Effect of dredging and disposal on tidal bifurcations and flow asymmetry

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Background and Methodology

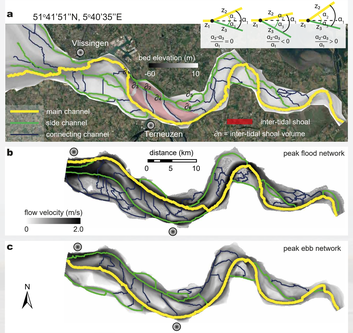
Shipping fairways in estuaries are continuously dredged to maintain access of large commercial ships to major ports. However, various estuaries worldwide show adverse side effects to dredging and disposal, including shifts from a multi-channel system to a single channel and loss of ecologically-valuable intertidal areas. The morphological development of multi-channel estuaries is controlled by tidal asymmetry that determines sediment import and sediment division through the asymmetric bifurcations.

Objective:

Effects of dredging and disposal (DaD) on the tidal and bifurcation asymmetry.

Methodology

- Hydrodynamic and morphodynamic modelling with Delft3D.
- Channel network extraction that includes channel junctions.
- Analyse tidal asymmetry and tidal bifurcations on the channel network.



Tidal asymmetry
tidal duration ratio:

$$T_d = \frac{T_{flood}}{T_{ebb}}$$

peak velocity ratio:

$$u_p = \frac{\hat{u}_{flood}}{\hat{u}_{ebb}}$$

with $\hat{u}_{ebb} = u_{cr}$ when $\hat{u}_{ebb} < u_{cr}$
u_{cr} is the critical motion.

Bifurcation asymmetry
elevation jump:

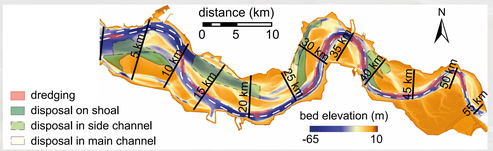
$$Z_n = \frac{Z_2 - Z_3}{Z_1}$$

bifurcation angle:

$$\alpha_n = \frac{\alpha_2 - \alpha_3}{\alpha_1}$$

Analysis conducted on the different channel networks.

Overview of the Western Scheldt Estuary (Netherlands). (a) Channel network extracted from the bathymetry. The inset shows the branch numbers (high-order = 2 and bifurcated = 3) and bifurcation angle that are analysed. (b) Channel network extracted from the peak flood flow. (c) Channel network extracted from the peak ebb flow.

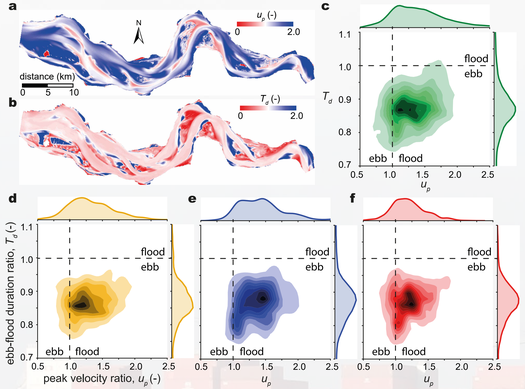


Three disposal strategies:
1. Straigthforward disposal, 50/50 disposal in side and main channel.
2. Alternative shoal disposal, 20% disposal on shoal rest equally in side and main channel.
3. Foreseen scour disposal, all disposal in the main channel (scours).

Current Western Scheldt

Tidal Asymmetry

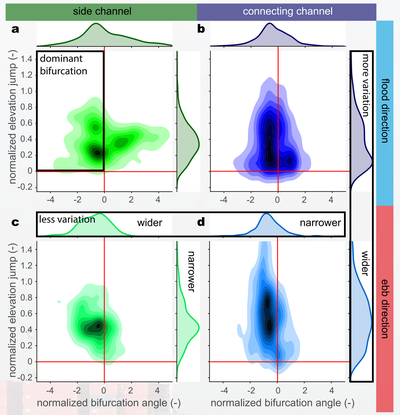
1. Peak velocity is stronger during flood flow ($u_p > 1$);
2. The ebb phase is longer than the flood phase ($T_d < 1$);
3. The ebb channel network shows less flood dominance.



