MONITORING THE SILTATION RATE AT DEURGANCKDOK, PORT OF ANTWERP, AND ITS REDUCTION BY A CURRENT DEFLECTING WALL

B. Decrop[1], F. Roose[2], N. Zimmermann[3] and M. Sas[4]

Abstract: The tidal dock called Deurganckdok (Port of Antwerp) is situated in the macro tidal estuary of the Scheldt River and is directly connected to the river without the shielding properties of a lock. Due to its position in the estuary near the Estuarine Turbidity Maximum (ETM) of the estuary, large amounts of silt and clay are available for sedimentation. The dock effectively acts as a sediment trap, with a trapping efficiency as high as 0.43. During the first five years after its commissioning, the sedimentation of the dock has been closely followed by means of intensive monitoring of both long-term point measurements and through tide campaigns with high spatial resolution. The mass balance of the dock's sediment bed has been monitored using density profiling. It was shown that the average rate of sedimentation of the dock is as high as 1 cm/day.

A semi-empirical model of the siltation of the dock has been developed to gain insights in the contribution of the different mechanisms of sediment exchange with the Scheldt River. Long term siltation calculations shown the model is capable of reproducing the sediment balance of the dock.

After numerical and physical modeling it was shown that a Current Deflecting Wall (CDW) has the potential to reduce the sedimentation in the dock (Roose et al, 2013). The construction of this structure has now been executed and the first monitoring results are available of the post-construction period. Due to the natural variability of the estuarine sediment concentration levels, the statistical trend change cannot be proven yet, but measurements of the flow pattern near the dock entrance reveal changes that can be incorporated in a semi-empirical model of the sedimentation, bringing forward first estimates of the sedimentation reduction in the dock.

Keywords: Sedimentation, tidal dock, Port of Antwerp, Current deflecting wall

[1] Hydraulic Engineer, International Marine and Dredging Consultants, Coveliersstraat 15, B-2600 Antwerp, Belgium. T: +32 3 287 25 19, F: +32 3 235 67 11, Boudewijn.Decrop@imdc.be , www.imdc.be

[2] Department of Maritime Access, Ministry of Public Works, Flemish Government, Belgium. T: +32 3 222 08 25, F: +32 3 231 20 62, Frederik.Roose@mow.vlaanderen.be , www.maritiemetoegang.be

[3] Hydraulic Engineer, International Marine and Dredging Consultants, Coveliersstraat 15, B-2600 Antwerp, Belgium. T: +32 3 270 92 70, F: +32 3 235 67 11, Nicolas.Zimmermann@imdc.be , www.imdc.be

[4] Manager Coastal and Estuarine Section, International Marine and Dredging Consultants, Coveliersstraat 15, B-2600 Antwerp, Belgium. T: +32 3 270 92 95, F: +32 3 235 67 11, Marc.Sas@imdc.be , www.imdc.be

NOMENCLATURE

$\alpha_{set,dens}$	Coefficient for settled fraction due to density currents [-]
$\alpha_{set,eddy}$	Coefficient for settled fraction due to eddy formation [-]
$\alpha_{set,tide}$	Coefficient for settled fraction due to tidal filling (previously coefficient c1) [-]
$\Delta\rho$	Density difference [kg/m³], taken equal to salinity amplitude (variation per tide) [ppt]
ε	Relative vertical salinity gradient $\Delta\rho/\rho$ [-]
ρ	Water density [kg/m³]
A_{cs}	Dock entrance cross-sectional area [m²]
A_h	Dock surface area [m²]
c	Suspended sediment concentration [mg/l]
$F_{density}$	Sediment influx due to density currents [kg/tidal cycle]
F_{eddy}	Sediment influx due to eddies (horizontal entrainment) [kg/tidal cycle]
F_{tide}	Sediment influx due to tidal filling [kg/tidal cycle]
F_{total}	Total sediment influx into dock [kg/tidal cycle]
h	Tidal amplitude [m]
H_{dock}	Average water depth at dock entrance [m]
T_{dens}	Duration of density currents during half a tidal period [hours]
T_{eddy}	Duration of eddy currents during half a tidal period [hours]
T_{tide}	Tidal period (~12.4h)
v_{dens}	Flow velocity related to density currents (previously ud) [m/s]
v_{eddy}	Flow velocity related to eddy currents [m/s]
v_{tide}	Flow velocity related to tidal filling [m/s]
v_{rest}	Rest flow velocity when decomposing the total flow velocity into components [m/s]
V_{dens}	Water volume exchanged by density currents [m³]
V_{eddy}	Water volume exchanged by eddy currents [m³]
V_{prism}	Tidal prism [m³]

1. INTRODUCTION

Deurganckdok is a tidal dock situated at the left bank in the Lower Sea Scheldt (Figure 1). Deurganckdok has the following characteristics: a total length of 2750 m and a width of 450 m at the river side and 400 m wide at the landward side of the dock. The bottom of Deurganckdok is designed at a depth of –17m TAW near the quay walls and of –19m TAW in the central trench. The central trench was built to collect sediment from sweep beam dredging along the quay walls. From the central trench the sediment could then be removed by hoppers. The dock rapidly silted up to about -15.5 m TAW, at which depth it was maintained.

The Lower Sea Scheldt is the downstream stretch of the Belgian part of the macro tidal estuary of the Scheldt River. Tidal amplitudes range from 3 m to over 6 m. Like in many tidal estuaries with an important upstream source of fine sediments, an Estuarine Turbidity Maximum (ETM) is located where tidal pumping and river runoff dominated regions meet. In that region, also a salt wedge is found with horizontal and vertical gradients in salinity. It is the border area between marine and river systems. The residual current formed by river and salt wedge make that a high amount of fine sediment is trapped in the ETM, which is resuspended by every flood and ebb current. The Port of Antwerp is largely located in this ETM zone of the Scheldt Estuary. Therefore, the average turbidity is high and large amounts of sediment are available for sedimentation in docks. Especially the tidal dock Deurganckdok, which is not shielded by locks, is prone to large sedimentation rates.

