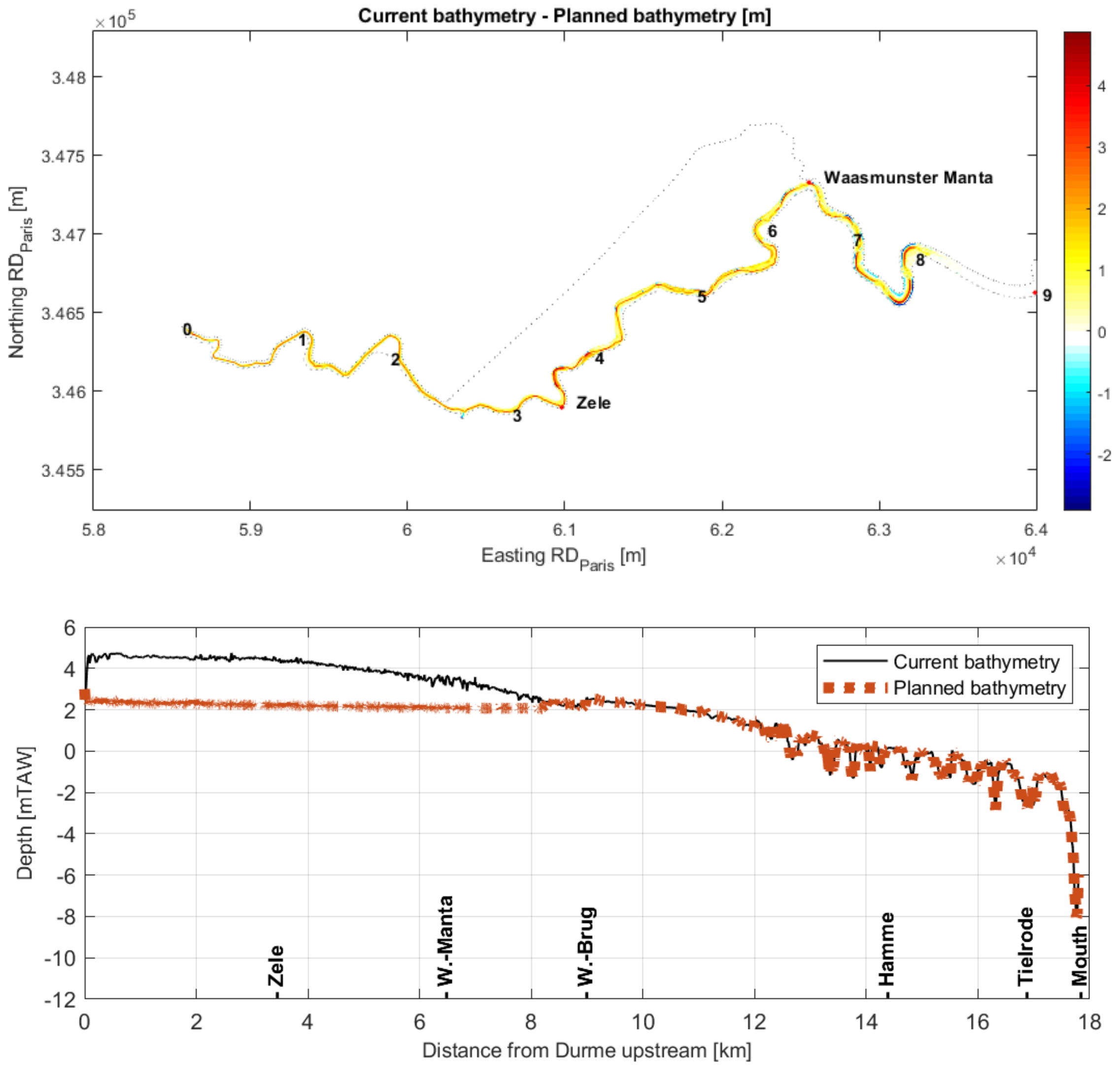


Figure 6 – Deepening at upstream of the Durme river in the planned bathymetry. Upper: Difference between the current and planned bathymetry. Lower: Thalweg elevation of the current and planned bathymetry

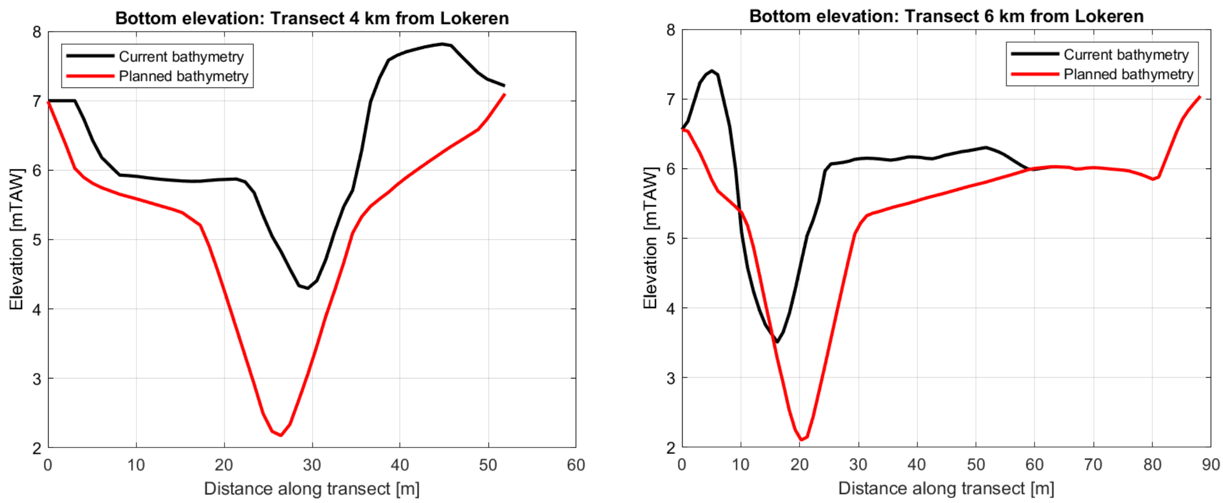


Figure 7 – Bottom elevation at a cross-section respectively 4 km (left) and 6 km (right) from Lokeren for the current and planned bathymetry

3.2 Scenario runs

Scenario runs are conducted to study the effect of the river upstream deepening and the discharge imposed at the upstream model boundary on the hydrodynamics of the Durme.

In total, seven discharge cases are considered as shown in Table 1. In the first four discharge cases Q1 - Q4, a constant discharge (0.0168, 6, 15, 20 m^3/s) is imposed at the upstream boundary of the model. In the next two cases, a river discharge of 6 m^3/s is implemented for a period of 1 hour around the moment of peak flood (Q5) or peak ebb (Q6) while the reference discharge value of 0.168 m^3/s is applied for the rest of the tidal cycle (see Figure 8 and Figure 9 for the implementation of variable upstream discharge).

For the scenarios with a flushing discharge, the modelled velocity at Waasmunster-Brug, located in the middle of the river, is used for the determination of flood and ebb moments that higher discharge (6 m^3/s) is applied (for 1 hour) at the upstream boundary. It is noted that the flood peaks at the upstream end lag behind those at Waasmunster-Brug about 2 - 2.5 hrs and 1 – 1.5 hrs for the cases with CB and PB, respectively. The idea behind these particular runs is to study the effect of high flushing during peak flow condition on the current velocity and tidal asymmetry, and thus on sediment transport. The last case Q7 (constant value of 0.72 m^3/s) is used for comparison with cases Q5 and Q6 as this discharge ensures that a similar volume enters the river from upstream.

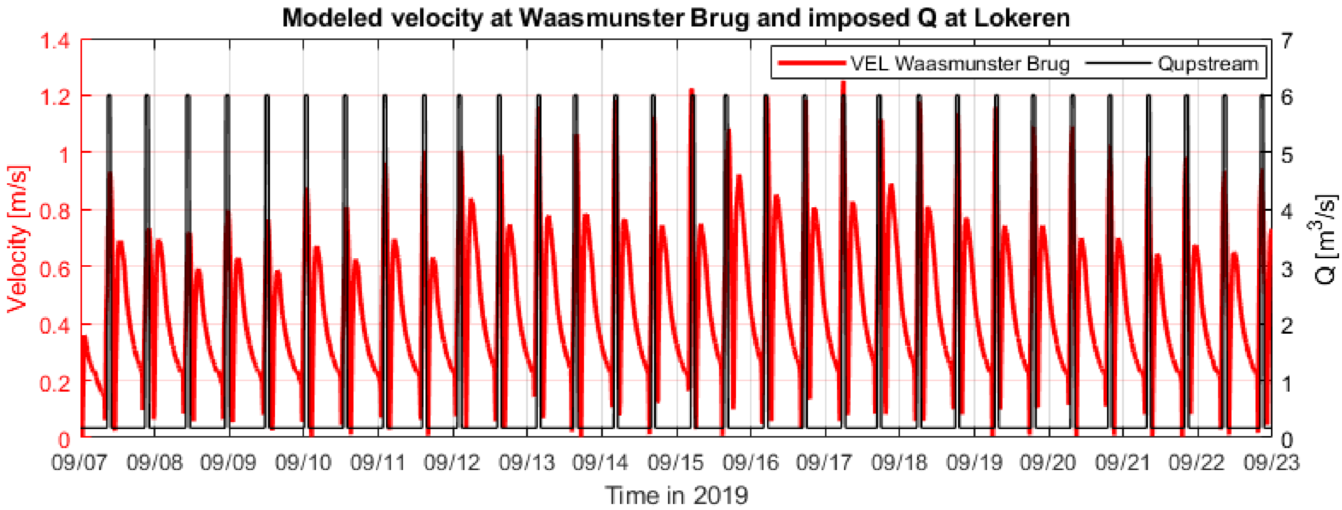
For each discharge case, two model runs were conducted: one with current bathymetry and one with planned bathymetry. In total, 14 scenario runs were carried out (Table 2).

Table 1 – Selected discharges imposed at Durme upstream for the scenario runs

	Q upstream [m^3/s]	Remark
Q1	0.168	mean discharge in 2019 from the wastewater treatment plant, which is the only discharge measurement available in the area
Q2	6	maximum discharge of the pump at Lokeren dam (7.5m^3/s) taking into account a pumping efficiency of 80%
Q3	15	sum of discharges from three sources at the upstream end of the Durme river
Q4	20	Theoretical maximum discharge entering the area
Q5	0.168 (1h around peak flood: Q = 6)	velocity at Waasmunster-Brug is used for the determination of flood and ebb moments
Q6	0.168 (1h around peak ebb: Q = 6)	
Q7	0.72	with this value, the same volume as in case Q5 and Q6 enters the Durme river

Table 2 – Scenario runs

Q upstream [m^3/s]	Current Bathymetry (CB)	Planned bathymetry (PB)
0.168	Run58	Run72
6	Run66	Run75
15	Run70	Run76
20	Run71	Run77
0.168 (1h around peak flood: Q = 6)	Run67	Run87
0.168 (1h around peak ebb: Q = 6)	Run68	Run88
0.72	Run89	Run90



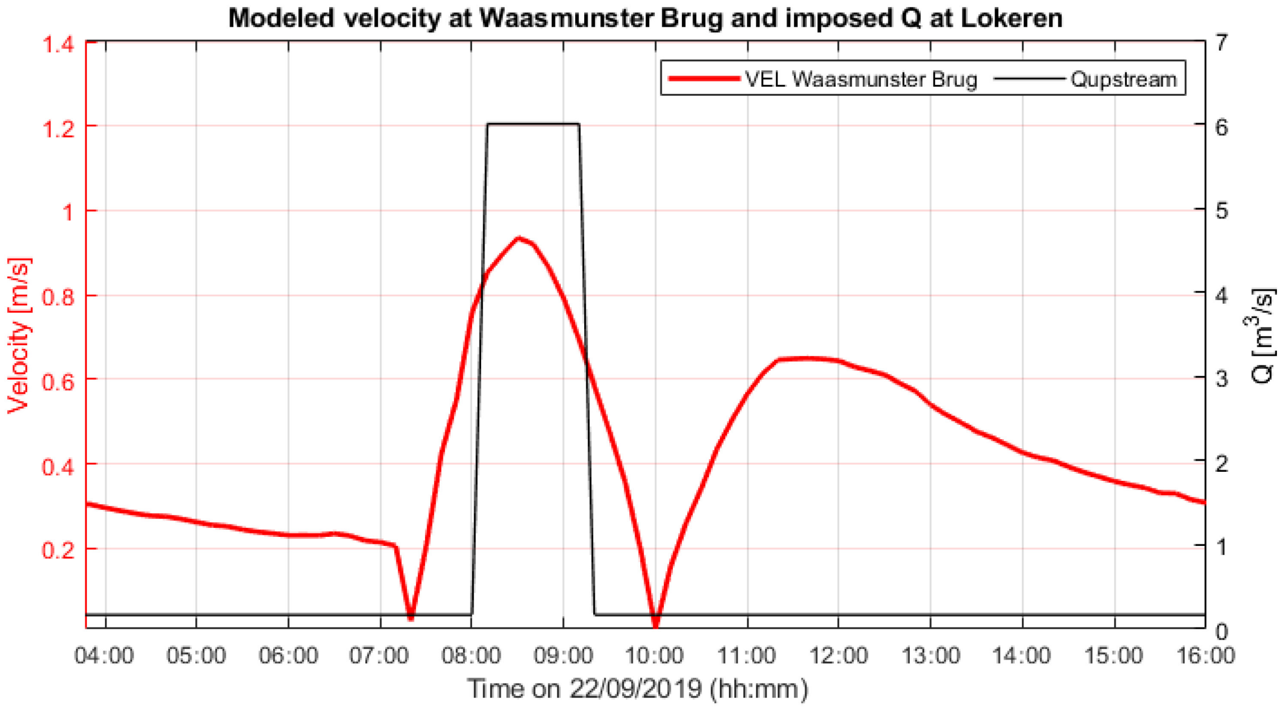


Figure 8 – Upstream discharge with high flushing around peak flood, example for PB scenario.
Upper: the whole simulation period. Lower: zoom to one tide

