Oplegnotitie

Aan
TKI-Deltatechnologie, SmartPort, Havenbedrijf Rotterdam

Datum	**Kenmerk**	**Aantal pagina's**
19 februari 2018	11201209-000-ZWS-0004	2
Van	**Doorkiesnummer**	**E-mail**
Rolien van der Mark	+31(0)88 335 7646	Rolien.vanderMark@deltares.nl

Onderwerp
Verkenning CoVadem voor het Havenbedrijf Rotterdam

1.1 Achtergrond

De slimste en beste haven ter wereld. Dat wil Rotterdam in 2030 zijn. Europa's belangrijkste haven- en industrieel complex, koploper op het gebied van effectiviteit, kwaliteit en duurzaamheid. SmartPort heeft op basis van deze ambitie een programma opgezet waar samen met bedrijven, kennisinstellingen en het havenbedrijf Rotterdam verschillende onderzoeksprojecten worden opgestart. SmartPort treedt hierbij op als aanjager, organisator en financier van kennisontwikkeling en kennisdisseminatie in het havengebied in Rotterdam.

Vanuit deze achtergrond zijn er met het Havenbedrijf Rotterdam (HbR) / Smartport gesprekken gevoerd om te bezien of de CoVadem data van meerwaarde kunnen zijn om deze ambitie verdere invulling te geven. CoVadem (Coöperatieve Vaardiepte- en performance Meting) is een gezamenlijk initiatief vanuit MARIN, Deltares, BTB en Autena Marine voor een betrouwbare en moderne data- & informatiedienst voor alle vaarwegbeheerders en -gebruikers. In 2014 is het project CoVadem geïnitieerd met de inwinning en benutting van scheepsgegevens vanuit de binnenvaart. De informatie is gebaseerd op een netwerk van schepen die continue kielspeling en performance meten door echolood, beladingsmeter en GPS automatisch met elkaar te verbinden. Een beperkt gedeelte van de vloot is uitgerust met brandstofverbruikssensoren.

Afgelopen jaren is de geschiktheid van deze CoVadem meetgegevens getoetst aan multibeam metingen voor een beter inzicht in de morfologische ontwikkeling in het rivierengebied (Van der Mark et al., 2015). Recentelijk is een pilot uitgevoerd samen met Van Oord N.V. om te verkennen of de CoVadem metingen in combinatie met een morfologisch riviermodel toegevoegde waarde heeft bij het efficiënt en effectief onderhouden van de vaargeul in de rivier (Van der Mark, 2017). De resultaten waren positief.

1.2 CoVadem en Havenbedrijf Rotterdam

Een logische vervolgstap is nu om te bezien in hoeverre de CoVadem metingen voor het HbR toegevoegde waarde hebben. Daartoe is een gezamenlijk project (DEL059) opgezet met TKI-Deltatechnologie financiering, een cash bijdrage van SmartPort en een in-kind bijdrage van het HbR, waarin de volgende doelstelling is geformuleerd:

Doel is het bepalen van de bruikbaarheid en het perspectief van de CoVadem data voor het Havenbedrijf Rotterdam met betrekking tot bodemligging en luchtemissie, met het oog op effectief asset management, betere benutting van de infrastructuur, en de ambitie op het gebied van duurzaamheid.

1.3 Activiteiten

In gezamenlijk overleg tussen de TKI-partners Deltares, MARIN, HbR en SmartPort, zijn de volgende activiteiten gedefinieerd:

1. Verkennend onderzoek naar de bruikbaarheid (dekkingsgraad, nauwkeurigheid) van de uit scheepsgegevens afgeleide bodemligging ter ondersteuning van reguliere bodempeilingen en de bepaling van de onderhoudsbehoefte in de havenbekkens (trekker Deltares);
2. Verkenning naar verband tussen hydro-meteo condities en havenaanslibbing (trekker Deltares);
3. Uitrusten van een aantal HbR patrouilleschepen (RPA's) met een CoVadem-box, zodat de frequentie en dichtheid van de scheepsgegevens in het havengebied verder toenemen (trekker MARIN);
4. Onderzoek naar welke bijdrage de CoVadem data kan leveren aan het onderbouwen van aannames in het te ontwikkelen luchtemissiemodel voor de binnenvaart door HbR (trekker MARIN).

1.4 Rapportages

Elke activiteit heeft geresulteerd in een rapportage. De volgende rapportages zijn gemaakt:

1. Niesten, I. & R. van der Mark (2018). Verkenning naar de bruikbaarheid van CoVadem meetgegevens voor Havenbedrijf Rotterdam. Deltares-rapport met kenmerk 11201209-001-ZWS-0002.
2. Meshkati Shahmirzadi, M.E. & T. van Kessel (2018). Sedimentation in Achtste Petroleumhaven, Botlekhaven and Waalhaven within the first 6 months of 2017. Deltares-memo met kenmerk 11201209-003-ZWS-001.
3. Wirdum Van, M. & R. van der Mark (2018). Uitrusten van HbR patrouilleschepen met een CoVadem-box. Memo met kenmerk 11201209-002-ZWS-0001.
4. Cotteleer, A. (2017). CoVadem Eindrapport Onderdeel Emissies TKI HbR. MARIN-rapport.

Voorliggend document betreft activiteit / rapportage 2.

Memo

Aan
TKI-Deltatechnologie, SmartPort, Havenbedrijf Rotterdam

Datum	**Kenmerk**	**Aantal pagina's**
20 februari 2018	11201209-003-ZWS-0001	19
Van	**Doorkiesnummer**	**E-mail**
Ebi Meshkati Shahmirzadi Thijs van Kessel	+31(0)88 335 7965	ebi.meshkatishahmirzadi@deltares.nl

Onderwerp
Verkenning naar verband tussen hydro-meteo condities en sedimentatie

---

Sedimentation in Achtste Petroleumhaven , Botlekhaven and Waalhaven within the first 6 months of 2017

Summary
The Port of Rotterdam experiences sedimentation rates and the formation of soft fluid mud layers in its basins and access channels, which lead to high maintenance costs. This report aims to investigate the possible correlation between physical parameters such as water level, wind, wave and salinity, and the amount of sedimentation in three basins of the Port of Rotterdam (namely Achtste Petroleumhaven, Botlekhaven and Waalhaven) within the time window of 1st January 2017 to 1st July 2017. Due to a lack of sufficient data we could not provide a statistical analysis but an attempt was made to at least highlight those physical parameters that may play a role in the sedimentation. Among all studied physical parameters it was found that wave intensity and salinity may be steering factors for the sedimentation volume.

Version	Date	Author
1	Feb. 2018	M. E. Meshkati Shahmirzadi
		Thijs van Kessel

1 Introduction

The Port of Rotterdam suffers from high sedimentation rates and the formation of soft fluid mud layers in its basins and access channels, which lead to high maintenance costs. Therefore, the third task in the CoVadem project is devoted to the understanding and quantification of the processes responsible for sedimentation in three main basins of the Port of Rotterdam, i.e. Achtste Petroleumhaven, Botlekhaven and Waalhaven. The original idea was to investigate the possible correlation between physical parameters such as water level, wind (velocities) and salinity (conductivity), and the amount of sedimentation using high-frequency CoVadem data. However, task number 2 in the current CoVadem project revealed that the CoVadem data are lacking sufficient accuracy and need further improvement before being used in the analysis of this study. Therefore, we decided to base the analysis in this study only on the regular bathymetric surveys. Figure 1.1 depicts the Port of Rotterdam and its basins under study. The time window considered for the investigation is from 1st January 2017 to 1st July 2017. In this time window, the sedimentation is quantified and used for a statistical analysis on the relation between forcing factors (such as tide, wind, freshwater discharge and sediment supply) and sedimentation. A correlation coefficient quantifies the linear dependency between two parameters: one of the various physical parameters and the sedimentation.

Figure 1.1: Location of three basins (of the Port of Rotterdam) under study in yellow and the measurement stations in green.

2 Description of the physical parameters

In this section the physical parameters used for correlation coefficients analysis is described. The selection of these physical parameters was based on literature review and availability of data. The data types used in this study along with their respective measurement stations are as follow:

- Water level [cm relative to NAP] at Hoek van Holland and Parkhaven;
- Tidal amplitude [cm relative to NAP] at Hoek van Holland and Parkhaven;
- Wind velocity [m/s] and direction [degree] at Noorderpier and VCS Lekhaven;
- Wave heights [m] at Europlatform2 and Maeslantkering Zeezijde Noord Meetpaal;
- Salinity (Conductivity) [mg/l] at Hoek van Holland and Lekhaven;
- Suspended particulate matter (SPM) concentration [mg/l] at GOEREE2.