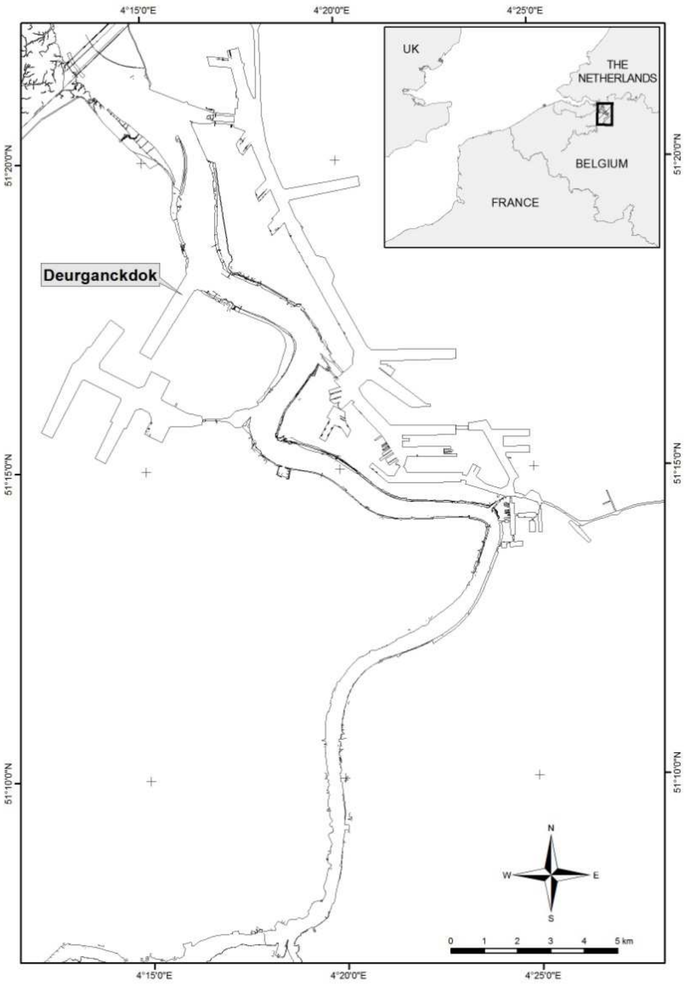

Figure 1. Situation of the Lower Sea Scheldt in the North of Belgium and of the tidal dock Deurganckdok in the Port of Antwerp.

Since keeping the dock at navigation depth requires dredging of about 1 million m³ per year, the Maritime Access Department of the Flemish Government investigated mitigating measures. The concept of a current deflecting wall (CDW) was proven in the Köhlfleet Harbour in Hamburg, Germany. Although the latter is situated beyond the limit of salt intrusion, the concept was adopted and investigations on its capacity of reducing sedimentation begun.

Several mechanisms are known to cause siltation in harbour basins:

1. exchange flow by horizontal entrainment due to velocity differences between the river and the harbour basin;
2. exchange flow by tidal filling and emptying;
3. exchange flow by density currents due to salinity differences between the river and the harbour basin;
4. exchange flow by sediment-induced density currents.

All of these mechanisms are relevant at the entrance of the Deurganckdok. The first three are inevitable due to the local estuarine hydrodynamics, the latter was investigated by measurements of sediment concentration near the river bed. So far, density currents related to highly-concentrated benthic sediment layers have not been observed at the dock’s entrance (the recent removal of a sill might have changed this situation).

Since the year 2005 -and ongoing- long term measurements of salinity, suspended sediment concentration and temperature have been conducted in and around the dock. During the same period, regular measurements of through-tide water and sediment fluxes through the dock's entrance have been executed, and the sediment mass present on the bottom of the dock has been monitored. In this way, the net sediment fluxes into the dock are determined and the associated physical processes are investigated. Consecutively, the gathered knowledge of the physical processes have been translated into an empirical long term sedimentation model. For each tidal cycle in a period of six years, the net sediment influx was calculated. The time series of tidal sedimentation rates allows then for an analysis of the relation between sedimentation rates and ambient conditions in the estuary (such as turbidity, tidal salinity variations, tidal amplitude, river runoff).

After the completion of the CDW in August 2011, the flow pattern near the entrance of Deurganckdok is altered (see Figure 2). During flood tide, near-bed flows carrying higher sediment concentrations are deflected, away from the dock entrance, while lower turbidity waters near the surface are guided towards the dock. It is expected that, in several ways, this has an influence on the mechanisms causing sediment exchange and the resulting sedimentation rates.

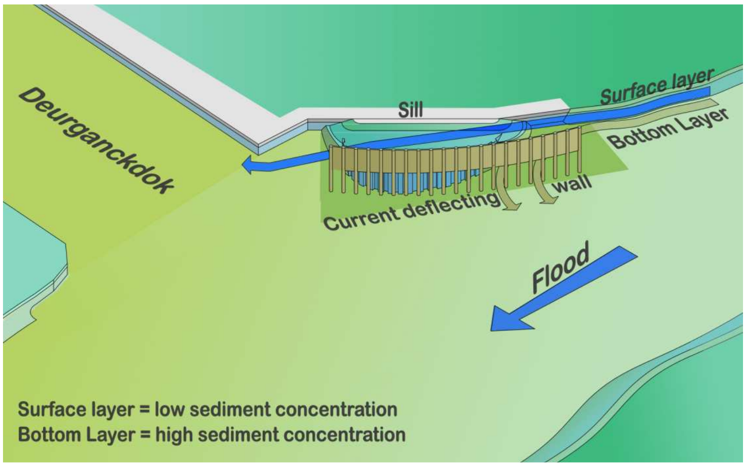

Figure 2. Design and working principle of the Current Deflecting Wall installed North of Deurganckdok, Port of Antwerp.