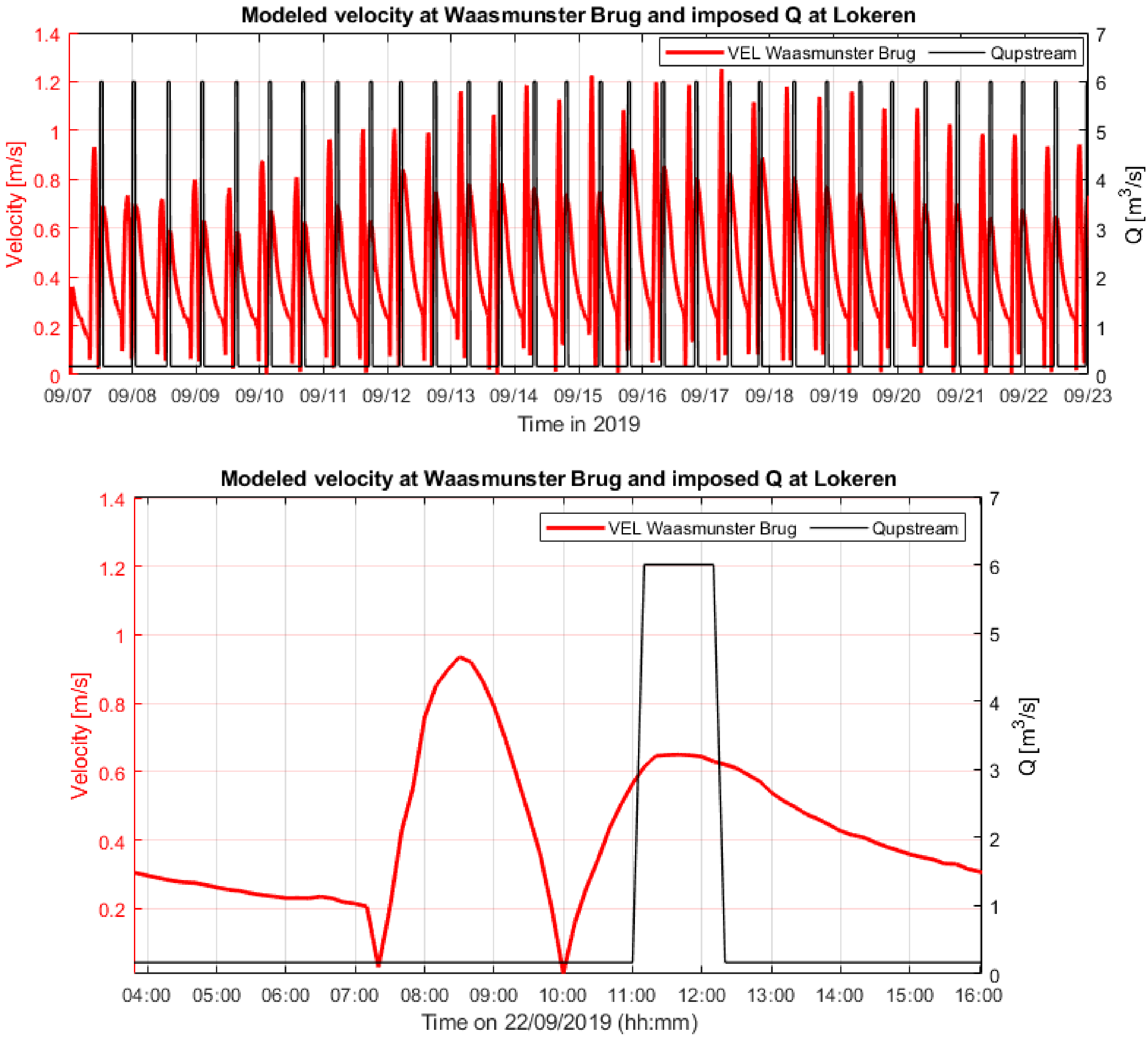


Figure 9 – Upstream discharge with high flushing around peak ebb, example for PB scenario.
Upper: the whole simulation period. Lower: zoom to one tide

3.3 Scenario analysis

The following results are considered in the analysis of the model scenarios:

- Water levels and tidal range during the spring-neap tidal cycle at six tidal stations: Driegoten, Tielrode, Hamme, Waasmunster-Brug, Waasmunster-Manta, and Zele (see Figure 10)
- Cross-sectional averaged velocities
- Longitudinal variation of HW, LW, tidal range, peak flood, ebb current velocity

- Tidal asymmetry along the Durme: two types of the tidal asymmetry are investigated:
  - *Asymmetry in tidal duration,* which is represented by the ratio of tidal duration during flood and ebb. A ratio larger than 1 indicates flood dominance, a ratio smaller than 1 means ebb dominance.
  - *Asymmetry in peak current velocity,* which is 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 non cohesive sediment transport as these sediment transport formulas are mostly dependent on velocity magnitude.

The analysis is performed for the spring-neap cycle 09/09/2019-23/09/2019 with detailed discussion for a selected spring tide (16/09/2019 13:00 - 17/09/2019 01:20) and a selected neap tide (22/09/2019 03:50 - 22/09/2019 16:00) (see Figure 11 and Table 3).

Along the Durme river, 91 cross-sections were defined with approximately 200 m interval as shown in Figure 10. On these transects the model results are extracted and analyzed. The water levels, current velocities and tidal asymmetry are discussed for the selected spring tide and neap tide. The longitudinal variation of water levels, current velocities and tidal asymmetry are smoothed with a three-point moving averaged.

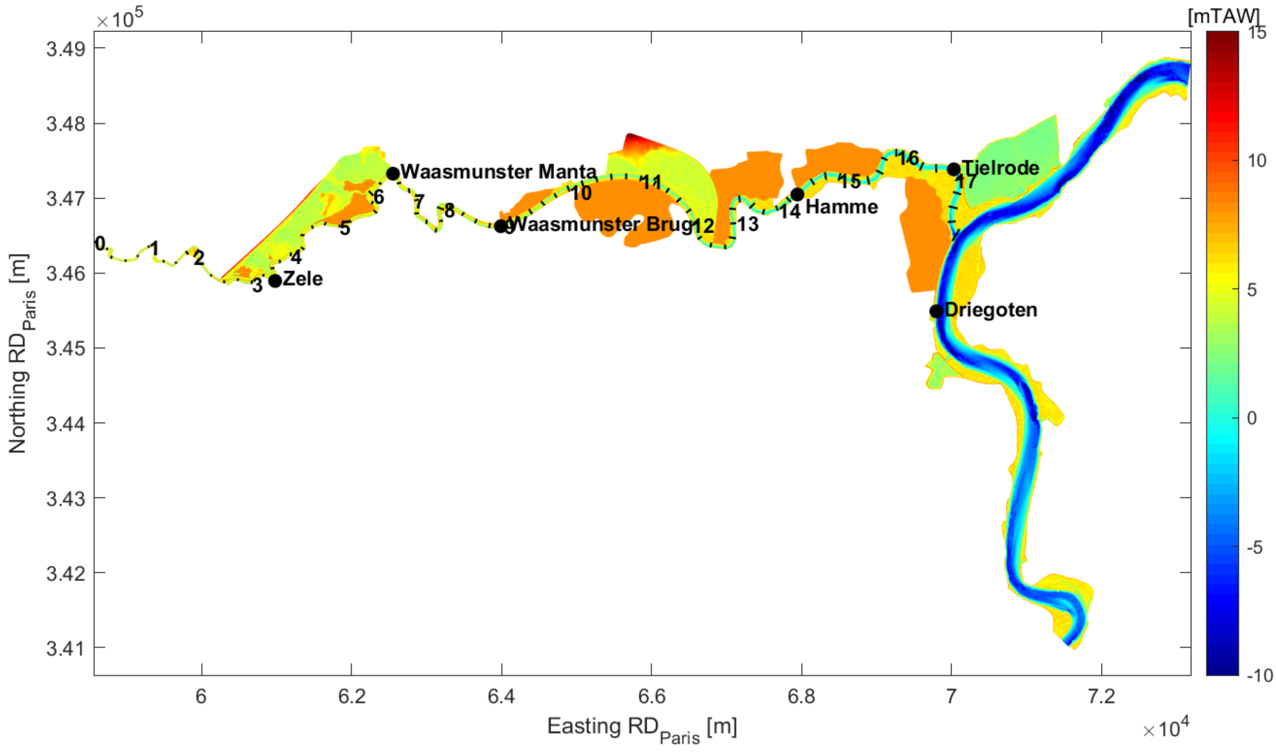


Figure 10 – Observation stations and cross-sections for the scenarios analysis.
The numbers show the distance in km from the upstream end of Durme river

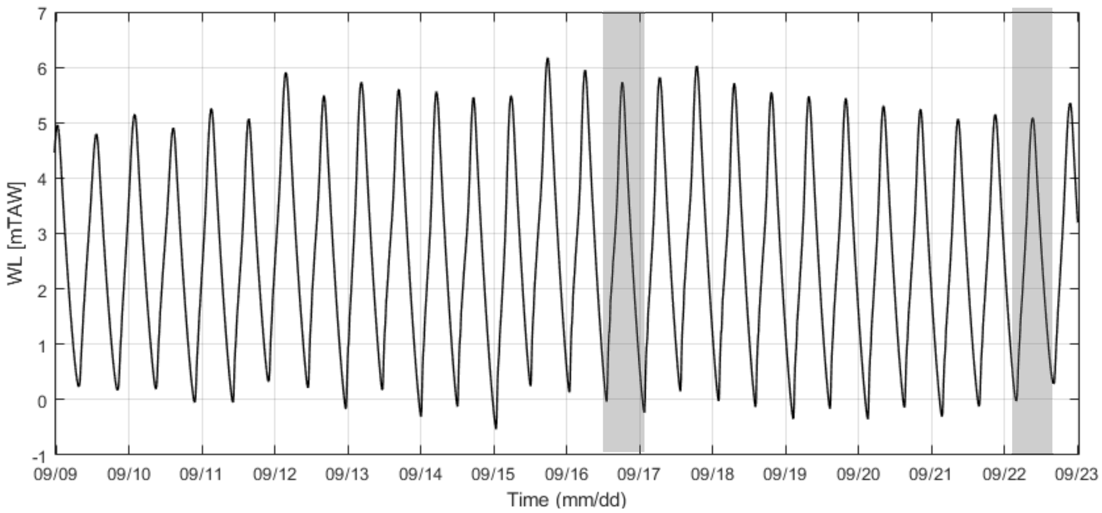


Figure 11 – Selected spring tide and neap tide for the scenario analysis

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)*

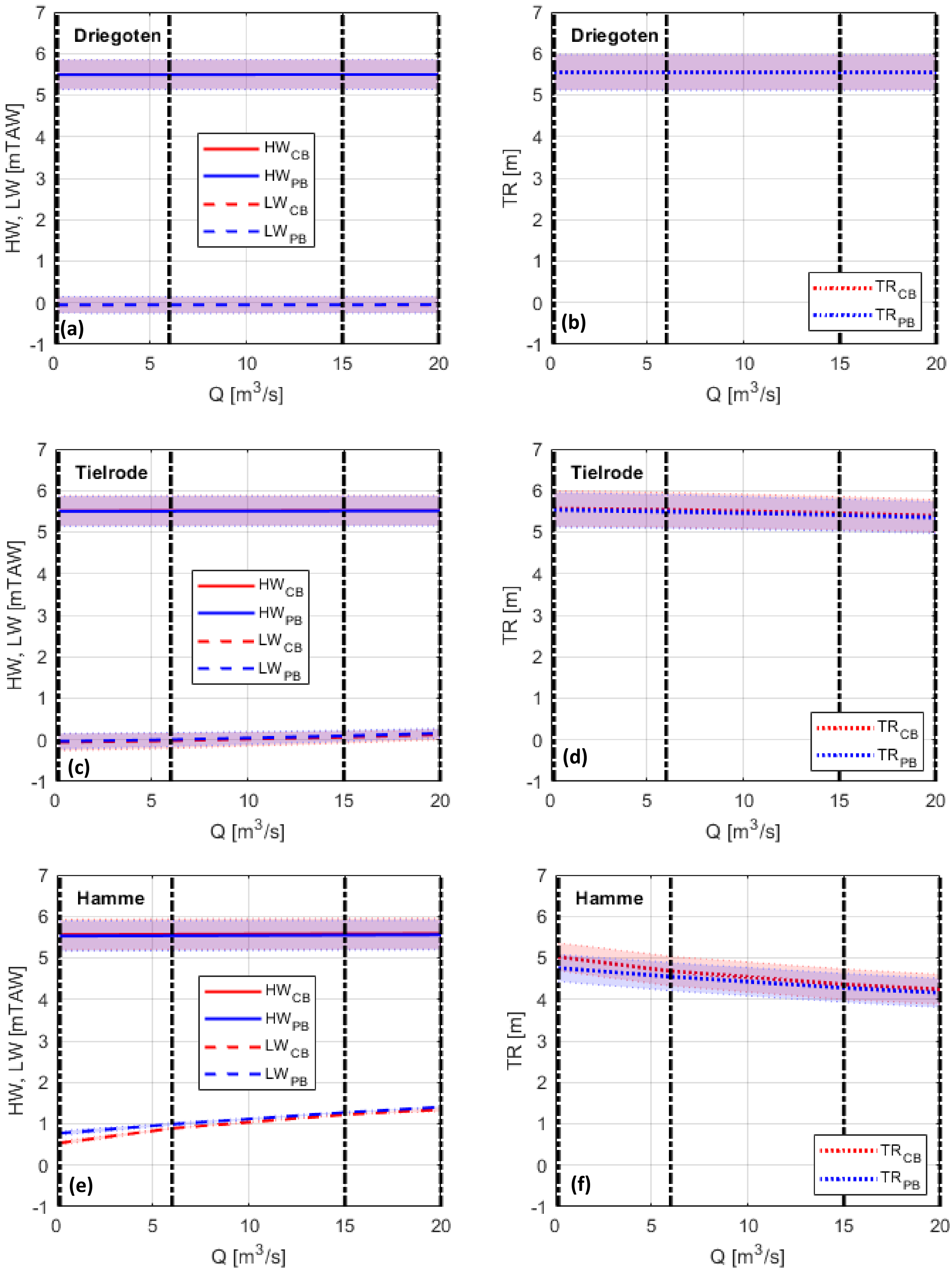
4 Scenario results

4.1 Effects of upstream river discharge and deepening on water levels and tidal range

Figure 12 compares high water (HW), low water (LW) and tidal range (TR) computed with the current and planned bathymetry at six tidal stations: Driegoten, Tielrode, Hamme, Waasmunster-Brug, Waasmunster-Manta, and Zele (see Figure 5 for the bathymetries and Figure 10 for the location of the stations). The figure shows ensembled mean and standard deviation of HW, LW and TR for the simulated spring-neap tidal cycle, 09/09/2019 - 23/09/2019 for five representative, constant values of upstream discharges: 0.168, 6, 15 and 20 m^3/s.

In the planned bathymetry, a section of about 8 km in the upstream part of the river, from km 0 to km 8 is dredged (see Figure 5, Figure 6). The effect of river deepening is obvious at the two stations located within the deepened section, i.e. Waasmunster-Manta and Zele (Figure 12i-l). The water levels are reduced for all discharges. The reduction is stronger for LW than for HW (Figure 12i,k), leading to a higher tidal range for the planned bathymetry (Figure 12j,l). The influence of upstream deepening extends outside the dredging area, towards station Hamme located in the middle section of the river, although effects are less pronounced. For locations near the mouth of the Durme river, Driegoten and Tielrode, the water levels are very similar for the current and planned bathymetry (Figure 12a-d).

All locations show more variation (larger band) of HW than of LW during the spring-neap cycle. In particular, almost no variation in LW over time was calculated for locations in the middle and upstream of the river, i.e. Hamme, Waasmunster-Brug, Waasmunster-Manta and Zele. Here the water levels are determined by the bed level rather than the downstream spring-neap variation.