In Figure 1.1 all the measurement stations are marked (except Europlatform 2 which is located offshore at 3.28 E, 52 N) namely: Hoek van Holland as HOEK, Noorderpier as NRDP, Lekhaven as LEKH, Parkhaven as PARK and Maeslantkering Zeezijde Noord Meetpaal as MZNM.

2.1 Water level

Figure 2.1 and Figure 2.2 show the variation of water level with time at HOEK and PARK within the selected period. The red, green and blue line in this figure indicates the daily maximum, mean and minimum water level respectively. These records suggest that the water level has relatively higher peaks in January (related to storm surge) compared to the other months of the study period.

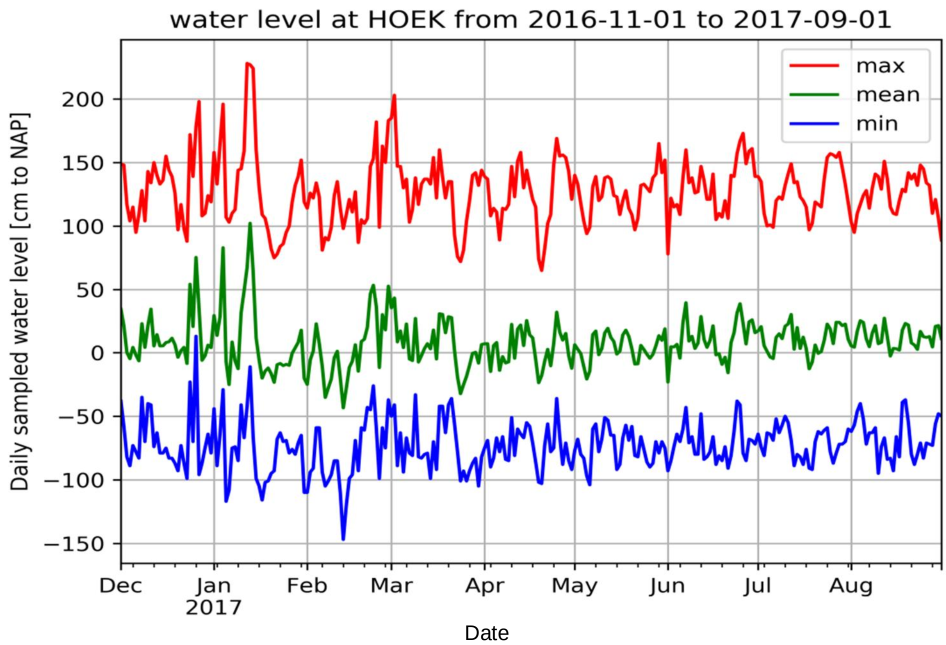


Figure 2.1 Daily sampled max, mean and min water level at HOEK.

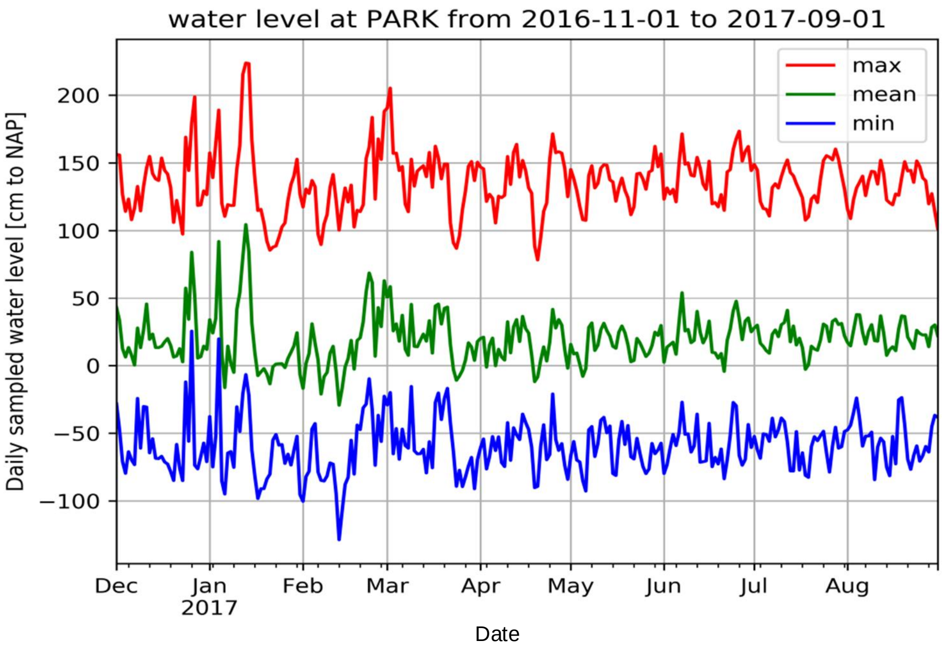


Figure 2.2 Daily sampled max, mean and min water level at PARK.

2.2 Wind

Wind data measured at NRDP and VCSL are used in this study. Wind data includes both wind velocity and wind direction. Figure 2.3 and Figure 2.4 depict respectively the change in wind velocity and wind direction at NRDP as time progresses. The variation of wind velocity at VCSL is found to be very similar to NRDP. In these figures, red, green and blue line indicates the daily maximum, mean and minimum velocity of wind. Wind velocity data depicts substantial fluctuations over the time window of this study with no clear seasonal change.

Figure 2.5 and Figure 2.6 are histograms of wind direction at VCSL and NRDP within the time window under study. These figures are made to provide us with an impression of the wind distribution. Wind direction data is provided in degree ranging from 0 to 360 with time resolution of 10 minutes. The width of bins in these histograms is equal to 22.5 degree. Thus the distribution of wind over 16 different sectors is investigated. It is found that for both stations, VCSL and NRDP, the most frequently occurring wind direction is south west (from 180 to 270 degree).