This paper summarises the measurement campaigns conducted and describes the sedimentation model. Further, the observed effects of the CDW on the local flow conditions, salinity gradients and other factors influencing sedimentation rates are described and their application in the empirical sedimentation model. No definitive reductions in sedimentation due to the impact of the CDW can be determined, but the first indicators towards it are laid out.

2. MEASUREMENT CAMPAIGNS

A total of 5 years of sediment balance and hydrodynamic measurements have been collected after the commissioning of the Deurganckdok, without CDW, between 2005 and 2010. After completion of the CDW, in September 2011, one year of measurements have been collected to observe the CDW-induced difference in flow pattern and sediment distribution near the entrance of the dock.

2.1 Density profiling

A way to determine accurately the mass of sediment present in the bed above a fixed reference level is by taking density profiles. A grid has been defined covering the complete dock at which vertical profiles of the density of the mud bed are taken. Both the Navitracker and Densitune systems have been used. The first is based on radiation transmission, the latter on acoustic backscattering. The profiles of bulk mud density are converted to profiles of dry sediment concentrations. Integrating the sediment concentrations (kg/m³) over the vertical distance between the reference level (at which it is assumed no significant consolidation occurs) and the water-mud interface gives a value of the dry sediment mass in the bottom of the dock per unit of surface area (kg/m²), for each density profile. Integrating these values over the total surface area of the dock results in a total sediment mass present in the dock (in Tons of Dry solids, TDS).

2.2 Acoustic flow and sediment concentration profiling

An Acoustic Doppler Current Profiler (ADCP) has been used to measure the flow velocity and direction as well as the suspended sediment concentration over the full vertical section at the dock's entrance. The distributions along the entrance show very clearly the flow patterns related to the mechanisms for water and sediment exchange: density currents induced by a salinity difference between dock and river (Figure 3, left top panel and Figure 4) and a horizontal eddy induced by a shear layer along the dock entrance (Figure 3, left bottom panel). In addition, the sediment concentrations associated with in- and outflows associated with these exchange flows are obtained. Applying all measured transects over a tidal cycle, an overview of the in- and outflow at Top (T), Middle (M) and Bottom (B) averaged layers, as well as at North (N), Middle (M) and South (S) averaged water columns is made using the Christiansen method (Figure 3, right panel). This image gives a good overview of the occurrence of eddies (inflow N and outflow S, or vice versa) and density currents (inflow B and outflow T, or vice versa).

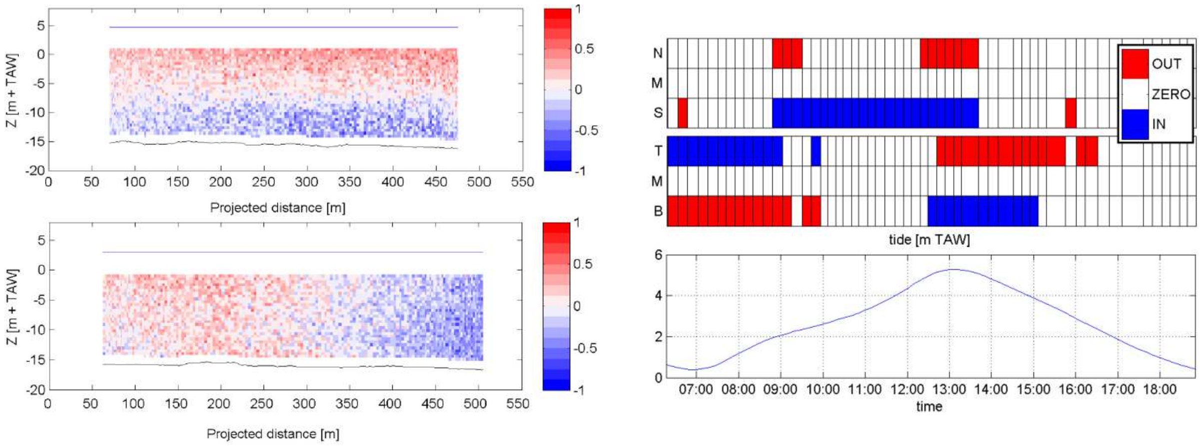

Figure 3. Left: Flow velocity component along the axis of the Deurganckdok, measured along the entrance of the dock. Positive flow velocity is directed towards the river. Top panel: High water density current. Bottom panel: Flood tide eddy. Right: identification of eddy and density current using Christiansen method (10/12/2008).

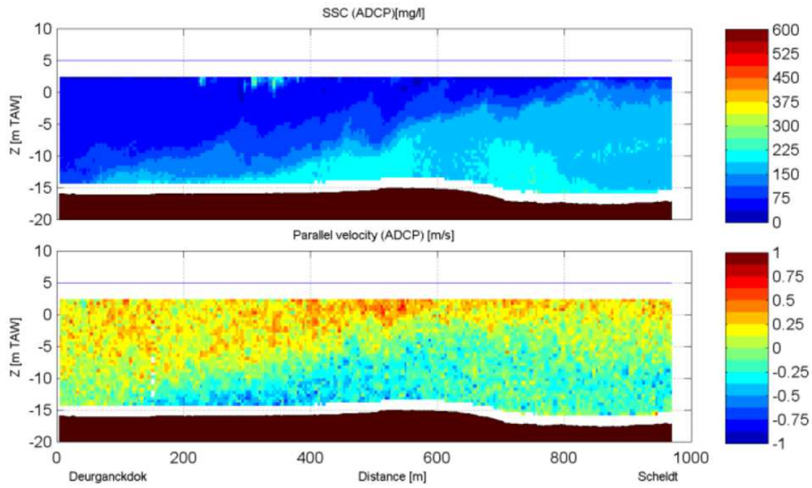

Figure 4. ADCP transect along the dock axis at high water slack, starting within the dock (left, X=0 m), ending in the Scheldt river. Both SSC and velocity profiles show a density current importing sediment laden waters near the bed. Positive flow velocity directed outbound the dock (IMDC, 2012).

