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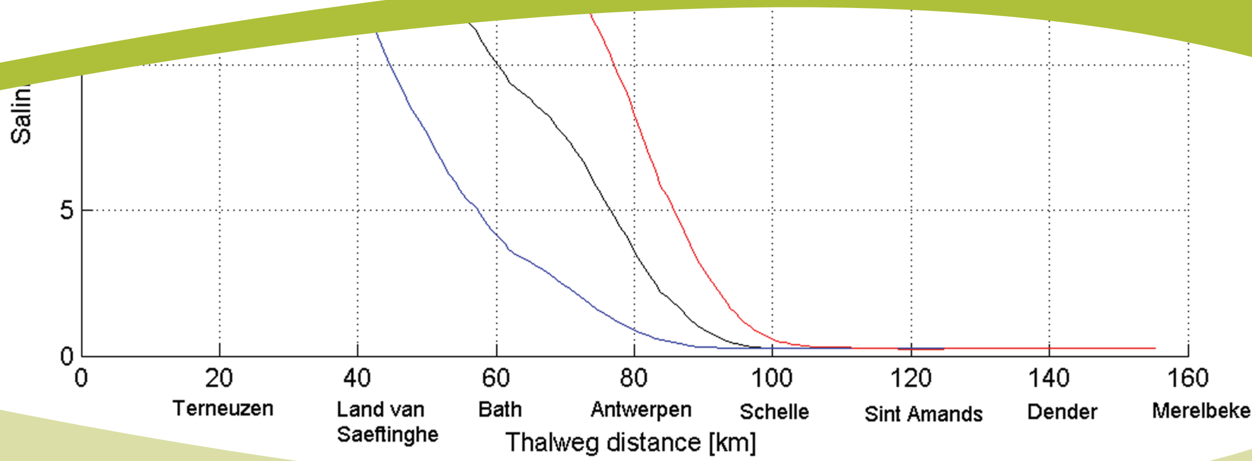
Effect of fresh water discharge on the salinity intrusion in the Scheldt estuary

FINAL REPORT



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Effect of fresh water discharge on the salinity intrusion in the Scheldt estuary

Final Report

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Abstract

This report includes a study of the effect of fresh water discharge in salinity of the river Scheldt. The study consists of a series of simulations with the NEVLA3D model to investigate salinity variation in several upstream discharge conditions.

Three scenarios were set up. The reference scenario includes constant discharges at 8 river sources taken as the mean annual discharge for the year 2006. A scenario with doubled discharges (N002) and another one with half reduced discharges (N003) are implemented. Simulations were carried out for a period of three months.

Transient effects are investigated by modelling a single-day discharge peak.

The results of this study can be used to model sediment transport in DELWAQ, in order to investigate the effect of fresh water inflow on (cohesive) sediment transport, through changes in estuarine circulation.

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1. Introduction

This report includes a study of the effect of fresh water discharge in salinity of the river Scheldt. The study consists of a series of simulations setup to investigate salinity variation in several conditions. To accomplish this study, numerical modelling is used by implementing the NEVLA model. This model is written in SIMONA and it covers the whole river Scheldt and part of the North sea. It is constantly being developed, calibrated and improved by FHR. A validated version of NEVLA (2006) is used here to compute the hydrodynamics of the research area. In this study, the NEVLA setup of this version was not modified. For the purpose of this project, the crucial factor was the river discharges along the river Scheldt and upstream of it. Therefore, the river flow is taken different in each simulation and results are then compared. The river data is found in previous studies and modified according to the needs of the current project. In the following chapters, every step of this work is explained in detail. At first, the methodology that was followed to set up the model is described. The background work, on which this project was based on, is presented and the changes required to be done are explained. The available river data is given afterwards and the analysis that led to the final model input. Model implementation and required modification is available in chapter 4. Next, the model results are discussed and a comparison is done between the scenarios. At last, following the aforementioned results, conclusions are listed to summarize the whole project work.

2. Methodology

The current project is based on the work that was done within the project entitled ‘Verbetering randvoorwaardenmodel‘ (Verheyen et al, 2013), where an improved version of the NEVLA model was accomplished. In the framework of that project the hydrodynamic run simG19, which has been previously used by van Kessel for sediment transport modelling for the Scheldt estuary (van Kessel et al., 2010), was extended to the scenario with runID simG34. In this scenario , improvements of the model grid and bathymetry made by FHR (Maximova et al 2009a & 2009b) were integrated. This scenario was further extended with an update of the bathymetry of the BCS. The discharge location and bathymetry in Merelbeke was also changed and new initial conditions were applied. In this model the hydrodynamics for year 2006 were calculated. The scenario simG34 is used as the reference run of the current project. Instead of the whole 2006 year, only the first trimester is simulated here to cope with storage space and computation time. Nevertheless, it is considered to be a representative period. The basic set up of simG34 (hydrodynamic, boundary and initial conditions, model grid and bathymetry, time parameters) is not modified.

The scope of the project is to investigate the effect of fresh water discharge on the salinity intrusion in the Scheldt estuary. Several scenarios were applied with different upstream river discharges. Totally, four scenarios were analysed. Apart from the reference run, one case with double increased and one with half reduced discharge values were executed. Finally, another scenario with a discharge peak at the first day is done to investigate the effect of transient flows to the salinity intrusion.

The discharges are analysed from the input data of simG34. In run simG34, river sources of fresh water inflow are present at 8 specific locations (see chapter 3). Timeseries of discharges every 10 minutes, 1 hour or 1 day are given there for one year. In this project timeseries were replaced by their mean values. The fresh water flows remain constant for the whole simulation period. Furthermore, the initial conditions for salinity are prescribed as a single value per location along the offshore boundaries , equal to the mean value of the salinity timeseries applied in simG34 at the same locations. The same applies for the small (less than 0.30ppt) salt intrusion from the river sources.

A comparison is done between the salinity results of each scenario. Results are obtained as timeseries of water flow and salinity in preselected locations along the navigation channel and they cover the whole simulation period. The salinity is further analysed over the last spring neap tidal cycle. In addition, the salinity evolution over time in the vertical and horizontal direction is examined and presented in several time frames.

3. Analysis of Fresh Water inflow

In the NEVLA model 8 discharges are imposed upstream (Verheyen et al, 2013). Distribution of river discharges over the entire year 2006 (simG34) can be found in Figure 1. The location of the discharges can be seen in Figure 2. Data from simG34 in these stations is analysed and the discharges shown in Table 1 are finally introduced in the model. The mean value of simG34 over a year is implemented. The discharge is constant in time for the whole simulation period (simulation period is also given in Table 1). Scenario N001 is the reference case based on simG34. N002 has doubled discharges from N001 and N003 half values. In Table 1 the distance of each station from the estuary mouth is given. For scenario N004 and to make a peak, a 10times higher discharge than the reference (N001) is used for the first day. After the first day the N001 discharges are imposed again.

Table 1 River flows per station for each scenario

STATION	SCENARIO				
	N001	N002	N003	N004	
	TIME PERIOD				
	05/January05:30 05/April 05:30	05/January05:30 05/April 05:30	05/January05:30 05/April 05:30	05/January05:30 06/January05:30	06/January05:30 05/April 05:30
	DISCHARGES (m^3/s)				
Scheldt-Merelbeke (>160km)	28	56	14	280	28
Zenne –Zemst	9	18	4	90	9
Dijle – Haacht	22	44	11	220	22
Grote Nete	5	10	2	50	5
Kleine Nete	7	14	3	70	7
Schelde–Dendermonde (135km)	11	22	5	110	11
Gent Terneuzen (20km)	18	36	9	180	18
SpuikanaalBath (40km)	12	24	6	120	12

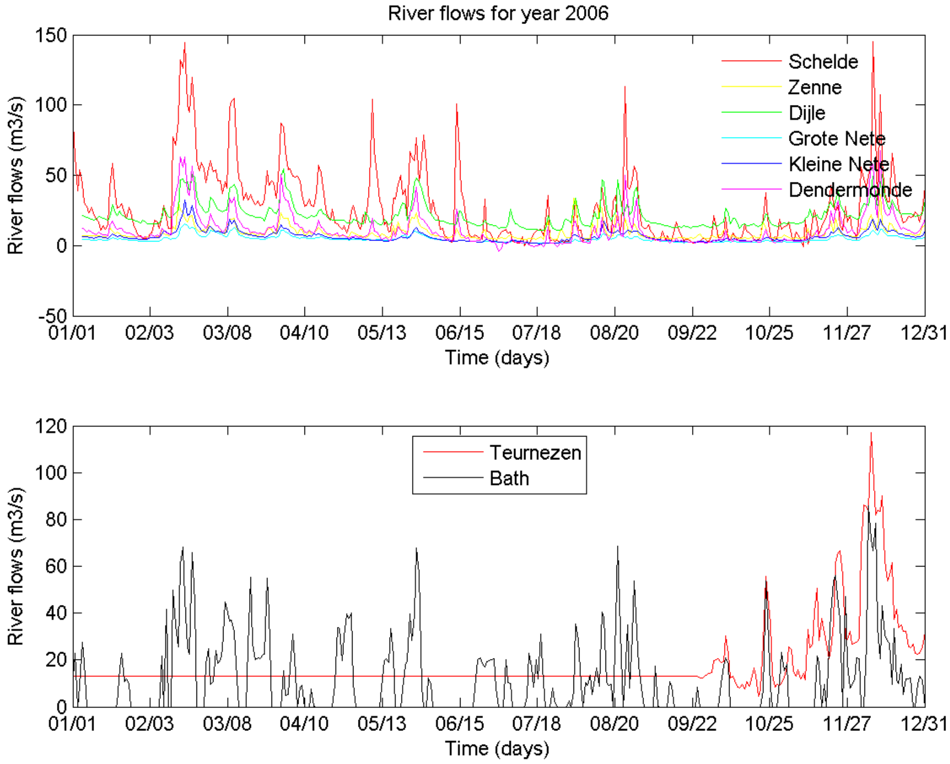

Figure 1 Fresh water discharge measured at different survey stations for year 2006 (source: Flanders Hydraulics Research – HIC)