Driegoten
HW, LW [mTAW]
HW_CB
HW_PB
LW_CB
LW_PB
(a)
Q [m^3/s]
Driegoten
TR [m]
TR_CB
TR_PB
(b)
Q [m^3/s]
Tielrode
HW, LW [mTAW]
HW_CB
HW_PB
LW_CB
LW_PB
(c)
Q [m^3/s]
Tielrode
TR [m]
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(d)
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Hamme
HW, LW [mTAW]
HW_CB
HW_PB
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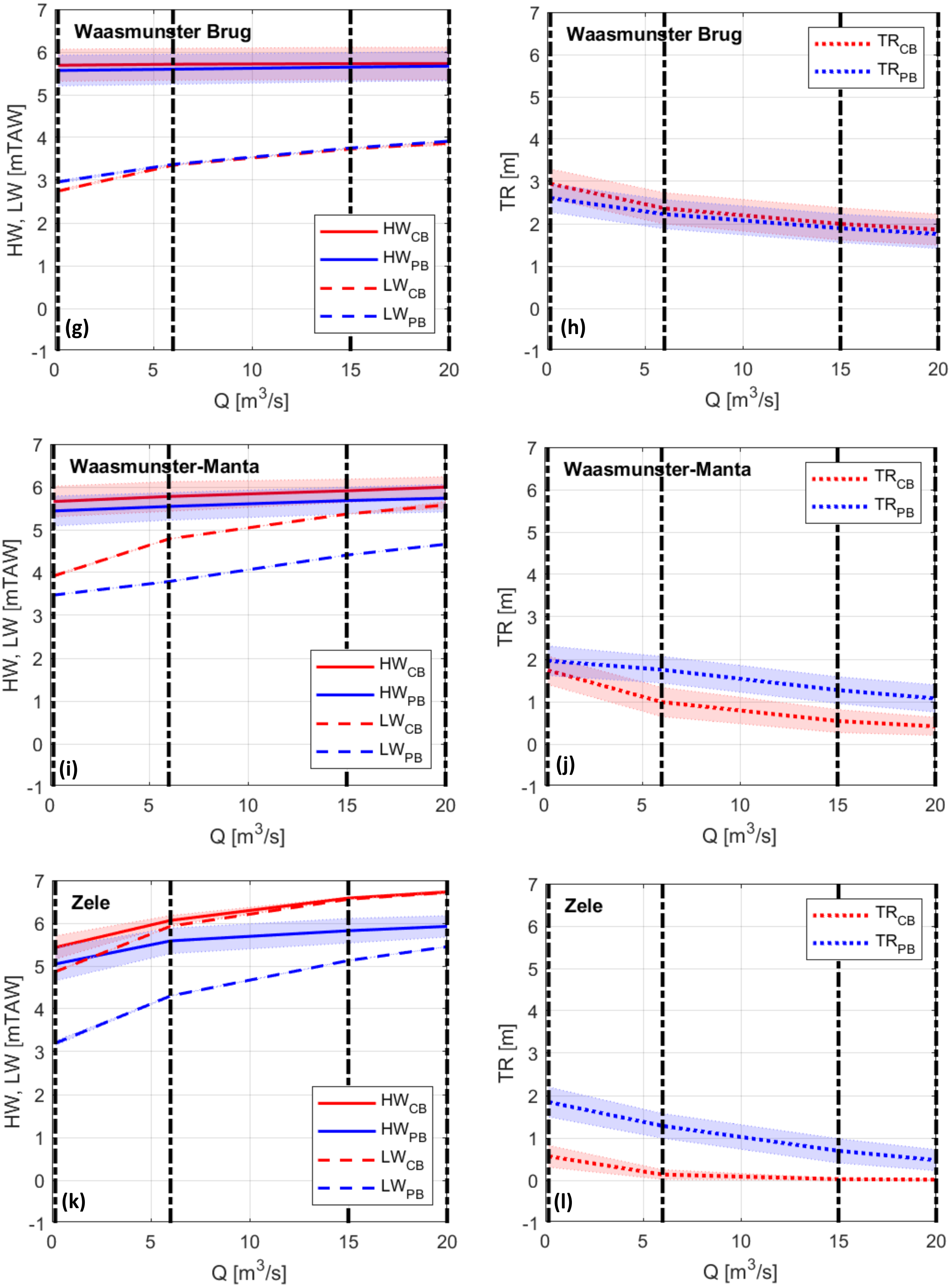


Figure 12 – Effect of bathymetry on high water (HW), low water (LW) and tidal range (TR) at Driegoten, Tielrode, Hamme, Waasmunster-Brug, Waasmunster-Manta and Zele for different upstream discharges. Bold lines and error bands present mean and standard deviation of HW, LW and TR computed for the spring-neap tidal cycle

Along the Durme river, eight representative cross-sections were selected for the analysis of the scenario results of the water levels and velocities (in §4.2): from the river mouth to the upstream: km 17.8, km 15, km 12, km 9, km 7, km 5, km 3 and km 1 (see Figure 10).

The water levels at eight selected cross-sections computed with current bathymetry (CB) and planned bathymetry (PB) for four constant river discharges are compared in Figure 13 and Figure 14 for the spring tide and neap tide, respectively. The water levels are presented for the deepest point along a cross-section.

The deepening at the upstream section and the discharge forcing at the upstream end have almost no influence the water levels at the Durme mouth (km 17.8) (Figure 13a and Figure 14a). Further to the middle of the river at km 15, km 12, km 9, the effects on high waters are limited but a clear raise in low waters is observed as the river discharge increases (Figure 13b,c,d and Figure 14 b,c,d). The tidal signals become flatter as the river discharge is higher. With the current bathymetry, LW at the middle of the river (km 9) is increased about 1.2 m if the upstream discharge is increased from the present minimum value (0.168 m^3/s) to its maximum (20 m^3/s).

The water levels at four cross-sections km 7, km 5, km 3 and km 1 are strongly affected by the change of upstream forcing and also bathymetry, as they are located near the discharge source and within the dredging area. As the result of river deepening, tidal penetration is enhanced in the most upstream part of the Durme river and the modelled water levels are lowered for all discharges. The latter effect is stronger for low water than for high water. Especially for the most upstream locations (km 1, km 3, km 5), the model runs with the current bathymetry show almost constant water levels for higher discharges, whereas a clear tidal signal can still be detected with the dredged bathymetry.

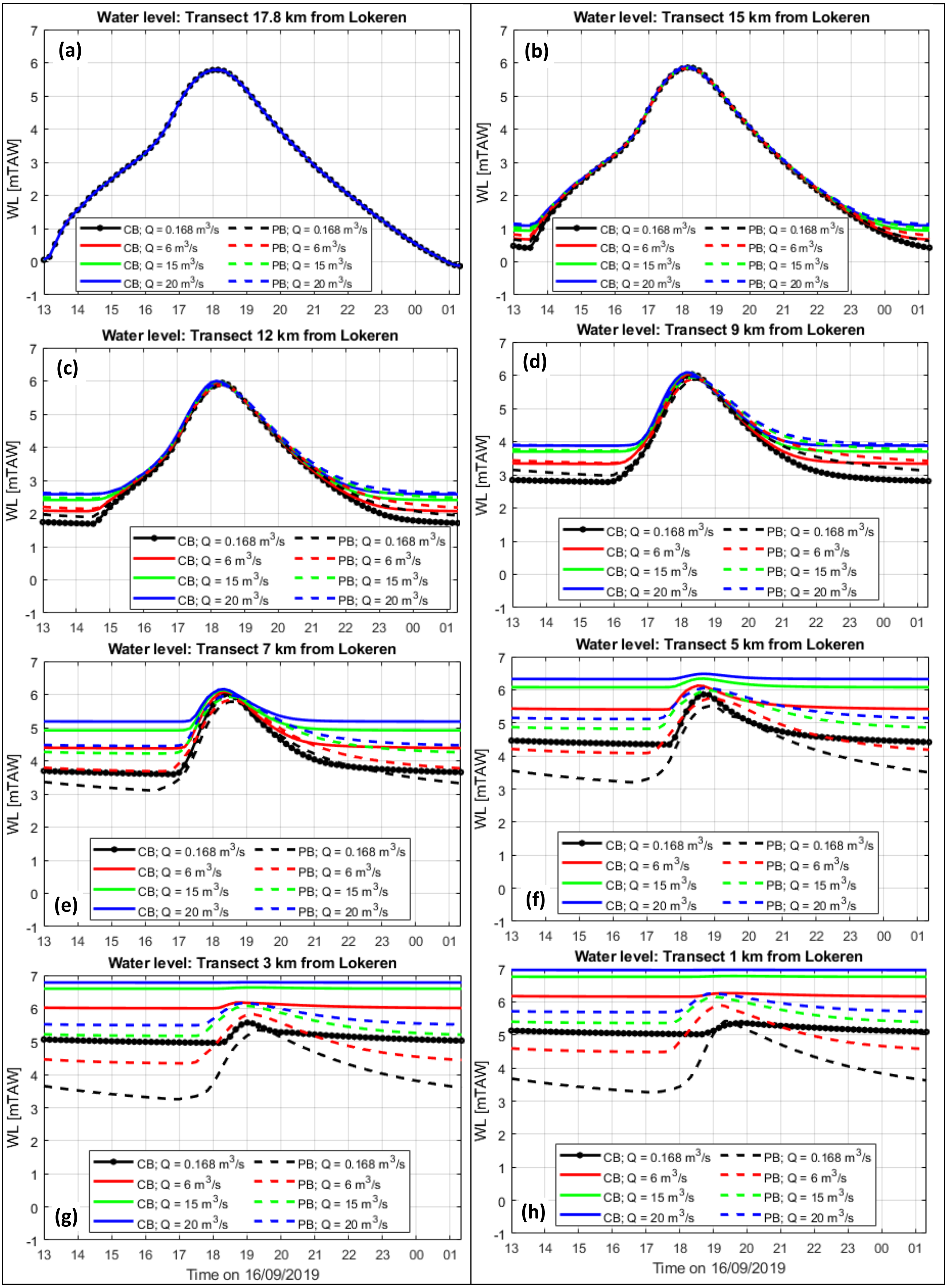


Figure 13 – Water levels computed with current (CB) and planned bathymetry (PB) for different discharges during spring tide

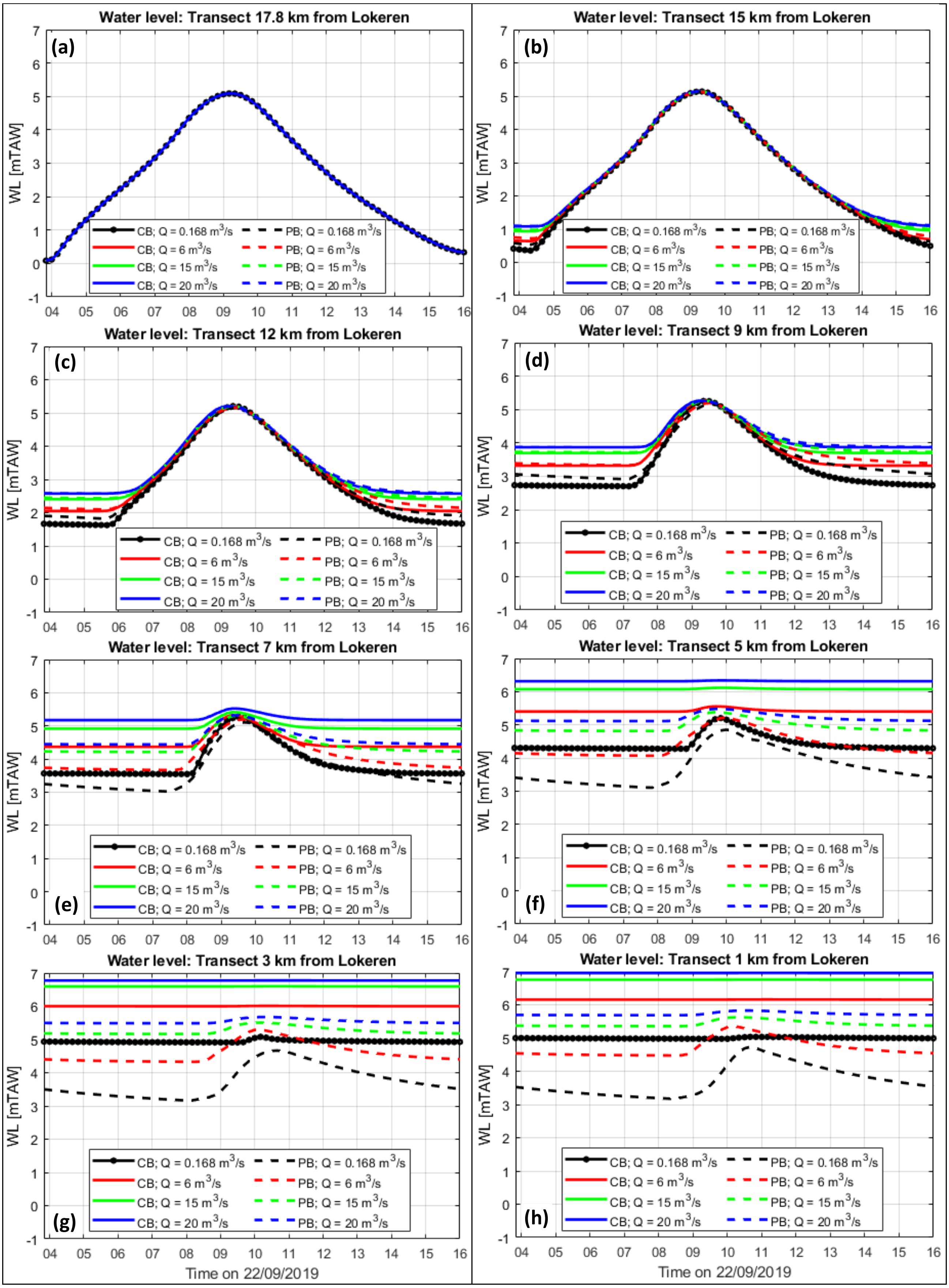


Figure 14 – Water levels computed with current (CB) and planned bathymetry (PB) for different discharges during neap tide

The effect of upstream discharge on HW, LW and tidal range along the Durme river are presented in Figure 15 and Figure 16 for the selected spring tide and neap tide. The results for the case of current bathymetry are presented in full lines while dashed lines represent the planned bathymetry.

As expected, an increase of river discharge results in an increase of water levels in the river as higher water volumes enter the river (Figure 15a,b and Figure 16a,b). The response to the variation of the river discharge differs for HW and LW. Both bathymetries show stronger influence of the variation of river flow on LW than on HW. The increase of LW with increasing river flow occurs throughout the river, almost up to the Durme mouth, while the effect of river flow on HW is neglectable from the middle of the river (km 8) to the mouth.

Within the deepened section (from km 0 to km 8), both HW and LW drop in the planned bathymetry. The decrease is stronger for LW than HW, leading to an increase of tidal range in this river section (Figure 15c, Figure 16c). Outside the dredging area (km 8 - mouth), the model shows some discrepancy between responses of LW and HW to river deepening. HW with the planned bathymetry is slightly reduced or unchanged while LW is slightly increased. These combined effects result in a reduction in tidal range in this downstream river section. The response to river deepening of tidal range (i.e. increase within dredging area and decrease outside deepening area) decreases with the increase of upstream discharge.

The tidal range in the Durme decreases with the distance from the mouth and with the increase of the upstream discharge (Figure 15c, Figure 16c). This decrease is also presented in Figure 17 which shows the ratio of the tidal range along the river and the tidal range at the river mouth. Compared to the current bathymetry, the planned bathymetry produces gentler tidal range attenuation, implying an enhanced tidal penetration into the upstream part of the river. With the minimum discharge of 0.168 m^3/s, the tidal range computed with CB is attenuated by about 45% for the spring tide and 50 % for the neap tide between the mouth and Waasmunster-Brug (located in the middle of the river, around km 9). Upstream deepening leads to an additional reduction in tidal range of 6%. Under high river flow (Q = 15; 20 m^3/s), the tidal range at Waasmunster-Brug drops to 30% - 40% the value at the mouth.