2.3 Long term point measurements

Instruments collecting time series of salinity, suspended sediment concentration *SSC* and temperature have been installed at different locations along the dock's quay walls. At each location, instruments have been positioned at two depths below the water surface. This allows to monitor the different quantities at these positions, but it also allows for the observation of vertical, along-dock and cross-dock gradients of salinity, suspended sediments and temperature. Initially, eight Optical BackScatter (OBS) instruments have been installed at four locations and two depths (Figure 5). In a later phase of the project, only the two positions at the dock's entrance have been retained. Measurements at these two locations are applied as input for the empirical sedimentation model, see below.

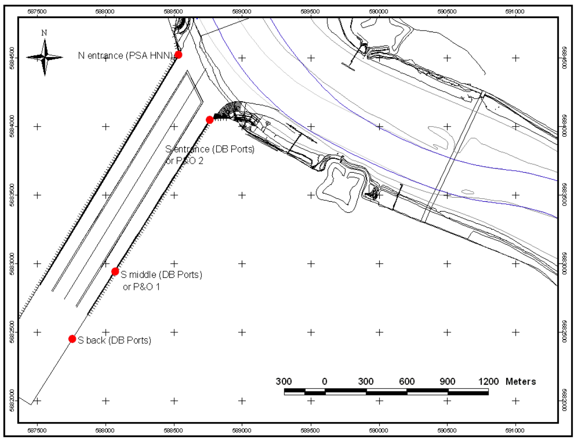

Figure 5. Location of the long-term observations of salinity, suspended sediments and temperature.

3. DATA ANALYSIS

3.1 Flow pattern at the dock entrance

As shown in Figure 3, the exchange flows along the dock entrance can be decomposed into three components. Density currents occur due to a difference in salinity between dock and river. The horizontal mass density gradient causes a near-bed difference in hydrostatic pressure between river and dock. The result of higher salinity in the river is the inflow of saline water in the dock in the lower water layers during high tide, while fresher water is flowing out of the dock at the same time (Figure 6, upper right panel). The average salinity in the dock rises because of this exchange. During low tide the salinity in the river has fallen and the water in the dock is more saline; the opposite direction density current occurs.

An important horizontal exchange mechanism is caused by the difference in flow velocity between the tidal river and the dock. A shear layer develops along the dock's entrance and entrains water due to which it grows. The shear layer collides with the downstream quay wall of the dock and causes inflow at the downstream end. At the upstream corner of the dock entrance this inflow is compensated with outflow, and a large horizontal eddy is formed across the dock entrance (Figure 6, upper left panel).

The large difference in water level between high and low water causes a high tidal prism in a tidal dock: an average of 5 million m³. This forms the third important exchange mechanism at Deurganckdok (uniform inflow pattern shown in Figure 6). Tidal inflow does not occur individually but interacts always with one of the other exchange mechanisms. Obviously, all three mechanisms can occur simultaneously, resulting in a complex flow pattern shown in the lower right panel of Figure 6.

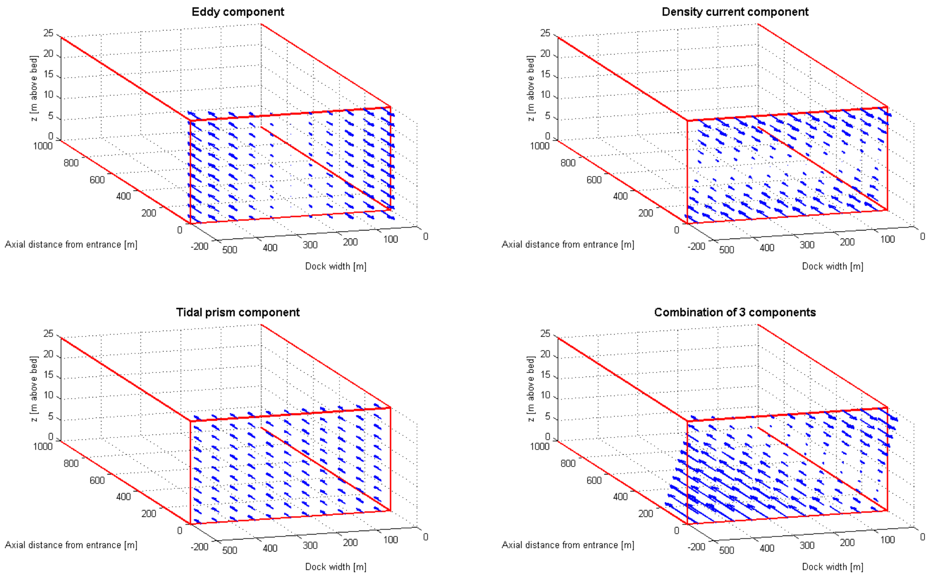

Figure 6. Schematised components of exchange flows along the Deurganckdok entrance. In the lower right panel a superposition of the three components is shown.

3.2 Net sediment influx per tide

Calibration of the acoustic backscatter measured by the ADCP results in sediment concentration values at all points at which a flow velocity is measured. Combining all in- and outgoing sediment fluxes over one tidal cycle, one can obtain a net amount of sediment retained by the dock. A wide variation in sedimentation rates has been observed: between 200 and 3400 TDS/tide (Figure 7). This variation is attributed to a number of ambient factors:

- The tidal amplitude has an influence of the flow velocity in the river. The consequence of higher tidal flow velocities is (i) more energy to keep sediment in suspension and (ii) more shear for the development of a large eddy across the dock entrance. Further, a larger tidal amplitude causes larger volume of water to enter and leave the dock due to tidal filling.
- Second, the Scheldt River runoff plays an important role in the position of the Estuarine Turbidity Maximum. In periods of high river discharge, the ETM is moved more downstream of Antwerp, i.e. closer to Deurganckdok. The ETM is related with a local maximum in sediment concentration, providing a higher amount of sediment available for sedimentation. A second effect of the position of the ETM is its relation with the so-called salt wedge, the location in the estuary where the saline sea waters and fresh river waters meet. When the zone with the highest salinity gradients is near the dock, a higher difference in salinity between high and low tide causes a higher intensity of density currents and an increase in exchange and sedimentation.
- Third, seasonal variations in sediment concentration have an influence on sediment availability. In winter months, the suspended sediment concentrations are higher compared to the summer months.