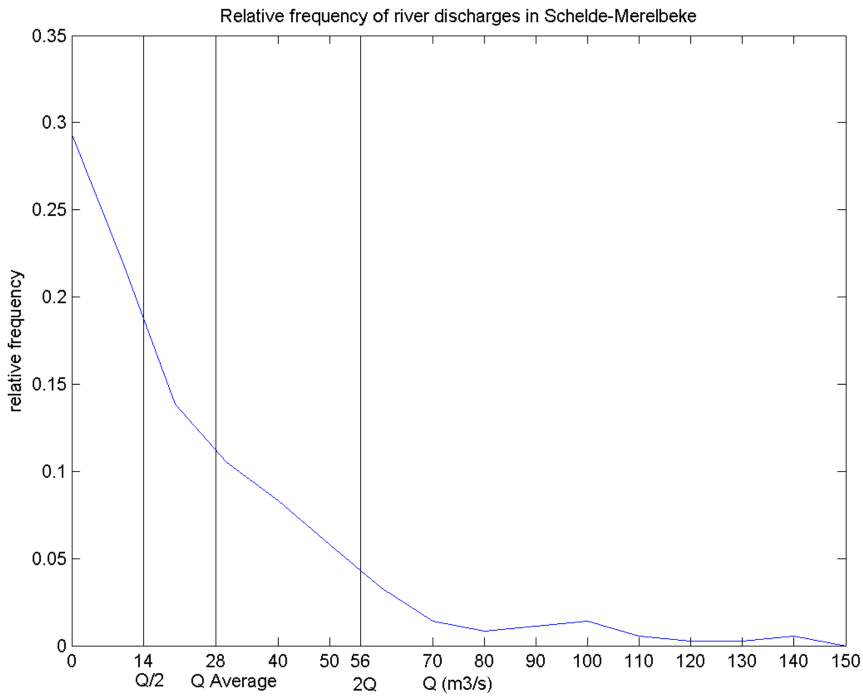

Figure 2 Relative frequencies of river discharges in Merelbeke

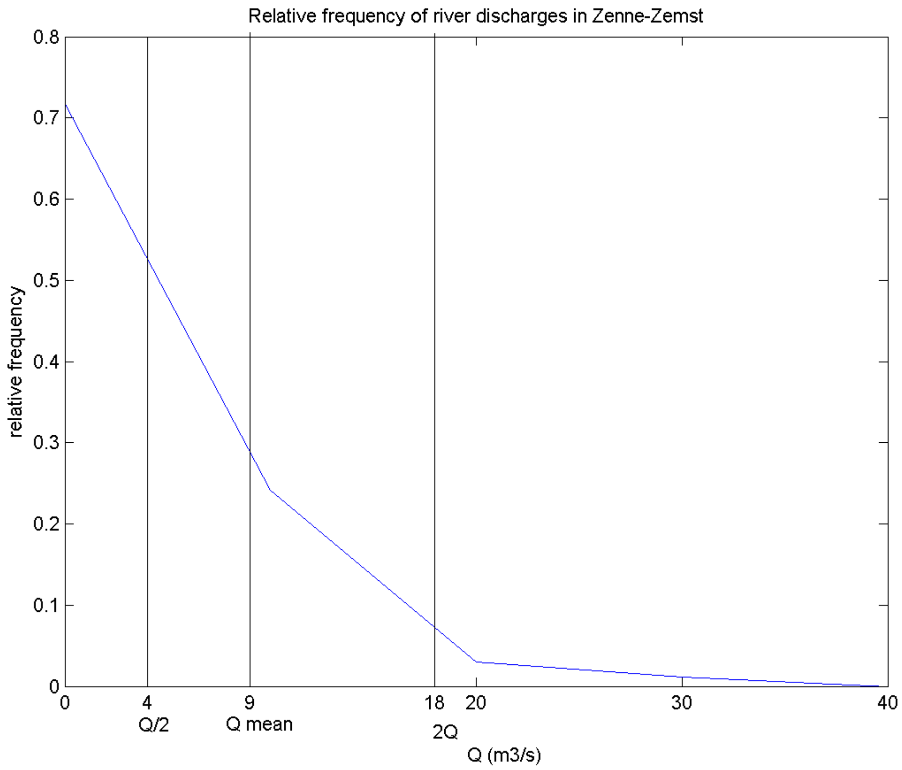

Figure 3 Relative frequencies of river discharges in Zenne

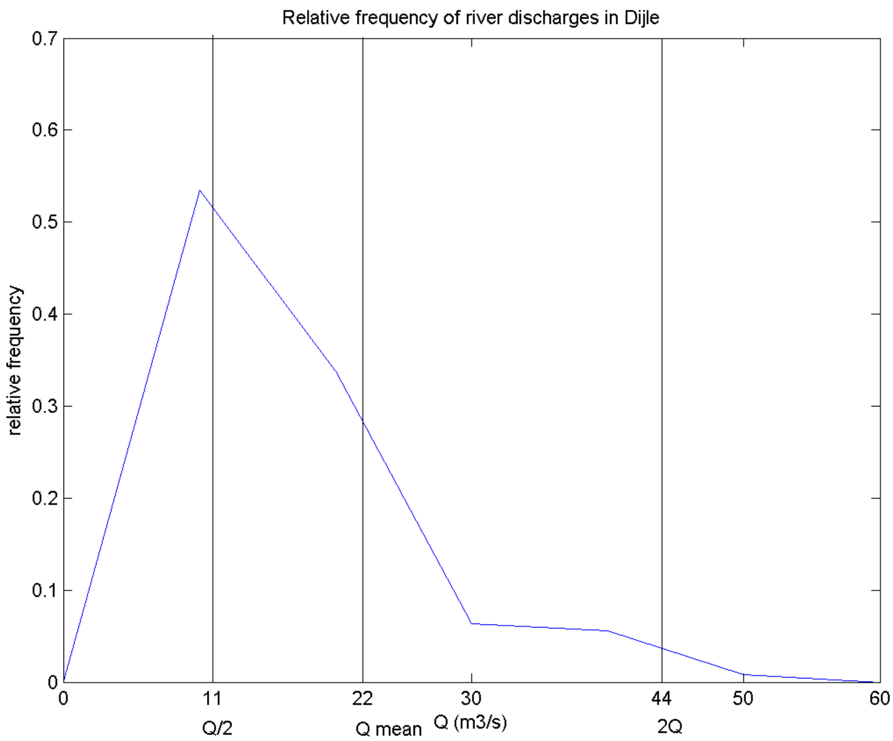

Figure 4 Relative frequencies of river discharges in Dijle

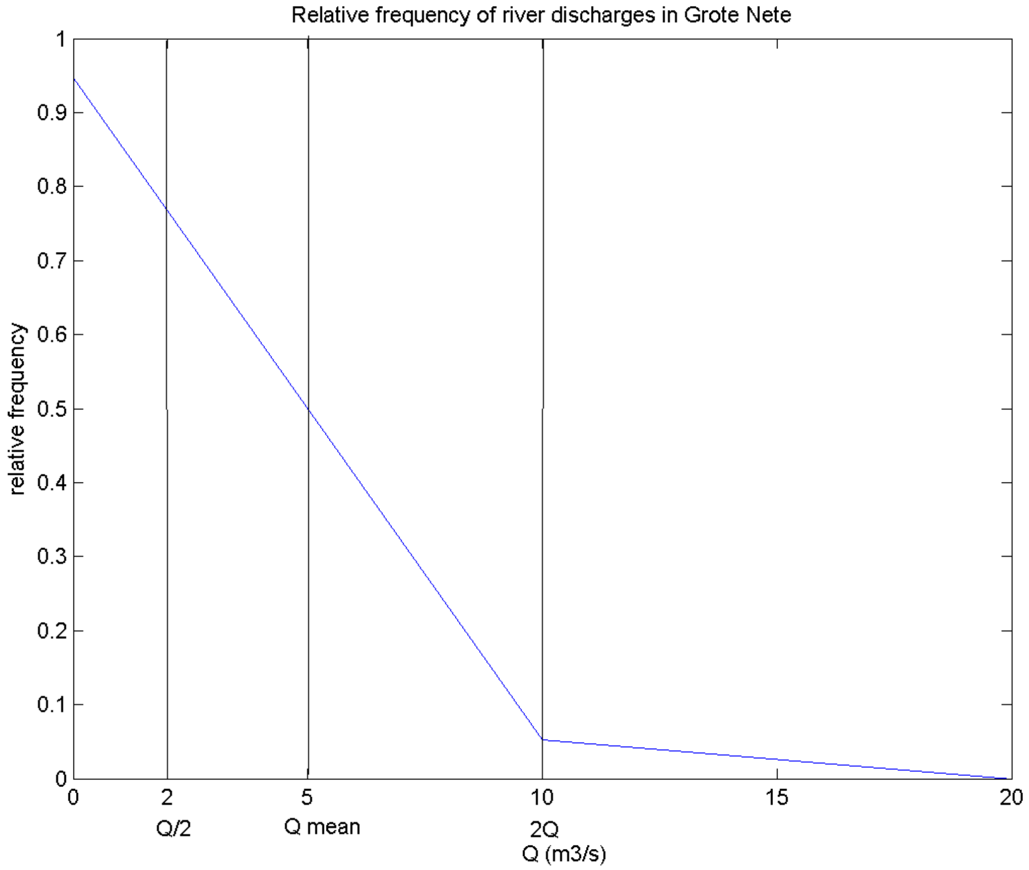

Figure 5 Relative frequencies of river discharges in Grote Nete

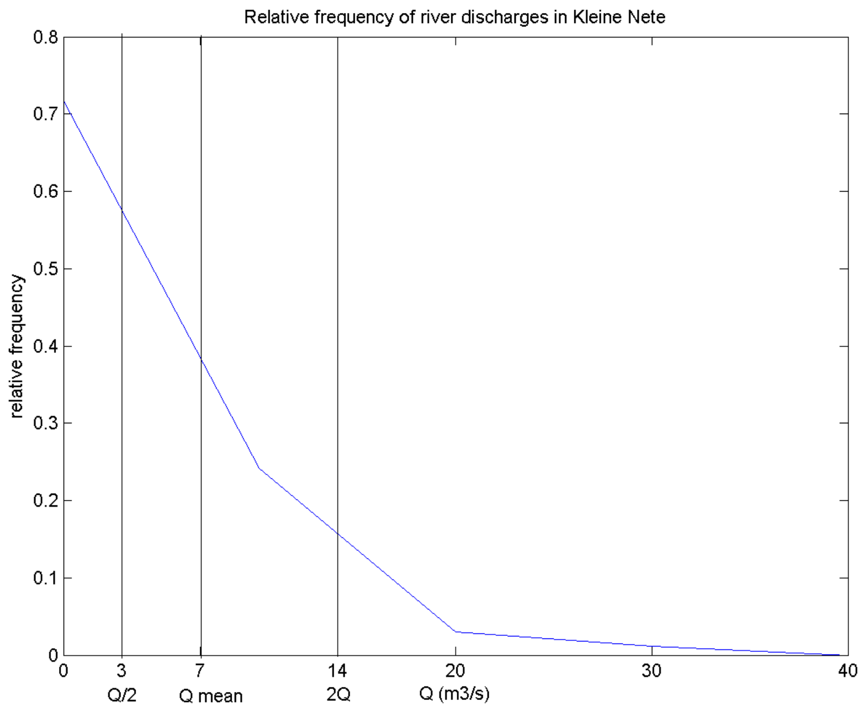

Figure 6 Relative frequencies of river discharges in Kleine Nete

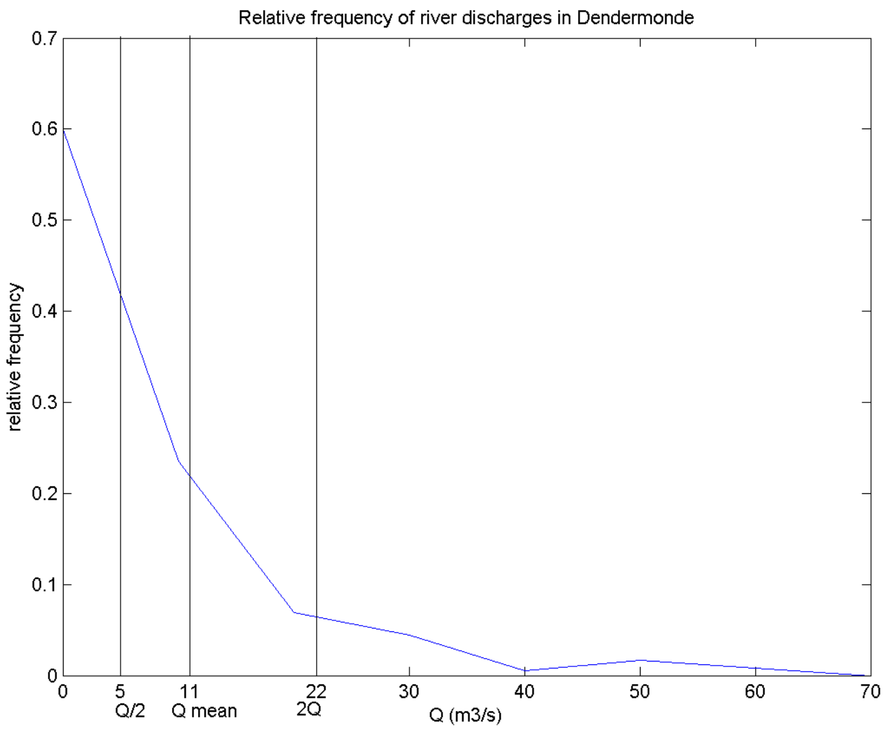

Figure 7 Relative frequencies of river discharges in Dendermonde

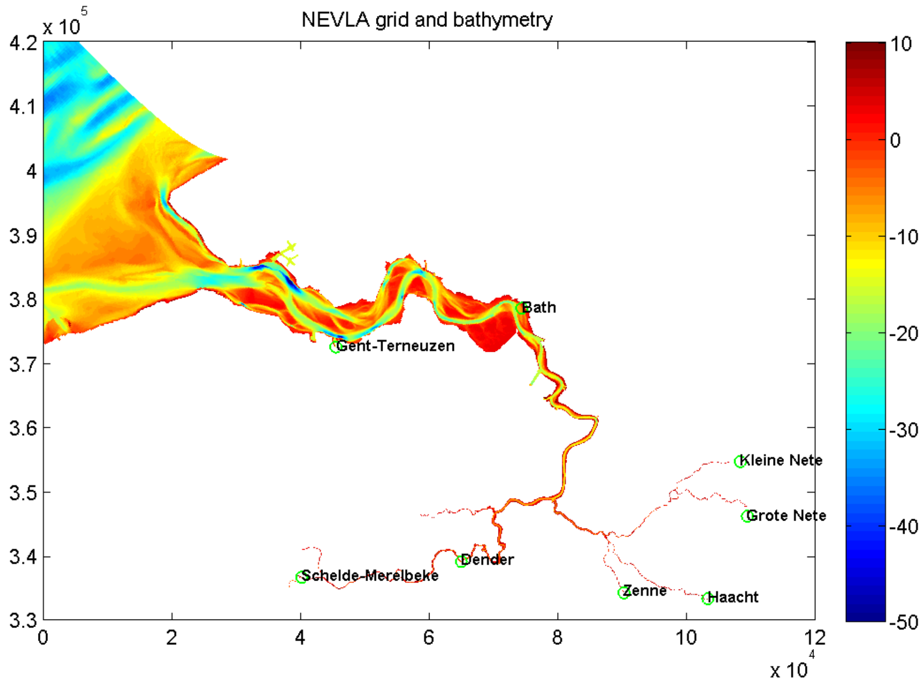

Figure 8 Location of river discharges

As in Terneuzen there is a lack of measurements until a specific day, a constant flow is filling the gap in time that can describe realistically the river flow at that place. A similar problem can be seen in Bath, where there is also sporadic lack of data. Despite these issues, it was decided to follow there the same procedure for data analysis as in the other locations. The same approach should be chosen for each case so that the results can be analysed in the same way for every station However, these stations are not included in Figure 2 to Figure 7 which show the relative frequency of occurrence for every discharge value in each river discharge. From these figures it can be seen that the 10 times higher discharge implemented in scenario N004 is not a value included in the current data but it is usually somewhat higher or lower than the doubled maximum discharge measured in year 2006. It could be concluded then that it is an extreme scenario mainly focused on investigating the behaviour of the system in such a shock rather than studying a likely case. Model implementation