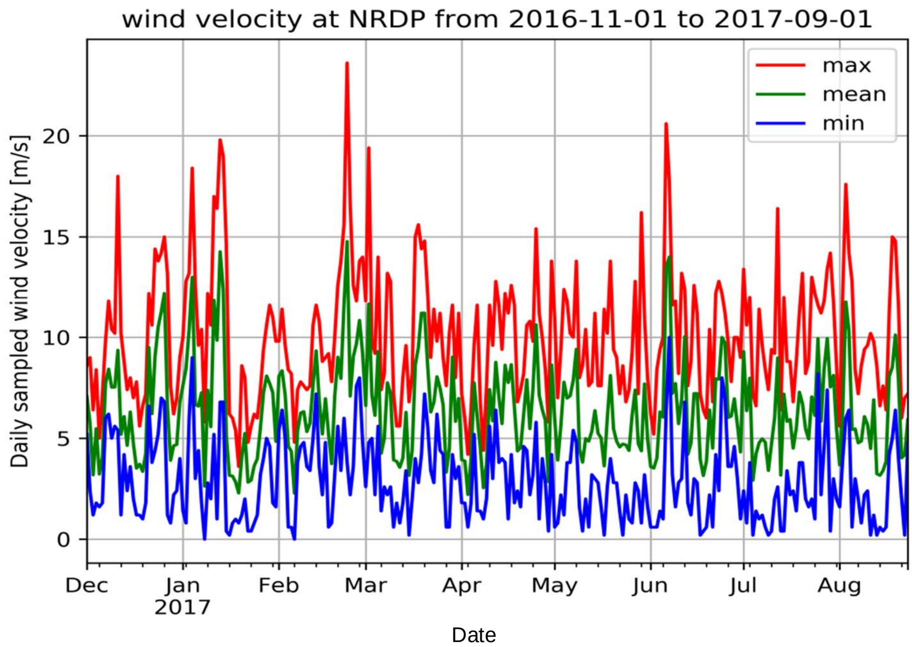


Figure 2.3 *Daily sampled max, mean and min wind velocity at NRDP.*

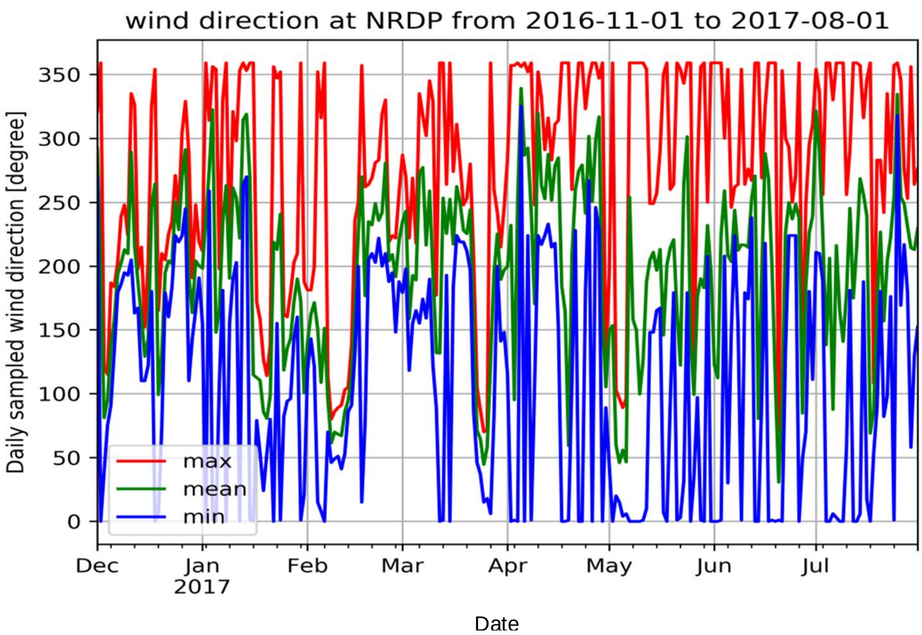


Figure 2.4 *Daily sampled max, mean and min wind direction at NRDP.*

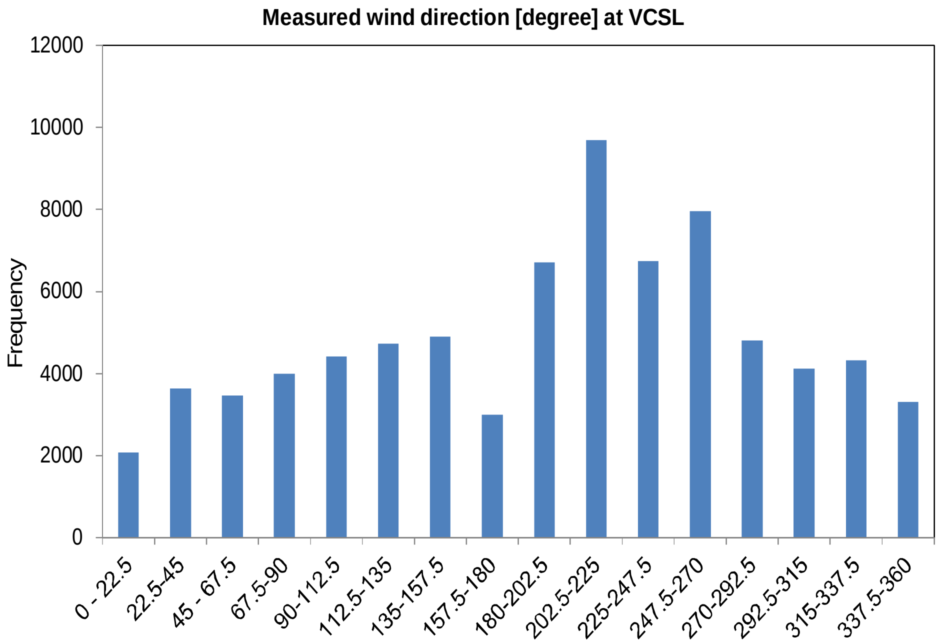


Figure 2.5 *Histogram of wind direction (measurement every 10 minutes) at VCSL.*

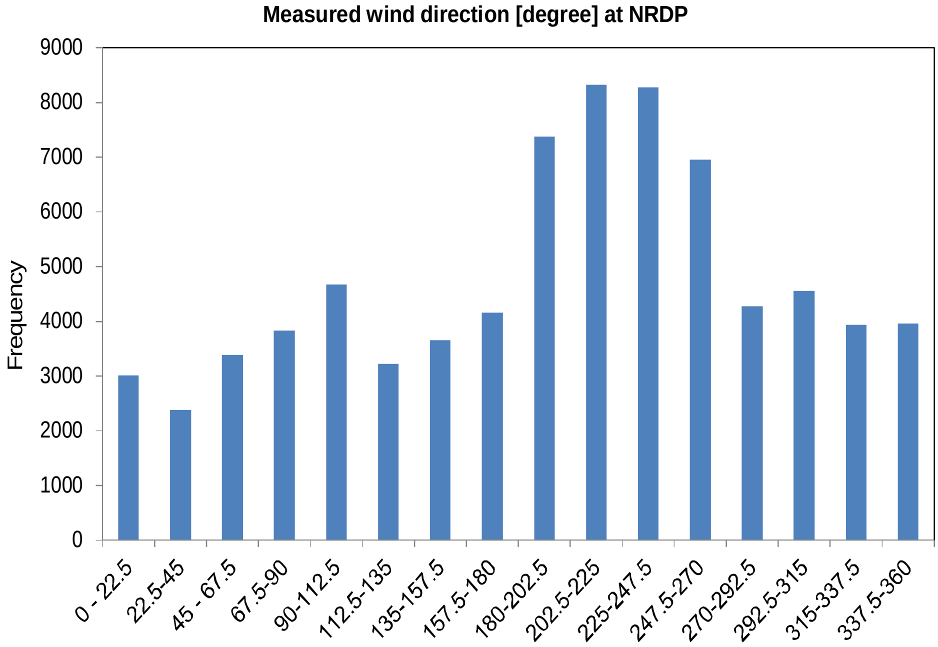


Figure 2.6 *Histogram of wind direction (measurement every 10 minutes) at NRDP.*

2.3 Waves

Measured wave height (Hm0 [cm] value, which has been stored in Matroos Deltares: http://matroos.deltares.nl/timeseries/start/) at Europlatfrom2 (located offshore) and at Maeslantkering Zeezijde Noord Meetpaal (located inland) are used in this study (see in Figure 2.7and Figure 2.8). Obviously, the magnitude and variation of wave height at inner part of the port of Rotterdam (inland side) is much lower than the recorded offshore wave height.