Upstream deepening weakens the tidal damping within the dredged section (km 8 - upstream end). At minimum discharge, the tidal range at the most 3 km river upstream is 30% - 40% as large as the tidal range at the mouth with PB while the tidal range ratio is smaller than 10% with CB.

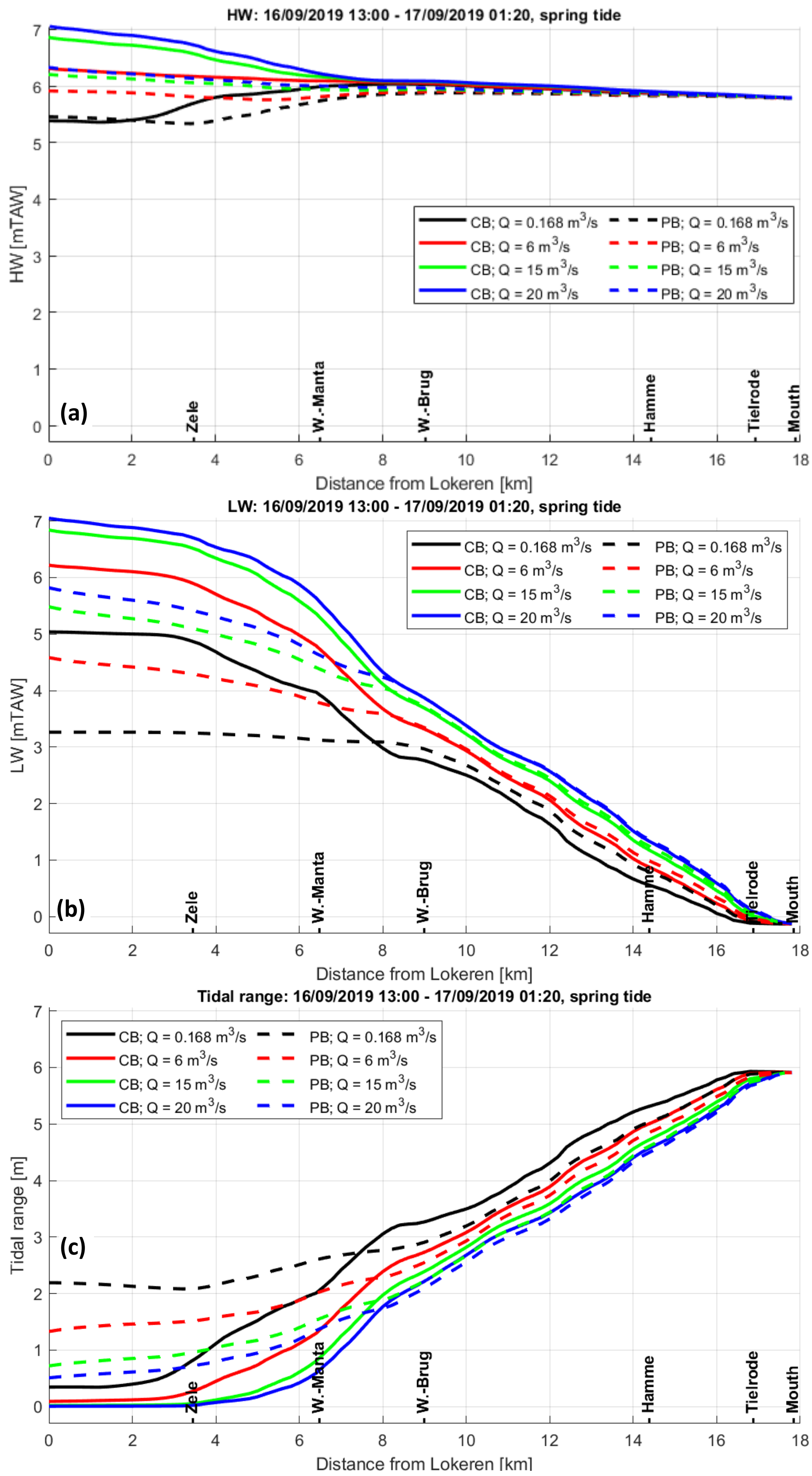


Figure 15 – High water, low water and tidal range along the Durme river during spring tide computed with current bathymetry (CB, full lines) and planned bathymetry (PB, dashed lines) for different upstream discharges

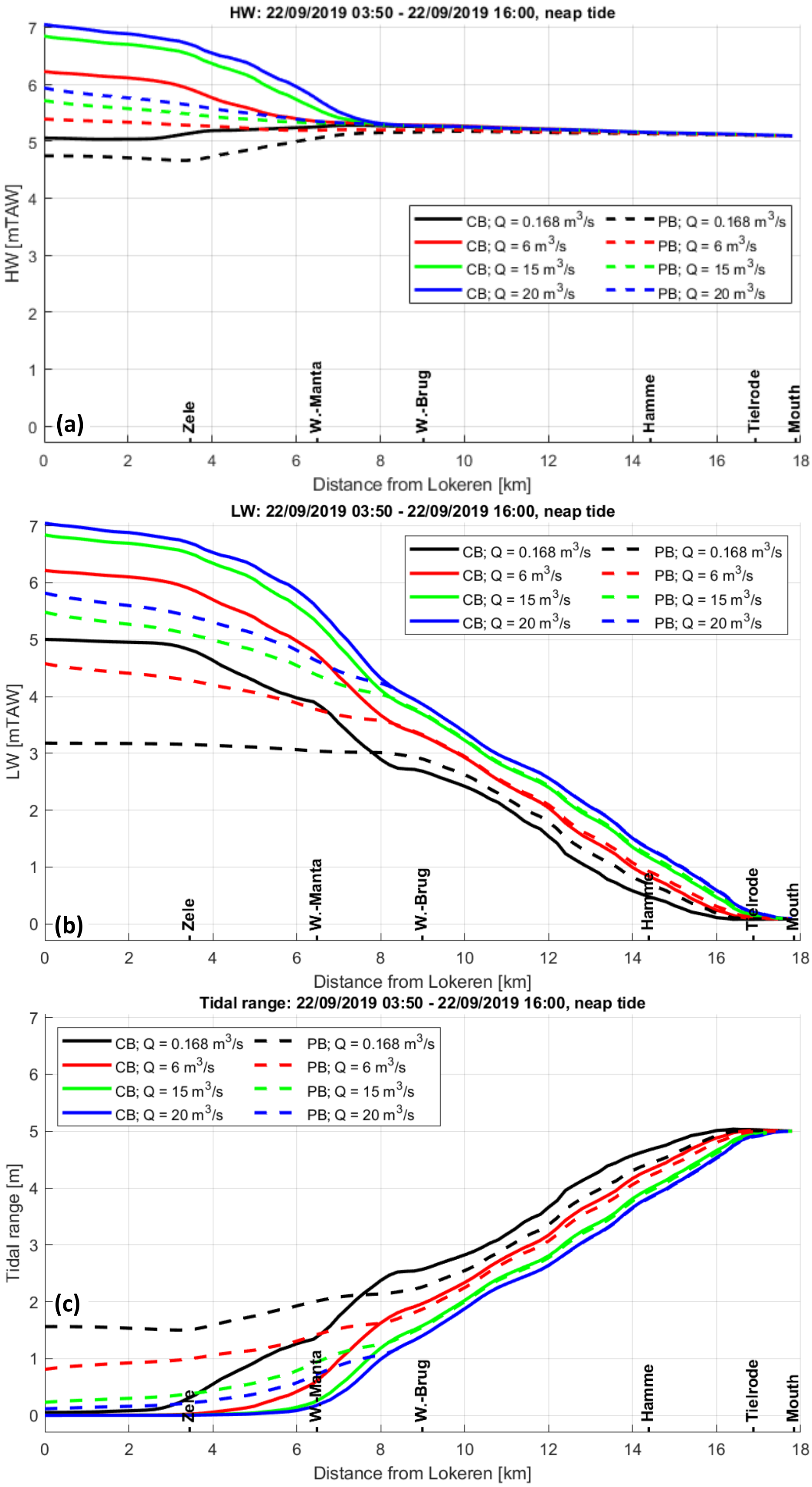


Figure 16 – High water, low water and tidal range along the Durme river during neap tide computed with current bathymetry (CB, full lines) and planned bathymetry (PB, dashed lines) for different upstream discharges

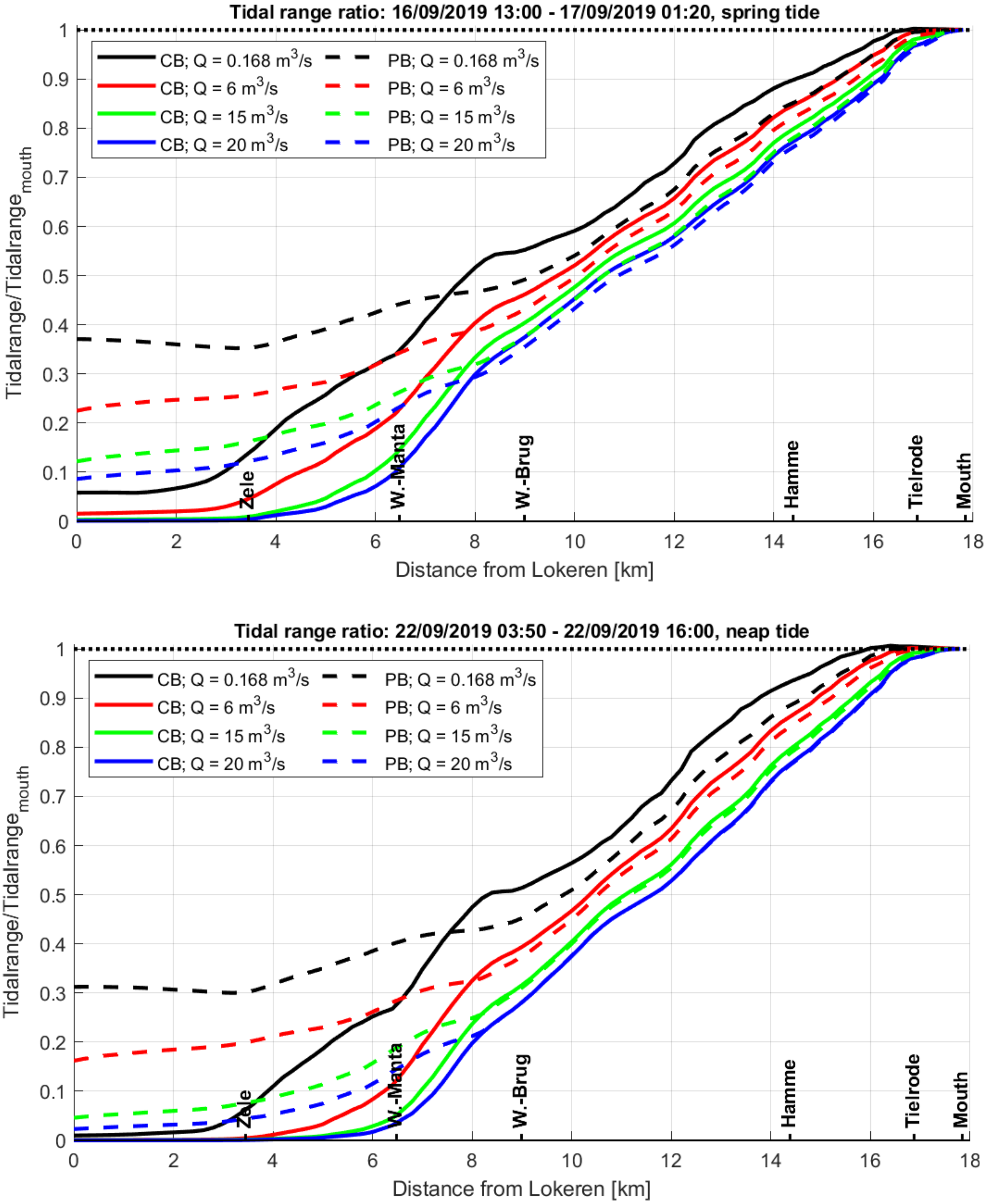


Figure 17 –Tidal range ratio along the Durme river with current bathymetry (CB) and planned bathymetry (PB) for different upstream discharges. Upper: spring tide; lower: neap tide

4.2 Effects of upstream river discharge and deepening on current velocities

The cross-sectional averaged velocities at the eight cross-sections along the Durme river computed with the current bathymetry and planned bathymetry and with four different discharges are compared in Figure 18 for the spring tide and in Figure 19 for the neap tide. The longitudinal cross-sectional averaged peak current velocities during flood and ebb under different river flow for the two bathymetries are shown in Figure 20 and Figure 21 for the spring tide and neap tide. Positive values indicate flood current velocity and negative values represent ebb flow.

The cross-sectional peak velocities at the mouth (km 17.8) are in the order of 0.2 - 0.3 m/s, which is a factor of 3 smaller than those near Tielrode considering the minimum discharge 0.168 m^3/s (Figure 18a, Figure 19a, Figure 20, Figure 21). This low current velocity is due to higher depth at the river mouth, thus higher cross-sectional area (see Figure 5 and Figure 6 for the bathymetry).

The effect of upstream dredging and discharge on the current velocity is limited at the river mouth (Figure 18a, Figure 19a, Figure 20, Figure 21). Further upstream along the river, a stronger river flow weakens flood velocities and enhances ebb velocities, as expected. In the upstream part, a “no flood current” zone is present and expands towards downstream as the river discharge increases (Figure 18e-h, Figure 19d-h, Figure 20). Under the highest upstream inflow, this zone covers half of the river, from upstream to around station Waasmunster-Brug for the case of the current bathymetry (Figure 20).

The model calculates a strong variability in peak current velocity (Figure 20, Figure 21). Within the deepening section (km 0 – km 8), the planned bathymetry produces much smoother longitudinal tidal peak flow, especially during ebb phase. This is due to a smoother bottom in the designed bathymetry compared to the natural river in the current bathymetry (see Figure 6 for the elevation along the thalweg). At this upstream section, the deepening leads to a clear increase of peak flood current velocity for all discharge values. A raise can be as high as 0.6 m/s at km 6, upstream of Waasmunster-Manta during spring tide for the river flow of 6 m^3/s. The response of peak ebb velocities to the dredging varies with the river flow conditions.

Although the deepening of the river is implemented within the upstream part from km 0 to km 8, its effect extends further downstream. The increase in flood peak for planned bathymetry continues (with reduced rate) up to km 10 – km 12 for all discharges. The influence on peak ebb velocity is up to near the river mouth, with higher peak ebb outside the dredging area for the planned bathymetry.