The full NEVLA model domain and its bathymetry can be seen in Figure 9. The NEVLA model and its setup for simG34 won't be described in detail in this report as it can be found in the document 'Verbetering randvoorwaardenmodel ' (Verheyen et al, 2013). The general setup of the model has not been modified. Boundary conditions downstream are prescribed as Riemann boundaries at the offshore and velocities at the lateral sides. Boundary conditions are defined by timeseries for the entire year 2006 on a 30 minutes time interval. The basic model parameters are included in Table 2.

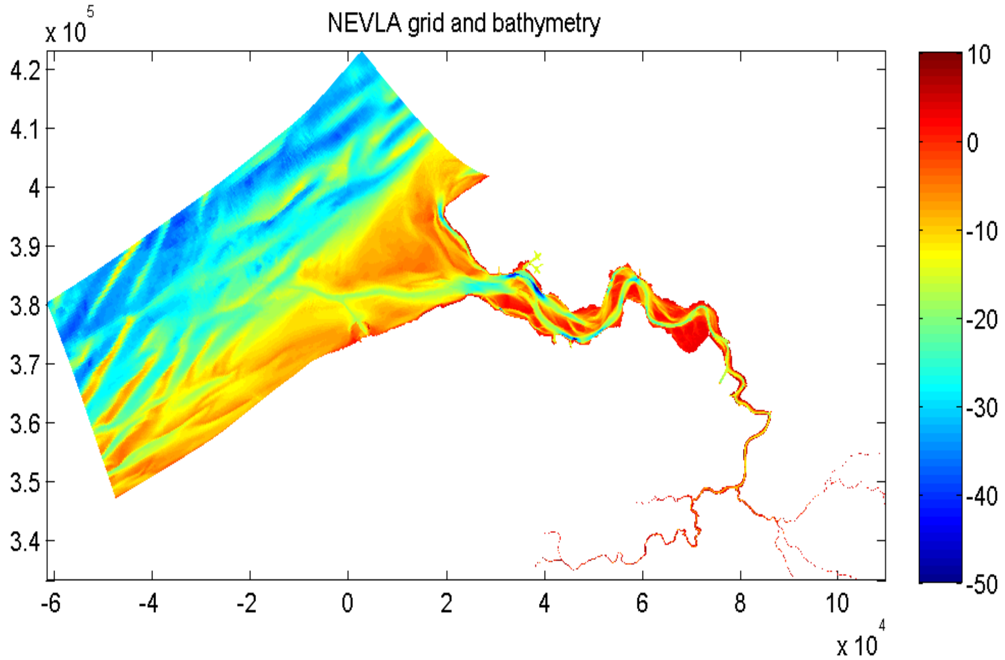

Figure 9 NEVLA model, grid and bathymetry

Table 2 Model parameters

Grid size	380*3001 cells
Hydrodynamic layers in the vertical direction	6
Time step	0.125 minutes
Viscosity	1 m^2/s
Horizontal diffusion	10 m^2/s
Bottom roughness	Space-varying Manning coefficient
Simulation period	05/01/2006 05:30:00 - 05/04/2006 05:30:00

To follow the constant fresh water inflow, the salinity boundary conditions are replaced also by a constant mean value of simG34 data at each of the North Sea locations where boundary conditions are specified. The salinity intrusion is applied for the entire simulation period (three months). In contrast, simG34 applies timeseries every 30mins for year 2006. In Figure 10 the positions where boundary conditions are specified can be seen. The implemented salinity boundary conditions are represented in Figure 11, Figure 12 and Figure 13.

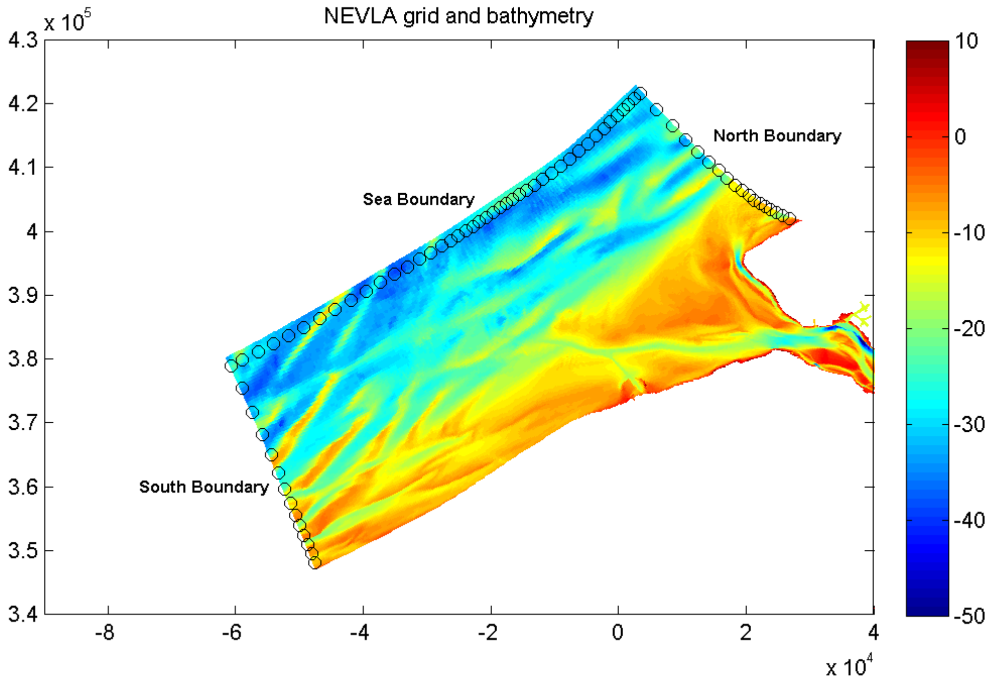

Figure 10 Offshore positions where salinity boundary conditions are specified

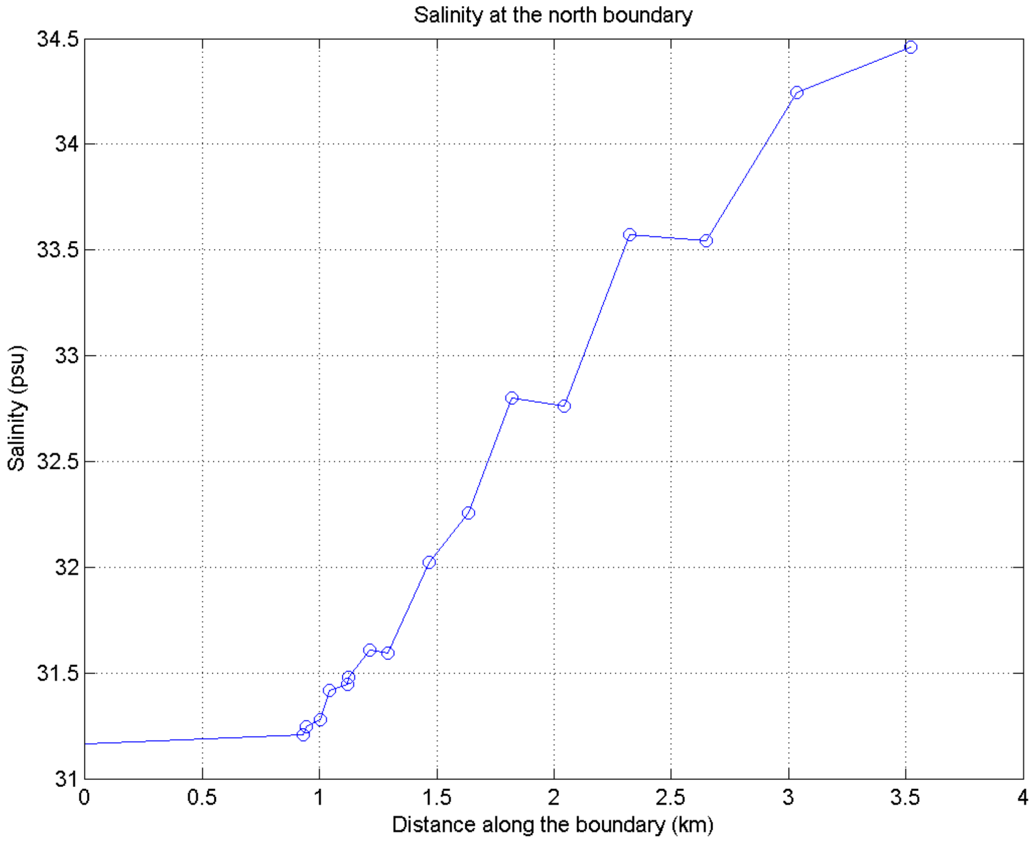

Figure 11 Salinity boundary conditions along the north boundary (offshore-onshore direction)

As it can be seen, salinity values vary between 31 and 35 psu. At the same time a very small salinity intrusion is considered to occur from the 8 river flow sources. Salinity is also taken there constant through a period of three months and is equal to 0.30psu.

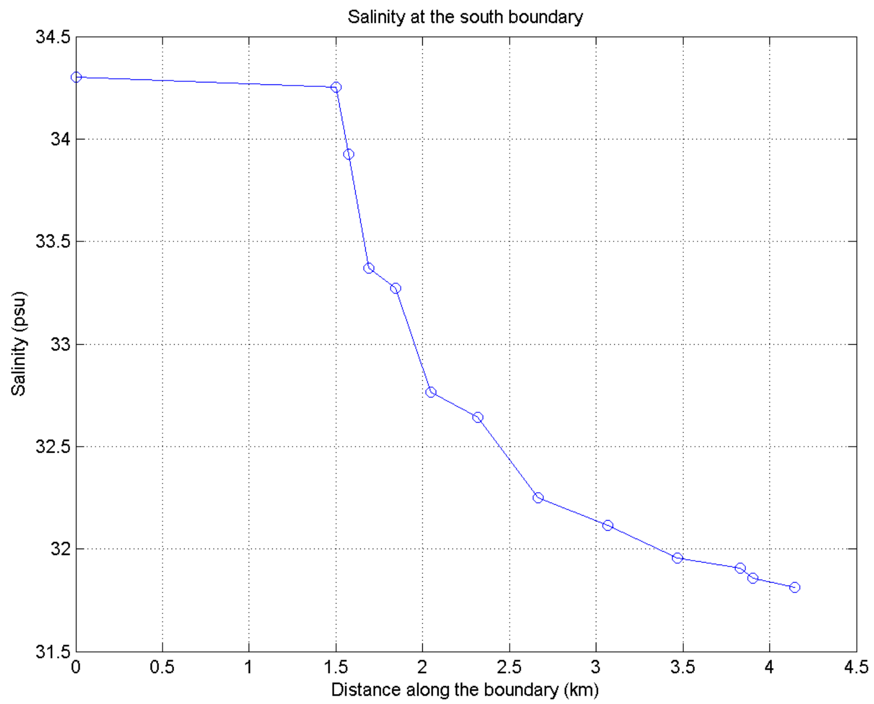

Figure 12 Salinity boundary conditions along the south boundary (offshore-onshore direction)