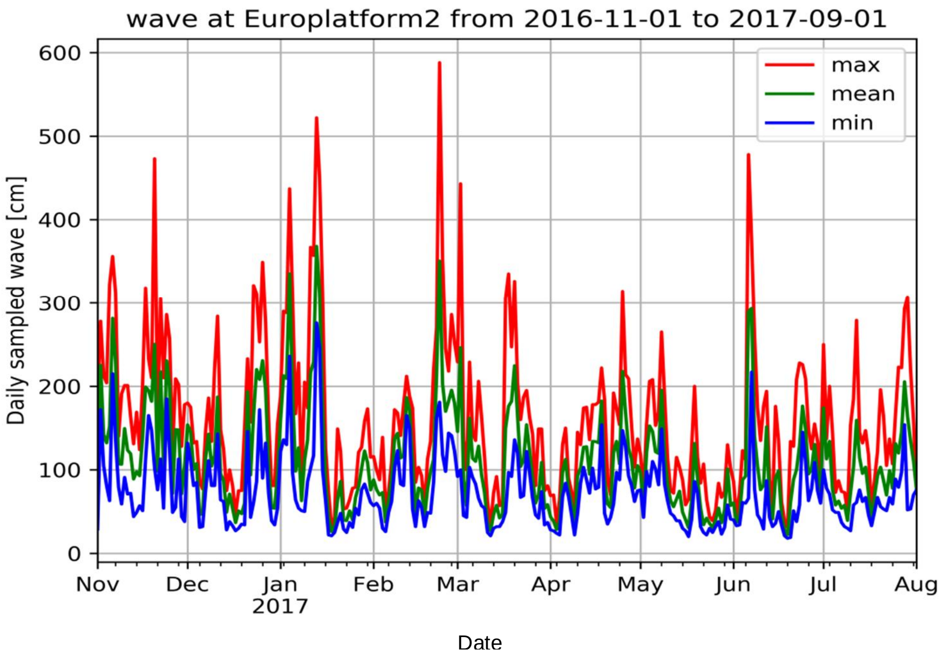


Figure 2.7 *Daily sampled max, mean and min wave height at Europlatform2.*

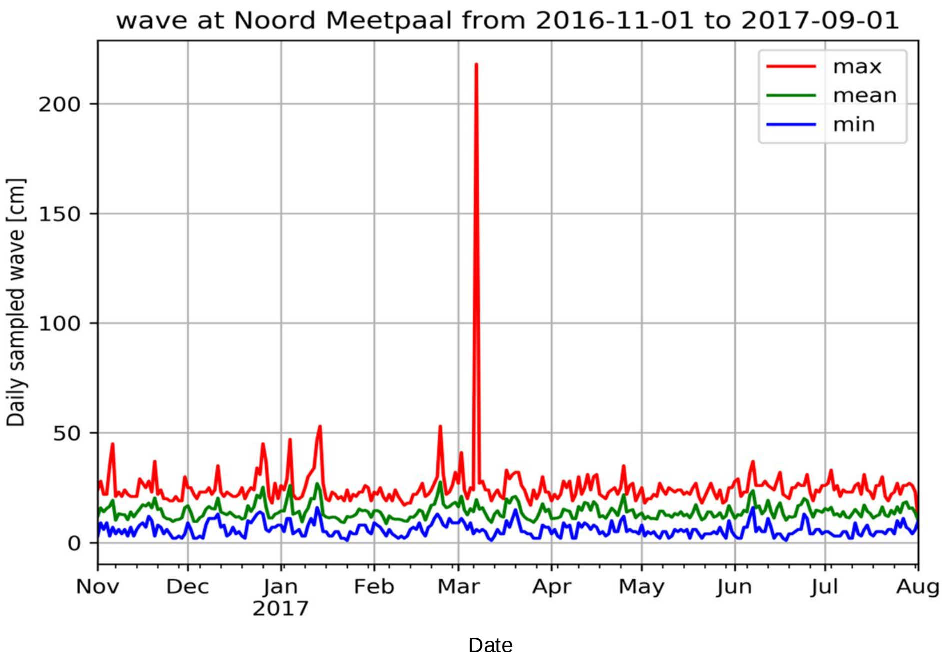


Figure 2.8 *Daily sampled max, mean and min wave height at Maeslantkering Zeezijde Noord Meetpaal.*

2.4 Salinity

Figure 2.9 and Figure 2.10 illustrate the variation of salinity with time at HOEK and LEKH. It is found that the daily change in salinity at HOEK (which is closer to the river mouth at the port of Rotterdam) is much larger than the change in salinity at LEKH (which is located at much upstream from the river mouth).

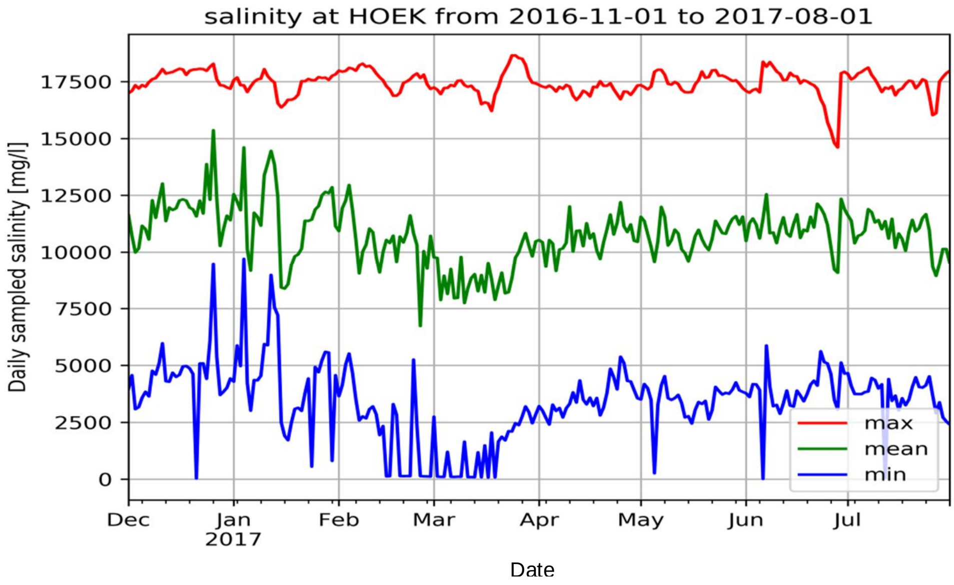


Figure 2.9 *Daily sampled max, mean and min salinity at HOEK.*

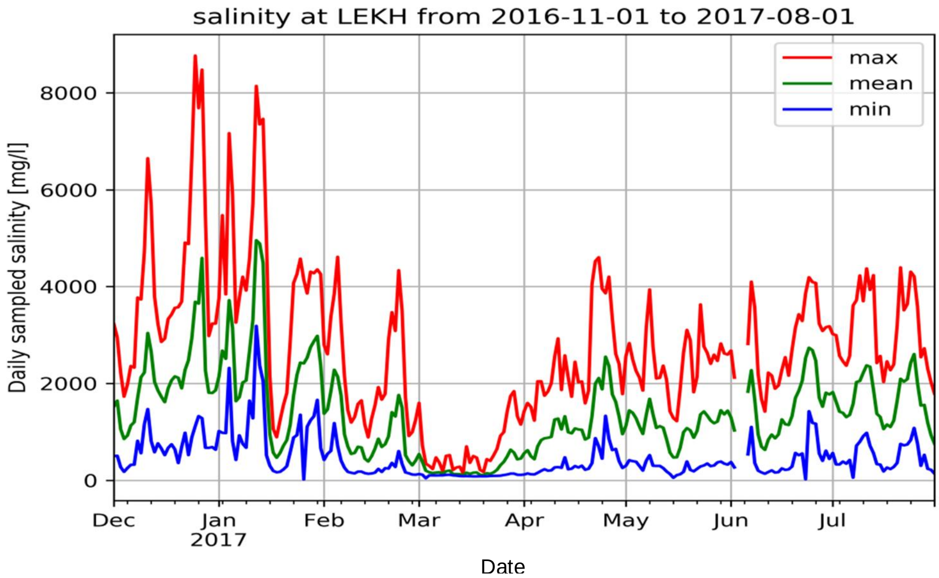


Figure 2.10 *Daily sampled max, mean and min salinity at LEKH.*

2.5 Suspended particulate matter (SPM) concentration

Figure 2.11 shows the variation of suspended particle matter (SPM) with time at GOERE2. A limited measured SPM data points were available (only one per month).

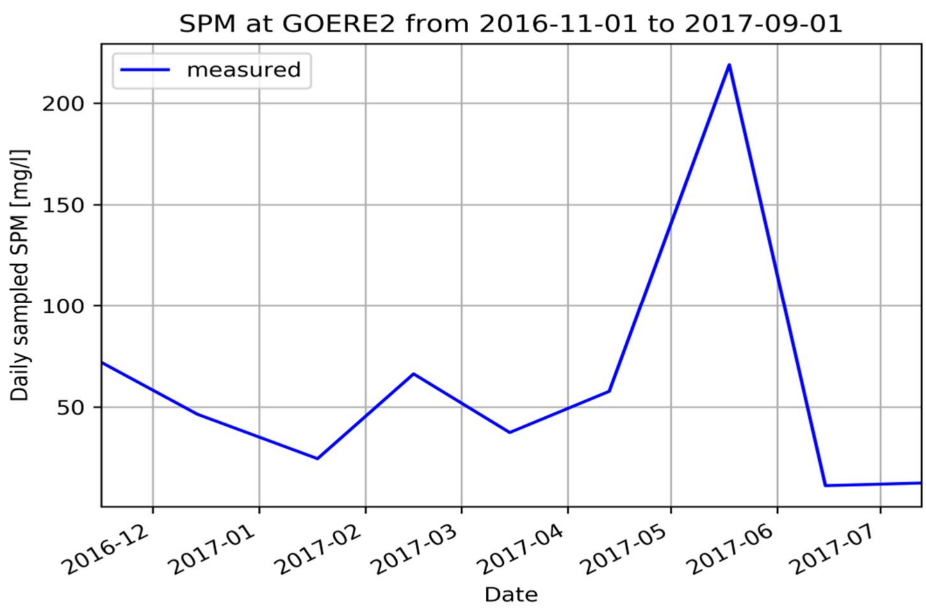


Figure 2.11 SPM concentration at GOERE2.