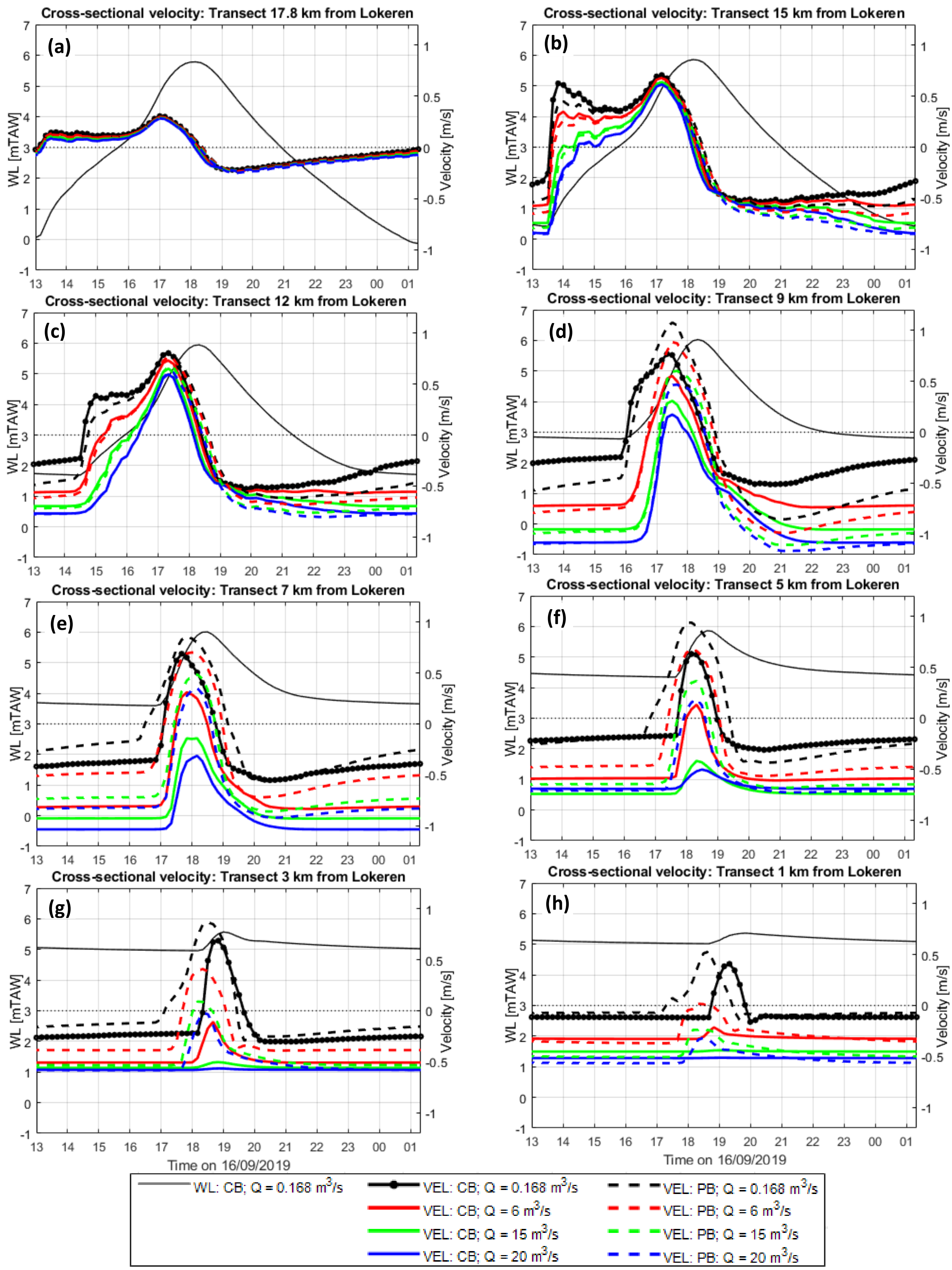


Figure 18 – Cross-sectional current velocity computed with current (CB) and planned bathymetry (PB) for different discharges during spring tide. Positive values indicate flood current

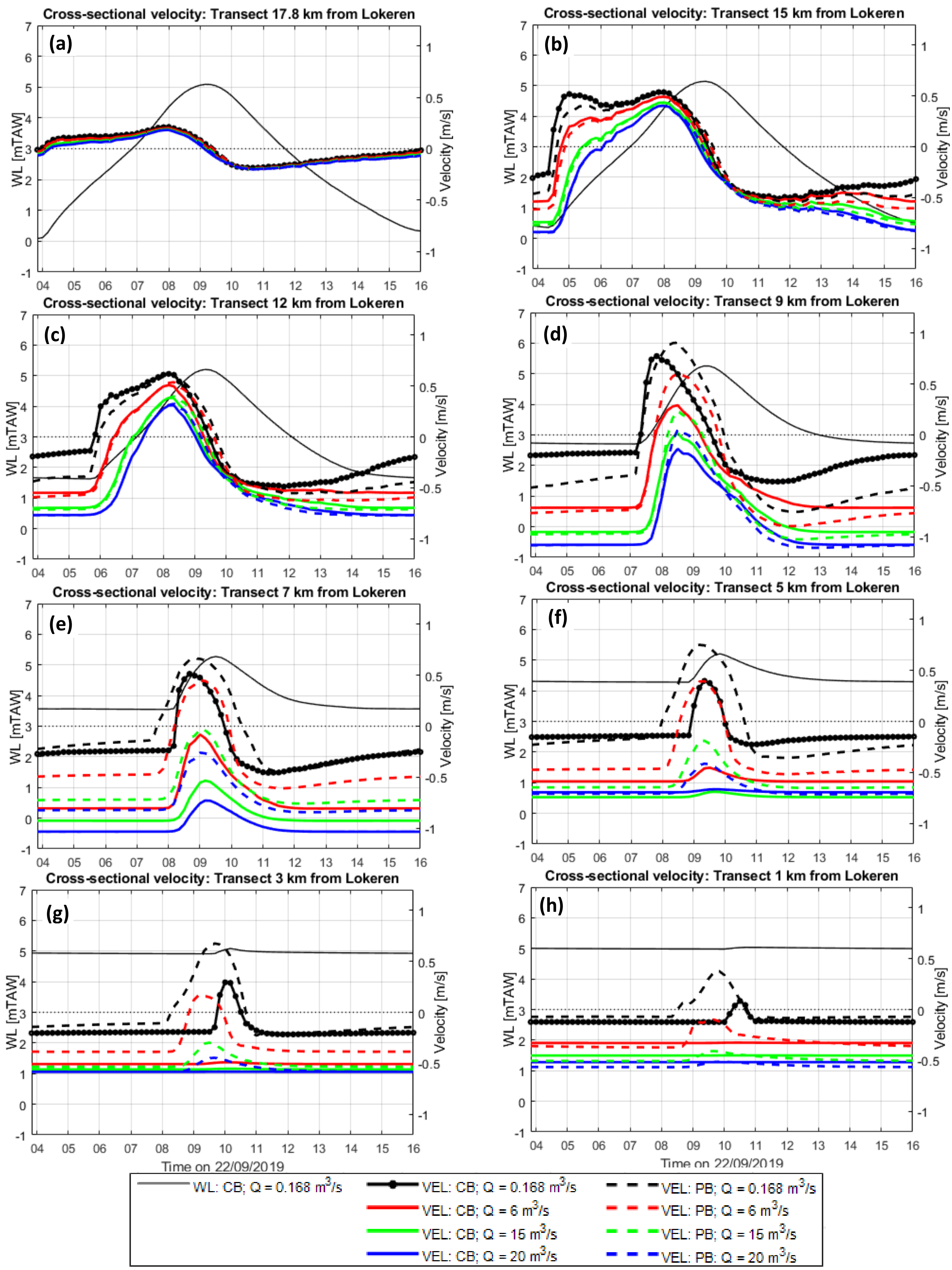
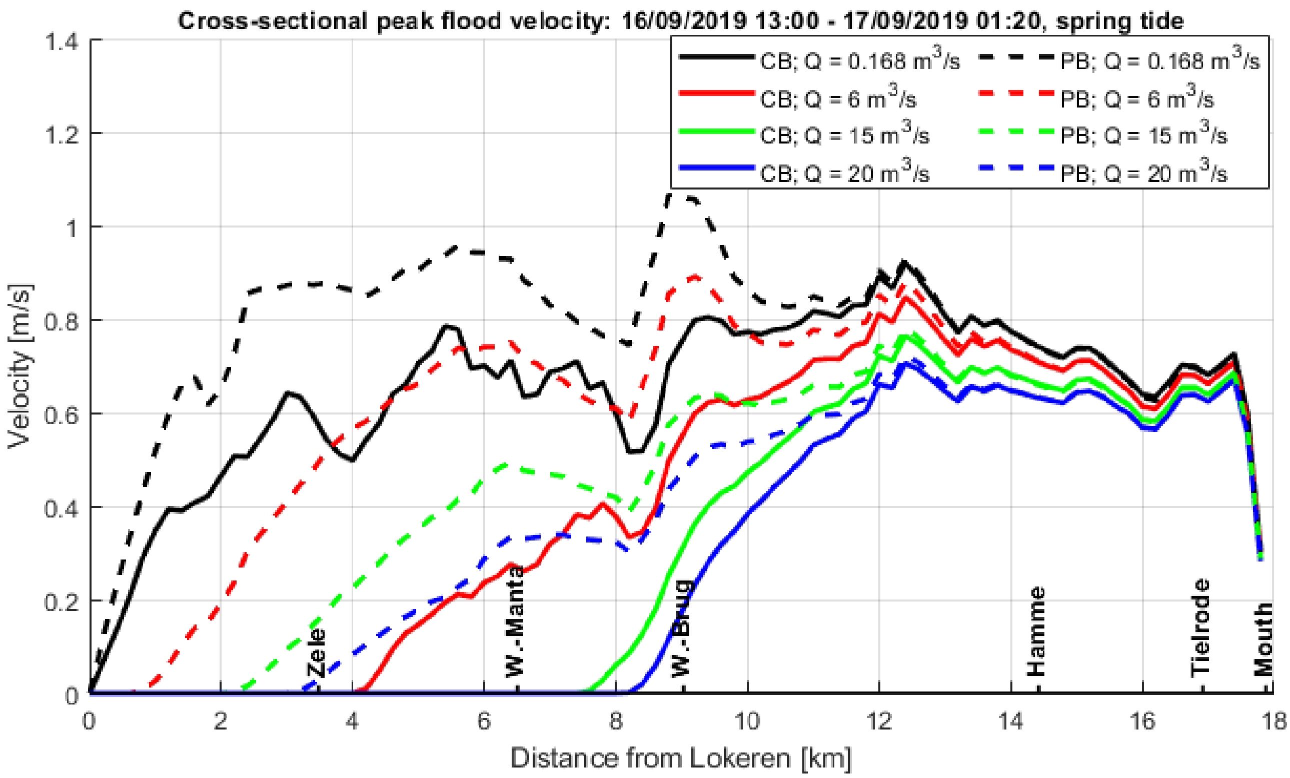


Figure 19 – C ross-sectional current velocity computed with current (CB) and planned bathymetry (PB) for different discharges during neap tide. Positive values indicate flood current



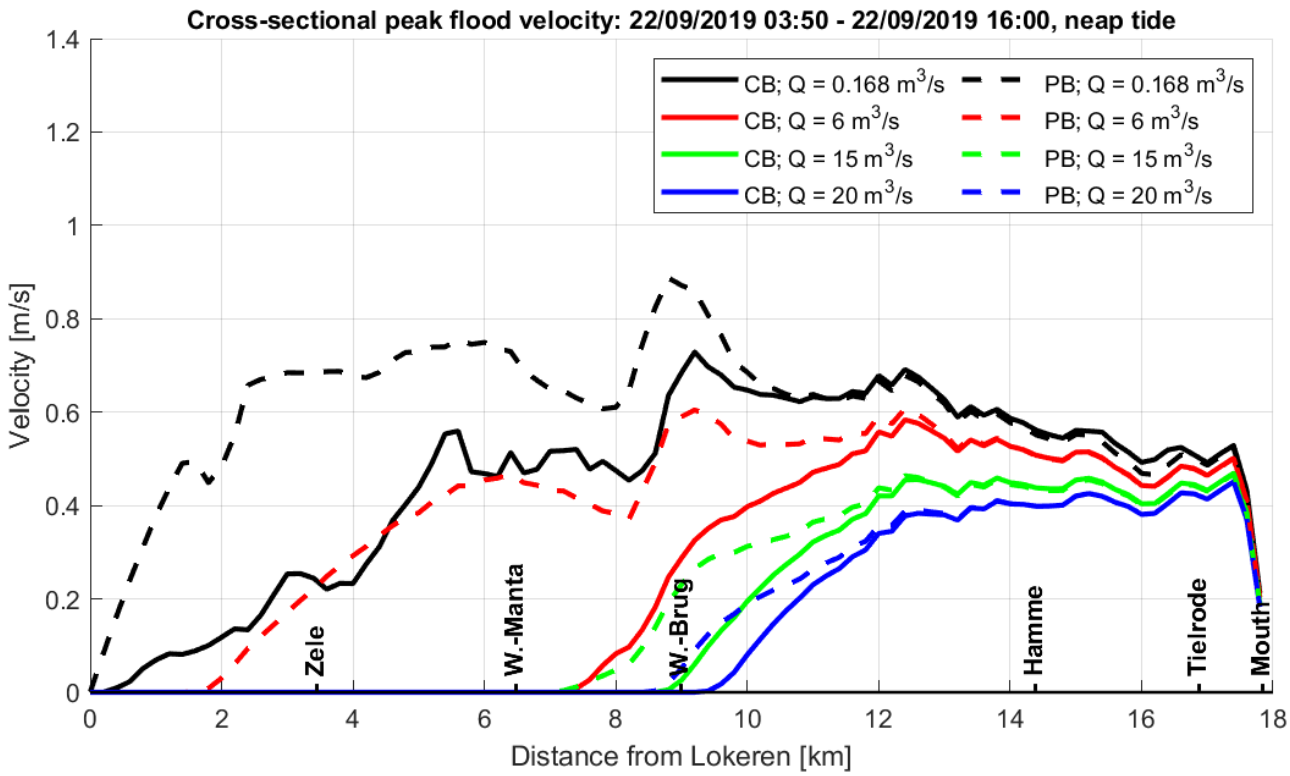
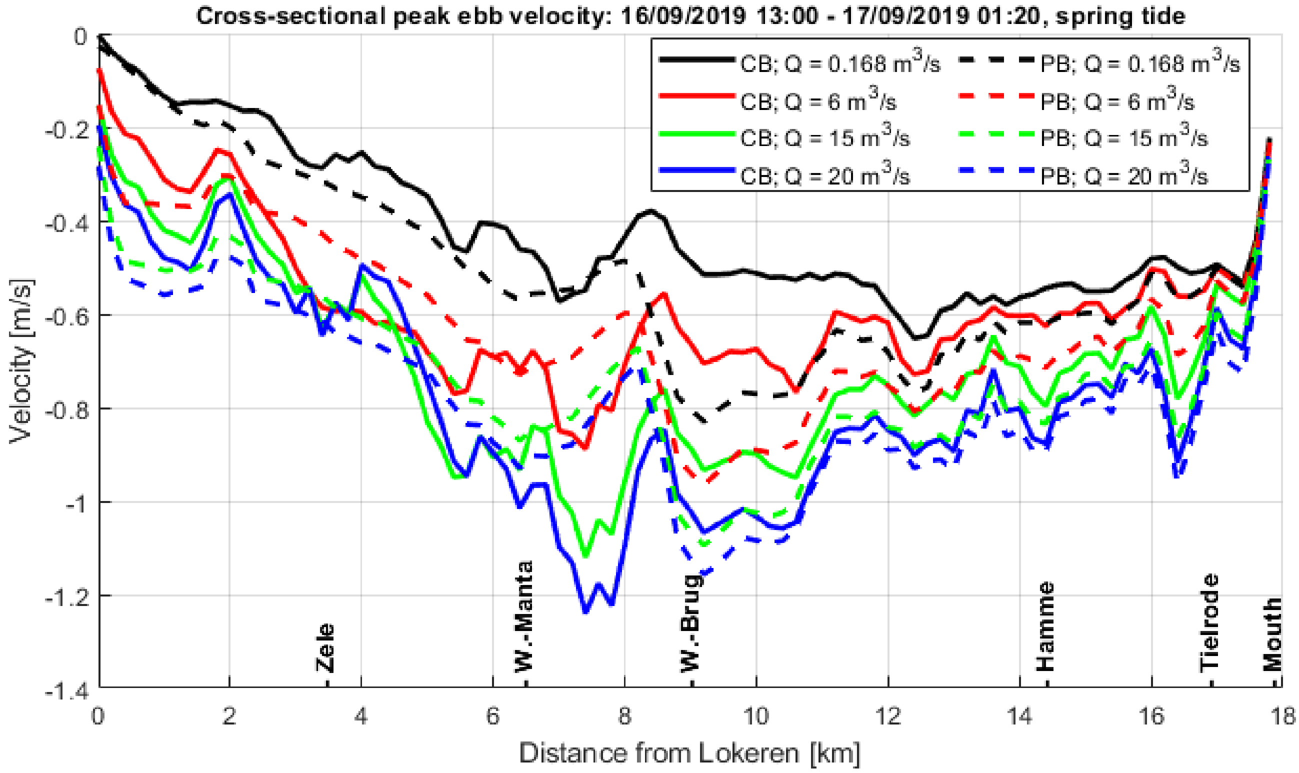