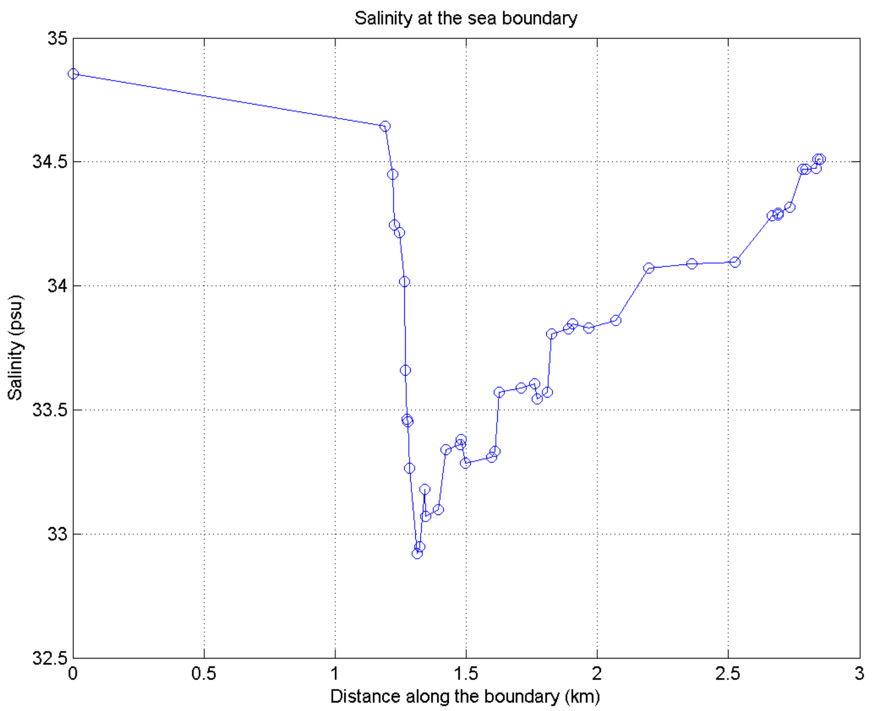

Figure 13 Salinity boundary conditions along the sea boundary (left-right direction)

The results will be analysed along the thalweg. In order to enhance post-processing and manage the data storage, a series of observation points along the thalweg from the estuary mouth until Ghent are defined within the model. These points(210 in total) cover a distance of 150km and are selected every 0.5km approximately. They are selected inside the navigation channel to allow an assessment of the salinity levels along the river and the salinity distribution in the vertical. Figure 14 displays a line connecting all the available observation points and marks the distance from the mouth until the end of the line every 10km.

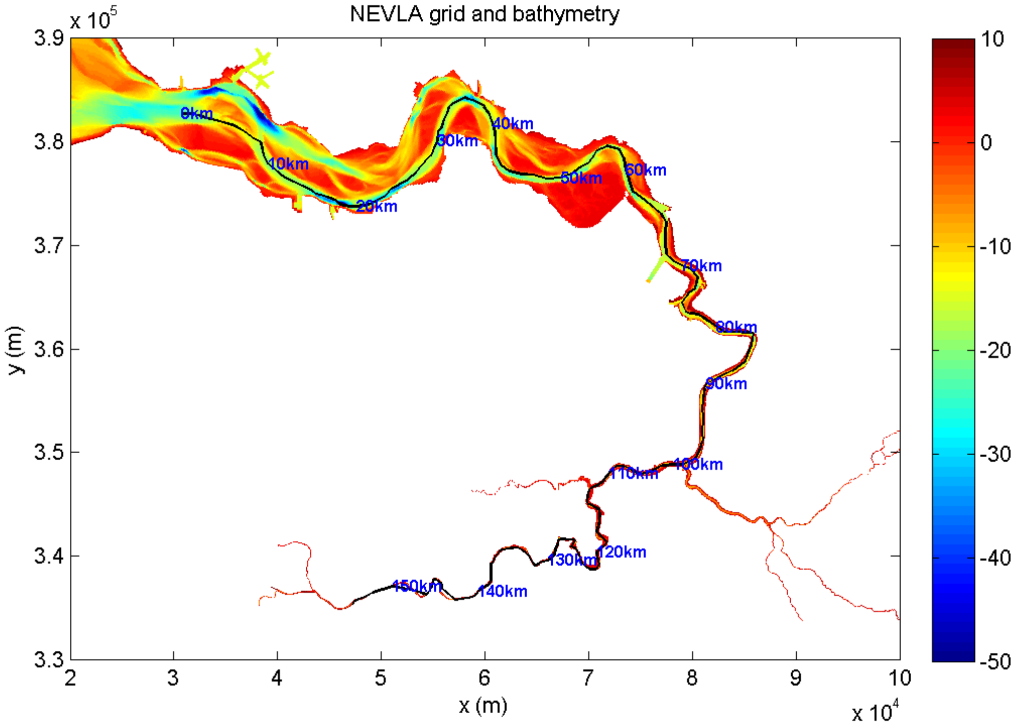

Figure 14 Observation points taken along the thalweg from the mouth of the estuary until Ghent

4. Model Results

In this chapter the model results are presented and discussed. A comparison has been done between results of the first three scenarios and separately a comparison between N001 and N004 to estimate in particular the effect of the peak discharge. As it was not possible to predict salinity levels for doubled or half discharge values, the salinity initial conditions were taken equal for each case. However, it can be concluded, looking in the plots between Figure 15 and Figure 20 that this is a good consideration as in all of the cases the same ,approximately, behaviour is observed. These figures show the salinity and daily averaged salinity at the last spring neap tidal cycle in three locations: downstream (Bath),in Antwerp and upstream (Schelle). Although an equilibrium is explicitly obtained only for scenario N002 (higher river discharges) , it can be seen that in the other two scenarios, salinity is close to an equilibrium. From Table 3 it is easy to see that deviation between the first and the last day of the last spring neap tide is very small. This doesn't occur only in Schelle where high percentages are noticed for scenarios N001 and N002. This is to some extend normal because this location is very close to the salinity intrusion considered from the initial conditions. This small salinity discharge (see chapter 0) prevents from reaching an equilibrium after the same time that is needed for the other locations. In general, a further extension of the simulation time for one or two months would be needed to reach constant values and variation. In any case, it is considered that salinity evolution is in a stage where result analysis is possible and accurate enough.