3 Results

3.1 Determination of sedimentation

The sedimentation is determined by means of a volume balance, in which use is made of multibeam survey data and dredged quantities. The dredging quantities are supplied by the port of Rotterdam. Gridded multibeam elevation data (1x1 m resolution, horizontal datum: RD New, vertical datum: m NAP) were imported into ArcMap as points and converted to rasters. For each study area, the rasters were overlayed to make a mask identifying which grid cells had data for all time steps. Each of the rasters was then clipped to the mask extent to ensure a constant area over which the volume calculations were performed. Change rasters were calculated by subtracting sequential rasters (t2 – t1) and visualized in map form. Volume changes were calculated using the Cut Fill tool in ArcMap, which summarizes the areas and volumes of change between two surfaces. Figure 3.1 and Figure 3.2 are examples of final product after subtracting two successive multibeam survey data. In these figures the dredging works can be clearly observed. The estimated volume change and sediment deposition volume for each basin under study can be found in Table 3.1.

Table 3.1: Volume change estimated by Cut Fill tool in ArcMap and volume removed due to dredging between sequential multi-beam surveys.

Basin name	Time between two successive surveys	Volume changed [m3]**	Volume removed by dredging [m3]**	Total sediment deposition [m3]**
Achtste Petroleum haven	From 21-12-16 to 07-02-17	- 3217	-64455	61238
	From 07-02-17 to 24-03-17	-12459	-114353	101894
	From 24-03-17 to 16-05-17	87510	-10730	98240
	From 16-05-17 to 29-06-17	-62048	-21481	-40567
Botlek	From 27-12-16 to 30-01-17	-19	-8760	8741
	Form 30-01-17 to 01-03-17	26027	-41449	67476
	From 01-03-17 to 29-03-17	39486	-9365	48851
	From 29-03-17 to 03-05-17	-32524	0	-32524
	From 03-05-17 to 21-05-17	2530	0	2530
	From 21-05-17 to 30-06-17	-19816	0	-19816
Waalhaven - S	From 21-01-17 to 31-03-17	18616	0	18616
	From 31-03-17 to 15-06-17	-9135	-6242	-2893
Waalhaven - N	From 01-11-16 to 07-02-17	20278	-13685	33963
	From 07-02-17 to 17-05-17	57856	-10593	68499

**: + deposited, - removed

Botlek: Change T4 (29-03-2017) to T5 (03-05-2017)

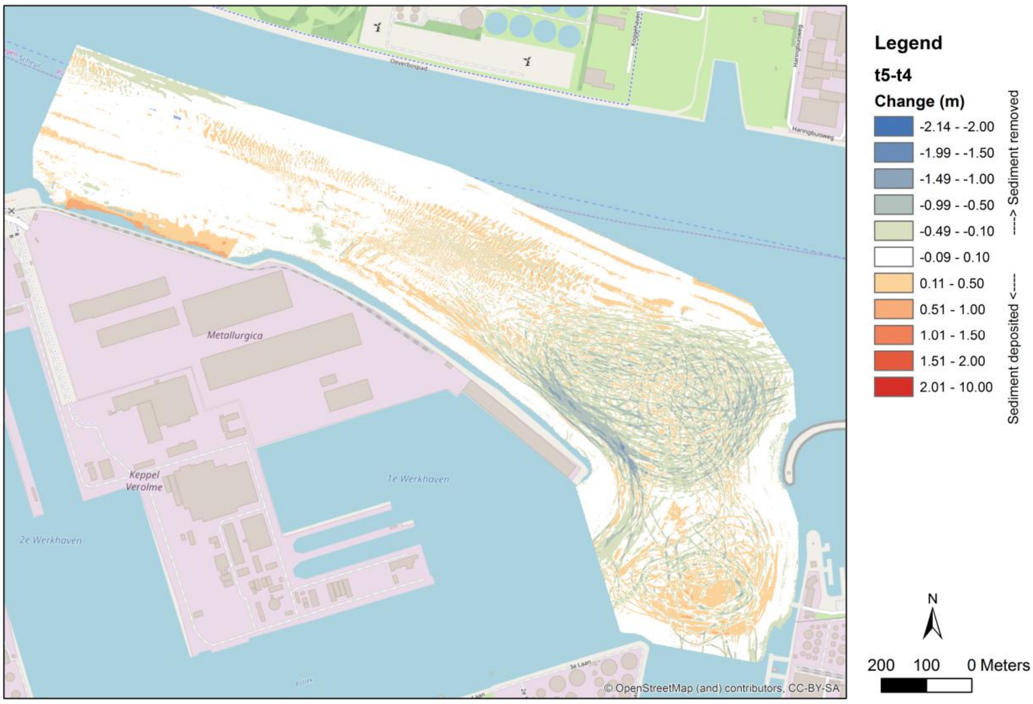


Figure 3.1: Change in bathymetry of bed at Botlek harbour from 29-03-17 to 03-05-17.

Achtste: Change T4 (16-05-2017) to T5 (29-06-2017)

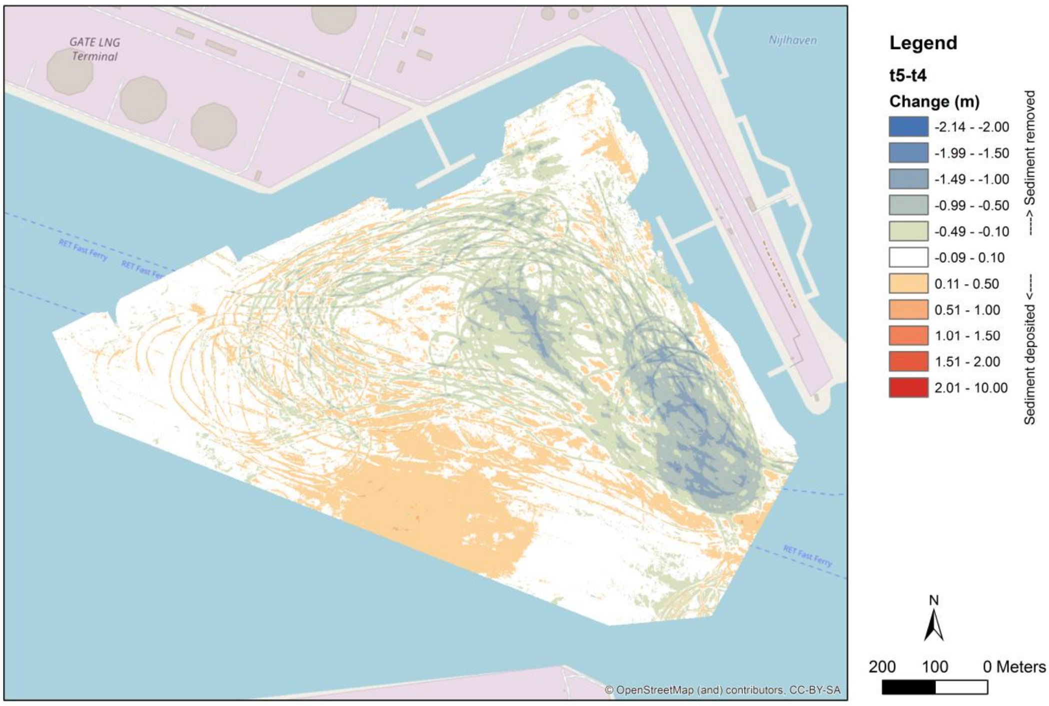


Figure 3.2: Change in bathymetry of bed at Achtste Petroleumhaven harbour from 16-05-17 to 29-06-17.

Figure 3.3 shows the variation of average daily sedimentation versus time. During winter, the average daily sedimentation in Achtste Petroleumhaven is much larger than Botlek and Waalhaven harbours. This can be related to the fact that Achtste Petroleumhaven is located close to the river mouth, facing towards North Sea. During the first six months of the year 2017, both Waalhaven–S and –N (–S= south, –N= north) harbours had much less sedimentation compared to Achtste Petroleumhaven and Botlek harbour. From the beginning of spring towards the middle of June, the sedimentation in the harbour of Achtste Petroleumhaven, Botlek and Waalhaven–S markedly lower. It is even found that the sediment volume in these harbours decreases (corrected for dredging activities). This natural removal of sediment was stronger during the second half of spring. It seems the sedimentation pattern in the harbour of Achtste Petroleumhaven and Botlek is similar to each other from the second half of the winter onwards. Seasonal effect on sedimentation can be observed from the results.