Figure 20 – Peak flood current velocity along the Durme river computed with current bathymetry (CB, full lines) and planned bathymetry (PB, dashed lines) for different upstream discharges. Upper: spring tide, lower: neap tide



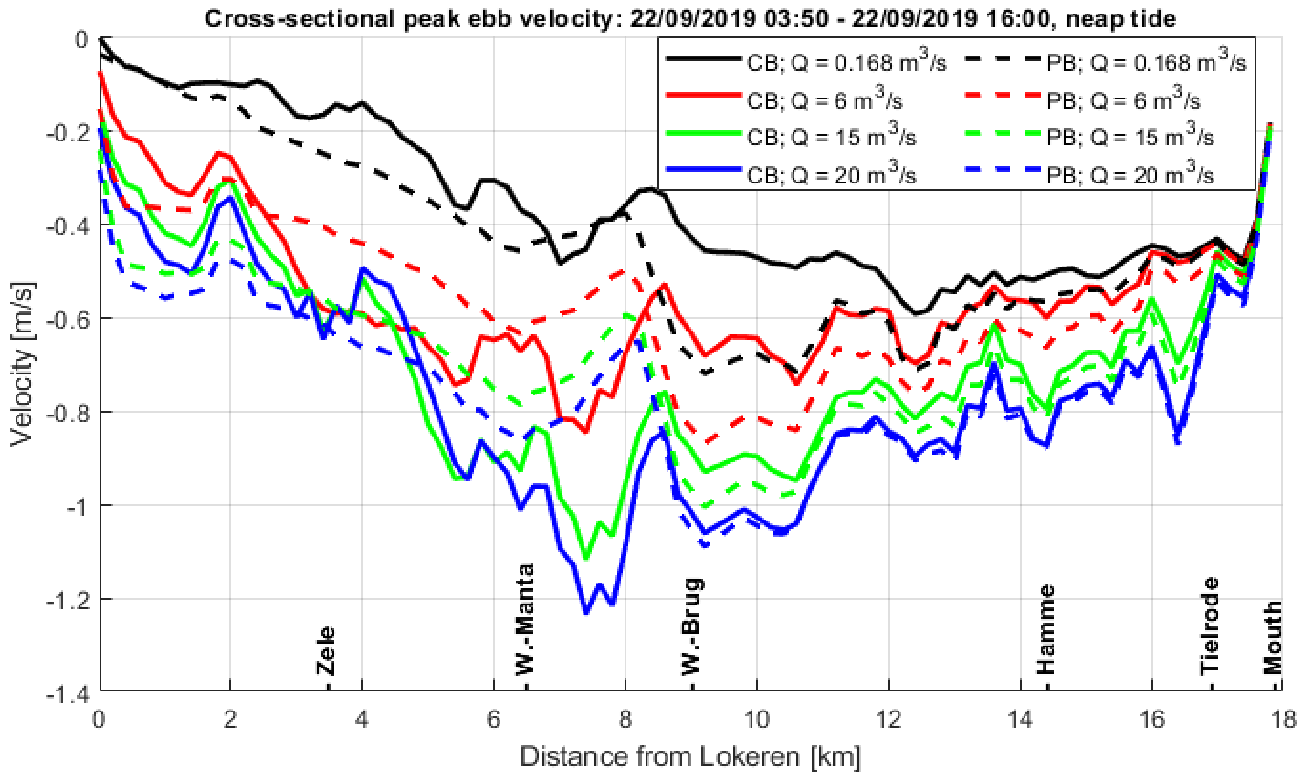


Figure 21 – Peak ebb current velocity along the Durme river computed with current bathymetry (CB, full lines) and planned bathymetry (PB, dashed lines) for different upstream discharges. Upper: spring tide, lower: neap tide

4.3 Effects of upstream river discharge and deepening on tidal asymmetry

4.3.1 Asymmetry in tidal duration

Figure 22 shows the longitudinal variation of the tidal duration asymmetry computed for the current bathymetry and planned bathymetry scenarios and for the different river discharges. All eight scenarios show a clear ebb dominance of the tidal duration asymmetry, with the ratio of flood duration and ebb duration smaller than 0.7 and 0.8 for the spring tide and neap tide (Figure 22). The ebb dominance increases towards upstream and is stronger for higher river flow.

Within the dredging area, the planned bathymetry results in higher ratio between flood and ebb duration, i.e. weaker ebb dominance. The effect gradually reduces outside the deepening area and is negligible in the downstream section.

4.3.2 Asymmetry in peak velocity

Figure 23 presents the variation of the peak velocity asymmetry along the river under different river discharges for the two bathymetries for the spring tide and neap tide.

Under the minimum discharge (0.168 m^3/s), the velocity asymmetry is flood dominant in most of the river section (Figure 23), which is opposed to the duration asymmetry in §4.3.1. A higher river flow results in a lower asymmetry ratio (i.e. less flood dominant) and the river switches to ebb dominant condition at a certain discharge. The model shows that almost the whole Durme river exhibits ebb dominance as the upstream discharge is higher than 6 m^3/s for the selected neap tide and 15 m^3/s for the spring tide. The peak velocity asymmetry remains flood dominant at the mouth however during spring tide.

Within the dredging zone (km 0 - km 8), the planned bathymetry (PB) shows stronger asymmetry due to greater increase of flood peak velocity than ebb peak (see Figure 20 and Figure 21). The effect is extended further downstream as the river discharge is stronger. At the downstream section, the PB results in lower asymmetry compared to the CB for lower discharge and shows more or less the same asymmetry for high river flow.

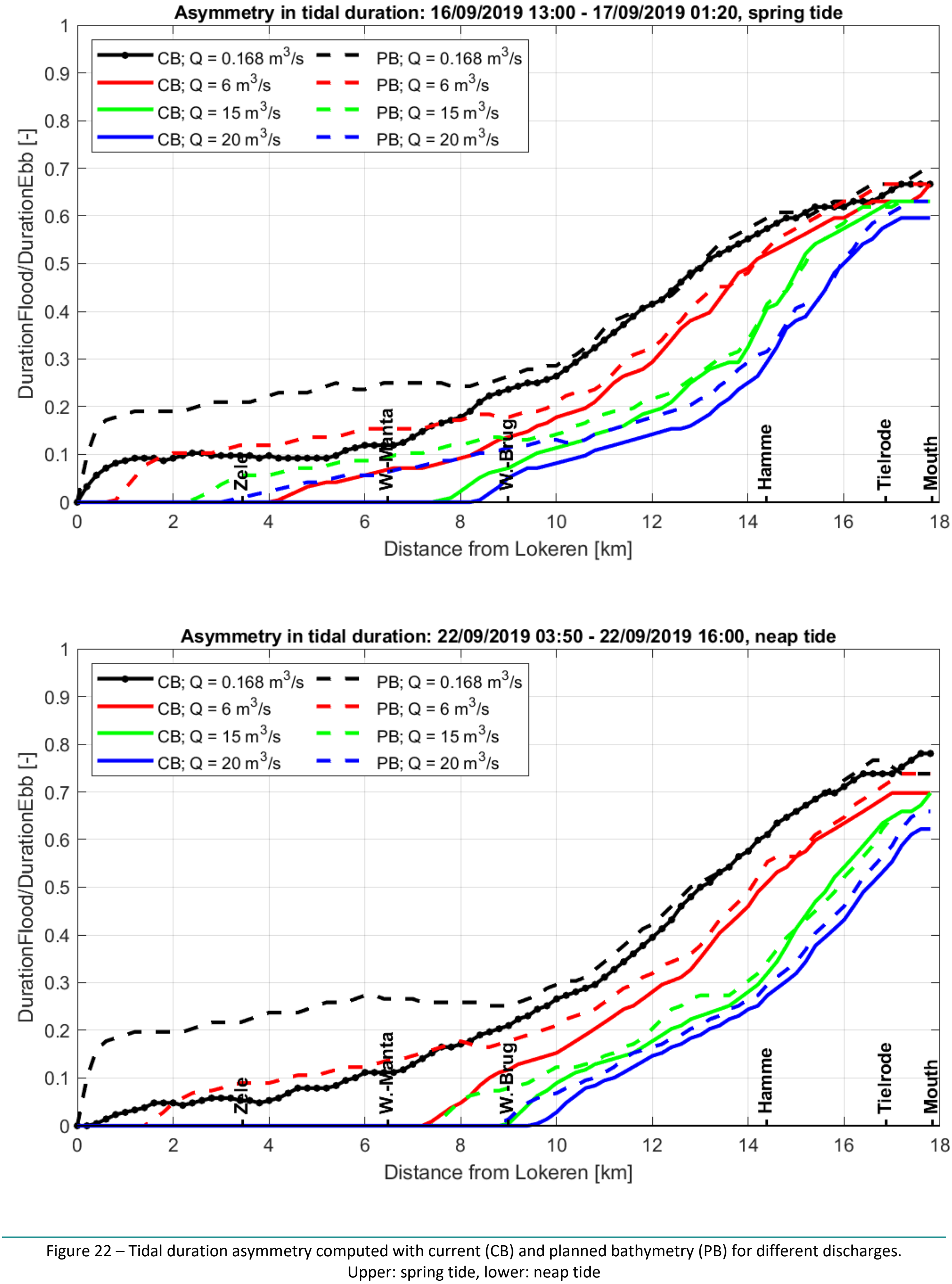
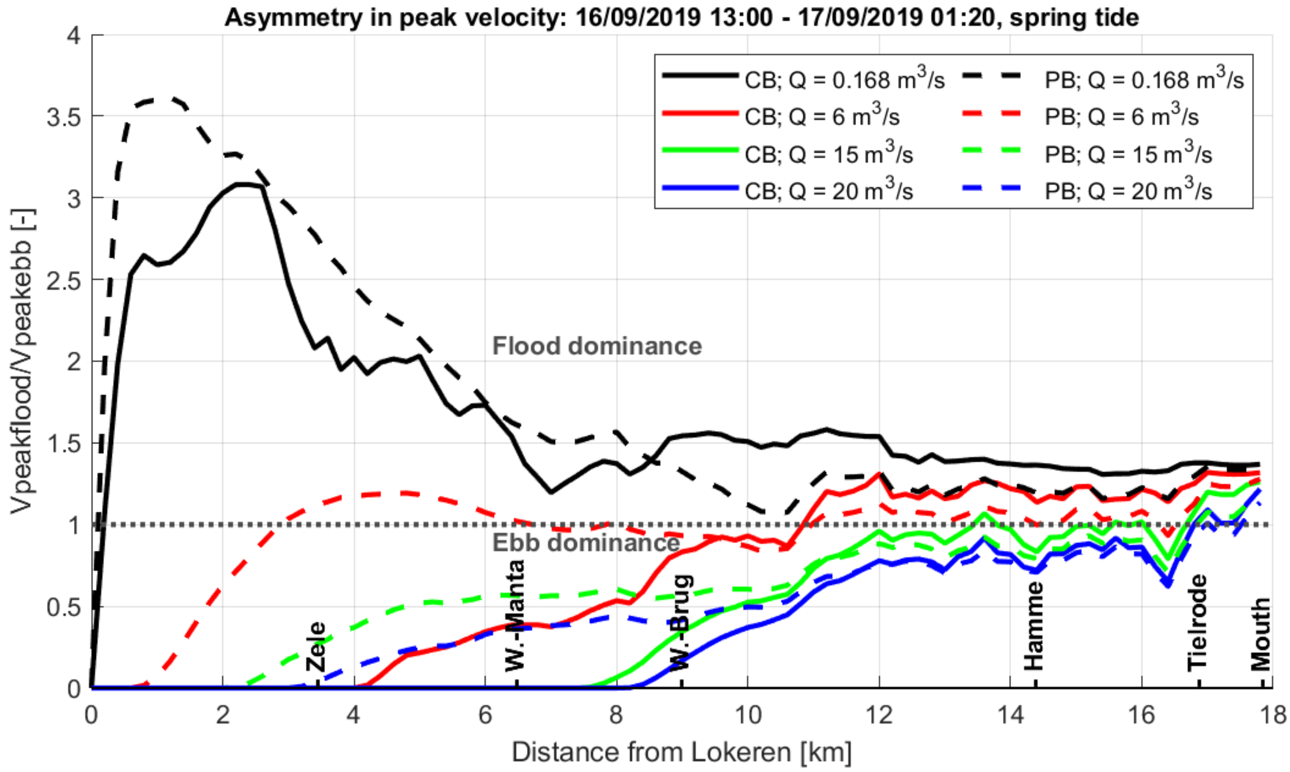


Figure 22 – Tidal duration asymmetry computed with current (CB) and planned bathymetry (PB) for different discharges.
Upper: spring tide, lower: neap tide