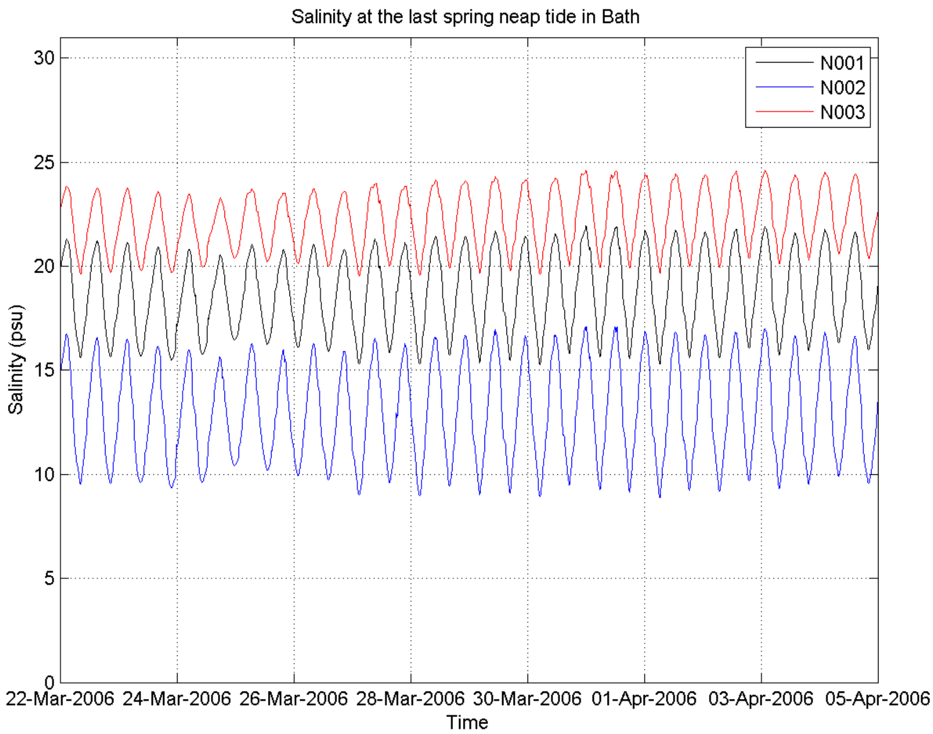

Figure 15 Salinity at the last spring neap tide in Bath

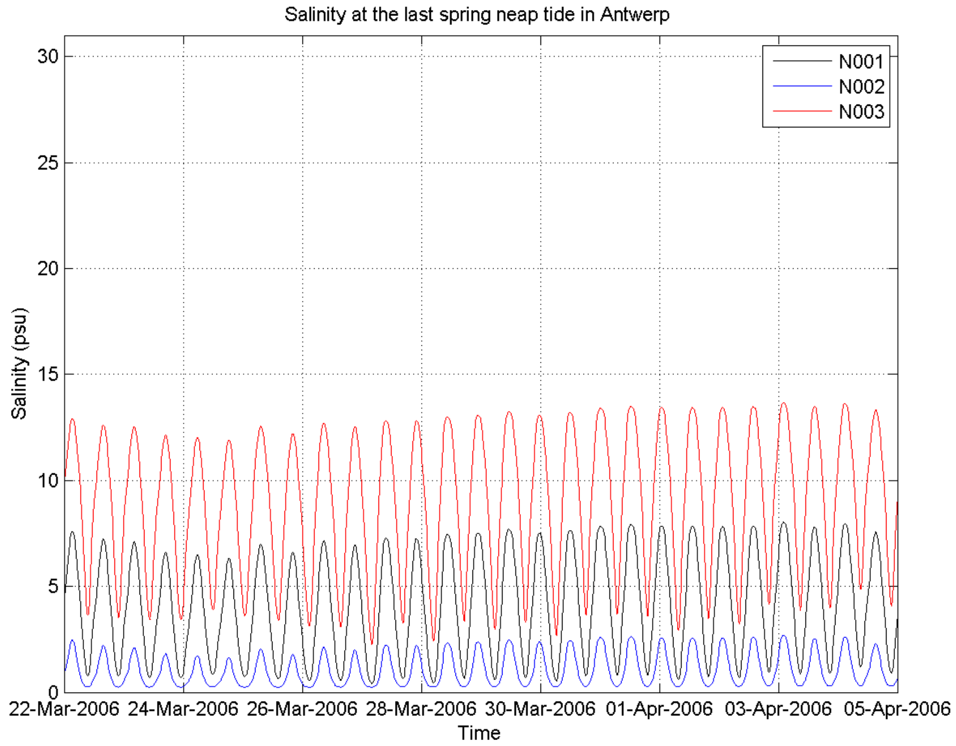

Figure 16 Salinity at the last spring neap tide in Antwerp

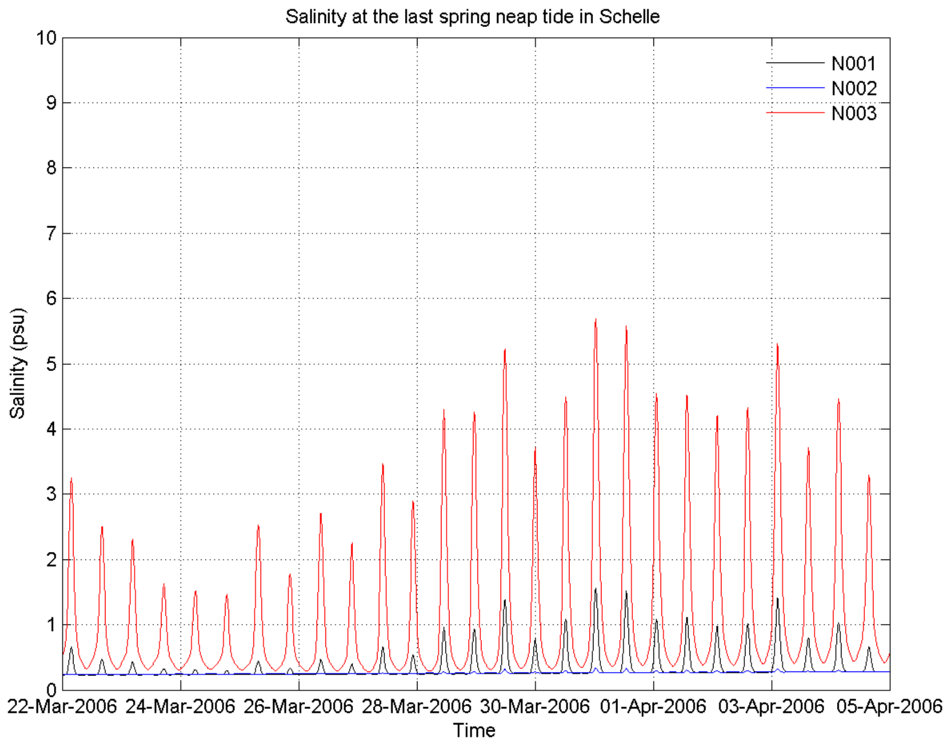

Figure 17 Salinity at the last spring neap tide in Schelle

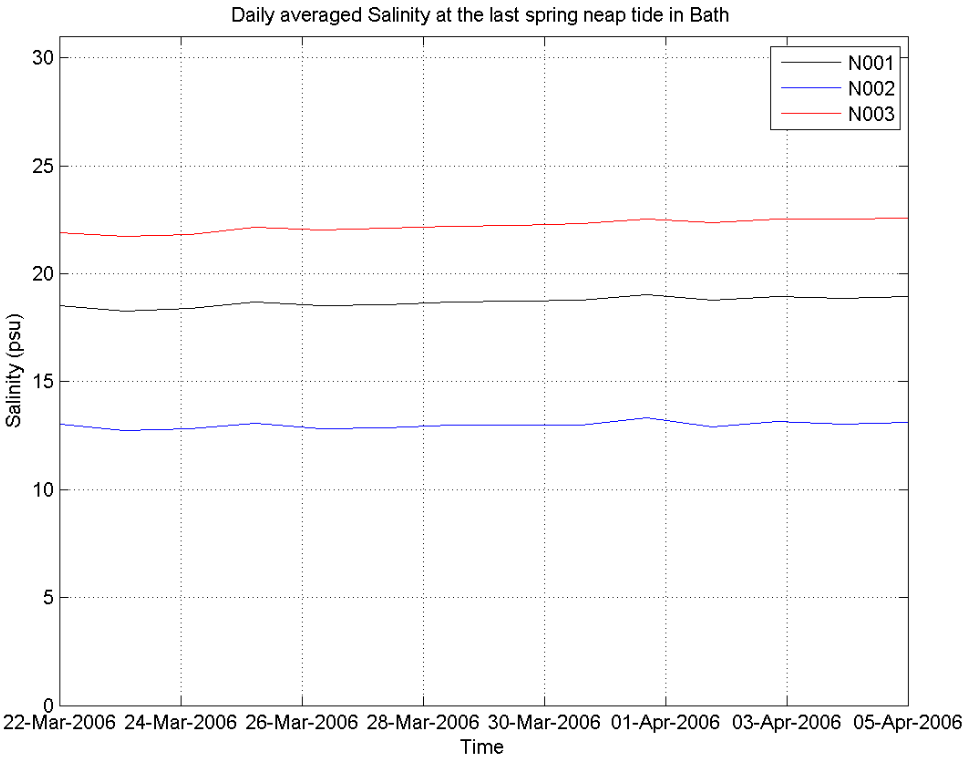

Figure 18 Daily averaged salinity at the last spring neap tide in Bath

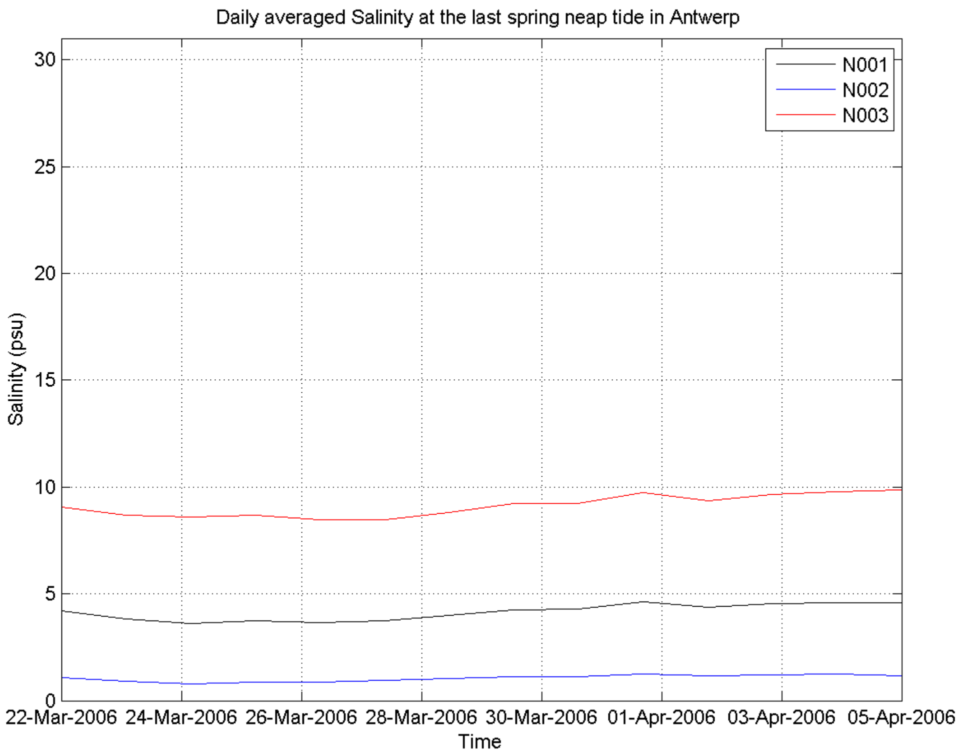

Figure 19 Daily averaged salinity at the last spring neap tide in Antwerp

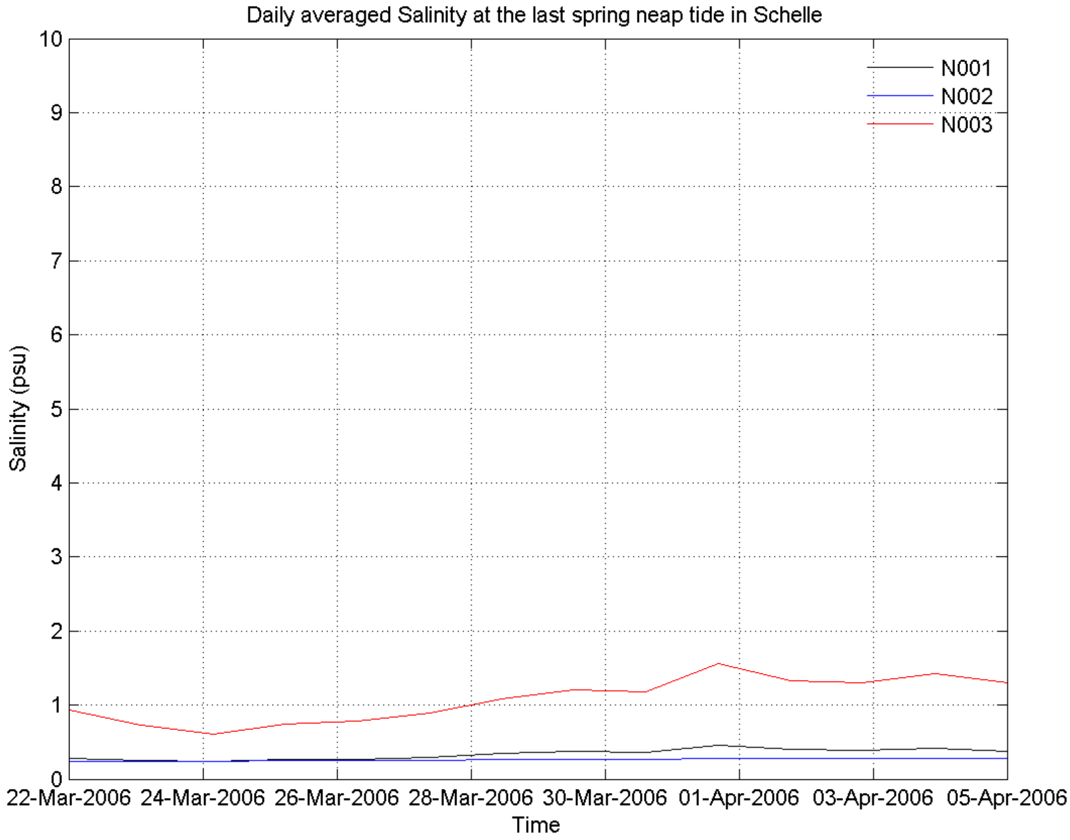

Figure 20 Daily averaged salinity at the last spring neap tide in Schelle

Table 3 Deviation (%) of daily averaged salinity between the first and the last day of the last spring neap tide

	ANTWERP	BATH	SCHELLE
N001	0.04	0.3	15
N002	0.04	0.5	0.3
N003	0.01	0.2	13

4.1. Scenarios N001,N002,N003

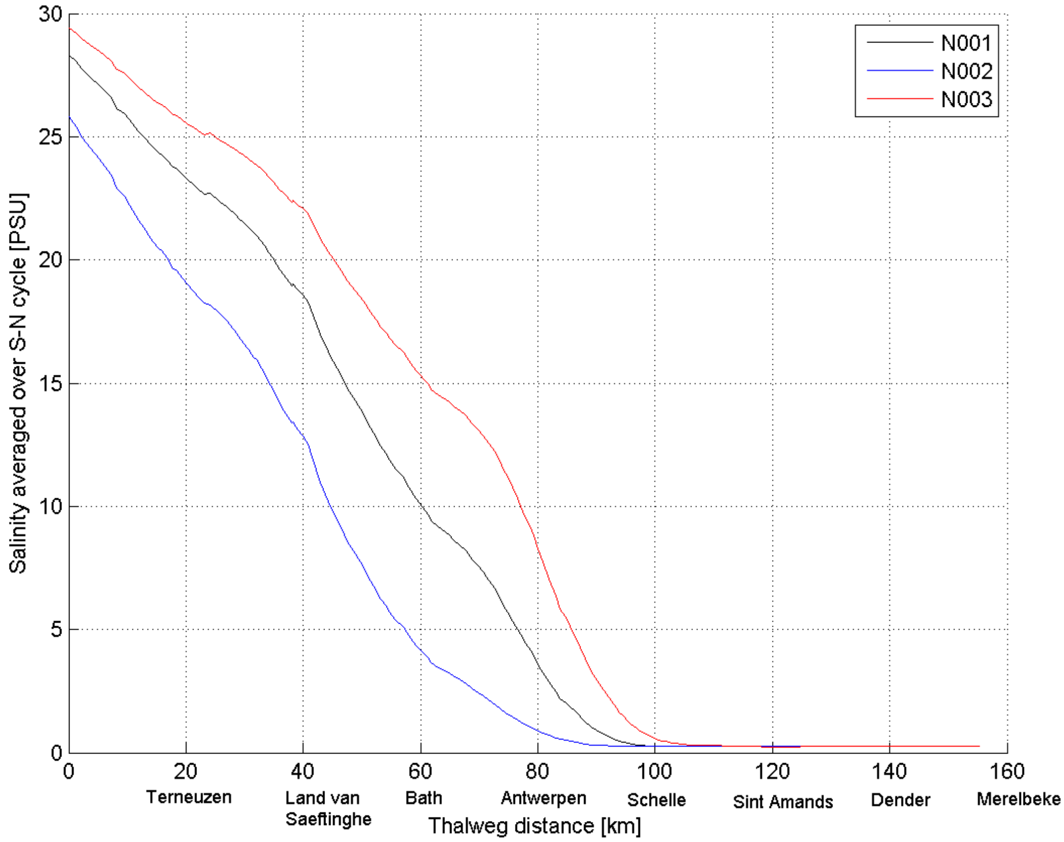

Figure 21 Depth averaged salinity for the last spring neap tidal cycle along the thalweg

For the comparison of the first three scenarios where constant discharges are applied over a three months period, an average salinity is taken over the last spring neap tidal cycle. The depth averaged distribution of salinity along the thalweg is illustrated in Figure 21 for each scenario. Salinity at the entrance of the estuary mouth starts from values between 25psu (N002) and 29psu (N003) and drops gradually to almost zero while entering in the river tributaries. As expected, scenario N003 that is set up with the half reduced river discharge leads to the higher salinity levels and normally needs the longer distance to drop to zero. This is happening very close to Schelle. For the reference scenario this is happening a few kilometres downstream. Salinity in scenario N002, where the double river discharges occur is already flushed out near to Antwerp. Figure 22 is a set of figures that shows the difference (Delta Salinity) of N002 and N003 with the reference scenario and the difference in distance at which the same salinity levels are observed in each scenario. Delta Salinity (DS) reaches a maximum of 5 psu. Maximum difference between N001 and N002 is observed around 50km from the mouth (very close to Land van Saeftinghe). The maximum difference between N001 and N003 is observed in Antwerp. It is clear then, that when the river discharges are minimum then salinity travels a longer distance in the estuary before starting to drop. The salinity levels of the reference scenario occur 10km to 20km more downstream in scenario N002 and 10km to 20km upstream in scenario N003.