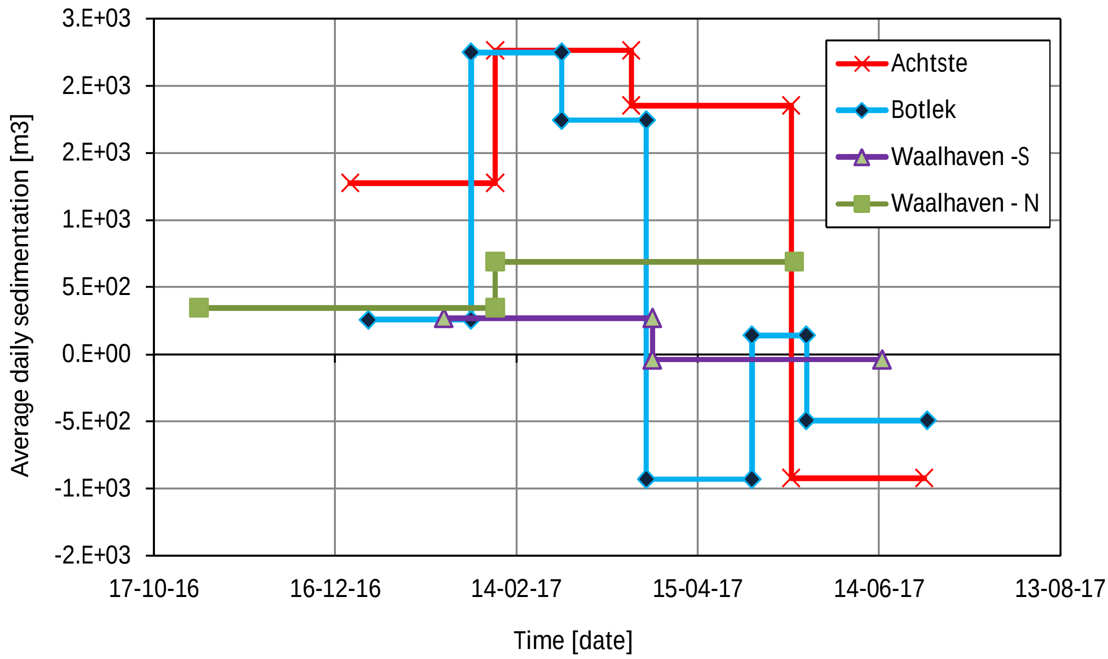


Figure 3.3: Average daily sedimentation volume.

Table 3.2 provides the sedimentation rate in the basins under study between each successive multibeam survey. As can be seen the sedimentation rate in both Waalhaven –S and Waalhaven –N is about an order of magnitude lower than the sedimentation rate in Achtste Petroleumhaven. The seasonal variation of sedimentation in Botlek is stronger compared to other basins.

Table 3.2: Sedimentation rate per period in the basins under study.

Basin name	Time between two successive surveys	Sedimentation rate [cm/day]
Achtste Petroleumhaven	21-12-16 to 07-02-17	0.160
	07-02-17 to 24-03-17	0.284
	24-03-17 to 16-05-17	0.233
	16-05-17 to 29-06-17	-0.116
Botlek haven	27-12-16 to 30-01-17	0.033
	30-01-17 to 01-03-17	0.286
	01-03-17 to 29-03-17	0.222
	29-03-17 to 03-05-17	-0.118
	03-05-17 to 21-05-17	0.017
	21-05-2017 to 30-06-17	-0.063
Waalhaven -S	21-01-17 to 31-03-17	0.025
	31-03-17 to 15-06-17	- 0.001
Waalhaven -N	01-11-2016 to 07-02-17	0.029
	07-02-17 to 17-05-2017	0.063

3.2 Effect of water level on sedimentation

The correlation between several indication of water level and sedimentation volume for the basins under study is investigated. These indications of water level include the:

- maximum water level;
- minimum water level;
- mean water level;
- cumulative tidal amplitude;
- maximum tidal amplitude between two surveys.

Among all these different interpretations of water level, only the cumulative tidal amplitude showed a (weak) association with the sedimentation volume. For this reason only the variation between the cumulative tidal amplitude and the sedimentation volume is presented (see in Figure 3.4 and Figure 3.5). As can be seen, different basins showed different relationship with their cumulative tidal amplitude. Note that since too few data points is used, hardly any conclusion can be made for the correlation between the cumulative tidal amplitude and sedimentation volume.

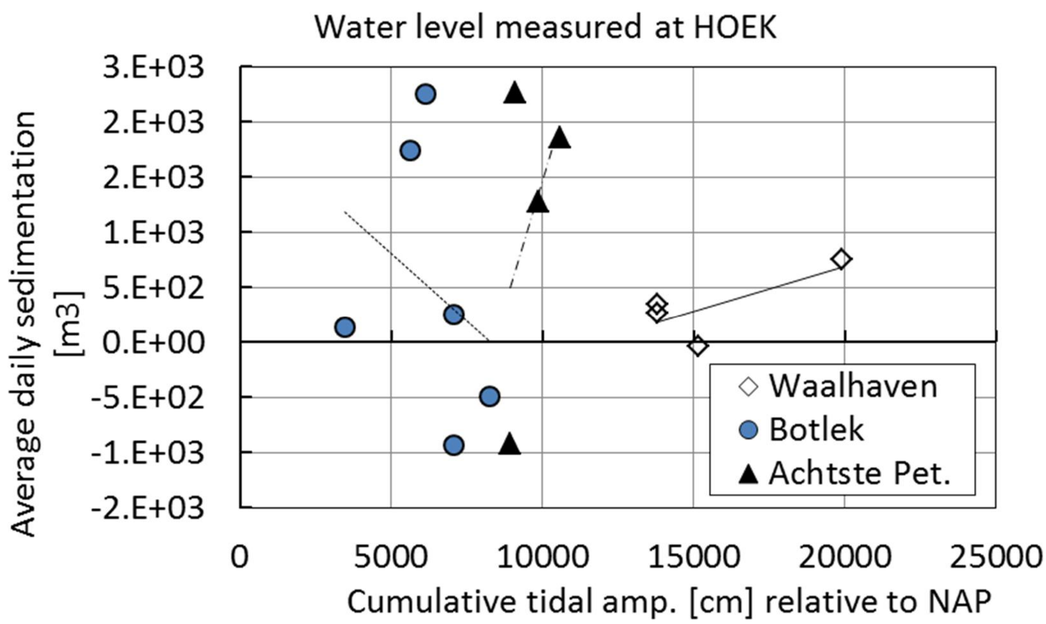
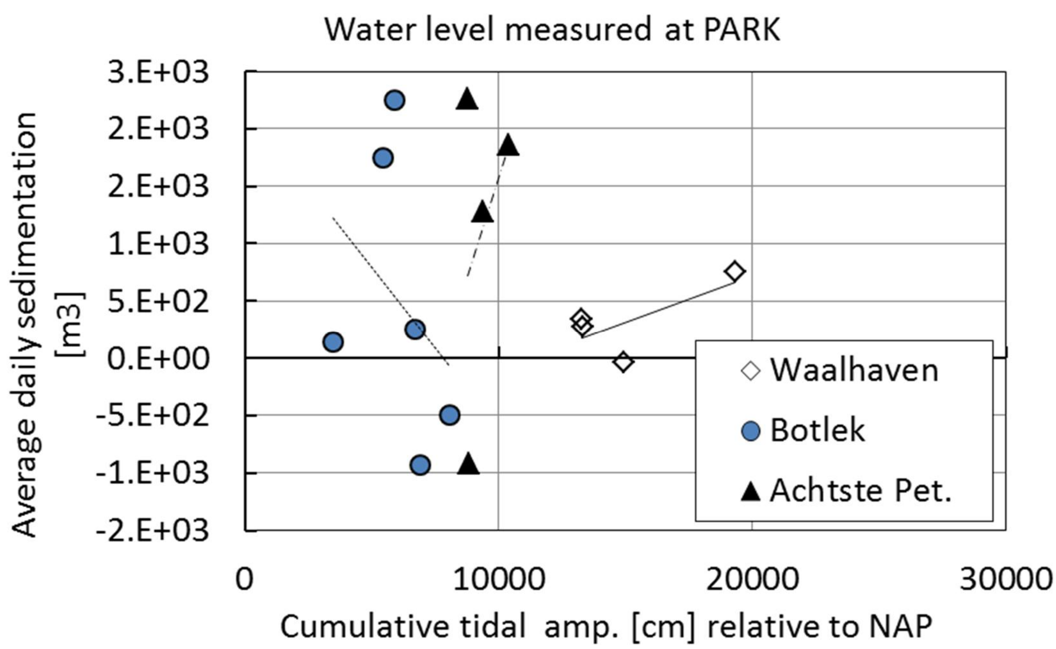


Figure 3.4 Cumulative tidal amplitude (calculated using water level data measured at HOEK) versus sedimentation volume at three different basins of the port of Rotterdam.