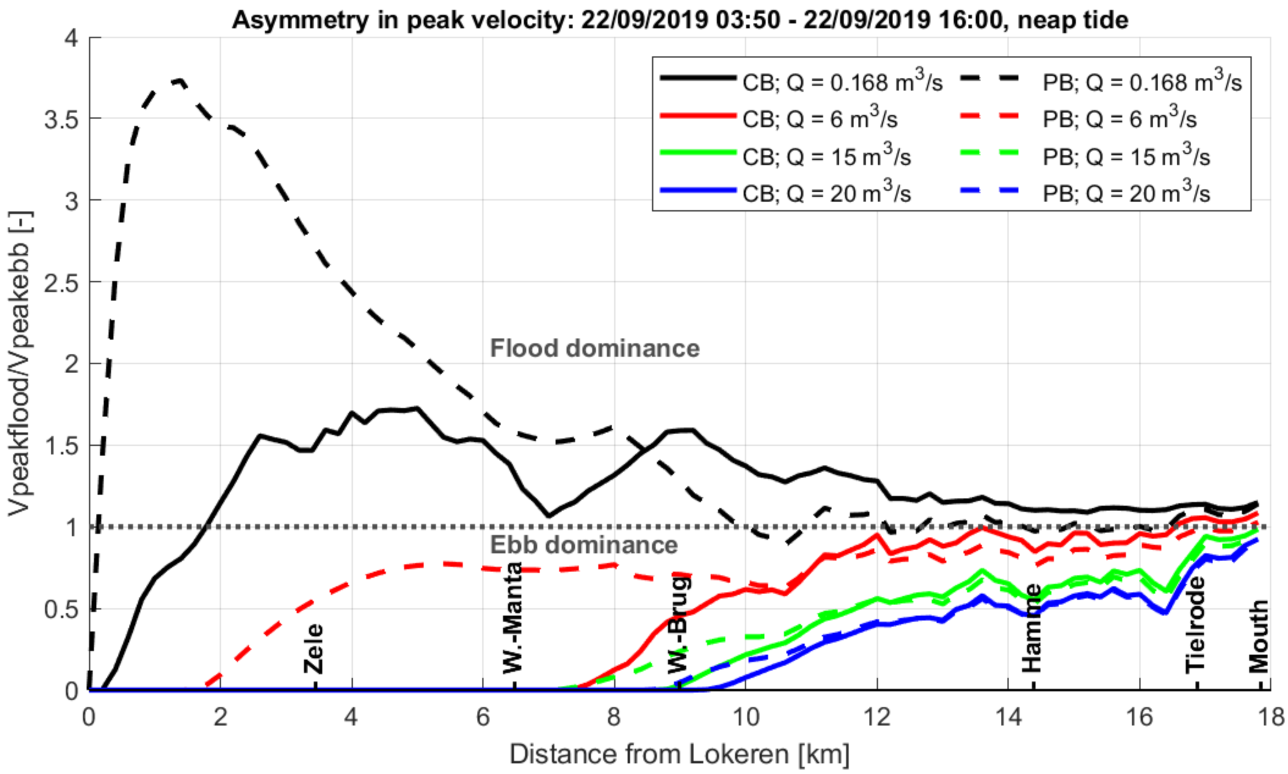


Figure 23 – Asymmetry in peak current velocity computed with current (CB) and planned bathymetry (PB) for different discharges. Upper: spring tide, lower: neap tide

4.4 Effects of temporally varying river flushing on current velocity and tidal asymmetry

It is hypothesized that the sediment accumulated within the river can be flushed towards the Sea Scheldt by applying a higher upstream discharge during peak flow condition. The efficiency of the method can be evaluated by examining the peak current velocity asymmetry.

For each bathymetry, two scenarios were conducted with an increased upstream discharge of 6 m^3/s during one hour around the moment of peak flood/peak ebb velocity (Table 2). The current velocity at Waasmunster-Brug is used for the determination of flood and ebb moments (Figure 8 and Figure 9). Figure 24, Figure 25 and Figure 26 compare the simulation results of peak flood, peak ebb current velocities and asymmetry in peak velocities. The comparison includes a constant discharge scenario with the same volume entering the upstream boundary (by imposing a constant discharge of 0.72 m^3/s) as well as the minimum discharge scenario (0.168 m^3/s). The cross-sectional averaged velocities along the Durme river can be found in Appendix 1.

The figures show that the two scenarios with variable flushing have negligible influence on peak flood and ebb velocities, and thus velocity asymmetry from the middle of the river at km 8, between Waasmunster-Brug and Waasmunster-Manta to the mouth. In the upstream section however, peak flood velocity is decreased if high flushing is implemented during flood phase (Figure 24). Furthermore, higher river flushing during peak flow enhances peak ebb velocity in the upstream river section (Figure 25). The effect is stronger for the current bathymetry than for the planned bathymetry. Both bathymetries show a strong increase in the peak ebb velocity in the most 2 km upstream section, up to 0.6 m/s due to the increased upstream flushing in the flood phase.

As the result of enhanced ebb peak and decreased (or unchanged) flood peak, the variable flushing scenarios produce lower asymmetry ratio in the upstream river section, up to around Waasmunster-Manta (Figure 26). The ebb dominant river section upstream is extended further downstream. When flushing is enhanced during flood, about 5 km most upstream river section exhibits ebb dominant condition for CB scenario.

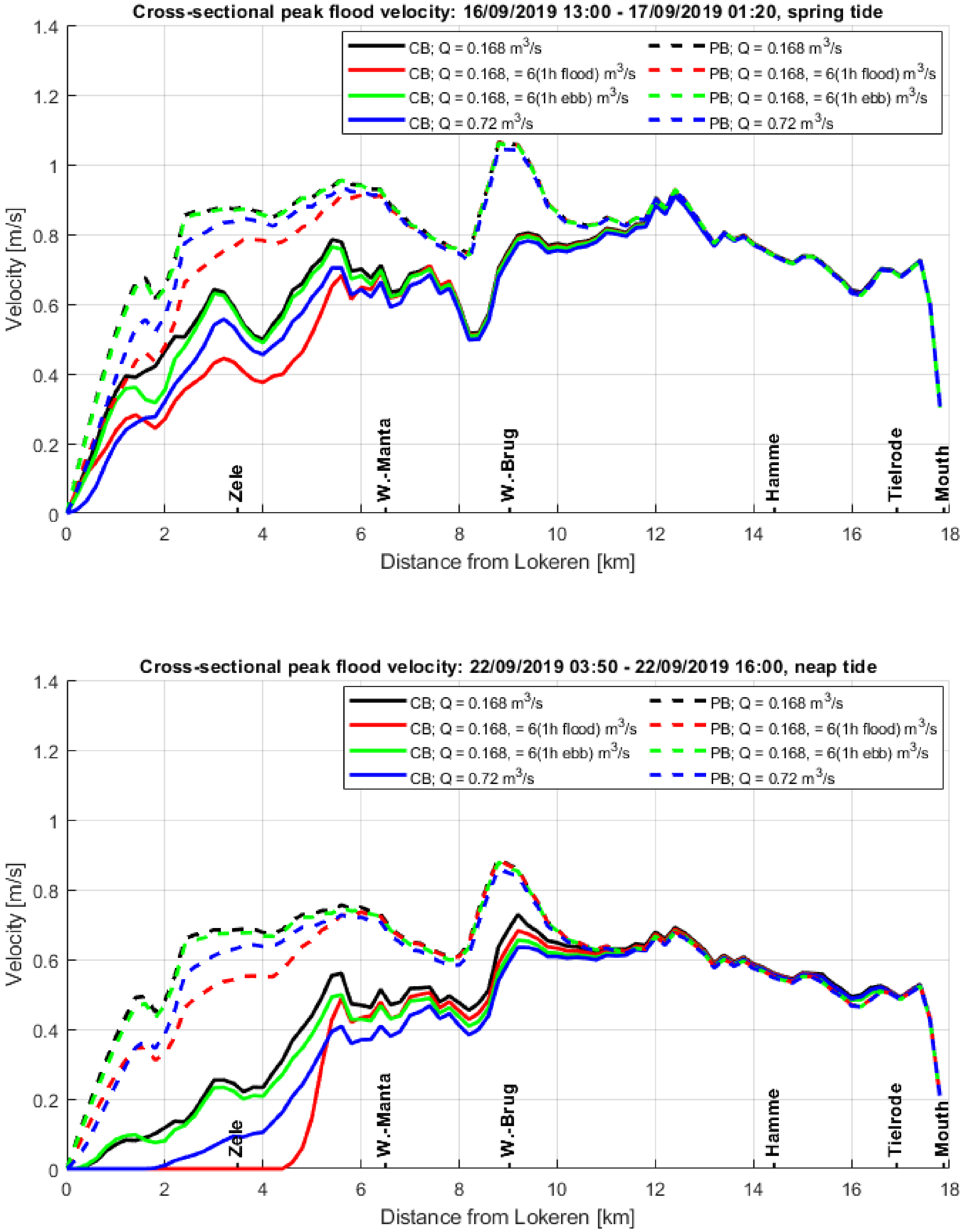


Figure 24 – Effect of variable flushing on peak flood current velocity along the Durme river for current bathymetry (CB) and planned bathymetry (PB). Upper: spring tide, lower: neap tide

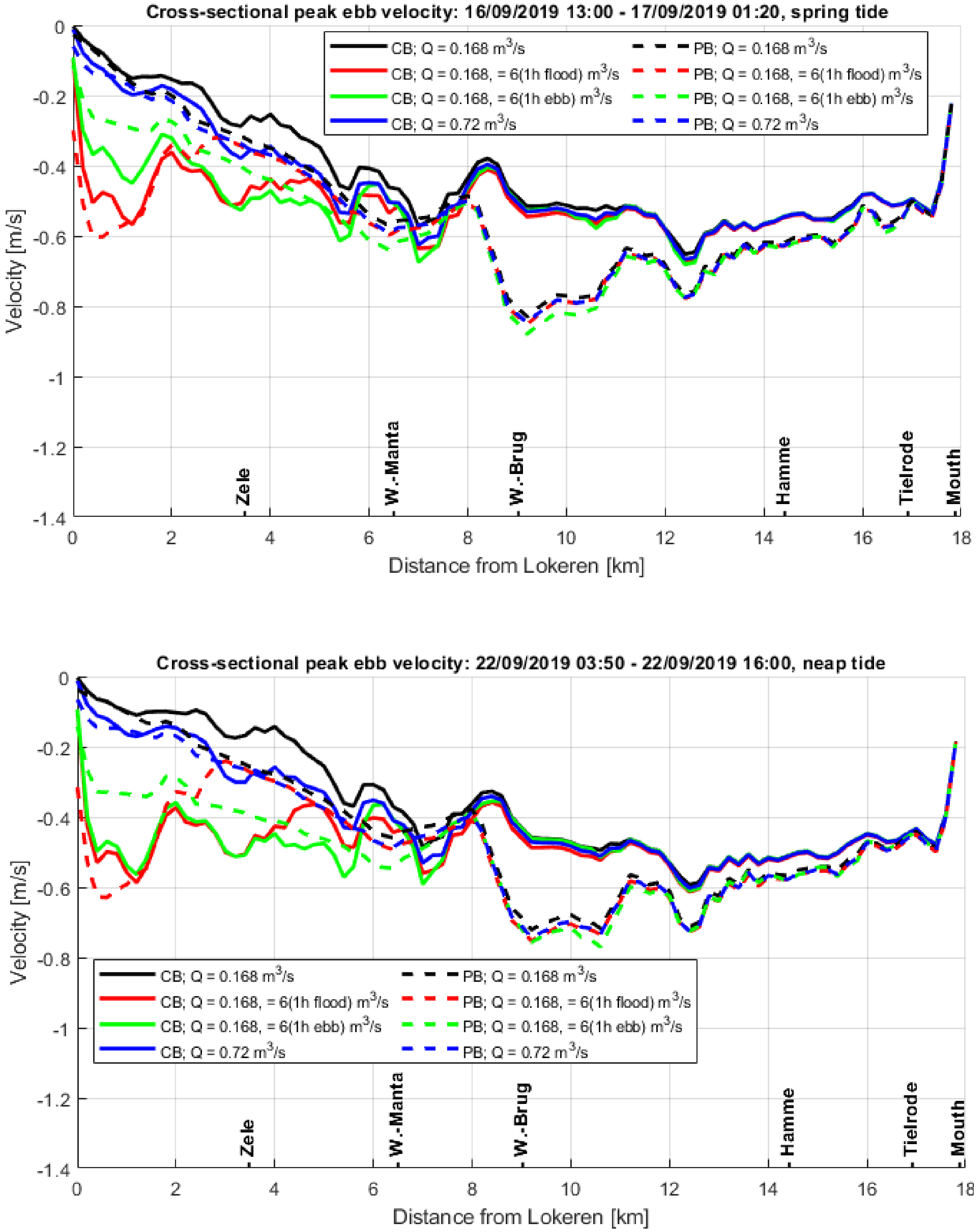
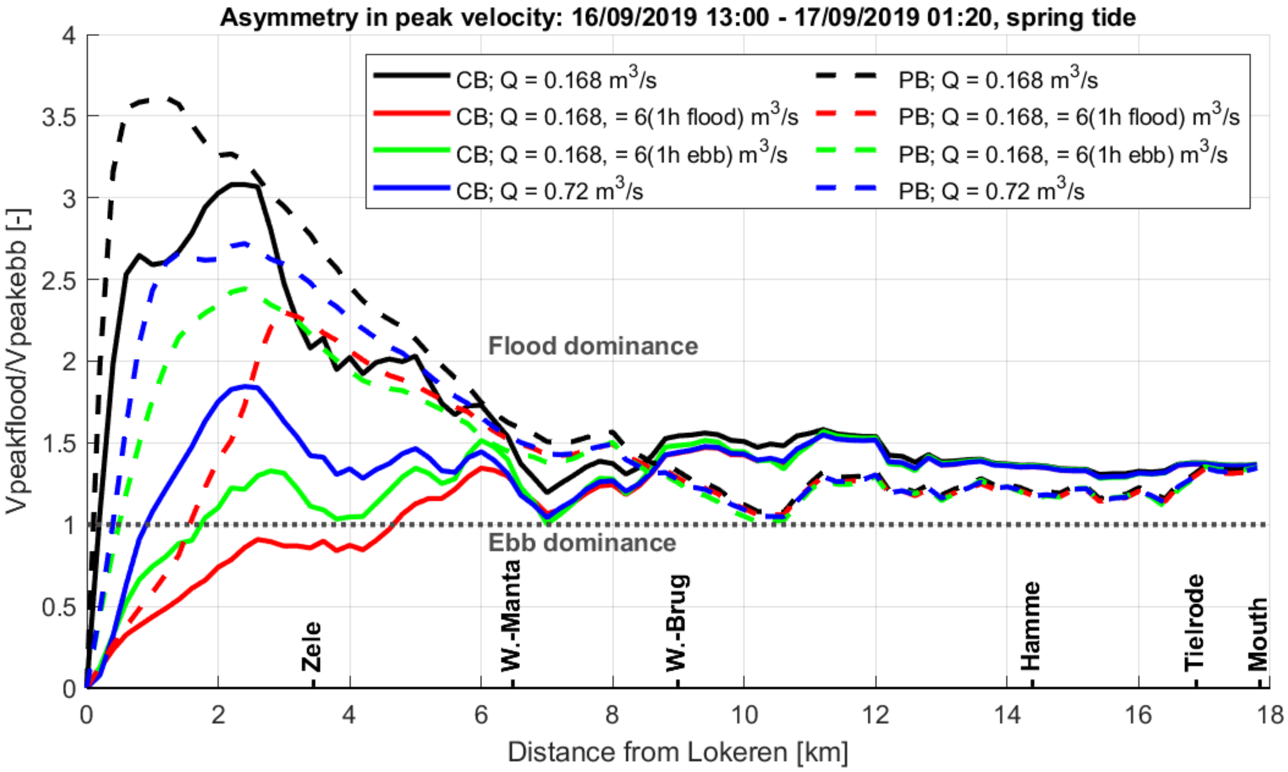