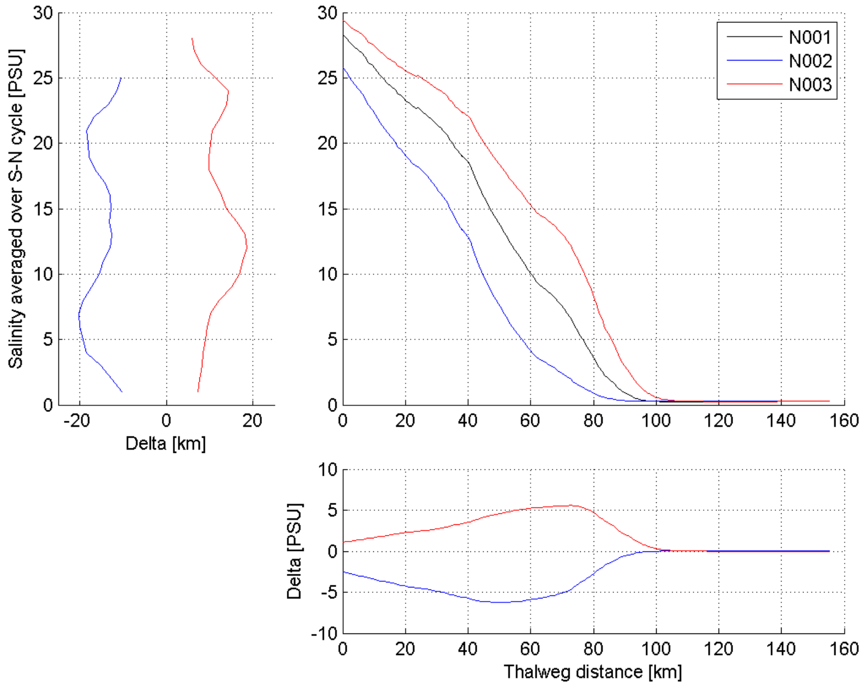

Figure 22 Delta Salinities (bottom) and Delta Distances (left) for each scenario

An analysis of the salinity evolution in the horizontal and vertical direction is done too. Timeseries of salinity are available for every 10 minutes. These can be seen for several timeframes in the contour figures in the next page. The contour figures for every timestep are also available in Appendix A and digitally on the provided CD-ROM, including animated time-lapses. The top line represents the water levels and the bottom one describes the river bed. These figures illustrate what has been discussed above. Figure 23 shows the higher and Figure 24 the lower salinity intrusion for the three scenarios. Salinity in N003 has the longer residence time. The initial salinity levels (between 25psu to 30psu) are diminished significantly only after 60km and drop below 5psu after 100km from the mouth. Results show an evolution of salinity levels according to the tidal motion. Salinity in N002 shows the minimum values at the mouth of the estuary.

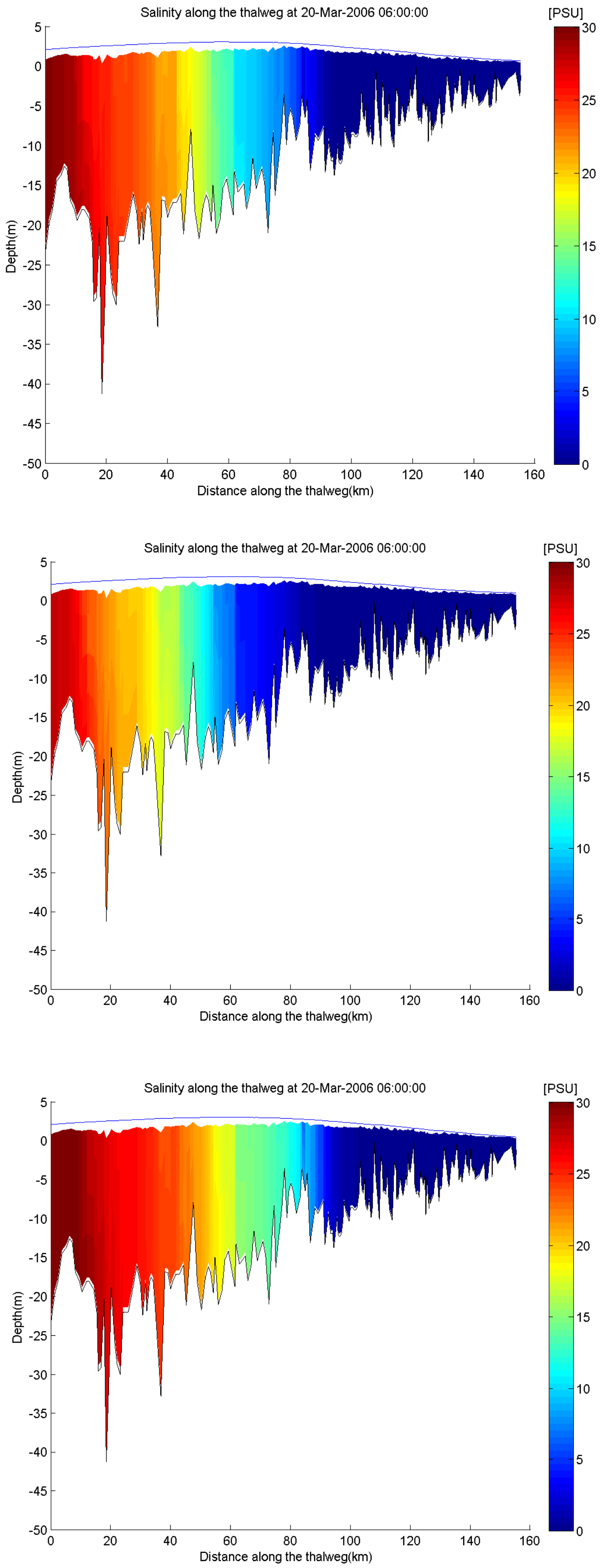

Figure 23 Salinity max intrusion at the first high tide of the last spring neap cycle for N001(top),N002(medium),N003(bottom)

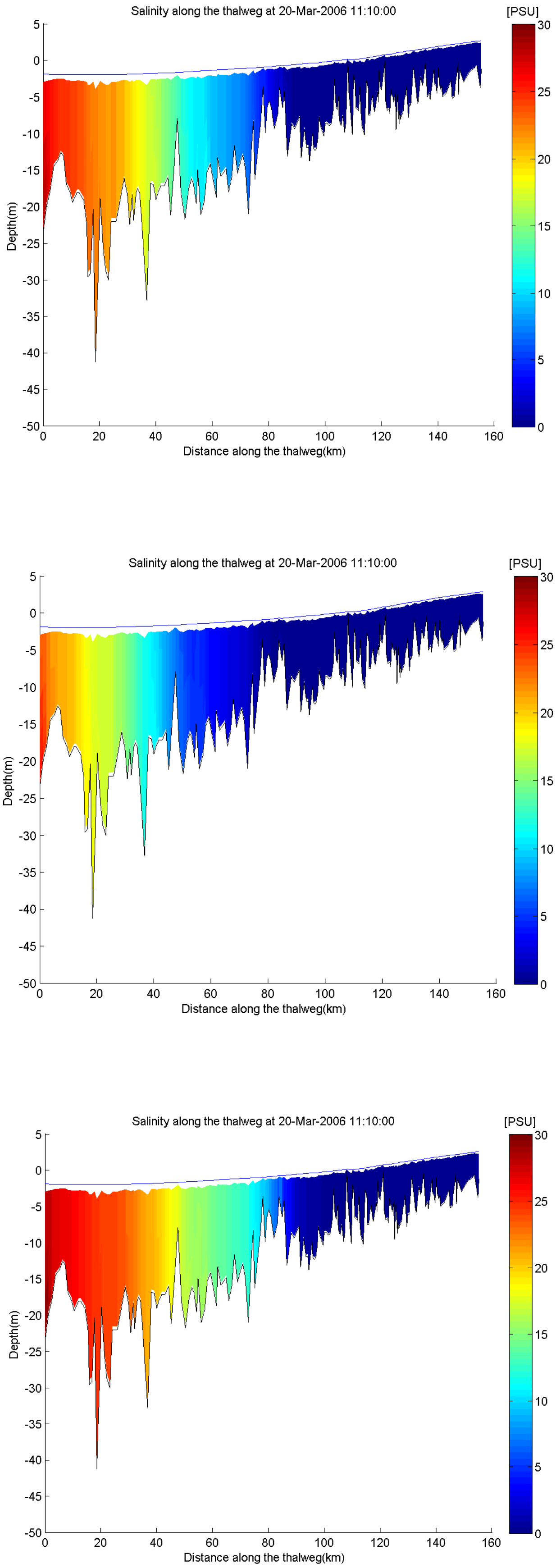

Figure 24 Salinity min intrusion at the first low tide of the last spring neap cycle for N001(top),N002(medium),N003(bottom)

4.2. Comparison between N001 and N004

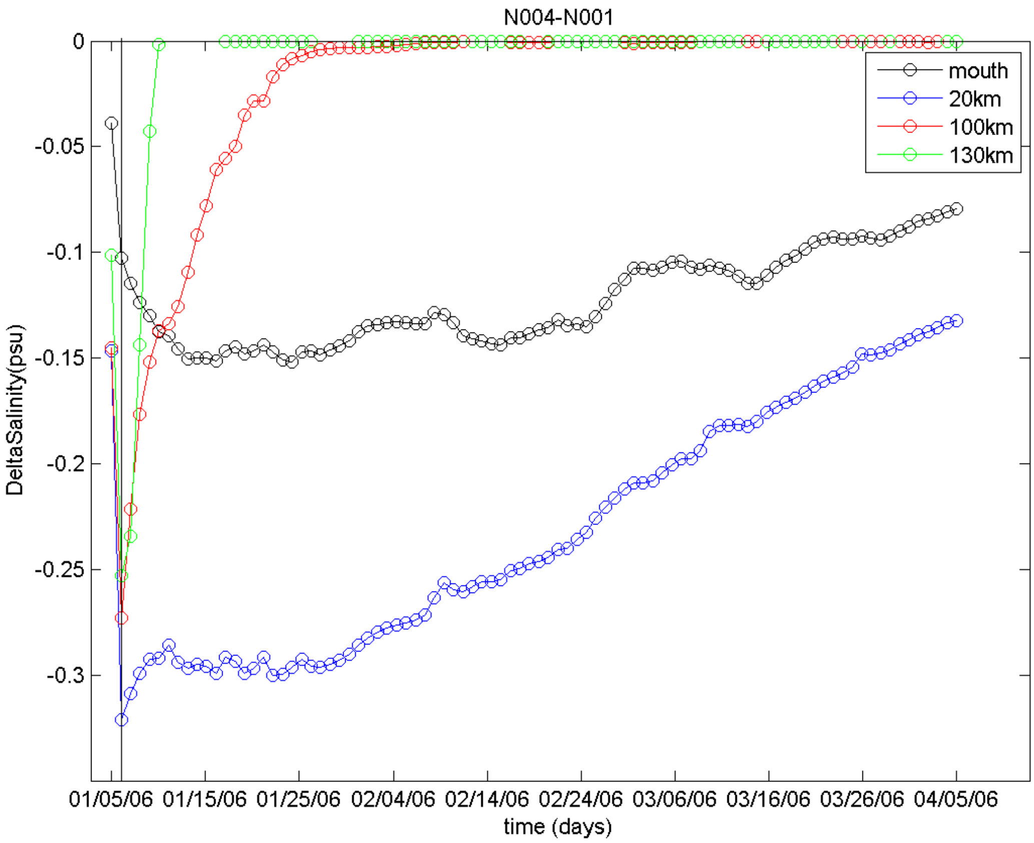

Figure 25 Drop of daily averaged salinity between scenarios N001 and N004 for the entire simulation period

For the comparison between N001 and N004, it is considered that the effect of the four river stations that are included in the thalweg between the mouth and Ghent is the most important. The stations, in sequence, are : Terneuzen, Bath, Dendermonde and Merelbeke. Therefore, it was decided to select four locations at which the effect can be better estimated and justified. The mouth of the estuary is selected to investigate the mixed influenced by the tidal flow and the neighbour river discharges. A location close to Terneuzen to see the impact of its discharge, Schelle to examine the salinity transfer along the thalweg and just before entering in the tributaries. The fourth location is really upstream, between the discharges of Dendermonde and Merelbeke. The rest four of the discharges (Grote and Kleine Nete, Zenne and Haacht) are not included in the analysis of the results. The stations are further upstream. It can be seen in Figure 23 and Figure 24 that in Schelle (around 100km from the mouth) salinity levels have already dropped a lot, reaching almost zero. As a consequence, it can be concluded that in the rest of the river tributaries, where the rest of discharges are located, the salinity is negligible. Figure 25 depicts the drop of daily averaged salinities between scenario N001 and N004 per day. The black vertical line limits the first day in which the peak discharge is applied in N004. Each circle corresponds to one day (90days in total, 24hrs spacing). The graph, as mentioned, includes four characteristic locations:

- Mouth of the estuary
- 20km from the mouth (Terneuzen)
- 100km from the mouth (Schelle)
- 130km from the mouth (Dendermonde)

The biggest effect of the peak is expected in locations upstream of the river and close to the stations . It can be seen in the graph that at the start of the simulation the biggest drop in salinity corresponds to the locations next to Terneuzen (blue line) and Schelle (red line). The import of the peak leads to a salinity fall of 0.15 PSU for both cases. On the contrary, the salinity difference in Dendermonde is smaller (0.1psu).