In the month of March, all three ambient factors influencing the sedimentation rate are often in a sedimentation-favourable phase. A period of strong spring tides, low water temperature and a salt wedge located relatively close to Deurganckdok due to a long period of high river runoff contribute to optimal conditions for high exchange rates and high sedimentation rates. In the field, six out of the ten highest sedimentation rates per tide have been observed in the month of March (Figure 7).

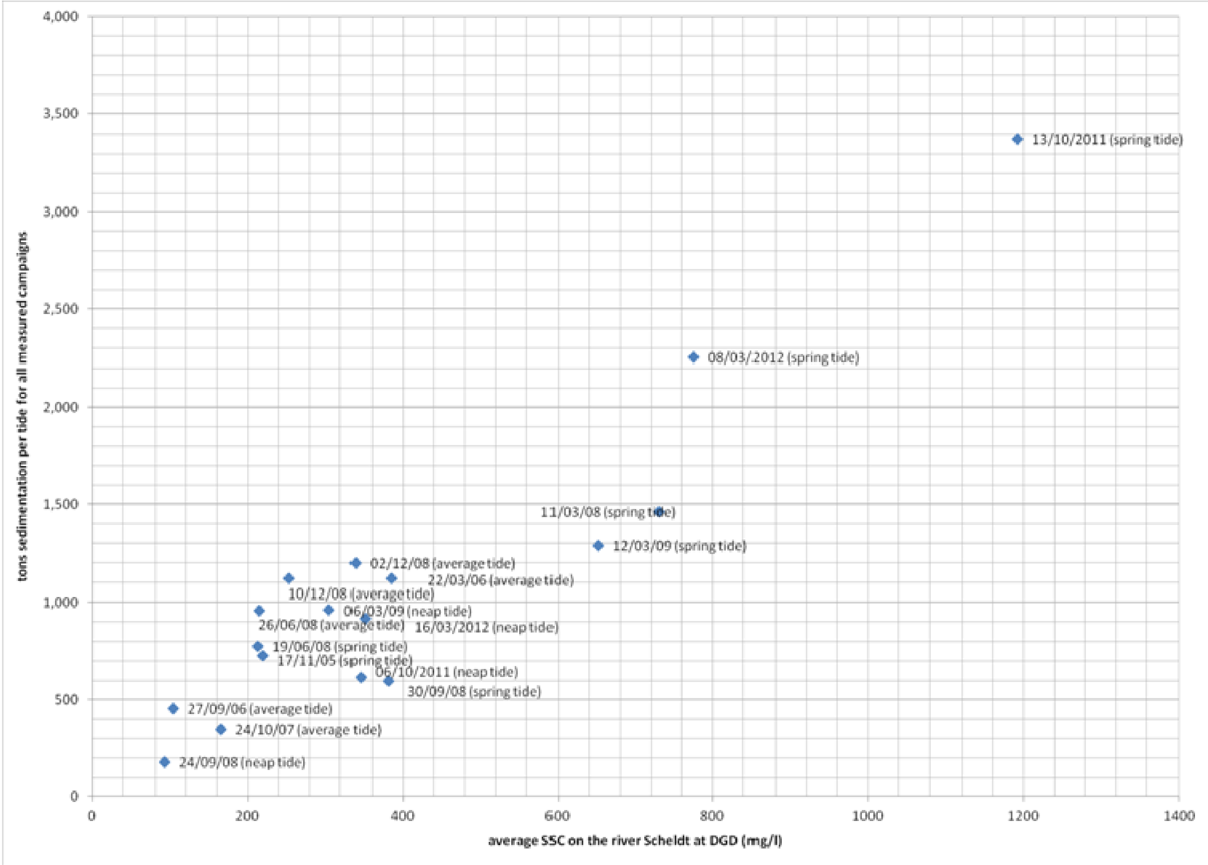

Figure 7. Relation between Scheldt River suspended sediment concentration and net sediment influx per tide, measured during 16 through-tide ADCP campaigns between November 2005 and March 2012.

3.3 Average tidal cycles

Long-term measurements of suspended sediment concentration *SSC*, temperature *T* and salinity *S* have been subdivided into tidal cycles. Subsequently, all tidal signals are averaged to form an average tidal cycle. These average tidal cycles have also been determined for the horizontal and vertical gradients of *SSC*, *T* and *S*. Figure 8 gives an example of the average (over 267 tidal cycles) evolution of the vertical gradient in sediment concentration. During this period, *SSC* was 15 mg/l higher per meter water depth near the bed compared to near the surface between high water (HW) and HW+1.5h. During this phase in the tidal cycle, density currents with flow field as shown in Figure 3 (top panel) are present. Water with a higher sediment content flows in the dock near the bed, less turbid waters flow out near the surface.