Figure 25 – Effect of variable flushing on peak ebb current velocity along the Durme river for current bathymetry (CB) and planned bathymetry (PB). Upper: spring tide, lower: neap tide



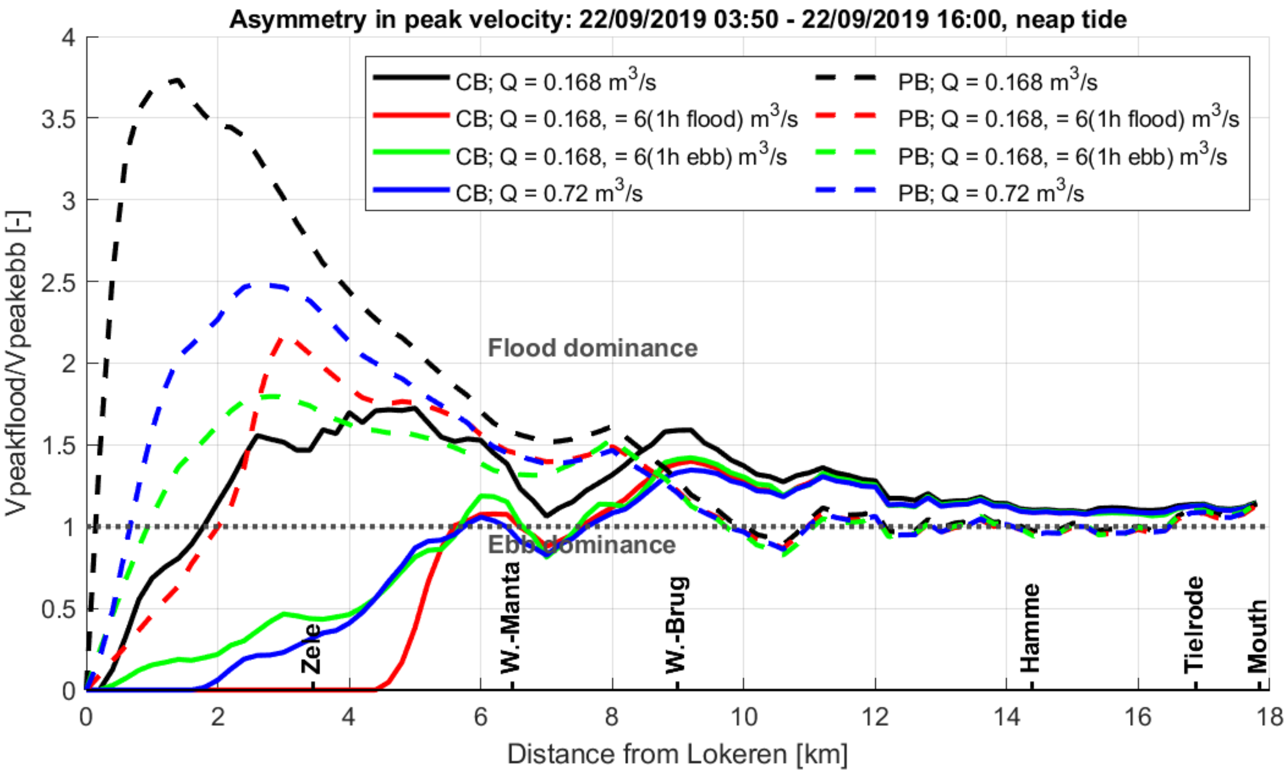


Figure 26 – Effect of variable flushing on asymmetry in peak current velocity along the Durme river for current bathymetry (CB) and planned bathymetry (PB). Upper: spring tide, lower: neap tide

5 Conclusions

In this report, the effects of the river deepening and upstream river discharge on the hydrodynamics in the Durme river have been studied by means of numerical modelling. The Durme hydrodynamic model constructed and calibrated within Telemac (Nguyen et al., 2022) has been used. In total, 14 scenario runs were conducted using two bathymetries and with different river discharges imposed at the upstream boundary. The model runs were carried out for a spring-neap tidal cycle. The analysis was done for this period, with a detailed discussion for a selected spring tide and neap tide.

The response of water levels, current velocities and tidal asymmetry to changes in upstream discharge and to upstream deepening varies along the river. As the changes occur at the upstream part of the Durme, the effects are stronger in the upstream section. The variation of the upstream discharge and deepening have no (or limited influence) on hydrodynamics near the Durme mouth.

River discharge

An increase in the river discharge has a limited effect on high waters in the middle of the river, but results in increased low waters. This increase of LW is more pronounced in the upstream section. The increase in HW in relation to discharge is less pronounced than for low water, but clearly present.

Higher river flow results in a decrease of the flood current and an increase of the ebb current. The velocity asymmetry is therefore weaker for higher upstream discharge. Under low river flow, the river demonstrates flood dominance along most of its length. The condition could be reverted to ebb dominant (using the formulation of peak velocities) from a discharge of 6 m^3/s onwards for the neap tide and from 15 m^3/s onwards for the spring tide. The former value corresponds to maximum discharge of the pump at Lokeren dam taking in to account the pumping efficiency while the later value (15 m^3/s) is the sum of discharges from three sources at the upstream end of the Durme river. A shift towards an ebb-dominant velocity asymmetry suggests that the residual sediment transport direction may also shift towards ebb-dominance. This could on its turn imply that sediment that is currently accumulated in the upstream part of the Durme river can be transported downstream under higher discharge conditions. However, at the mouth the asymmetry based on peak velocities remains flood dominant (under spring tide condition). As such this high discharges could probably lead to an internal redistribution of sediment within the Durme, rather than reversing the trend of sediment import to the Durme as a whole.

Deepening

The response of the water levels to river deepening mainly takes place within the dredged river section itself, with an obvious drop in both HW and LW. The reduction is larger for LW than for HW, resulting in a higher tidal range within the considered area. An opposite effect on tidal range was found outside the dredging section, from km 8 to near the mouth where the planned bathymetry gives a lower tidal range. The river deepening at the upstream causes a decrease of about 5% in the tidal attenuation (tidal range/tidal range at river mouth) in the middle and downstream of the river under the minimum discharge ($Q = 0.168$ m^3/s). The effect is weaker for higher river flow.

Upstream deepening causes higher velocity asymmetry within the dredged section, mainly due to a stronger peak flood velocity. In terms of sediment transport, accumulation of sediment could occur faster within the deepened river section upstream compared to the current situation. Downstream of the altered section, the effect reverses, implying that the river becomes less flood dominant or more ebb dominant due to upstream dredging. This reversed effect is most obvious for normal flow conditions; characterized by small river discharge.

Time-dependent flushing

Model scenarios were carried out in which a time-dependent flushing strategy, with an increased discharge around maximum flood or maximum ebb, was applied. The impact of these flushing strategies on the peak velocities is negligible from the mid-section of the river up until its mouth. In the upstream part of the Durme river, these flushing strategies lead to higher peak ebb velocities and a decrease in flood dominance or increase in ebb-dominance. Furthermore, a decrease in the flood peak is obvious for the case of high flushing during the flood phase. The resulted velocity asymmetry suggests that the flushing strategy might not influence the sediment import to the Durme but can alter sedimentation pattern in the upstream part of the river.

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Appendix 1 Figures

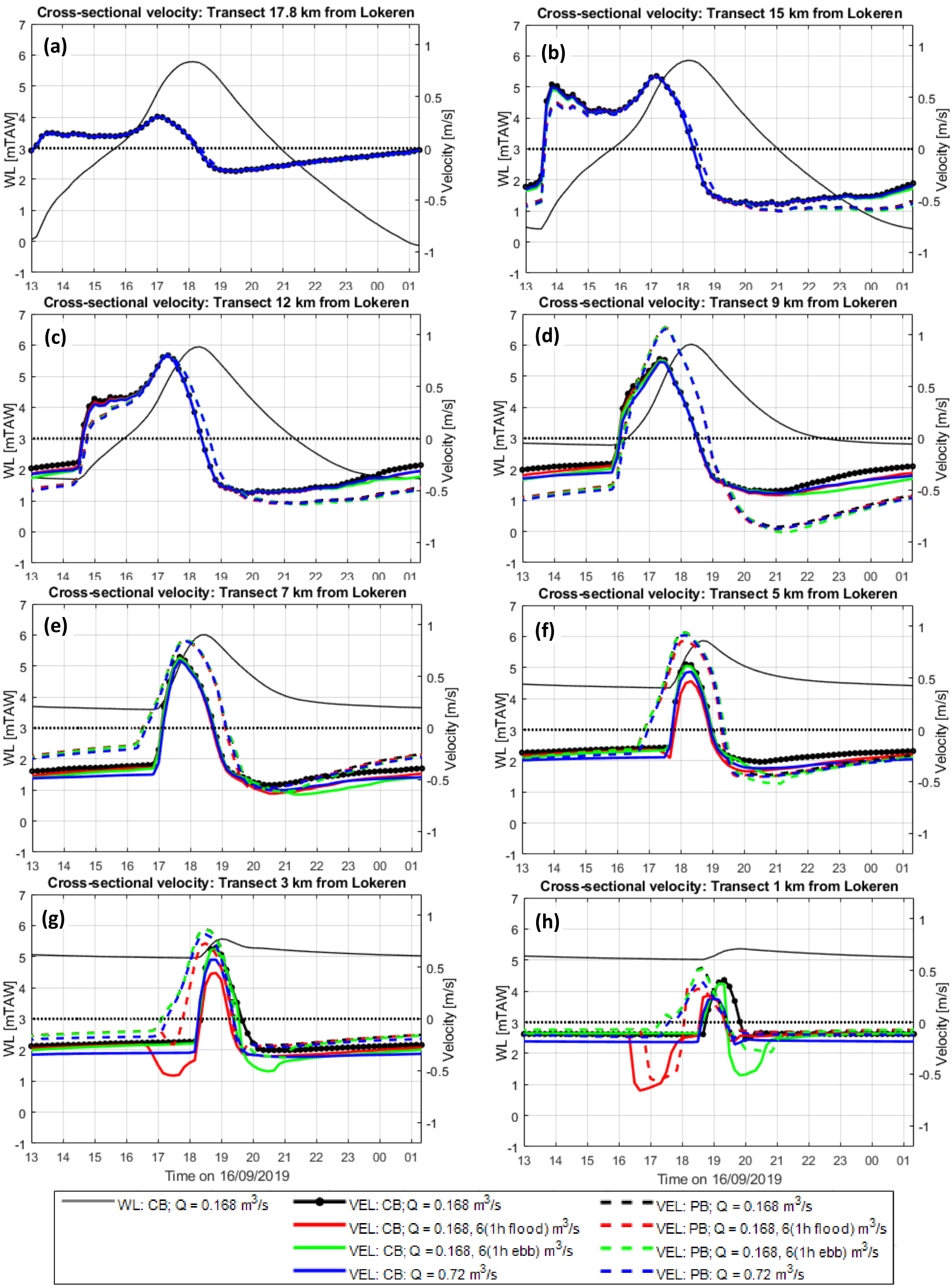

Figure 27 – Cross-sectional current velocity computed with current and planned bathymetry for different discharge regimes during spring tide. Positive values indicate flood current

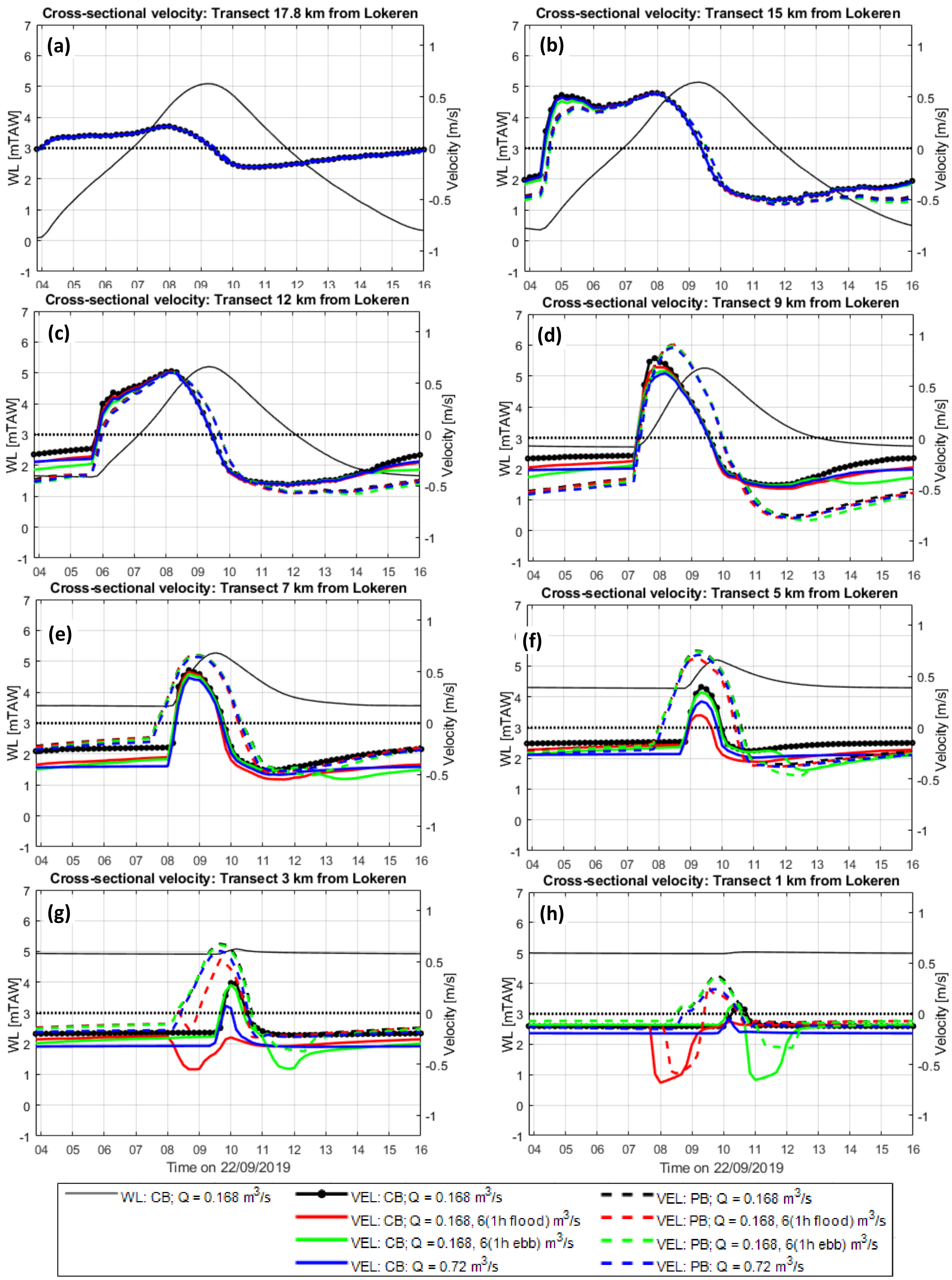

Figure 28 – Cross-sectional current velocity computed with current and planned bathymetry for different discharge regimes during neap tide. Positive values indicate flood current

DEPARTMENT **MOBILITY & PUBLIC WORKS**
Flanders hydraulics

Berchemlei 115, 2140 Antwerp
T +32 (0)3 224 60 35
F +32 (0)3 224 60 36
flanders.hydraulics@vlaanderen.be
www.flandershydraulics.be