It is considered that the small salinity intrusion (0.30psu) from the river station , which is applied in the model, increases slightly the salinity there despite the high fresh water flow. Consequently, the peak effect is smaller than in the other cases. The effect of the peak can be assessed better at the end of the first day, when the peak in the discharge is removed. Salinity differences between N001 and N004 close to the river stations (Dendermonde and Terneuzen) is doubled in comparison to the first day. Salinity differencein Schelle is increased too but in less magnitude. For both days, the less impact is observed at the mouth of the estuary where the tidal wave motion from the sea is still dominant. However, it is interesting to notice the speed at which the salinity levels of N004 reach the N001 levels as soon as the peak is removed. The closer to the mouth, the longer time is needed to expunge the effect of the peak. In Figure 25 it is observed that at the mouth and 20km from it, there is still a difference in salinities between N001 and N004 after 3 months. Although decreasing, salinity in scenario N004 needs more time to catch the levels of N001. As it is normal, salinity returns to the N001 conditions very soon in more upstream locations (like Schelle) and even sooner inside the tributaries (Dender). The outcome could be better explained and understood by the following contour figures showing the difference between N001 and N004 along the thalweg for several time frames.

The effect of the peak discharge is visible at first, 90minutes after the start time and occurs at the station Dendermonde (130km from the mouth, see Figure 26). It takes another half hour to see the effect from the discharge in Bath (60km, Figure 27) and another 10 minutes to see a difference in salinity levels due to the discharge in Terneuzen (20km, Figure 28). It can be seen that the tracer starts to develop fast from Terneuzen and closer to the mouth (Figure 29). After 6hrs, Bath is causing the biggest difference in salinity levels (more than 0.5psu in some locations) (Figure 30). Higher colour levels are present in Terneuzen, Bath, Schelle and between Dendermonde and Merelbeke. After half a day, a zone between Schelle and Terneuzen has been developed where the biggest impact from the peak is noticed (Figure 31). This zone reaches its maximum at the end of the first day and then starts to reduce (Figure 32). After one month, salinity differences have dropped to zero in upstream locations but it is still present downstream (Figure 33). Finally, at the end of the simulation (Figure 34) the effect of the peak is not present anymore but only in a zone between discharges of Terneuzen and Bath. This remark agrees with the observations of Figure 25. It can be concluded then, that a longer period is needed to remove the discharge peak effect in these areas.