`

Figure 3.5 Cumulative tidal amplitude (calculated using water level data measured at PARK) versus sedimentation volume at three different basins of the port of Rotterdam.

3.3 Effect of wind on sedimentation

No clear association between the wind direction /velocity and the sedimentation volume could be found.

3.4 Effect of wave intensity

Previous researchers suggested that the wave energy may be a more proper measure than wave heights for prediction of amount of sedimentation. For this reason, the wave intensity per time period between two successive multibeam surveys is determined as the mean-square value of the wave heights and is plotted versus the sedimentation volume (see Figure 3.6 and Figure 3.7). The wave intensity (W_{in}) as proposed in Merckelbach (1996) can be calculated using the following equation:

$$W_{in} = \frac{\sum_{1}^{n}(h-hm)^2}{n} \text{ [cm2[} \qquad (1)$$

where h is the wave height, hm is the mean wave height per time period, n is the number of observations. A weak positive association between the wave intensity and the sedimentation volume is found using wave data from both Europlatform2 (Figure 3.6) and Maeslantkering Zeezijde Noord Meetpaal (Figure 3.7).

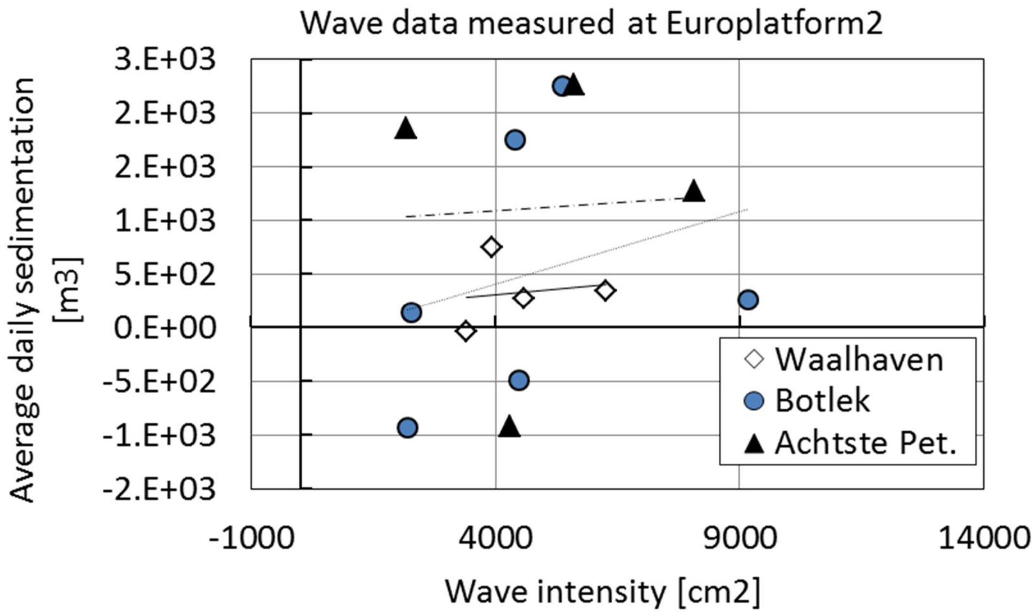


Figure 3.6 Wave intensity (calculated using wave height data measured at Europlatform2) versus sedimentation volume at three different basins of the port of Rotterdam.

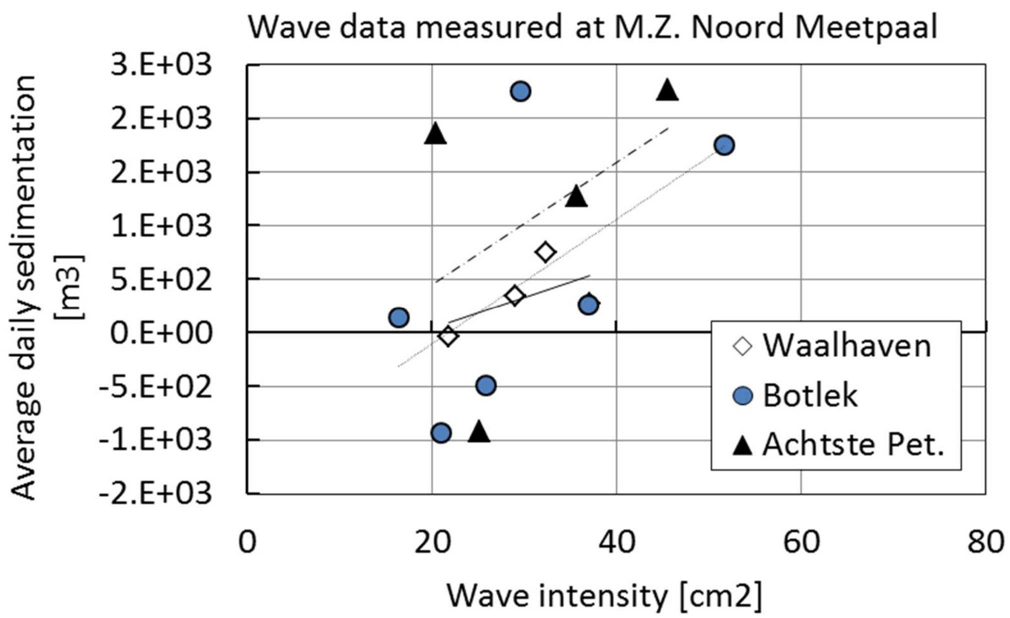


Figure 3.7 Wave intensity (calculated using wave height data measured at Maeslantkering Zeezijde Noord Meetpaal) versus sedimentation volume at three different basins of the port of Rotterdam.

3.5 Effect of salinity on sedimentation

The measured salinity data from both HOEK and LEKH are used to investigate possible association between the salinity and the sedimentation volume (Figure 3.8 and Figure 3.9). A weak negative association between salinity and sedimentation volume can be seen.

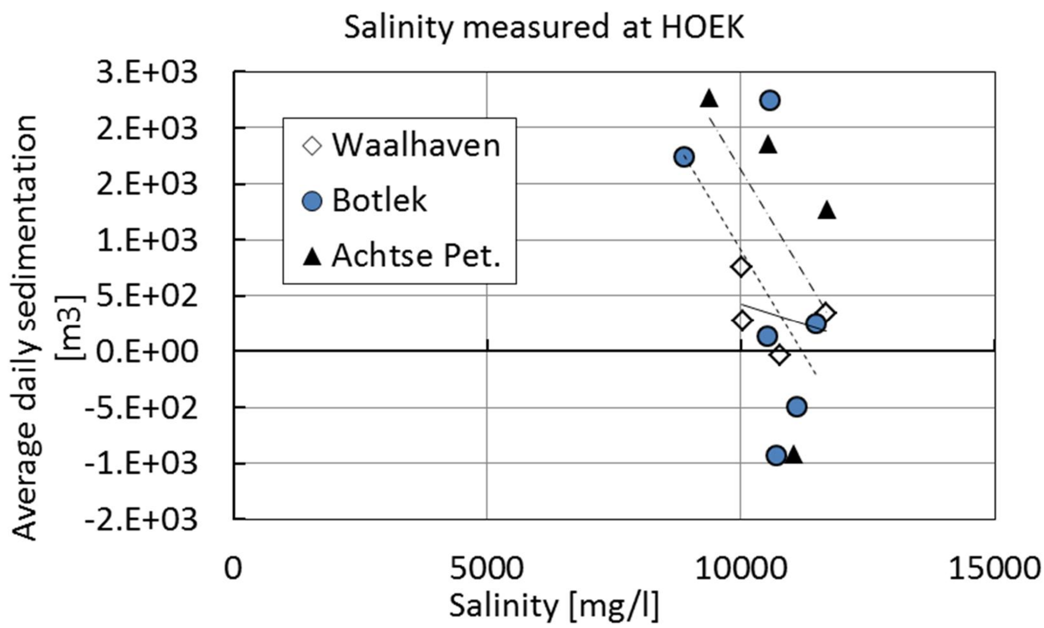


Figure 3.8 Salinity (calculated using conductivity data measured at HOEK) versus sedimentation volume at three different basins of the port of Rotterdam.