Tidal flow asymmetry in the Western Scheldt for 2014. (a) Peak velocity ratio (u_p), (b) Ebb-flood duration ratio (T_d). Peak velocity ratio against tidal duration ratio for the full model domain (c), extracted on the bathymetry channel network (d), on the flood channel network (e) and on the ebb channel network (f).

Bifurcation Asymmetry

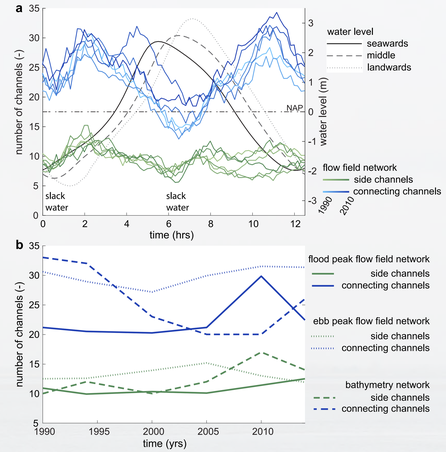
1. High-order channel smaller bifurcation angle and deeper ($Z_n > 0$ & $\alpha_n < 0$);
2. Connecting channels wider variation in elevation jump, but not in the angles;
3. Ebb direction bifurcation angle difference is smaller than flood direction.



Bifurcation asymmetry in the Western Scheldt for bathymetry data from 1955-2015. Bifurcation angle against elevation jump for side channels in flood direction (a) and ebb direction (b), for connecting channels in flood direction (c) and ebb direction (d).

Channel Network Complexity

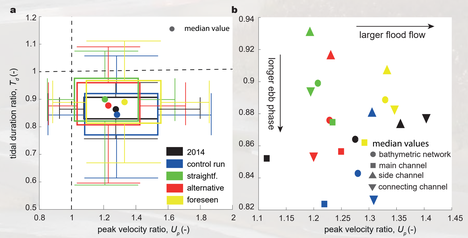
1. Number of channels (bathymetry) decreases over time due to dredging;
2. Channel network complexity varies over a tidal cycle, especially the number of connecting channels;
3. The channel network during ebb conditions is more complex than during flood.



Channel network complexity during a tidal cycle (a) and over the years (b) according to hydrodynamic modelling and bathymetry data. Channel network complexity is the lowest at slack water and highest just after peak ebb and/or peak flood flow.

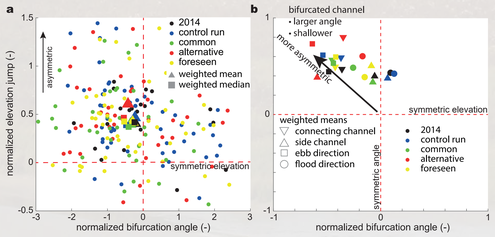
Dredged Model Runs

1. Peak velocity ratio (u_p) increases in case of foreseen scour disposal;
2. Flood duration (T_d) increases in case of dredging;
3. Stronger flood current suggests increasing sediment import into the estuary;
4. The flood duration increases the most for the side channels.



(a) Effect of dredging and disposal on the tidal asymmetry over the channel network. Dashed lines indicate equal peak flow and duration for the ebb and flood phase. (b) Effect on tidal asymmetry per channel scale.

1. Increasing bifurcation angle of the bifurcated channel in case of dredging;
2. Increasing elevation jump in case of alternative shoal disposal;
3. Bifurcation asymmetry increases mainly for the connecting channel scales and in ebb direction.



Effect of dredging and disposal on the bifurcation asymmetry. (a) All channel bifurcations at the end of the simulations. (b) The weighted means for different categories, illustrating the largest asymmetric bifurcation for the alternative disposal approach.

Conclusions

- The current alternative shoal disposal strategy increases the bifurcation asymmetry by increasing the elevation jump.
- Proposed future scour disposal strategy is most effective in increasing peak velocity ratios, which should result in more sediment import in the system.
- The tidal phase determines the number of connections within the estuary.
- Bifurcations are asymmetric and less stable at the connecting channel scale.
- Closing bifurcations will lead to a shift from multi-channel system to single-channel system and the loss of ecologically valuable intertidal flats.
- Changes in flood/ebb dominance affects salt-marshes growth.

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Photography encouraged