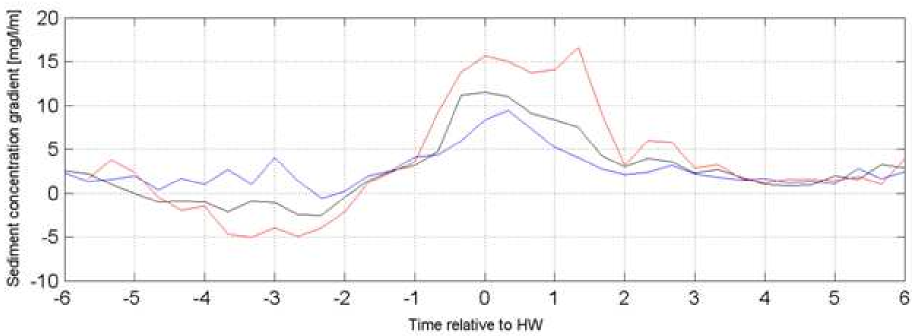

Figure 8. Average tidal evolution of the vertical sediment concentration gradient at the Deurganckdok entrance.

The aim of the construction of a CDW is to reduce the net sedimentation per tide. The observed exchange mechanisms on which a CDW can have an impact are:

- The shear layer at the entrance of the dock during high flow velocities in the river, and the associated large horizontal eddy are disturbed by the panels of the CDW, located in the top water layers. Reducing or eliminating the eddy leads to a decrease in exchange rates and a decrease in sedimentation rates.
- Density currents induced by salinity gradients cannot be avoided by a CDW, the sediment import related by them can be altered. The bottom sill part of the CDW can deflect sediment-laden waters away from the entrance of the dock during flood tide. At high water slack, when the density current flows, less turbid waters are then available for the density current near the bottom reducing the sediment influx.

4. MEASURED EFFECT OF THE CDW

The following observations have been made of the change of the gradients after completion of the CDW, within the tidal cycle.

4.1 North entrance vertical gradient

The salinity gradient is significantly changed during most of the tidal cycle (Figure 9). Instead of being constantly positive, it is decreased during entire flood by 1ppt. It is now negative from HW-1h to HW+1h, indicating more saline waters near the surface. In addition, the maximum gradient at LW (HW-5h) is reversed, from +2ppt to zero, and the average gradient value is now around zero. This suggests that the surface flow is forced into the dock via the CDW guiding wall, and that the retardation effect is approximately optimal. It also suggests that density currents at the North entrance are reduced during flood.

The SSC gradient has a 20% to 40% lower peak from HW-1h to HW+2h, with decreased SSC at the bottom but unchanged SSC near the surface. This suggests that the retarded sediment-laden bottom flow and the weaker density currents result in less sediment being brought into the dock or put into suspension. However, during spring tide around LW (HW-5h to HW-4h), a new small SSC peak is visible. It might be related to the vertical mixing induced by the vertical gradient.

4.2 South entrance vertical gradient

The salinity gradient displays a small gradient decrease of 0.5ppt from HW-1h to HW+2h, suggesting slightly weaker density currents at the South entrance during flood.

The SSC gradient displays a slight decrease from HW-1h to HW+2h, in line with the slightly lower SSC values observed at SBOT and STOP. It is possibly related to weaker density currents.

4.3 Near surface horizontal gradient

The salinity gradient has significantly changed during flood. Instead of being negative, it is now around zero during most of flood. This suggests a significant decrease or disappearance of the flood eddy at the surface. The SSC gradient is qualitatively similar.

4.4 ADCP measurements

From detailed acoustic flow measurements in the area of the entrance of Deurganckdok (e.g. IMDC, 2012), it is observed that the eddy indeed has weakened or disappeared during some tidal cycles (Figure 10). But, since the number of tidal cycles during which this type of measurement has been executed is limited, no definitive conclusions can be drawn on the change in frequency of occurrence of a large eddy.

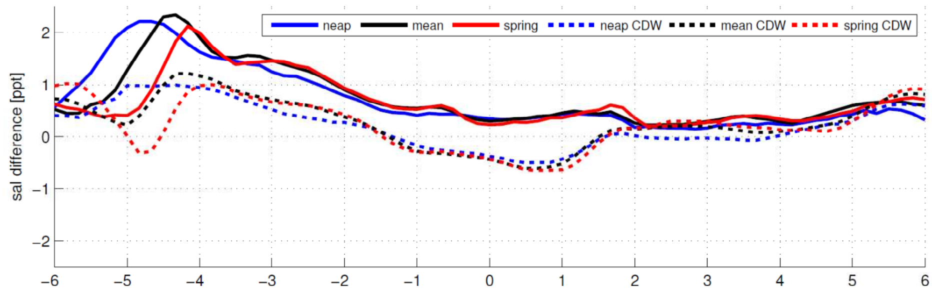

Figure 9. Vertical salinity gradient at the northern corner of the dock entrance, before and after the construction of the CDW.

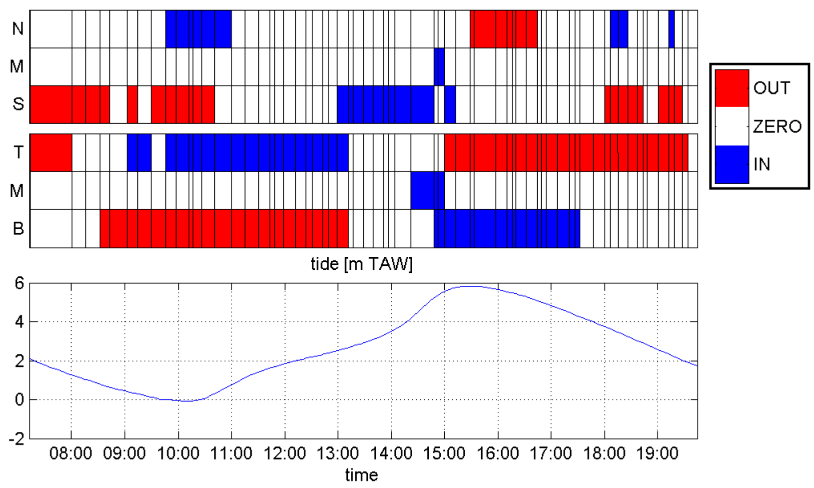

Figure 10. Christiansen method for density currents and eddy indication (with CDW, spring tide, 8/3/2012)

5. SEDIMENTATION MODEL

5.1 Introduction

A conceptual sedimentation model based on data assimilation has been developed over the years to estimate the sediment influx and deposition due to the three main water exchange mechanisms at the dock entrance : tidal filling, density currents and eddy currents (IMDC, 2009). In a later stage, further refinements have been added (IMDC, 2013). This model is used to estimate the sedimentation in the dock since its construction and in particular to model the impact of the CDW on the sedimentation. By implementing the changes in exchange mechanisms observed due to the construction of the CDW, the difference in sedimentation behaviour can be estimated. A concise overview of the current state of the model and relevant past assumptions is presented below.