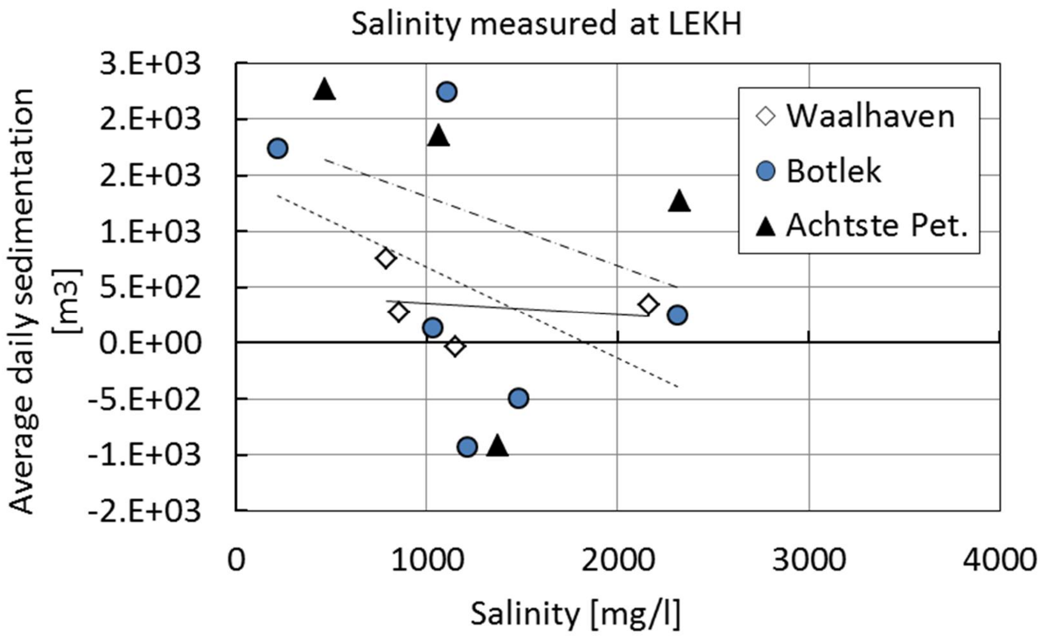


Figure 3.9 *Salinity (calculated using conductivity data measured at LEKH) versus sedimentation volume at three different basins of the port of Rotterdam.*

3.6 Effect of SPM concentration

No clear association between the SPM concentration and the sedimentation volume is found.

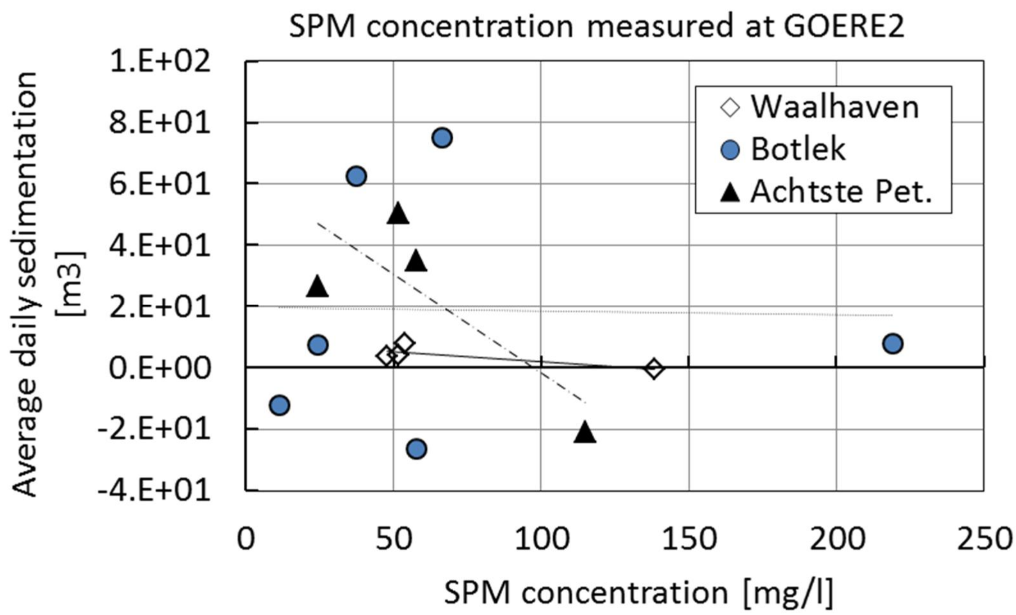


Figure 3.10 *SPM concentration (calculated using SPM data measured at GOERE2) versus sedimentation volume at three different basins of the port of Rotterdam.*

4 Linear correlation coefficient

The linear correlation coefficient (r also known as Pearson's r) can be calculated using (Rogers and Nicewander, 1988):

$$r = \frac{(\sum(x-mx)*(y-my))}{\sqrt{\sum(x-mx)^2*(y-my)^2}} \qquad (2)$$

where r is between -1 to 1; r = 1 means perfect positive correlation and r = -1 means perfect negative correlation. mx and my are the means of x and y variables.

As it is presented in the preceding section, a correlation may exist between wave intensity and sedimentation volume or between salinity and sedimentation volume. The linear correlation coefficient is thus calculated for these two physical parameters (see in Table 4.1). A weak positive correlation between wave intensity and sedimentation and a weak negative correlation between salinity and sedimentation is found. Note that the number of data points used in this study is too few to draw any statistically sound conclusions based on this correlation analysis. However, it could give a rough indication for the role of these physical parameters in the sedimentation of the port of Rotterdam.

Table 4.1: Calculate correlation of coefficient for different physical parameters presented in the preceding section.

	Wave intensity		Salinity	
	Euo2	m.z.n.m	HOEK	. LEKH
Achtste Pet.	0.05	0.45	-0.52	-0.34
Botlek	0.27	0.59	-0.54	-0.45
Waalhaven	0.15	0.55	-0.34	-0.20

5 Discussion and conclusions

In this study the relation between physical parameters and sedimentation was studied. Unfortunately the under keel clearance data from CoVadem data could not be used because they had to be further validated. Therefore, in this study we had to rely on multibeam data. The drawback was that too few multibeam surveys were available for the time window of this study. Due to a lack of sufficient data we could not provide a statistical analysis but an attempt was made to at least highlight those physical parameters that may play a role in the sedimentation. Among all studied physical parameters it was found that a relation may exist between wave intensity and sedimentation volume and between salinity and sedimentation volume. These findings are in agreement with the findings of Merckelbach (1996).

We recommend:

- to extend the study to a wider time window and including CoVadem data (when available);
- to conduct a multivariate regression analysis between the (governing) physical parameters and sedimentation volume;

In a possible follow-up project, the following activities might also be considered:

- The use of advance artificial intelligence such as deep learning to mine relations between physical parameters and sedimentation as a prediction tool and compare its results with multi variant regression analysis;
- A cross check of the accuracy of both CoVadem data and multibeam data with a reliable continuous measurement of the water-mud interface e.g. by using a fibre optic measurement system based on heat dissipation along the depth of the fibre optic cable.
- To gain more insight into the consolidation process of mud layers through a combination of CoVadem or multibeam data with vertical density profiles. Both CoVadem and multibeam data cannot determine whether a reduction in volume of deposited sediment in a harbour is due to natural sediment removal processes or because of consolidation.

References

Merckelbach, L. M. (1996), “Sedimentation in the Maasmond; a correlation analysis”, Directorate-General for Public Works and Water Management, Ministry of Transport, Public Works and Water Management.

Rogers J. L. and Nicewander W. A, (1988). "Thirteen Ways to Look at the Correlation Coefficient" (PDF). The American Statistician. 42 (1): 59–66