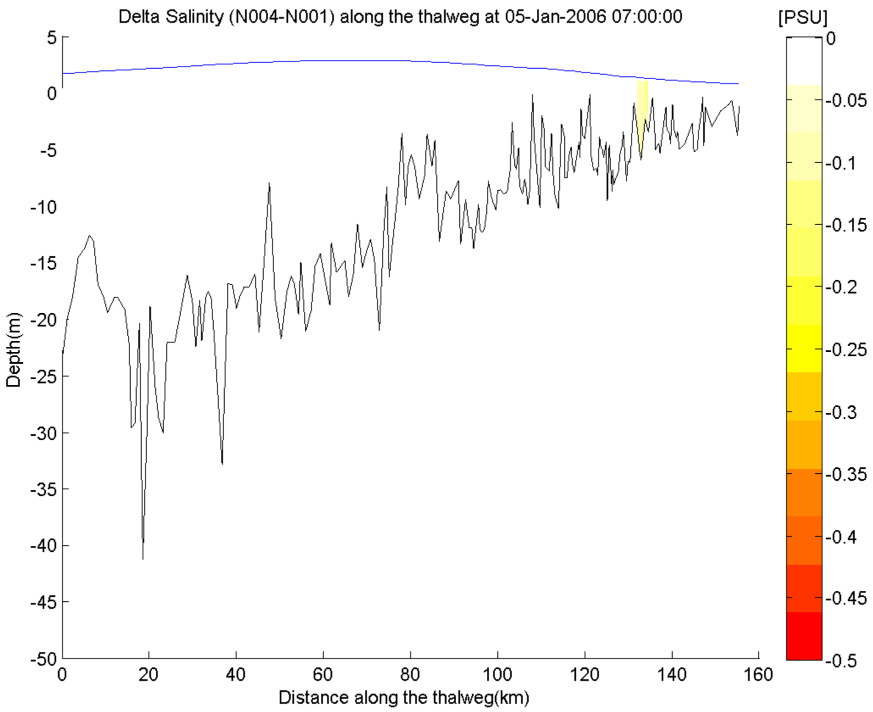

Figure 26 Drop of salinity (N001-N004) after 90minutes at flood stage

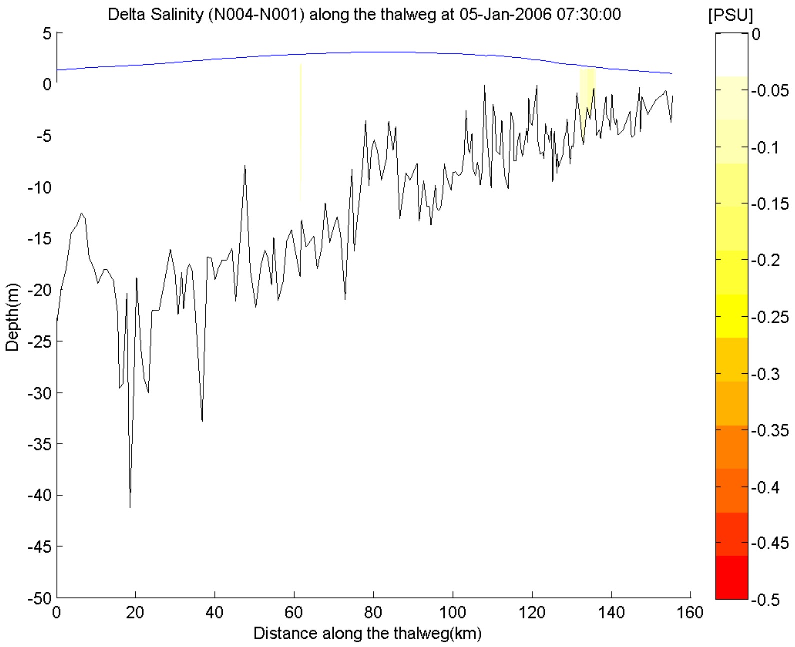

Figure 27 Drop of salinity (N001-N004) after 2 hours

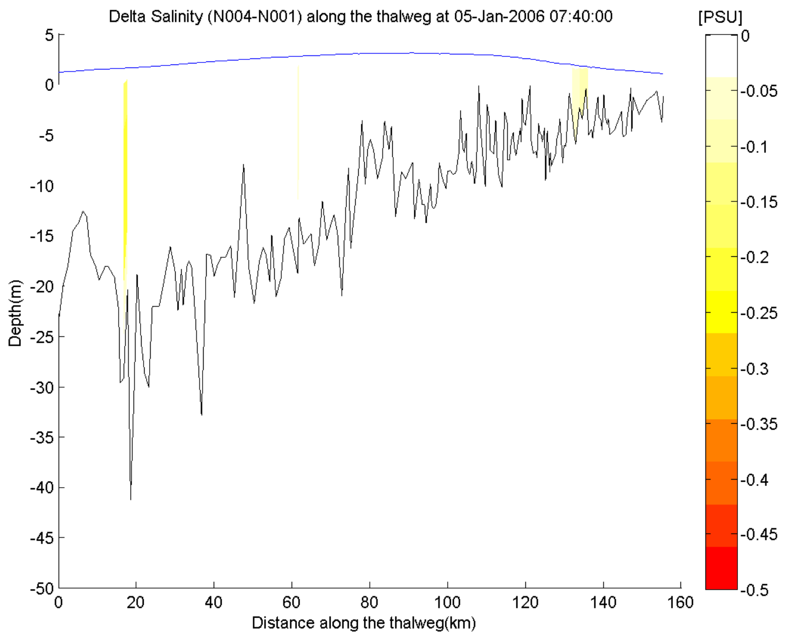

Figure 28 Drop of salinity (N001-N004) 2hrs after the start

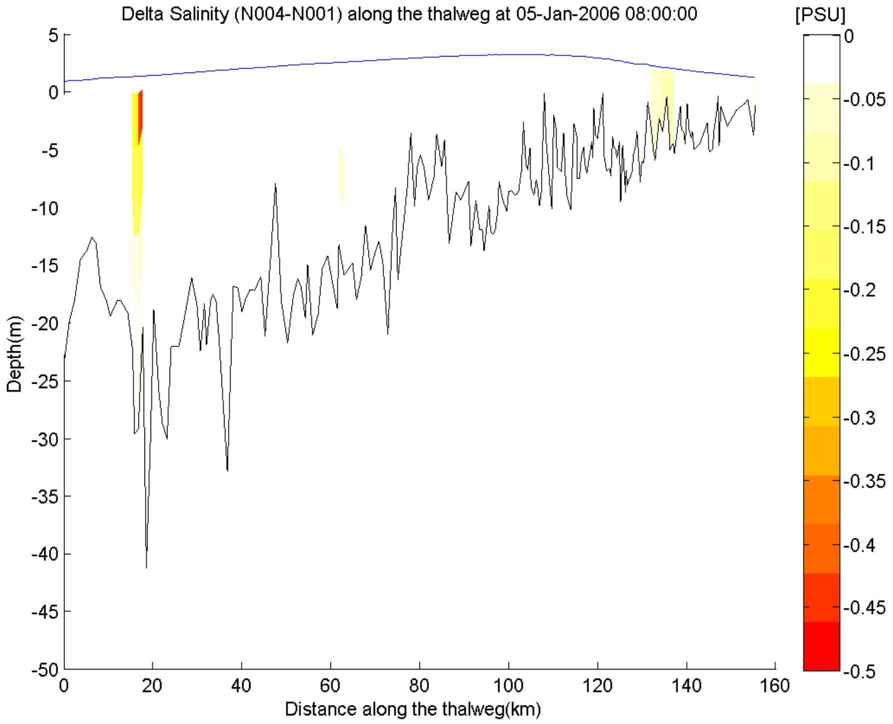

Figure 29 Drop of salinity (N001-N004) after 2.30hrs

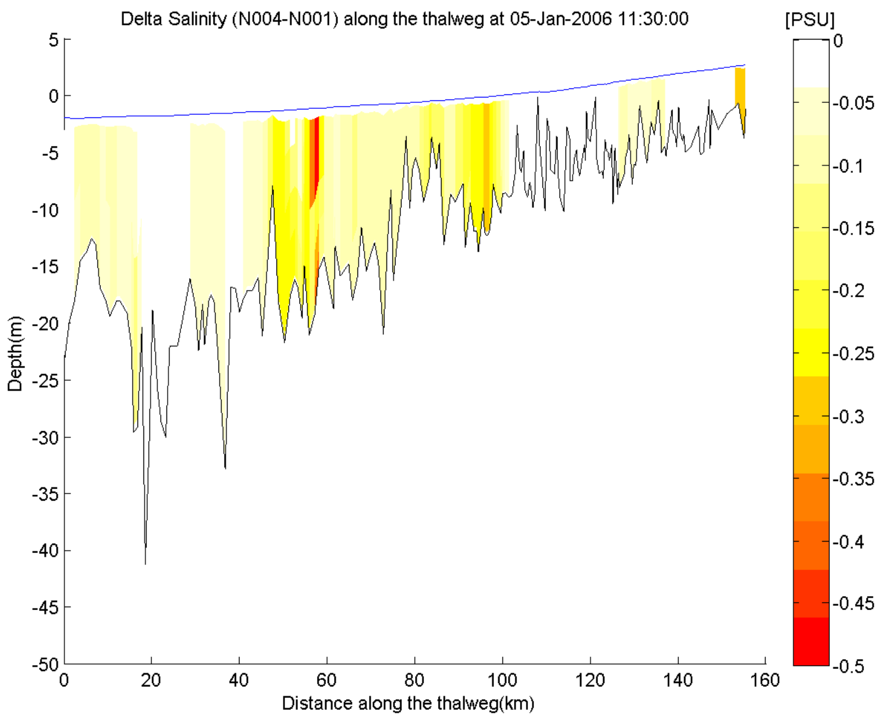

Figure 30 Drop of salinity (N001-N004) after 6hrs

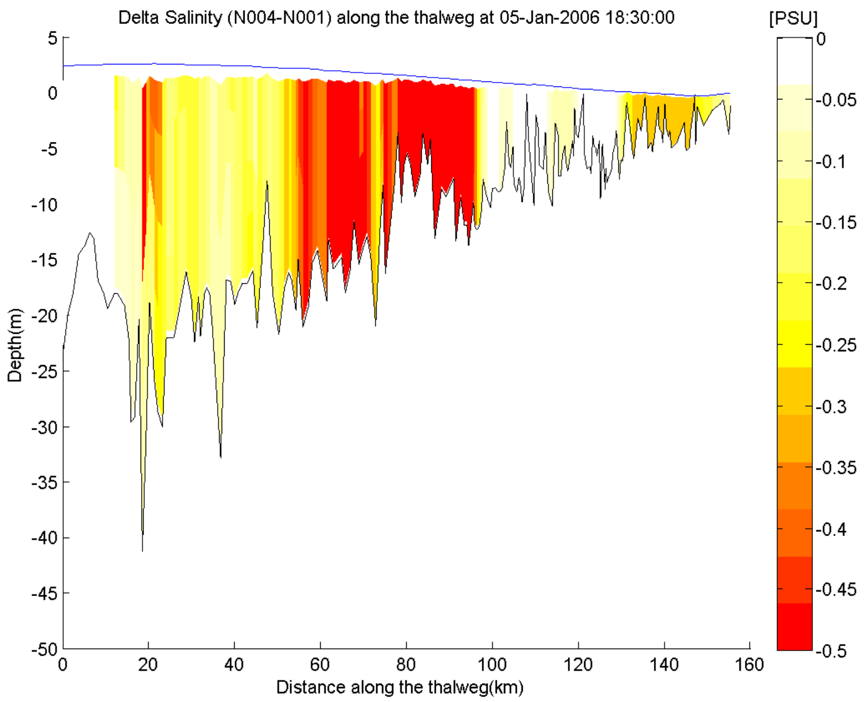

Figure 31 Drop of salinity (N001-N004) after 13hrs

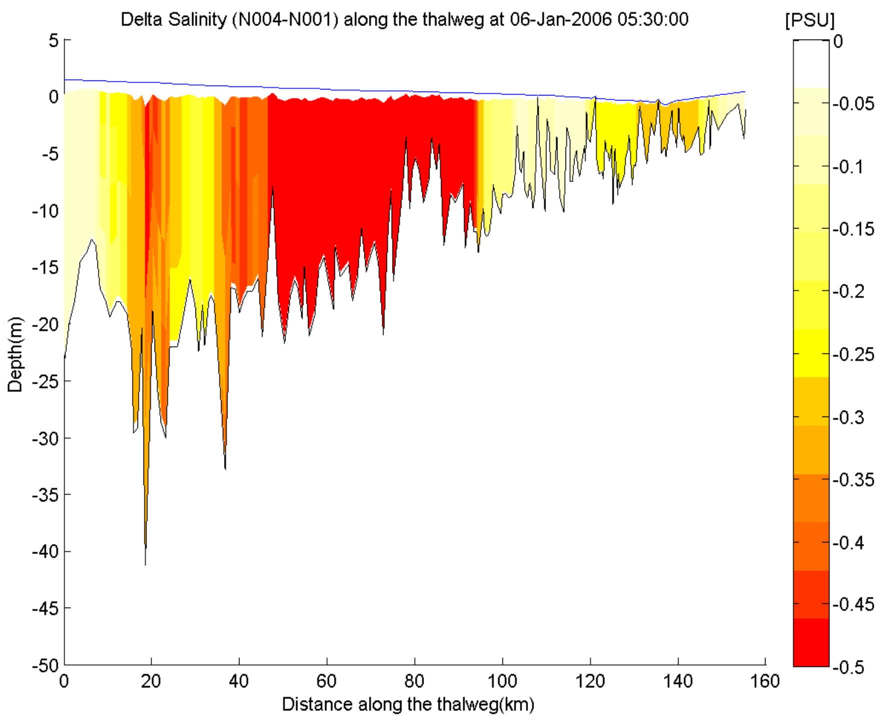

Figure 32 Drop of salinity (N001-N004) after one day

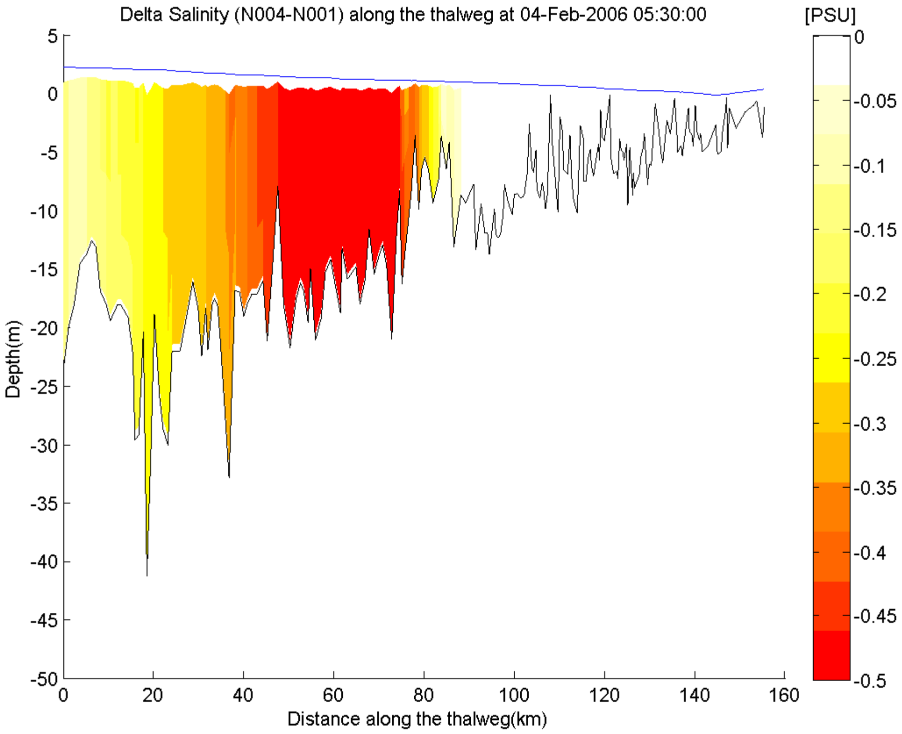

Figure 33 Drop of salinity (N001-N004) after one month

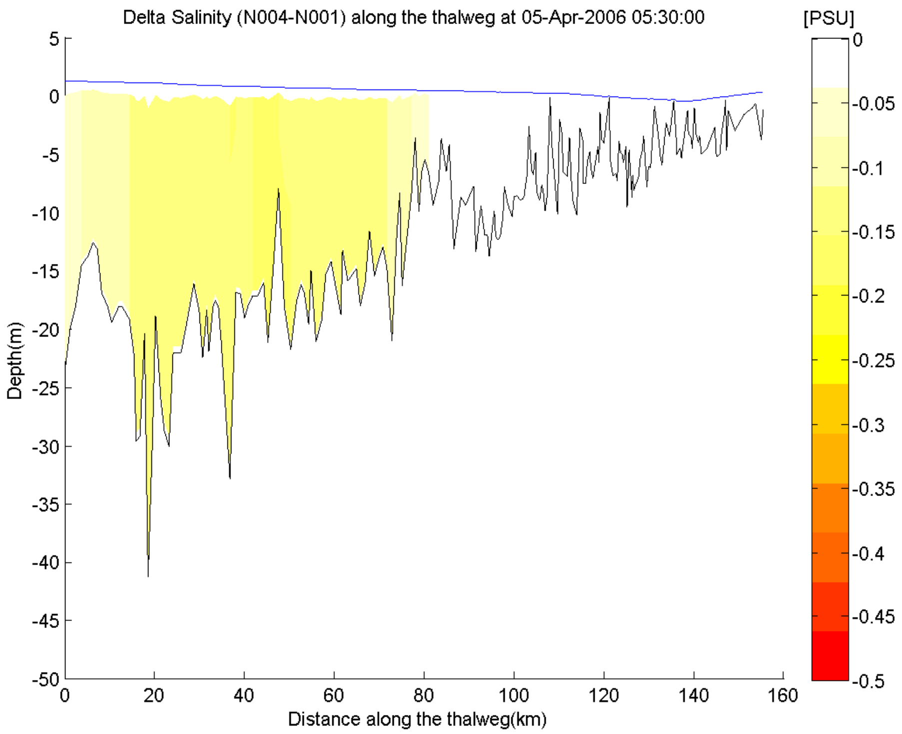

Figure 34 Drop of salinity (N001-N004) after three months

5. Summary and Conclusions

To investigate the effect of the fresh water discharges upstream in the Scheldt estuary three scenarios were set up. The reference scenario includes constant discharges at 8 river sources taken as the mean annual discharge for the year 2006. A scenario with doubled discharges (N002) and another one with half reduced discharges (N003) are implemented. Simulations were carried out for a period of three months (January to April 2006). From these simulations the following can be concluded:

- The fresh water inflow from the river results to a gradual fall of the salinity from 30psu in the mouth to zero upstream (inside the river tributaries).
- When the river flow is twice higher (N002), salinity in the river drops faster than in N001. Maximum difference between N001 and N002 is 5psu and occurs in Land van Saeftinghe.
- When the river discharge is doubled then salinity drops faster, reaching salinity levels of the reference case 10km to 20km more downstream.
- In scenario N002 salinity has reached already zero upstream of Antwerp.
- When the river flow is half reduced (N003), salinity in the river drops slower than N001. Maximum difference between N001 and N003 is 5psu and occurs in Antwerp.
- In scenario N003 salinity is reaching zero in Schelle. This is 20km further than in N002.
- When the river discharge is half reduced, then salinity drops slower reaching salinity levels of the reference case 10km to 20km more upstream.
- The magnitude of increase and decrease of salinities between the two scenarios and the reference one is equal (5psu).

In the second stage, a discharge peak 10 times higher than the reference condition is implemented in a new scenario. This peak is active only for the first day of simulation. From that simulation it can be deduced:

- The peak causes a drop of salinity in the areas close to the river discharges stations.
- The effect of the peak becomes active in Dendermonde 90 minutes after the start. After two hours of simulation, the effect has started being noticed in every discharge location.
- The peak effect is being transported through the river and develops enough during the first day of simulation.
- The peak effect is off higher magnitude 60km to 100km from the mouth. Outside this zone, either the tide or the fresh water intrusion decrease salinity levels.
- The peak effect reaches a maximum at the end of the first day when the peak is removed and then starts to drop gradually till the end.
- The difference in salinity between N001 and N004 becomes zero after a few days upstream of Schelle where the river flow is more dominant.
- The effect of the peak is still noticeable between Terneuzen and Antwerp even after 3 months More time is then needed to return to the reference situation.

The 10 times higher discharge is causing a small difference (less than 1psu) in salinities between the two scenarios.

The results of this study can be used to model sediment transport in DELWAQ, in order to investigate the effect of fresh water inflow on (cohesive) sediment transport, through changes in estuarine circulation.

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