5.2 Model concept

The model assumes that the water exchange can be split into three water exchange components : tidal filling, density currents and eddy currents. The sedimentation in the dock is computed as the sum of net sediment fluxes for each exchange mechanism.

$$F_{total} = F_{tide} + F_{density} + F_{eddy} \tag{1}$$

The expression used for each net flux has been chosen based on a mix of physics and observations. Net fluxes are computed per tidal cycle. In that way the expressions reduce to well-identified forcing factors with few calibration parameters. The main data sources used are the long-term measurements of salinity S and *SSC* and the through-tide measurements at the dock entrance.

5.3 Tidal filling

Tidal filling brings a known amount of water into the dock with a given concentration. The influx of sediment during flood is then defined as the tidal prism times a tidally-averaged concentration (variable at a larger time scale). Of this influx a fraction $\alpha_{set,tide}$ settles and is not evacuated during ebb. The net sediment flux due to tidal filling is then defined as :

$$F_{tide} = \alpha_{set,tide}.V_{prism}.c(t) \tag{2}$$

$$F_{tide} = \alpha_{set,tide}.\left(h(t).A_h\right).c(t) \tag{3}$$

where

- $\alpha_{set,tide}$ is the fraction of the influx settling in the dock
- h(t) is the tidal amplitude
- A_h is the horizontal dock area
- c(t) is the tidally averaged sediment concentration

5.4 Density currents

Density currents arise from an initially horizontal difference in density which is compensated by a water level gradient. The imbalance of hydrostatic forces over the vertical drives a two-layer current with the near-bed current towards the lower density region and the surface current in opposing direction.

The density current related velocity can be expressed as

$$v_{dens} = 0.5\sqrt{\frac{\Delta\rho}{\rho}gH_{dock}} \tag{4}$$

where

- ρ is the density
- Δρ is the density difference between the two layers (so vertical or horizontal)
- g is the gravity constant
- H_{dock} is the depth of the dock

The two layers of the density current are assumed to be of the same thickness and the current in each layer of equal magnitude. The density current distribution is assumed to be uniform over the entire dock cross-section and to last a certain duration during the tidal cycle in order to yield a volume of water exchanged in a tidal cycle. Like tidal filling, the net sediment flux is given by multiplying the water exchange with a tidally-averaged concentration and only a fraction $\alpha_{set,tide}$ settles in the dock :

$$F_{dens} = \alpha_{set,dens}.V_{dens}.c(t) \tag{5}$$

$$F_{dens} = \alpha_{set,dens}.\left(\frac{A_{cs}}{2}.\left(0.5\sqrt{\varepsilon(t)gH_{dock}}\right)T_{dens}\right).c(t) \tag{6}$$

where

- $\alpha_{set,dens}$ is the fraction of the influx settling in the dock
- A_{cs} is the cross-sectional entrance area
- ε(t)= Δρ/ρ is the relative density difference (computed from measured salinity difference)
- T_{dens} is the measured duration of the density currents

5.5 Eddy currents

The tidal eddy during flood results in water entering the dock via the Southern half of the entrance and leaving it via the Northern half. This process is reversed during ebb.

The eddy current velocity is taken as a measured average value modulated by the tidal coefficient. Like the density current, the eddy current is assumed to be equally strong in the two halves of the entrance but with an opposing sign, and it is assumed to last a certain duration during the tidal cycle. The net sediment flux is given by multiplying the influx with a tidally-averaged concentration and only a fraction $\alpha_{set,tide}$ settles in the dock :

$$F_{eddy} = \alpha_{set,eddy}.V_{eddy}.c(t) \tag{7}$$

$$F_{eddy} = \alpha_{set,eddy} \cdot \left(\frac{A_{cs}}{2} \bar{v}_{eddy} \frac{h(t)}{\bar{h}} T_{eddy} \right) . c(t) \tag{8}$$

where

- $\alpha_{set,eddy}$ is the fraction of the influx settling in the dock
- v_{eddy} is the measured mean eddy velocity
- h and h(t) are respectively the average and the varying tidal amplitude
- T_{eddy} is the measured duration of the eddy

The coefficients $\alpha_{set,dens}$ and $\alpha_{set,eddy}$ can be derived from measurements of vertical and horizontal gradients of *SSC*. The $\alpha_{set,tide}$ coefficient cannot be determined directly, but is derived from the equation expressing that the weighted average of these coefficients should equal the measured average trapping efficiency of Deurganckdok, equal to about 0.4. The latter means that 40% of all sediment particles entering the dock will not leave through natural circulation, but settle on the bed.

The model has been applied to compute sedimentation in the dock over the course of the first 3 years after its inauguration (Figure 11). Typical sedimentation rates of 300 to 3000 TDS per tidal cycle have been obtained (580 to 5800 TDS per day), this is in line with ADCP observations. The yearly sedimentation was between 0.7 and 0.9 million TDS/year. These figures can be seen as yearly maintenance dredging needed to keep the dock at the required depth. Indeed, over three years between April 1st 2006 and March 31st 2009 a total of 2.3 million TDS sediment influx has been calculated against a total of 2.7 million TDS dredged mass reported in BIS data.

5.6 Post CDW modifications

The CDW has been shown to have the following measured impacts on the exchange mechanisms , which should be reflected in modifications in the model compared to the pre-CDW model.

- A clear reduction of the eddy intensity. This is modeled by a shorter eddy duration. Smaller eddy velocities could alternatively be used with the same result.
- Weaker density currents as a result of weaker vertical salinity gradients. This should follow automatically from the salinity measurements.
- Lower SSC, as a result of the deviation of the bottom flow and/or of the weaker density currents. This should follow automatically from the SSC measurements.
- A global trapping efficiency which is qualitatively similar. In first instance the trapping efficiency is not modified with the CDW.

Effectively, only one correction is needed in the model: the duration of the eddy exchange per tidal cycle. The remaining effects of the CDW automatically enter the model through measurements.

When the model computations are continued after the completion of the CDW in the summer of 2011, predicted siltation rates (minus dredged mass) result in a steady decrease in the mass of the dock (Figure 11), while the measurements indicate a stable mass in the dock. It should be mentioned that in the same period as the completion of the CDW, the maintenance dredging depth in the dock has been increased by 2 m. This might have a substantial effect on density current duration (dock volume increased) and on the trapping efficiency of the dock, i.e. increasing the percentage of exchanged sediments that is retained in the dock. Moreover, in the same period, the construction of the second lock for the Waaslandhaven has started, which is located in the back of the Deurganckdok. This might also influence the presence of sediments in the dock and related sedimentation rates.

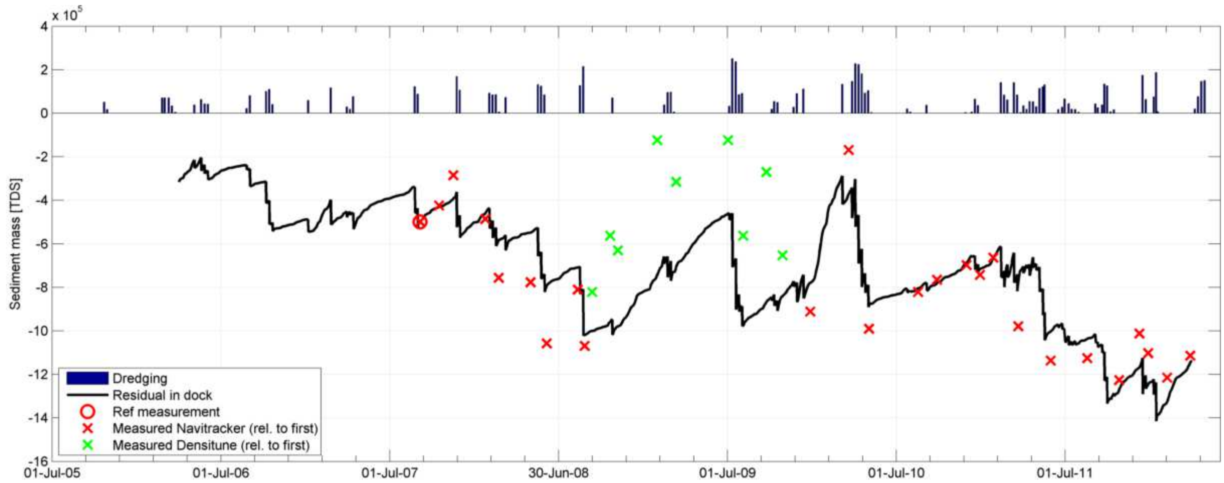

Figure 11. Comparison of the computed and measured evolution of the mass of sediments present at the bottom of the dock. Dredging events are deducted from the computed siltation mass and are indicated in blue bars.

6. CONCLUSIONS

The siltation of the tidal dock Deurganckdok and the flow mechanisms causing the siltation were intensely monitored during six years. The observed exchange mechanisms have been incorporated in a semi-empirical model for dock siltation. The model is able to hindcast the siltation rates before the construction of the CDW.

The completion of the CDW coincided with several events that possibly have an impact on sedimentation rates in the Deurganckdok: the deepening of the navigation channel in the Scheldt, the removal of a sill at the entrance of the dock, a 2 m increase in maintenance depth and construction works at the back end of Deurganckdok. Solely based on observations of the sedimentation on the dock bottom, the effect of the CDW cannot be isolated. However, intensive measurements campaigns have revealed important changes in the hydrodynamics and sediment movements near the entrance of the dock.

All results currently suggest that the CDW has the expected effect. It seems to retard the sediment-laden bottom flow and forces the surface flow to enter the dock via the CDW channel during flood, locally counteracting the development of density currents. As expected, the largest effects are visible at the North side of the dock entrance. The result should be a clear reduction of the flood eddy, and a slightly weaker density current. However, a new ebb eddy recently appeared in the measurements.

Current measurements suggest a decrease of the SSC by 20% to 30% near the bottom, both North and South of the entrance. This temporary decrease has however no impact on the average SSC values during a tidal cycle before and after construction of the CDW: at the North side bottom sensor for instance, slightly lower SSC during neap and spring tides are compensated by slightly higher SSC during mean tides. Over the same periods, the average SSC in the Scheldt is equally unchanged.

Eddy exchange was responsible for about 10% of the sediment input, if the eddy exchange has been reduced drastically, this could cause reduction in maintenance dredging by almost 10%. The sediment exchange due to density currents was attributed to 65% of siltation before building the CDW. It is not clear so far to how much the reduction in density current exchange amounts, the density current is certainly not affected in a major way, but the CDW causes changes in its intensity. The expected reduction in siltation rates due to the CDW of 10 to 20% holds after studying the first signs of changes in the system. A definitive reduction cannot be determined at this point.

Hence, more measurements are still needed to fully validate these conclusions. Furthermore, the weaker eddy has only been clearly reported in the cross-dock through tide measurements and not in the along-dock through tide measurements.

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